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8184-01, Session 1

Netforce and bluewater cyberboats

S. Allsopp, Allsopp Helikites Ltd. (United Kingdom)

A new blue-water naval force is in creation.

A synergistic combination of new digital Mobile Ad-Hoc Network (MANET) radios, carried on compact, high-altitude, all-weather Helikite aerostats, creates an extensive MANET infrastructure called Netforce. Netforce provides persistent video-relay over thousands of square miles of ocean. Cyberboats are tele-operated, unmanned boats that can roam anywhere within Netforce. Netforce links into cyberspace, enabling Cyberboats to be controlled from anywhere via the world-wide-web, or a secure private intranet. Netforce Helikites can be up to 100 miles apart, giving a radius range of 2,100 nautical miles from each internet portal, so Netforce can span the world's oceans.

Constant video radio-relay is essential for USV's to be viable. MANET radios make this easy if the radios can be lifted to high enough altitudes to give useful line-of-sight (LOS). A MANET radio lifted to 3000ft will have a radio LOS of 77 miles. When two such radios are both lifted to 3000ft, the LOS is 154 miles. The unique design of Helikites makes it easy to lift MANET radios to 3000ft for weeks. Normal, blimp-shaped aerostats are seldom used on boats due to their huge size and poor weatherkeeping. Helikites are significantly different from normal aerostats. The wind that pushes normal aerostats downwards actually pushes Helikites upwards and Helikites can cope with high winds with ease. Since 1993 many operators have flown Helikites at sea in varied weather up to 5000ft with no problems.

The latest MANET radios, weighing only a few kilos can send compressed internet-protocol video over 21 "hops" with only 1 millisecond latency between hops. They can sustain networks of up to 350 radio nodes. Many MANET radios have been lifted on Helikites. They all worked very well, creating reliable networks. It is logical that with the correct frequency, transmit power, receiver sensitivity and antenna design, a reliable, long-distance, MANET can be created.

The recent US Navy Expeditionary Overwatch trials have shown the ability of an Insitu Scan-Eagle UAV to successfully relay long-distances to unmanned boats. Scan-Eagle UAV's have an endurance of 15 hours. Any payload that can be lifted on a Scan Eagle, can be lifted on a Helikite for weeks.

Cyberboats can be of many different types and sizes including: fast attack; ASW; submarine, etc. The elimination of onboard crew allows tiny Cyberboats to have immense endurance and range. The permanent video link provided by Netforce allows the off-board crew to control the boat. The normal sense-and-avoid problems associated with autonomous unmanned boats are eliminated within Netforce. Cyberboats do not need complicated onboard satellite comms, so Cyberboats can be inexpensive. Thousands of Cyberboats can be launched and steamed millions of miles, over many years, for the cost of building one frigate.

Cyberboats and Netforce can be set-up and launched from small islands, mother-ships, or dropped from transport aircraft flying over the ocean. This enables a powerful blue-water naval force to be deployed on any part of the world's oceans within hours. Cyberboats and Netforce can dominate the seas.

8184-02, Session 1

Photon discrimination and signal integrity of a wireless radiation sensor

D. Katsis, Athena Energy Corp. (United States); M. S. Litz, U.S. Army Research Lab. (United States)

The US Army Research Laboratory has developed a wireless networked radiation sensor called ROCS: Radiation Observation Communication Sensor. This device communicates wirelessly through a low-power ZIGBEE communications protocol. It combines measurement with motion sensing, GPS, and energy management protocols for long-term deployment in areas needed security from radiological weapons and dirty bombs. The structure of the system is based on a Cesium Iodide (CsI) scintillator coupled to a pair of multi-pixel photon counters MPPC. The output from these sensors is converted into a digital signal and integrated to create a radiation measurement that sacrifices spectral data for sensitivity. Multiple design issues have challenged our group in the development of the ROCS. These issues include: scintillator packaging, sensitivity, power dissipation, maintaining stability in background measurement, and battery lifetime. Some issues have proven more difficult to address such as the challenges in maintaining a stable background count over time. As we have increased the sensitivity of the detector, the electrical variations in the power supply and detector circuit have been magnified as well. Part of the structure for making sensitive measurements is the direct feed of the photon pulses into a comparator circuit. This counting method skips the amplifier, relying only on the inherent amplification of the MPPC. The photon pulses are measured above background so the adjustment of the background trigger level of the comparator is essential. Our paper details the development of an adaptive digital discriminator that adjusts for this background level while maintaining constant gain over parameter variations. The development of the other design challenges of ROCS is also discussed to determine its usefulness in field applications that require quickly deployable strategic defense and monitoring solutions.

8184-05, Session 1

Analysis of MEMS-based acoustic particle velocity sensor for transient localization

L. Solomon, L. Sim, U.S. Army Research Lab. (United States)

The U.S. Army Research Laboratory (ARL) has made tremendous progress in the area of acoustic target tracking. Current systems are reliable and provide actionable situational awareness, but they are often bulky. In an effort to reduce size, weight, and power, ARL evaluated the feasibility of replacing our current acoustic sensor with that of a 3-D micro-electro-mechanical systems (MEMS) based acoustic particle velocity sensor developed by Microflown Technologies. This sensor has the potential to simplify sensor setup and maintenance, as well as reduce the computational requirements of the signal processing algorithms. This effort will validate specified frequency response, identify sensor limitations and capabilities, and quantify sensor localization accuracy. Experimental results conducted in both ARL's anechoic chamber as well as outdoor environments will be analyzed.

8184-06, Session 1

Stereo vision aided automatic target recognition for ground vehicle applications

V. C. Ravindra, V. K. Madyastha, National Aerospace Labs. (India); R. K. Gupta, Univ. of Amsterdam (Netherlands) and National Aerospace Labs. (India); M. Guerriero, ELETTRONICA S.p.A. (Italy); G. Gopalratnam, National Aerospace Labs. (India)

Automatic target recognition (ATR) has been solved as a maximum a posteriori (MAP) estimation problem in the past by expressing the problem in the Bayesian framework. Given a scenario, for e.g., a ground scene consisting of vehicles in a known background, the scene is parameterized in such a way that hypothetical scenes can be constructed using parameters. Such parameters typically used to describe a scene are position of target(s), pose (orientation) of target(s),

number of targets and identity of targets. The function that maps the hypothetical scene to the observed scene is the sensor model and is expressed by the likelihood function. However, this approach suffers from the scaling problem, i.e., it is assumed that the scale of the CAD models used to hypothesize scenes is known. In this paper we address the scale invariance problem by adding the scale of the target as an additional parameter in the parameter set to be estimated.

The scenario of interest to us is a ground scene with targets being observed by an imaging sensor such as electro-optical (EO) or forward looking infrared (FLIR) camera. In this paper, we propose the use of a stereo vision camera to augment the existing imaging camera. The stereo vision camera gives the ``depth" (range to sensor) of the detected objects in its field of view. It is possible to reconstruct the scale of the CAD model template using the depth information obtained by the stereo vision camera. This paper aims to study and model the joint likelihood function of the augmented measurement set, i.e., pixel intensities from the imaging sensor and the depth information from a stereo vision camera, in order to calculate the posterior of the parameter set that includes the scale of target(s). This paper, to our knowledge, will be the first to accommodate stereo vision camera calculated depth information in the parameter set to be estimated. The advantage of using stereo vision cameras is that they are passive sensors, hence making them valuable in surveillance applications, and they have been used in the past for different applications for 3D scene or terrain reconstruction. We propose to design and implement the above mentioned scale invariant Bayesian algorithm and evaluate it on a real world scenario.

8184-07, Session 2

Ten years of the LuAG-based scintillators development: state of art and prospects

M. Nikl, J. A. Mares, Institute of Physics of the ASCR, v.v.i. (Czech Republic); A. Yoshikawa, Tohoku Univ. (Japan); H. Ogino, The Univ. of Tokyo (Japan); K. Nejezchleb, K. Blazek, Crytur Ltd. (Czech Republic); A. G. Vedda, Univ. degli Studi di Milano-Bicocca (Italy)

The Ce-doped Lu3Al5O12 (LuAG:Ce) single crystal is the high density analogue of the well known YAG:Ce scintillator. We started systematical study of Czochralski (Cz) prepared LuAG:Ce single around the year 2000 and even the first comparison of radioluminescence intensity with YAP:Ce proved similar scintillation efficiency of both materials. The problem of retrapping at shallow electron traps in the transfer stage of scintillator mechanism was identified as the main cause of low light yield of LuAG:Ce. Systematic study of such traps and their impact on scintillation response was published including the new model and explanation of scintillation decay shape in LuAG:Ce [1]. Recently, high light yield has been reported for LuAG:Ce grown by Bridgman method [2] and LuAG:Ce characteristics were compared with another advanced scintillators.

In 2004-2005 we started the study of Pr-doped LuAG single crystal [3]. LuAG:Pr has shown an exceptional figure-of-merit among Pr-doped garnets and silicates [4] mainly due to negligible thermal quenching of Pr3+ center up to 500 K, fast luminescence and scintillation response dominated by the 20 ns component and excellent energy resolution around 5%@662keV. In the attempt to minimize effect of the mentioned shallow electron traps in the transport stage of scintillation mechanism the Ga-admixed LuAG:Pr appeared as a very promising material system [5].

In this presentation we survey the Ce- and Pr-doped LuAG luminescence characteristics, scintillation performance, current understanding of their scintillation mechanism and intrinsic figure of merit in comparison with other advanced complex oxide scintillators. New results including temporal characteristics of scintillation response and light yield will be reported for the latest generation of crystals grown by optimized Czochralski technique in CRYTUR, Ltd., Czech Republic. Comparison between single crystals and the latest optical ceramics of these materials [6] will be provided as well. Future prospects of these scintillators for the applications focused on the detection of X-rays and high resolution 2D imaging will be discussed.

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8184-08, Session 2

Integrated mobile radar-camera system in airport perimeter security.

M. Zyczkowski, M. Szustakowski, W. M. Ciurapinski, R. Dulski, M. Kastek, P. Trzaskawka, Military Univ. of Technology (Poland)

The nature of recent conflicts terrorist attacks and military conflicts as well as the necessity to protect bases, convoys and patrols gave serious impact to the development of more effective security systems. Widely-used so far concepts of perimeter protection with zone sensors will be replaced in the near future with multi-sensor systems. This kind of systems can utilize day/night cameras, IR uncooled thermal cameras as well as millimeter-wave radars detecting radiation reflected from target. Ranges of detection, recognition and identification for all targets depends on the parameters of the sensors used and the observed scene itself. In this paper we present the results of our research into a mobile perimeter system.

8184-09, Session 2

Gas sensing and focal plane array imaging based on optical properties of crystalline silicon carbide

G. Lim, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); A. Kar, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Crystalline silicon carbide (SiC) is a wide bandgap semiconductor material whose optoelectronic properties can be modified by incorporating dopant atoms into the crystal lattice to fabricate a sensor. The energy gap between the dopant energy level and the valence band determines the photon energy required to excite the valence electrons to the dopant level. This variation in the electron density in these two energy levels changes the refractive index of SiC and, therefore, its reflectance is modified. A laser beam, such as a He-Ne laser of wavelength 632.8 nm, is used to determine the change in the reflectance as the optical response of the sensor. This principle is used to fabricate chemical sensors utilizing the characteristic spectral emission line in the spectroscopic data of a given chemical. The emission line of NO gas is 5.25 μm which corresponds to a quantum of energy 0.23 eV. A sensor is fabricated for this gas by doping an n-type 6H-SiC with Al dopant atoms to create an energy gap of 0.23 eV between the dopant energy level and the valence band. The formation of this energy gap was confirmed by optical absorption spectroscopic studies of the doped sample. The optical response of the doped sample was also studied in the presence of NO gas at the surface of the doped sample.

Similarly, other dopant atoms can be incorporated into SiC or any other semiconductor material for fabricating sensors for other gases. SiC can be doped with Ga to produce an energy level of 0.29 eV corresponding to photons of wavelength 4.3 μm for sensing CO2 gas. This type of SiC-based sensor does not require any cooling. The operation of the sensor at 4.3 μm wavelength indicates that the device is suitable for applications in the MWIR range. Other dopants can be incorporated into the substrate to create energy levels for different wavelengths in the MWIR range. Thus the optoelectronic principle of this study can be utilized to fabricate uncooled MWIR detectors. Doped pixels can be created for focal plane array imaging applications by doping localized regions in the semiconductor.

8184-10, Session 2

EO/IR sensor development using nanostructures for unattended ground sensor applications

A. K. Sood, J. W. Zeller, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States); A. F. M. Anwar, Univ. of Connecticut (United States)

Next Generation EO/IR focal plane arrays using nanostructure materials are being developed for a variety of Defense Applications including Unattended Ground Sensor Applications. Several different nanomaterials are being evaluated for these applications. These include ZnO nanowires that have demonstrated large signal to noise ratio as a wide band gap nanostructure material in the UV band. Similarly, the work is under way using Carbon Nanotubes (CNT) for a high speed detector and focal plane array as bolometer for IR bands of interest, which can be implemented for the unattended ground sensor applications.

In this paper, we will discuss the sensor design and model predicting performance of an EO/IR focal plane array that can cover the UV to IR bands of interest. The model can provide a robust means for comparing performance of the EO/IR FPA's and Sensors that can operate in the UV, Visible-NIR (0.4-1.8μm), SWIR (2.0-2.5μm), MWIR (3-5μm), and LWIR bands (8-14μm). This sensor model can be used as a tool for predicting performance of nanostructure arrays under development. We will also discuss our results on growth and characterization of ZnO/ MgZnO nanowires and CNT's for the next generation sensor applications.

8184-11, Session 2

Adaptive fusion of infrared and visible images in dynamic scene

G. Yang, Y. Yin, H. Man, Stevens Institute of Technology (United States); S. Desai, US Army RDECOM (United States)

Multiple modalities sensor fusion has been widely employed in various surveillance and military applications. Many techniques on image fusion including PCA, wavelet, curvelet and HSV have been proposed in recent years to improve human visual perception for object detection. One of the main challenges for visible and infrared image fusion is to automatically determine an optimal fusion strategy for different input scenes along with an acceptable computational cost.

This paper proposes a fast and adaptive feature selection based image fusion method to obtain high contrast regions from visible and infrared sensors for targets detection. At first, fuzzy c-means clustering is applied on the infrared image to highlight possible hotspot regions, which will be considered as potential targets' locations. After that, the region around the target area is segmented as the local background. Then the fusion method is locally applied with the selected target and background regions by computing different linear combination of color components from the pixel-wise aligned visible and infrared image pairs. After obtaining different fused images, histogram distributions are computed and collected in the set of candidate features. The variance ratio which is based on Linear Discriminative Analysis (LDA) measure is employed to sort the candidate set and the most discriminative one will be used for the complete image fusion strategy. As the candidate feature selection performing over time, the process will dynamically determine the most suitable fusion rule for each different image scene. Experiments are conducted on the OSU Color-Thermal database, and TNO Human Factor dataset. The fusion results indicate that our proposed method could achieve a competitive performance compared with other fusion algorithms.

8184-13, Session 3

Utilization of wildlife behaviors and mobility to the mutually benefit of homeland security and wildlife management functions

C. S. Bendall, Space and Naval Warfare Systems Ctr. Pacific (United States); E. M. Carapezza, Univ. of Connecticut (United States) and DARPA (United States); J. T. Barnett, Engineering Special Programs Corp. (United States)

This paper explores the connections between fish and wildlife conservation-management tasks and homeland security, with the ultimate goal of developing strategies and sensing technologies that are mutually beneficial to both homeland security and wildlife management functions. Two basic strategies are discussed and investigated. One strategy identifies specific fish or wildlife behaviors that can be monitored as a harbinger of homeland security threats either by human architects or of natural origin. Such threats include contamination of water sources, threats to important infrastructures such as dams & power plants, border security, wildfires, climatic changes, detecting invasive plant species and protecting aquaculture from bird predation. Under the second strategy fish, birds and wildlife are considered as mobile sensor platforms. Fish, birds and wildlife are a highly dynamic and mobile resource that poses a difficult problem for wildlife management. This inherent mobility could provide a unique homeland security capability if one considers fish and wildlife as mobile unattended sensor platforms. Extensions of existing telemetry and banding technologies used for wildlife monitoring could be expanded to provide environmental surveillance capabilities. Wildlife aggregates such as bird flocks or fish schools might serve as remote mobile sensor arrays by exploiting their organic biosensors and tagging with small, low power sensors. Distributing functionality among the individual sensors would mitigate weight penalties. Combining knowledge of wildlife behavior with information gathered from remote mobile sensor arrays would augment current homeland security and wildlife conservation/management monitoring strategies in situations where fixed sensors or human observations are impractical or inadequate.

8184-14, Session 3

Precision Long-Range Projectile Tracker

S. Rajic, Oak Ridge National Laboratory (United States)

We will present, analysis, designs, and measurements involved in our development of a novel long-range precision bullet tracking approach. The projectile itself is completely passive in this approach and thus contains no emitter, batteries, or electronics of any kind. This type of approach can provide covert projectile precision location information even in daylight conditions at ranges over 2km. The unique signature of the round can be used to track the projectile and determine its location all along the flight path with a very high signal-to-noise ratio.

8184-15, Session 3

Model for small arms fire muzzle blast wave propagation in air

J. R. Aguilar, Academia Politécnica Militar. Ejército de Chile. Avenida Valenzuela Llanos 623. Santiago 7860251. (Chile) and Facultad de Ingenierías. Universidad de San Buenaventura. Carrera 56C N° 5190. Medellín 050010. (Colombia); S. V. Desai, U. S. Army, Armament Research, Development and Engineering Center. Picatinny NJ 07608. (United States)

Accurate acoustical modeling of small firearms muzzle blast wave propagation is critical to predict sound pressure levels, and other acoustical variables like impulse durations and rise times, and its dependence on propagation distance. Such a task being relevant to a number of military applications including the determination of human response to blast noise, gunfire detection and localization and gun suppressor design. In this paper, a model for predict muzzle blast wave propagation in air of small arms fire is introduced. The model

implements a time domain Friedlander wave with finite rise time which propagates at constant speed and diverges spherically from the gun muzzle. In addition to the inverse square law, the effects in blast wave of atmospheric absorption of sound were also incorporated in the model. Differential model for predict atmospheric absorption as function of distance consider both thermoviscous and molecular relaxational processes of nitrogen and oxygen. Instead of traditional frequency based algorithms, in this work atmospheric absorption of blast waves was implemented in the time domain using a recursive formula derived from numerical integration of corresponding differential equations. Solutions were obtained by means of a Crank-Nicholson finite difference scheme. Theoretical predictions obtained from our model were compared to data base of previously recorded real world muzzle blast wave signatures. Recordings containing gunfire acoustical signatures were taken outdoors by shooting a set different sniper weapons of varying calibers and placing the microphone at distances between 100 and 600 meters from the gun muzzle, in steps of approximately 100 meters. Real world signature analysis yields curves of muzzle blast wave overpressures, durations and rise times against propagation distance. The recorded wave forms also reveal the existence of an oscillatory phenomenon which modulates the amplitude of the exponential decay of after blast overpressure. This has been reported previously in the literature and appears to be highly dependent on the ground surface nature, e.g. grassland, snow. There are some approaches trying to explain the causes of this effect including ground acoustical impedance effects and the occurrence of creeping waves. In order to obtain a better characterization of this phenomenon, high resolution time frequency analysis using the Wigner-Ville distribution technique were performed to the recorded blast wave time series. In order to detect oscillatory components from exponential decay, autocorrelation analysis was also carried out. Plots of time series containing simulated blast wave forms were then compared to the plots of measured signatures. The results indicate that the proposed model is able to produce blast wave forms which qualitatively agree with measured data. It is observed that the model can predict well the rise slope and the mean of the exponential decay. On the other hand, the model tends to overestimates peak overpressure, which could be attributable to the low pass filtering effect imposed by atmospheric absorption model is not able to round enough the sharp peak of the Friedlander wave.

8184-16, Session 4

Effects of evaporation layer on free-space optical communication links near sea surface at 1.55 µm

J. W. Zeller, T. Manzur, Naval Undersea Warfare Ctr. (United States)

Free-space optics (FSO) holds the potential for high bandwidth communication in situations where landline communication is not practical, with relatively low cost, low maintenance, quick installation times, and average 70-80% connectivity. However, atmospheric conditions can significantly affect the capability of this type of communication system to operate effectively. For FSO communication in maritime environments, laser beams propagating through the evaporation layer near the sea surface are affected by turbulence, the scattering coefficients of the water particles, and the salt water itself. To better gauge and understand the effects of turbulence on FSO communication, a propagation model is developed that is applicable to the evaporation layer of the seawater and takes into account wavelength diversity. This model is validated by comparison with experimental data for different wavelengths measured by an array of sensors distributed along the propagation path. For this model, boundary layer measurements are taken of the refractive index structure parameter Cn2. Because directly measuring Cn2 over the ocean can be very difficult, Cn2 is determined from measured local environmental parameters such as temperature and humidity in conjunction with parametric models such as the Hufnagel-Valley model. This data is compared with the MODTRAN based atmospheric modeling results to provide an overall assessment of the factors contributing to optical attenuation along the FSO beam pathway. The determination of Cn2 will be also be useful in calculating the time-dependent Fried parameter, r0, which provides an indication of the magnitude of the phase distortion of an optical wavefront by scintillation in accordance with the Kalomogorov model. A high speed (175 fps) Shack-Hartmann wavefront sensor is utilized to measure wavefront distortion of a beam transmitted though the evaporation layer, and thus determine the extent of turbulence encountered along the optical pathway. Through the use of adaptive optics, the wavefront of a transmitted beam is modulated in real time to compensate for turbulence, thereby providing optimal FSO reception. The Kalman filter method is also employed to reconstruct an original undistorted image from a series of sequential transmitted images altered by turbulence. This recursive technique takes into account both measurements and their associated uncertainties to predict the original state in a way that minimizes the mean squared error, for which the theoretical accuracy of the image estimation becomes higher as the number of image samples increases. In addition, atmospheric, free-space, and scintillation losses are analyzed and predicted for extended optical path lengths in view of their impact on FSO data transfer and communication. Furthermore, the effects of weather conditions on FSO transmission are investigated through MODTRAN modeling at the 1.55 µm wavelength. Simulations were performed for multiple elevation angles in atmospheric weather conditions including clear maritime, desert extinction, and various levels of rain and fog to model surface-to-surface and surface-to-air FSO communication networks. Using advanced techniques, many limitations associated with infrared FSO transmission and reception in the evaporation layer may be overcome or circumvented to enable high data rate communication links where the use of fiber is not practical or prohibited.

8184-17, Session 4

5.625 Gbps bidirectional laser communications measurements between the NFIRE satellite and an optical ground

C. T. Lunde, The Aerospace Corp. (United States); M. Gregory, B. Wandernoth, Tesat-Spacecom GmbH & Co. KG (Germany); D. Kozlowski, H. T. Yura, The Aerospace Corp. (United States); F. F. Heine, Tesat-Spacecom GmbH & Co. KG (Germany); A. Paape, German Liaison Office for Defense Material (Germany); R. Meyer, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); R. L. Wong, J. M. Wicker, R. A. Fields, The Aerospace Corp. (United States); W. Hartmann, Orbital Sciences Corp. (United States)

5.625 Gbps bidirectional laser communication has been demonstrated on a repeatable basis between a Tesat Coherent laser communication terminal with a 6.5 cm diameter ground aperture mounted inside the European Space Agency Optical Ground Station dome at Izana, Tenerife and a similar space-based terminal (12.4 cm diameter aperture) on the Near Field Infrared Experiment (NFIRE) low-earth-orbiting spacecraft. Both night and day bidirectional links were demonstrated, with the longest being 177 seconds in duration. Preliminary sub-meter range measurements have been obtained during many of the links, further anchoring absolute pointing knowledge of the space terminal. Correlation with atmospheric models and preliminary atmospheric r0 and scintillation measurements have been made for the conditions tested, suggesting that such systems can be deployed successfully at still lower altitudes without the use of adaptive optics.

8184-18, Session 4

Design and early development of a UAV terminal and a ground station for laser communications

A. Carrasco Casado, R. Vergaz Benito, J. M. Sánchez Pena, Univ. Carlos III de Madrid (Spain)

A free-space laser communication system has been designed and partially developed as an improvement to standard radio frequency links from Unmanned Aerial Vehicles (UAV) to ground stations. This project belongs to the SINTONIA program (acronym in Spanish for

low environmental-impact unmanned systems), led by BR&TE (Boeing Research and Technology Europe) with the purpose of boosting Spanish UAV technology. The work of GDAF-UC3M is under the coordination of INDRA, S.A. and INSA, S.A.

A modulating retroreflector (MRR) has been proposed as a communication terminal on board the UAV, allowing both the laser transmitter subsystem and the acquisition, tracking and pointing (ATP) subsystem to be fully eliminated. This results in an important reduction of power, size and weight onboard the UAV, moving the burden to the ground station. A MEMS-based (Micro ElectroMechanical Systems) modulator has been chosen as the active element in the MRR, capable of modulating a continuous laser beam by switching between an unpowered flat-mirror state to an energized-diffractive state in the order of hundreds of kbps.

In the ground station, the ATP subsystem is based on a GPS-aided two-axis gimbal for tracking and coarse pointing, and a fast steering mirror (FSM) for fine pointing. A beacon-based system has been designed, taking advantage of the retroreflector optical principle, in order to determine the exact position of the UAV in real-time, allowing the FSM system to sustain a continuous fine pointing.

Using an MRR as a transmitter in an optical communication link creates the problem of having the same optical axis for the transmitted and the received beam. The solution proposed in this design is creating two different optical paths within the same physical path. This is possible by deflecting the laser on its way back to a different direction without loss of power using different states of polarization. Since the UAV-to-ground station distance may vary greatly, a beam-width control has been designed to maintain the same beam width of the two lasers (a wider beacon-laser and a narrow communication laser) that reach the UAV. The beam-width control and the polarization-dependent path discrimination makes it possible to use the laser power in an optimal way.

8184-19, Session 4

Nonmechanical beam steering using optical phased arrays

T. E. Dillon, C. A. Schuetz, R. D. Martin, Phase Sensitive Innovations, Inc. (United States); P. F. Curt, J. Bonnett, EM Photonics, Inc. (United States); D. Mackrides, Phase Sensitive Innovations, Inc. (United States); D. W. Prather, Univ. of Delaware (United States)

Interest in nonmechanical beam steering is driven by a number of military applications that utilize free space optical beams. Examples include establishment of communication links, directional IR countermeasures, and laser designators. Desirable traits include high slew rates, wide field of regard, and low SWaP. Beam shaping and the ability to form multiple beams may also be advantageous. As such, we propose the use of a phase-locked array of optical sources, i.e. an optical phased array, which is able to provide these traits to advantage over other proposed techniques.

To this end, we have demonstrated the critical ability to perform phase locking of an optical array and furthermore superpose arbitrary phase profiles over the array. The first function compensates for phase noise introduced into the system from external sources such as heat, stress, or vibration that would otherwise prevent coherent reconstruction of the beam. We are currently able to correct phase errors at 200 kHz and have demonstrated phase stability when subject to a typical CH-53 vibration profile. The second function allows for phases to be added to each channel independently to shape the beam, perform focusing, and enable beam steering.

Quality of the reconstructed beam is influenced by the number of optical fibers or channels in the array, their layout, and the effective fill factor of the array. Our in-house fabrication capabilities are amenable to fiber counts in excess of hundreds, which presents the possibility for low sidelobe levels and significant aggregate power levels. Fill factor can be controlled by the use of collimating microlenses mated to the optical fiber array to provide a high quality output beam.

We have constructed a system based on a 30 channel fiber array and successfully demonstrated beam steering capabilities. The reconstructed beam closely matches simulated results. A commercially available, hexagonally packed array was used at first due to availability, which had limited alias-free field of regard due to the periodicity of the array. As a result, we fabricated our own 30 channel aperiodic array, which avoids the aliasing problem due to its irregular pitch.

Because of constraints imposed by the diameter of optical fiber, minimum spacing of fiber arrays are on the order of 100 wavelengths, which limits the field of regard to a fraction of a degree. However, with the addition of auxiliary optics we have designed systems that demonstrate more than 40° x 40° field of regard. A number of potential designs were explored through Zemax simulations to achieve this. In this paper we present the architecture of our beam steering system and discuss experimental and simulation results that support the viability of our approach.

8184-26, Session KS

Energy and propulsion technologies for unmanned/unattended sensor systems and vehicles

J. A. Parmentola, General Atomics, Inc. (United States)

No abstract available

8184-21, Session 5

Development of a single-chip 6 DOF MEMS IMU for robotic and UV navigation

M. Boysel, T. E. Fiscus, L. J. Ross, Virtus Advanced Sensors (United States)

Urban operations are among the most challenging combat environments for U.S. soldiers. Tactics are complicated by an environment cluttered with buildings that afford many areas of concealment for the enemy. Soldiers often have no knowledge of building layouts and floor plans prior to entry into these structures. Availability of this data prior to follow-on missions in these buildings would significantly increase the U.S. Army's combat capabilities in urban areas resulting in casualty reduction and more rapid mission execution during these challenging and dangerous missions. The army is also increasingly incorporating unmanned systems as a force multiplier which especially is useful in serving as a substitute for soldiers sent into dangerous, unfamiliar territory.

Virtus is participating in efforts to develop soldier worn (or robot-mounted) systems that display the location of each wearer within a GPS-denied area and the map of the environment around the wearer. The system provides 3D mapping and localization for soldiers as they move through buildings. Data can be radioed to a team leader thus providing unparalleled situational awareness without using GPS. The soldier worn system includes a boot-mounted Personal Dead Reckoning (PDR) unit which incorporates an IMU. It is important that the size and cost of the PDR be minimized, so that it does not impede the soldier, and so that each soldier can have one. Such units would also greatly aid in the development and fielding of numerous (i.e. "swarms") of miniature unmanned vehicles sent to an area to perform reconnaissance.

As part of a federally funded project, Virtus is developing a single chip 6-degrees-of-freedom (6 DOF) MEMS IMU that is roughly the same size as, or smaller than, the individual MEMS accelerometers and gyros that make up current multi-chip IMUs. This IMU will be a key component of the systems being developed mentioned above. The IMU consists of a single proof mass 6 DOF MEMS motion sensor integrated into a single package with to a custom mixed signal ASIC containing capacitive drive / sense electronics and digital control and signal processing. The sensor is designed to provide inertial measurements in the +/-10 g and +/-2000 deg/sec ranges. The MEMS sensor chip is 4 mm square and 1.2 mm thick and eliminates the need for mounting sensors along multiple axes. This single chip approach provides a low IMU profile, and, in a volume approximately 100 times smaller, provides similar performance to current MEMS IMUs. This reduced profile IMU, when integrated with magnetometers or GPS in an Inertial Navigation Unit (INU) would in turn reduce the size of the INU. Such a small MEMS IMU should find wide applicability in numerous defense applications including miniature Unmanned Air Vehicles (UAVs), personal navigation and tracking for the warfighter, miniature autonomous robots, and inertial navigation for smart

munitions and missiles. The MEMS sensor has been fabricated and is being characterized. The ASIC, which is dependent upon the MEMS performance specifications is currently being designed. This paper describes the MEMS sensor design, fabrication, modeling, and test results.

8184-22, Session 5

A versatile sensor network for urban search and rescue operations

K. M. Känsälä, A. Mäyrä, VTT Automation (Finland)

The presentation is based in the research work carried out in EU funded project SGL for USaR (Second Generation Locator for Urban Search and Rescue Operations). The aim of this project was to develop wireless standalone communication system with embedded sensor network which can be globally used in rescue operations after accidents or terrorist attacks.

The following guidelines were followed during the development.

The system must be able to operate without external support for several days i.e it should have autonomy with power supply and communication. The devices must be lightweight so that rescue team can easily carry them and finally the devices must be easy to install and use. The range of the wireless communication must cover an area of several square kilometers.

Finally the embedded sensor system must be able to detect sings of life but also detect hazards threatening the rescue operators thus preventing more accidents. It should also support positioning and digital mapping as well as the management of the search and rescue operation.

The sensor system used in the field testing had following properties: CO and CO2 sensors for detection of life, thermal camera for locating live bodies and objects, vibration sensors to detect possible signals of life, to give alarms in case of collapsing buildings or aftershocks (in case of a big earthquake), sound sensor to detect and indicate voice patters coming from different sources. The system also provides a pointing device to locate objects on the search area.

The system has two independent positioning systems. The first one is based on GPS and is suitable for outdoor use and the other one is radio based and it can be used both indoor and outdoor positioning. The system can reduce energy consumption by switching to radio based positioning and switching of the GPS. Radio based positioning has got better accuracy than the GPS.

The communication is divided to two levels: short range local communication with sensor level network and long range high level communication between communication hubs. Local communication has got a coverage of few hundred meters with a high speed low power communication radio system. The same radio system is also used for local positioning of the sensors on the field. High level communication provides high speed communication over point to point links to the command post of the operation within I km range.

In the beginning of the operation each rescue team marks the search area by placing four so called anchor nodes to the four corners of the search area. After this the coordinates of the marked area will be send to the command post and the search are becomes active on digital map of the search operator. The rescue team can place the wireless sensor nodes on the desired spots on the search area. After a sensor is placed and activated it will be visible on the digital map as well and the sensor data also will be visualized and alarms given when necessary. All sensor data with positioning information and time stamps will be stored from each operation on a database for a further analysis of the operation.

This sensor network for urban search and rescue operations has been tested on a field conditions and it has proven to be robust and reliable and provides an energy efficient way of communication and positioning on harsh conditions.

8184-23, Session 5

Managing heterogeneous networks of mobile and stationary sensors

A. Bürkle, P. Solbrig, F. Segor, M. Arens, D. Bulatov, K. Jüngling, P. Wernerus, M. Kollmann, S. Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Protecting critical infrastructure against intrusion, sabotage or vandalism is a task that requires a comprehensive situation picture. Modern security systems should provide a total solution including sensors, software, hardware, and a “control unit” to ensure complete security. Incorporating unmanned mobile sensors can significantly help to close information gaps and gain an ad hoc picture of areas where no pre-installed supervision infrastructure is available or damaged after an incident. Furthermore, specific sensors should be easily deployable on demand, e.g. a gas sensor after an explosion in a chemical plant.

To this end, Fraunhofer IOSB has developed the generic ground control station AMFIS which is capable of managing sensor data acquisition with all kinds of unattended stationary sensors, mobile ad-hoc sensor networks, and mobile sensor platforms. Its main task is to work as an ergonomic user interface and a data integration hub between multiple sensors and a joint operation center. The system is highly mobile and able to control various mobile platforms such as small UAVs (Unmanned Aerial Vehicles) and UGVs (Unmanned Ground Vehicles). These platforms can be directed to potentially interesting locations (manually or autonomously) or sent on patrol.

In order to be adaptable to a wide range of different requirements and applications, AMFIS was developed as a mobile and generic system, which delivers an extensive situation picture in complex surroundings - even with the lack of stationary security technology. In order to achieve maximum flexibility, the system is implemented open and mostly generalized so that different stationary and mobile sensors and sensor platforms can be integrated with minimal effort, establishing interoperability with existing and future assets. The system is modular and can be scaled arbitrarily or be tailored by choosing the modules suitable to the specific requirements.

In order to establish a real-time situation picture, also an image exploitation process is used. In this process, video frames from different sources (mainly from small UAVs) are georeferenced by means of a system of image registration methods. Relevant information can be obtained by a motion detection module. Once detected, objects can be classified as human or non-human. Used with stationary or robot-mounted cameras, the classification process also supports the threat assessment by a classification of the motion itself (e.g. running or crawling). While the object evaluation is running, its position as well as direction and speed of its movement can already be annotated in the operators display. Thus, the image exploitation process can accelerate the situation assessment significantly.

8184-24, Session 5

Toward the development of tamper-resistant, ground-based mobile sensor nodes

D. Mascarenas, C. J. Stull, B. Z. Klein, C. R. Farrar, Los Alamos National Lab. (United States)

Mobile sensor nodes hold great potential for collecting field data using fewer resources than human operators would require and potentially requiring fewer sensors than a fixed-position sensor array. It would be very beneficial to allow these mobile sensor nodes to operate unattended with a minimum of human intervention. In order to allow mobile sensor nodes to operate unattended in a field environment, it is imperative that they be capable of identifying and responding to external agents that may attempt to tamper with, damage or steal the mobile sensor nodes, while still performing their data collection mission. Potentially hostile external agents could include animals, other mobile sensor nodes, or humans. This work will focus on developing control policies to help enable a mobile sensor node to identify and avoid capture by a hostile un-mounted human. The work is developed in a simulation environment, and demonstrated using a non-holonomic,

ground-based mobile sensor node. This work will be a preliminary step towards ensuring the cyber-physical security of groundbased mobile sensor nodes that operate unattended in potentially unfriendly environments.

8184-25, Session 5

An adaptive filter for a small attitude and heading reference system using low-cost sensors

Z. Gong, T. Gao, J. Rao, J. Luo, Shanghai Univ. (China)

Small Attitude And Heading Reference System (AHRS) based on MEMS are small size, light weight, low power consumption, and low cost by the inclusion of micro sensors, such as rate gyroscopes, accelerometers and magnetometer. Small AHRS have many potential uses beyond air- and spacecraft applications. However, the MEMS sensors have large noise, bias and scale factor errors due to drift. The traditional algorithm using a low-cost MEMS sensor is difficultly satisfying the attitude and heading performance requirements.

An extended Kalman filter with adaptive gain was used to build a small AHRS system based on a stochastic model. The adaptive filter has seven states with a time variable transition matrix. The seven states are four quaternion elements and three bias errors for the gyroscopes. The adaptive filter has three measurement variables which are Euler angles gotten for the measurement of accelerometer and magnetometer. The adaptive gain was driven by the movement state such as non-acceleration mode, acceleration mode and high dynamic mode. In one word, the adaptive filter tunes its gain automatically based on the system dynamitic sensed by the movement state to yield optimal performance.

To realize Small AHRS system based on the adaptive filter, Firstly, the hardware system of small AHRS system was designed. Secondely,the translation among three kinds of orientation expression were described.The orientation expression included Euler angle, quaternion and a 3x3 rotation matrix. Thirdly, based on sensors error reasons, the model of three MEMS sensors was set up. Furthermore, the magnetometer was compensated with environment disturb magnetic field by the data analysis. Then a KALMAN arithmetic model was put forward basing on analyzing several kinds of sensors. The state vector, the observation vector, the sate matrix, observation matrix and the adaptive gain were gotten. In order to implemthe arithmetic on the microprocessor, the extended Kalman was gotten through linearizing and discreting above new Kalman filter arithmetic.Finally, to testify the above Small AHRS system, an experiment in static and dynamic states was carried out. Average error and mean square error prove that the snesor system has good performace and satisfies the performance requirement.

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8185-02, Session 1

High operating temperature IR-modules with small pitch for SWaP reduction and high performance applications

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

Current development efforts in IR-module technology show two major trends: reducing size, weight and power (SWaP) of IR-systems and further increase of system performance by introducing 3rd Gen IR modules such as dual-color, dual-band and large format 2-dimensional arrays.

The challenging requirements for IR-modules are not only to reduce SWaP but also cost while still keeping high electro-optical performance. The key to satisfy all these requirements is to reduce pitch size of the detector arrays and integrate them in very compact dewars. Furthermore, necessary condition to use low power and compact cooling engines is to increase the operating temperatures of IR detectors. Therefore high operating temperatures (HOT) of > 120K up to 150K for MWIR detectors and > 80K up to 90K for LWIR detectors are aimed at AIM. The benefits on system level are manifold: on the one hand SWaP reduction is continued on system level, e.g. through no longer need for µ-scanning assemblies. On the other hand operational benefits like increased mission times, longer maintenance periods, high modularity of equipment of infantrymen or reduced vulnerability of platforms rise up. Promising performance data towards HOT IR-detectors were achieved with 640x512, 15µm pitch detector arrays in both spectral bands MWIR and LWIR at AIM. These data as well as latest results of cost-effective produced MCT layers grown on alternate substrates by MBE technology will be presented in the paper.

For advanced reduction of SWaP AIM started the development of a full TV format detector array with 640x480 elements and 12µm pitch size. This detector array is designed for achieving next level of SWaP reduced IR-modules having < 100mm total detector-dewar length and < 4W steady state input power.

Applications like threat warning, persistent surveillance or rotocraft pilotage demand high performance IR detector arrays having beyond one million elements. For these high performance applications AIM is developing large array detector arrays with 1280x1024 pixels in 15µm pitch. The paper will present development status and first results of these large format detector arrays.

8185-03, Session 1

MWIR mercury cadmium telluride detectors for high operating temperatures

P. Knowles, L. Hipwood, L. Pillans, R. Ash, P. Abbott, SELEX Galileo Infrared Ltd. (United Kingdom)

The variable band gap of MCT provides the ability to optimise the cut-off wavelength for a wide range of operating temperatures. In particular, it provides the means to produce a MW detector that is well matched to the 3-5µm atmospheric transmission window at any temperature in the range from 80K up to room temperature.

The practical upper limit of operating temperature for near-background limited performance is influenced by several factors: the fundamental physics of thermal dark current generation and black body emission from the radiation shield, and the technological limitations of MCT diode leakage currents, excess noise, and injection efficiency into the ROIC.

This paper summarises measurements and calculations of HOT performance in Selex Galileo's MWIR detectors and demonstrates that high quality imagery can be achieved up to 175K. The benefits of HOT operation for cooler performance and power dissipation are also quantified.

The baseline for this study is an f/4 detector with 5.5µm MCT cut-off at 80K. The array format is 640x512 with a pixel pitch of 16µm. High quality imagery has been demonstrated up to 175K. With the current state of the art in array processing we find, as temperature is increased, the detector performance is characterised by additional noise, with the median NETD in a 300K scene starting to increase above 160K. Measurements of dark current indicate that it would start to degrade performance above 150K in worst-case scene conditions of -40 degC and calculations of radiation shield emission indicate this would start to degrade performance above 160K in the same conditions.

8185-04, Session 1

New InGaAs SWIR imaging solutions from 3-5Lab

J. Reverchon, A. Djedidi, O. Huet, A. Rouvie, J. Truffer, E. M. Costard, Alcatel-Thales III-V Lab. (France); Y. Ni, B. Arion, Y. M. Zhu, P. Potet, New Imaging Technologies SAS (France)

SWIR imaging based on p-i-n photodiodes arrays presents a tremendous interest in applications such as passive and active imagery camera SWIR imaging based on p-i-n photodiodes arrays presents a tremendous interest in applications such as passive and active imagery camera for laser dew, hot spot or see-spot detection for Lasers Sensors, Enhanced Vision Systems or low light level sensors. The capability to work at room temperature with dark current equivalent to silicon based devices is another pushing reason for the fast development of this technology.

This paper presents several modules and camera based on InGaAs photodiodes arrays from 3-5Lab. First, we describe a module based on a 320x256 array with a pitch of 30 µm. We give the electro-optics performances and particularly the visible extension capabilities. This paper also describes a single-chip InGaAs SWIR camera with more than 120dB intrinsic operational dynamic range with an innovative CMOS ROIC technology initially developed by New Imaging Technologies for visible CMOS camera chip.

We will also present the next generation of focal plane arrays based on a VGA format of 640 x 512 pixels with a pitch of 15 µm. These focal plane arrays will be associated to CTIA based imagers and also to a logarithmic wide dynamic range ROIC. This VGA logarithmic device developed for automotive safety will involve visible extension capability and filtering at pixel levels.

8185-05, Session 1

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

A. Roer, Sensonor Technologies AS (Norway)

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

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

The quantum well thermistor material is transferred to the read-out integrated circuit (ROIC) by wafer bonding. The ROIC wafer containing

the released pixels is bonded in vacuum with a silicon cap wafer, providing hermetic encapsulation at low cost. The resulting wafer stack is mounted in a standard ceramic package.

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

8185-06, Session 1

Design and performance evaluation of graphene-based infrared detectors

N. Xi, Michigan State Univ. (United States)

Global materials scientists and electrical engineers have drawn attentions to study of graphene in recent years. Graphene is a single layer of carbon atomic arranged in a two-dimensional hexagonal honeycomb lattice. It is a fundamental building block for major carbon-based nano materials such as carbon nanotubes and fullerenes. It has be considering as one of the most versatile materials ever discovered. Graphene has many promising properties including unique band structure, zero band gapl, adjustable band structure and high charge carrier mobility. Besides, light-sensitive and flexible graphene can improve the efficiency of optical detectors. Strong photoresponse has been found at the graphene-metal interfaces and high charge carrier mobility makes it work as high-speed optical photodectectors in recent graphene studies. We found graphene has a strong graphene-photon interaction because of its unique and remarkable properties, and this opens up new possibilities for optical sensing applications especially in infrared (IR) regime. A pristine graphene can be considered as a zero bandgap metal and it is possible to open a very small bandgap in bilayer graphene by an applied electric field. These properties make graphene extremely important for IR detection because sensitivity of IR photodetectors is limited by bandgap of sensing materials. With a zero-bandgap graphene, electron-hole pairs can be generated easily by low energy photons such as middle-wave infrared signal. With proper design, the generated electron-hole pairs can contribute to a net photocurrent. A graphene-based IR detector consists of a graphene and metal electrodes. When the graphene contacts with a metal, a Schottky barrier forms at the contact, so a built-in potential forms at the interface. When IR signal illumines at the interface, the built-in potential separates the generated electron-hole pairs that flow as photocurrents. Based on this principle, we demonstrate using the graphene-based devices for infrared detection under a zero-bias operation at room temperature. We have evaluated the performance of the graphene-based detectors and compared them with carbon nanotube detectors. Results indicated that the active area of the graphene detector is 3 times larger than that of nanotube because larger contact area at the graphene-metal interfaces. Besides, we have developed a series of processes to fabricate graphene-based devices, which including an electric-field-assisted method to manipulate graphene flake between metal microelectrodes. The graphene-based IR detectors were fabricated from few-layer-graphene and multi-layer-graphene which were verified by atomic force microscopy and Raman spectroscopy. The results show high potential applications of the electric-field-assisted technique and nano assembly to the production of next-generation devices like graphene-based infrared photodetectors.

8185-07, Session 1

Longwave infrared metamaterials and nano-materials design, simulation, and laboratory test for target camouflage in the defence application

A. Albertoni, BFi OPTiLAS S.A. (Italy)

Metamaterials and nano-materials are suitable for manufacturing a new type of infrared (IR) thermal vision camouflage, useful for defence, military and security application.

The defence and military industry is in fact really interested in evaluating the capability of new kind of materials and structures in order to blocks night vision (NV) thermal sighting capabilities as new countermeasure technology. This is mainly generated by the very detailed signature characterization database, available in most automatic vision systems that are able to detect targets by the IR spectral sign provided by the IR sensor.

These meta and nano designed structures are very small and the order of magnitude of their dimension is about in the range of few decades of microns: it is possible to prepared these structures using a nano particle lattice in the long-wave infrared band (LWIR) band and in the mid-wave (MWIR) band. The infrared thermal properties in these two bands are analysed because popular cooled and uncooled focal plane array 3rd generation (FPA) sensors works in this bands and are currently used by the night vision devices.

The users and the manufacturers are then interested in evaluating the possibility to prepared IR camouflages, which effectively works in the LWIR, for the common uncooled detector, and in the MWIR, for the typical cooled long range devices.

The lattice is designed according to the phonics band gap devices (PBG) photonic crystal theory and works by tuning all the optical properties in the IR wavelengths with an appropriate nano design.

The design is made with the analysis of the electromagnetic wave (EM) wave propagation in the MWIR and LWIR band performed by the direct solutions of the Maxwell electromagnetic (EM) problem with numerical methods and with the traditional theory of the multi layers materials internal reflections, centered in the 4 micron and 10 micron wavelengths.

Photonic crystals samples are tested in the LWIR band, showing the emissivity reduction and camouflage specific properties.

This affects the infrared signature of the targets, by the modification and/or distortion of the emission, reflection and absorption radiance spectral properties.

The tests are done by using PBG samples on stabilized at different temperatures and then checking the emission of each one by an FPA thermal sensor.

During laboratory tests on multiple set of meta materials, it is shown that it is possible to achieve that the meta material act as a full absorbing or full reflecting or mixed (gray absorber) depending of the particular PBG structure used.

8185-08, Session 2

A Performance Figure of Merit for Focal Plane Array Semi-Active Laser Seekers

M. Bray, SELEX Galileo Ltd. (United Kingdom)

Several organisations are currently developing concepts for multi-functional seekers which provide a passive imaging and a semi-active laser (SAL) imaging capability in the same focal plane array. The combination of the two functions in the same seeker has the promise of reducing costs by reducing the number of missile variants. The combination also allows new concepts of operations, for example handover between the two imaging modes during a mission.

Performance of the SAL aspect relies on signal detection above both the detector noise and the solar clutter. Thus system specification is more complex than simply defining the sensitivity of the detector. Using parametric radiometric calculations, we propose a seeker Figure of Merit to take account of the solar clutter. The Figure of Merit could provide an additional specification to guarantee performance of the system. The requirement on the Figure of Merit is estimated for various engagement scenarios and conditions. The performance of the seekers, in this context, is evaluated using published and estimated values for the parameters.

8185-09, Session 2

Response analysis of thermal field disturbance sensor

F. Dvorák, J. Maschke, C. Vlcek, Univ. Obrany (Czech Republic)

The paper continuous to the previous research work dealing with study of sensor of thermal field disturbance. The utilization of polarization maintaining fiber (PMF) birefringence high sensitivity towards the temperature is taken in advantage. The ideal arrangement of proposed sensor is described by means of Stokes vectors and Mueller matrices. The effect of laser source wavelength and optical fiber beat length

towards the fiber response invoked by disturbing temperature field is theoretical analyzed. The development of polarization caused by temperature field is interpreted on the Poincaré sphere by means of MATLAB® environment. The sensitivity of optical fiber response towards the temperature disturbing is experimental verified. The input optical radiation is circularly polarized by means of quarter-wave linear retarder to invoke the excitation of both polarization states of PMF. The optical fibers for wavelength 633 nm and 1550 nm with its beat length 2 mm and 5 mm are used in experiment. Different wavelengths allow comparison between He-Ne and semiconductor laser sources. The experimental work were conducted for different length of disturbing temperature radiation sources from fiber-optic sensor and for different length of sensor exposed to the radiation. The relation of fiber response for wavelength 633 nm towards different magnitude of disturbing temperature radiation was also investigated. The particular results of experimental work are presented in paper. The construction of sensor system with desired sensitivity and selection of its parameters can be realized on the basis of obtained results. This sensor can be used for detection of admission into the guarded room or other similar systems where the fast reaction on the temperature changes is required.

8185-10, Session 2

Adaptive optimization of infrared emission from femtosecond filaments

D. Walter, H. Bürsing, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Over the last years it was demonstrated that femtosecond multi-filaments that are generated in the atmosphere by powerful laser pulses emit a broad supercontinuum spectrum that ranges from the UV up to the far-infrared [1,2]. However, due to the high number of involved filaments the detailed information of the contribution of each single filament remains concealed. To get a better understanding of the complex propagation dynamics of single filaments we investigated the supercontinuum emission in the infrared spectral region. Filaments with different output characteristics were formed in an iterative process with specially enginered femtosecond laser pulses.

The single filaments are generated with a 10 Hz Ti:Sa Laser System (800 nm, 50 fs) with pulse energies betweeen 2 and 5 mJ. Adaptive optics was included in the setup to optimize the emission of the filaments by controlling crucial laser parameters. The temporal phase of the laser pulses was modulated by a programmable Dazzler-device (Fastlite) within the stretcher of the laser amplifier and the spatial phase front was controlled by a 37-channel piezoelectric deformable mirror (PDM, Okotech). The emission of the filaments was recorded in a spectral window between 1.5 µm and 5.3 µm in a single shot setup.

With this optical setup the IR emission signal could be enhanced by a few orders of magnitude. After an optimization the filament emits ultrashort, broadband IR-pulses of high peak power. During the optimization a large variety of complex single shot emission patterns could be isolated. The detected emission of spiral patterns suggests the possibility of spiral propagation of laser light [3].

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8185-11, Session 2

Assessing EO image degradation from underwater optical turbulence

W. W. Hou, A. V. Kanaev, S. Woods, U.S. Naval Research Lab. (United States)

It is a well-known fact that the major degradation source on EO imaging underwater is from scatterings by the medium itself and the constituents within, namely particles of various origins and sizes. Recent researches indicate that under certain conditions, such degradations could yield to the variations of index of refractions associated with temperature and salinity micro-structures in the ocean. These would inherently affect the optical signal transmissions underwater, which are of vital interests to both civilian and military applications, as they could include diver visibility, search and rescue, mine detection and identification, and optical communications. The impacts from the optical turbulence are yet fully understood, in part due to the challenges associated in parameterization of individual factors. This study presents the initial attempts in studying the level of EO image degradation under controlled and measured conditions, in terms of modulation transfer functions, and enhancements using the lucky patch approaches derived from optical flow techniques. Image data collected in lab under controlled conditions, as well as field data during SOTEX (Skaneateles Optical Turbulence Exercise, July 22-31, 2010) using the Image Measurement Assembly for Subsurface Turbulence (IMAST) are presented. Controlled conditions are realized by a large Rayleigh-Benard convection tank. Optical properties of the water column in field were measured using WETLab's ac-9 and LISST (Laser In Situ Scattering and Transmissiometry, Sequoia Scientific), in coordination with temperature, conductivity and depth (CTD, Seabird), velocimeter and Conductivity/Temperature combo (Vector from Nortek, and CT PME), and Vertical Microstructure Profiler (VMP, Rockland).

8185-13, Session 3

A MWIR terrestrial demonstrator using adaptive coded aperture imaging

C. Slinger, Malvern Innovations (United Kingdom); H. Bennett, G. de Villiers, K. Gilholm, N. T. Gordon, D. A. Huckridge, M. McNie, QinetiQ Ltd. (United Kingdom); K. Rice, Goodrich Corp. (United States); K. Ridley, L. Russell, P. J. Watson, QinetiQ Ltd. (United Kingdom)

TBC

8185-15, Session 3

Optical sensors for urban search and rescue operations

A. P. Mäyrä, VTT Technical Research Ctr. of Finland (Finland); A. Agapiou, National Technical Univ. of Athens (Greece); L. Hildebrand, Technische Univ. Dortmund (Germany); K. M. Ojala, VTT Technical Research Ctr. of Finland (Finland); K. Mikedi, M. Statheropoulos, National Technical Univ. of Athens (Greece)

The Second Generation Locator for Urban Search and Rescue Operations (SGL for USaR) is a EU-funded mission oriented towards solving critical problems following massive destruction and large scale structural collapses in urban locations. One part of the project is the development of the standalone portable responder device (FIRST) for operational rescue teams.

Prototype of the FIRST-device include LWIR-camera, VIS/NIR-cameras and illumination optics for UV/VIS and NIR-range, two-way microphones, simple chemical sensors, radio- and GPS-based positioning sensors, accelerometers, Wi-Fi link, and an IMS-device. Integration of these components will allow combination of field chemical analysis, spectral analysis with audio and video analysis for early location of entrapped people, detection of buried people, air quality monitoring in confined spaces, safety and security monitoring

and remote medical support to the located victims.

Hardware selected for the optical sensors of the FIRST-device will be responsible for the fluorescence, VIS, NIR and LWIR range detection as well as supplying required illumination. Specifications were based on the requirements collected from the national rescue teams. Some of the critical properties for the selected components were compact physical size, low power consumption, refresh rate and adequate resolution of the sensor image data.

Optical system will also include two displays, graphical user interface and image processing unit. During the project special image libraries were collected and suitable image processing algorithms based on the collected data were developed. Ergonomics and usability of the device have been developed in co-operation with rescue teams. Special care has been taken to assure that the designed optics will fulfill the strict environmental requirements.

The operational prototype is expected to be finalised in 2011. In the latter stages of the project graphical user interface and image processing algorithms will be further developed in order to make the work and decision making of operational groups more efficient. The designed system will be thoroughly tested and evaluated using realistic scenarios and real rescue teams. SGL for USaR-project will last till October 2012.

8185-16, Session 3

Protection concepts for optronical sensors against laser radiation

G. Ritt, B. Eberle, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

The rapid developments in the laser field through the last years led to very compact laser devices with high brightness. In the visual and near infrared spectral range practically each wavelength is now available. For optronical sensors laser radiation states an increasing threat which cannot be encountered by conventional safety measures like absorption or interference filters.

We present a concept to protect imaging sensors against laser radiation. The system is based on the combination of a spatial light modulator and wavelength multiplexing and allows selective spectral filtering in a defined region of interest in the scene.

Such a system offers the possibility to suppress annoying laser radiation without losing spatial information in the region of interest. Depending on the used imaging sensor, we discuss different ways to realize a control loop to activate the appropriate pixels of the spatial light modulator for the attenuation of the laser light.

8185-17, Session 3

Canopy induced aberration correction in airborne electro-optical imaging systems

J. A. Harder, M. W. Sprague, Elbit Systems of America (United States)

The canopy of an aircraft is designed first and foremost as an aircraft component, with considerations like minimizing the drag co-efficient and the ability to survive a bird strike taking precedence over optical characteristics, but this can become problematic when electro-optical systems are being used by pilots in tactical aircraft to view imagery through an aircraft's canopy. Unfortunately the canopy functions as a less than ideal lens element in the electro-optical sensor optical path. This paper describes how the authors characterized the optical characteristics of an aircraft canopy, and were subsequently able to significantly reduce the effect of the canopy "lens" on the electro-optical system performance. This paper describes how we approached the problem and were able to compensate for the optical contributions in a high resolution imaging system. The methodolgy of how the canopy was analyzed and how the canopy aberrations were corrected is presented for one specific application, although the approach can be applied generally to any aircraft or other vehicle with a canopy or windscreen that demonstrates a lensing effect.

8185-18, Session 3

Architectural solutions of conformal network-centric staring-sensor systems with spherical field of view

A. V. Makarenko, A. V. Pravdivtsev, Constructive Cybernetics (Russian Federation)

The article presents the concept of network-centric conformal electro-optical systems (EOS) construction with spherical field of view. The abstract passive distributed EOS with array detectors based on a group of moving objects are discussed.

EOS conformality means separation of sensory subsystems in space.

Network-centric architecture of distributed EOS combines two interrelated aspects connected with concerted information processing in a integrated event-coordinate-time field.

The discussed class of conformal and network-centric EOS is very effective and productive in solving problems associated with obtaining the coordinates and noncoordinate information about the observed objects.

Distributed network-centric EOS lets you restore the most probable trajectory of the observed object in the global coordinate system, to classify the object and diagnose its state. Moreover, the coordinate data on the observed object is restored without constructing direction finder triangle. The classification/diagnosis of the object and its trajectory synthesis are carried out jointly by combining into a single unit of trajectory-kinematic estimation of the coordinates and logical-probabilistic models of operational and tactical situation and the object behavior with a new approach proposed by the authors - "the logical-kinematic filtration of hypothesis".

Special attention is paid to the question of the EOS boundary configurations, where the property of the distribution and network-centric systems architecture is correct. As the leading parameters were chosen: a combination of spectral bands, the effective number of pixels per steradian; elementary field of view pixel; frame rate; geometrical factor (the range of distances to the observed object and the range of distances between objects within a group). In addition a number of parameters associated with the sensitivity and noise immunity of the detector were analyzed.

In the discussed class of EOS usually use wide-angle optical systems with the individual field of view from 45 x 45 to 180 x 180 degrees. Therefore major parameters of the optical path such as field of view, distortion, PSF shape over the field, the unevenness of the elementary pixel field of view; uneven illumination on the detector depending on the field of view, were separate into specific analytical group. Additionally the question of the analyzing and minimizing the level of the integral stray radiation in optical train was discussed with a new approach proposed by the authors - "MINOS Technology". It was shown that in the case of lenses installation in cold area of the cooled detector the efficiency of MWIR optical systems increased.

Additionally attention was paid the following issues: the optimal allocation of functions between the EOS and IMS, the architecture of the information circuit distributed system, the composition, structure and volume of information flows, performance and stability of communication channels, content and quality of a priori and operational information for data processing algorithms in conformal EOS.

As seen from above the structure concept for described class of EOS is discussed by authors with the systematic and synergy approaches.

8185-19, Session 3

Cryogenic solid Schmidt camera as a base for future wide-field IR systems

A. N. Yudin, Consultant (Russian Federation)

Work is focused on study of capability of solid Schmidt camera to serve as a wide-field infrared lens for aircraft system with whole sphere coverage, working in 8-14 um spectral range, coupled with spherical focal array of megapixel class.

Traditional electro-optical IR systems for 8-14 um range are built around flat photodetector enclosed in cryostat with protective flat

window, containing cold stop. This implies a number of limitations for optical designer, the most significant are:

1. Large required back focal length.

2. Aiming of rays to stop located in cryostat.

3. Frequently there is a limitation of wanted avoidance of placing optical elements inside cryostat, for unification and/or reliability means.

For wide-field systems for whole sphere composite FOV coverage this usually means application of reverse-telephoto designs with refractive, reflective or catadioptric front negative optical group and positive refractive group to provide overall high optical power and to aim rays to aperture stop properly.

These considerations pose significant restrictions of optical design, most evident are:

1. Increase of number of elements, cost, size, reducing of transmission.

2. Aberrational strain on positive group, then it's hard to achieve very fast f/number.

3. Distortion, aberrational vignetting and angle of incidence to detector issues.

4. Uncooled lens contributes greatly to background noise.

Schmidt camera doesn't have problems with distortion and incidence angle, has great aberrational performance and minimum umber of elements. In traditional form it's medium-field lens, limited mostly by obscuration. But solid design, especially in infrared range with high-index materials can compare and outperform traditional reverse-telephoto lenses. Moreover, given fixed focal length and detector size, the faster is the focal number, the smaller is negative influence of obscuration by detector. Front-placed aperture stop naturally leads to all-cryogenic design.

A number of designs of 16 mm f/0.2 lens with 60 to 90 degrees sensor diagonal is presented, their image quality, size, weight and transmission are compared. Achromatic design with significantly improved performance, containing enclosed soft correcting lens behind protective front lens is proposed. Resulting design is mostly limited by lateral color, which is the main problem of all solid catadioptrics, but in discussed application is acceptable due to very low dispersion of germanium/

One of the main goals of the work is to estimate benefits from curved detector arrays in 8-14 um spectral range wide-field systems. Use of flat detector with systems of extreme speed is impractical, so development of spherically curved detector array would greatly improve performance of IR electro-optical wide-field systems.

Coupling of photodetector with solid Schmidt camera by means of frustrated total internal reflection is considered, with corresponding tolerance analysis. This solution simplifies system greatly, giving free choice for detector materials and designs and possibility to avoid use of immersion, impractical for discussed spectral range and high-index materials.

The whole lens, except front element, is considered to be cryogenic, with germanium solid Schmidt unit to be flown around by hydrogen for improvement of bulk transmission. Corresponding benefits from background noise reduction are estimated.

8185-32, Poster Session

Optical liquid-level sensor system using collimator in a metal pipe with small holes

C. Lee, J. Lee, Daegu Gyeongbuk Institute of Science & Technology (Korea, Republic of)

To measure the level of the flammable liquids, optical sensing methods have been reported more effective than other methods based on mechanical and electrical methods. This paper reports a new method that uses a collimator and a small-diameter pipe to measure continuously the height of liquid level.

The liquid-level sensor consists of a gradient-index lens (GRIN lens), a small-diameter metal pipe with small holes, and a floating object as a mirror. The liquid in the tank flow into the metal pipe through small holes and the floating object coated with metal will float over the liquid. The light collimated by a GRIN lens will be reflected at the floating object, which operates like mirror. The light reflected from the mirror is refocused through the GRIN lens and is varied as a function of the liquid distance. It is a simple design using a thin pipe to collect easily the light and controlling the source light intensity for long range. The experimental result was obtained using a thin pipe with a height of 1.0 m and an inner diameter of 1 cm. This configuration avoids using lens to focus the light reflected from the liquid surface and is easy to handle and economical.

8185-33, Poster Session

Detection of small surface vessels in near, medium and far infrared spectral bands.

R. Dulski, M. Kastek, S. Milewski, M. Szustakowski, W. M. Ciurapinski, M. Zyczkowski, Military Univ. of Technology (Poland)

Protection of naval bases and harbours requires close co-operation between security and access control systems covering land areas and those monitoring sea approach routes.

The typical location of naval bases and harbours - usually next to a large city - makes it difficult to detect and identify a threat in the dense regular traffic of various sea vessels (i.e. merchant ships, fishing boats, tourist ships).

Due to the properties of vessel control systems, such as AIS (Automatic Identification System), and the effectiveness of radar and optoelectronic systems against different targets it seems that fast motor boats called RIB (Rigid Inflatable Boat) could be the most serious threat to ships and harbour infrastructure.

In the paper the process and conditions for the detection and identification of high-speed boats in the areas of ports and naval bases in the near, medium and far infrared is presented. Based on the results of measurements and recorded thermal images the actual temperature contrast delta T (RIB / sea) will be determined, which will further allow to specify the theoretical ranges of detection and identification of the RIB-type targets for an operating security system. The data will also help to determine the possible advantages of image fusion where the component images are taken in different spectral ranges. This will increase the probability of identifying the object by the multi-sensor security system equipped additionally with the appropriate algorithms for detecting, tracking and performing the fusion of images from the visible and infrared cameras.

8185-34, Poster Session

Coatings masking in near, medium and far-infrared used for ship camouflage

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

The increasing range of naval engagements results in development of camouflages applied on warships that mask their signatures first in visible and next in and IR spectra. Camouflage applied on warships that mask their IR signatures is one of the most basic countermeasure methods against attacks by heat-seeking missiles. A set of special coatings applied to the ship's hull allows misidentification by enemies weapon and so make the ship harder to destroy. Thus the knowledge on actual thermal contrast between the ship and surrounding background is required in order to provide an effective antimissile defence.

The paper presents selected aspects related to ship's camouflage realized by altering its thermal signature as well as the results of radiometric measurement of thermal radiation of IR-masking coatings. Measurements were performed using IR imaging spectroradiometers in near, medium and far infrared spectra. The presented measurement results constitute the basis for the assessment of the effectiveness of IR masking methods and additionally provide the opportunity to effectively simulate the properties of masking coatings and further to optimize their radiometric properties in the infrared range.

8185-36, Poster Session

Study of time-varying velocity measurement using self-mixing laser diode by Polynomial phase parameter estimation method

Z. Zhang, Y. Gao, China Academy of Engineering Physics (China)

Laser Diode (LD) Self-Mixing (SM) interferometry is an emerging precision photoelectric measuring technology. When a small fraction of the light emitted by LD is backscattered or reflected by an external target and re-enter into the laser active cavity, the laser's output power and frequency are modulated. Because LD output signal's property is similar to the property of conventional two-beam interferometers, so it is called "Self-Mixing". The self-mixing interference measurement system has the merits of simple architecture, naturally self-aligned optical characteristics, compact size and low cost. So, it can replace conventional interferometers in many situations for physical measurements, such as displacement, distance, velocity, and vibration.

In 1970s and 1980s, LDSM had been already used to measure velocity. But all LDSM velocimeter documents we retrieved are aim at low-speed and invariable velocity motion target, variable velocity measurement is not covered. In many practical applications, the movement of objects is uniform, and therefore needs to solve the problems of variable velocity measurement by self-mixing interference. So, this paper puts forward a method based on polynomial phase parameter estimation to analyze laser self-mixing variable velocity measurement.

Laser's optical output power and frequency are modulated when the optical beam is back-scattered into the active cavity of the laser by the moving target. The relationship between laser output power's frequency fluctuation and Doppler frequency are obtained. By signal processing, the Doppler frequency can be acquired, and the target's velocity can be calculated. Based on these properties, an interferometry velocity sensor can be designed. When target move in time-varying velocity mode, it is difficult to extract the target's velocity. A signal processing method of polynomial phase parameter estimation method is presented at first. Then, based on the principle of self-mixing laser diode velocity measurement, the laser diode output's polynomial phase expressions is deduced when the self-mixing laser diode is used to measure time-varying velocity .Namely, a model is proposed for the simulation of time-varying velocity measurement. At last, the signal processing based on polynomial phase is used to obtain target's velocity and acceleration, and the simulation results are presented. The simulation results show that even when the signal-to-noise ratio (SNR) is -21dB, the comparative error of target's velocity and acceleration parameter is 1.56% and 0.03% respectively. The simulation results prove the validity of the algorithm even in the situation of low SNR.

8185-38, Poster Session

Robust scanning scheme over large area for airborne EO/IR camera

Y. Yoon, G. H. Yu, C. G. Noh, D. B. Song, ADD, Agency for Defense Development (Korea, Republic of)

Airborne EO/IR camera(EO/IR) is designed to obtain images of large area. Most of airborne cameras usually have two actuation axes(roll and pitch) to stabilize LOS(line of sight) under angular disturbances as well as to point its LOS to desirable direction. This two-axes actuation structure makes LOS become vulnerable to angular rate disturbance around yaw(heading)axis of aircraft and allows camera to obtain images of only strip vicinity of target instead of rectangular coverage around the target in moderate pitch lead/lag angle direction. These shortcomings, however, can be supplemented through the implementation of proper LOS scanning scheme suggested in this paper.

Generation of pitch angular reference rate command considering predetermined trace of LOS projected on target(earth surface) can be applied to acquire rectangular-shaped image of the target area. Scanning commands for airborne cameras consist of three terms, which are constant scanning rate with respect to earth fixed target, angular rate induced by the translation of sensor frame with respect to the earth fixed target, and the earth craft rate. Unlike other similar airborne camera system where there is only roll component of constant scanning rate, EO/IR has pitch component additionally, which contributes to guarantee LOS tracks on target to be always perpendicular to the direction of aircraft advancement. The pitch constant scanning rate is determined by current pitch/roll angle, flight altitude, aircraft velocity and required roll constant scanning rate with constraint that aircraft should proceed along straight path. As a result, overall scan area around target always maintains rectangular shape regardless of pitch lead/lag angle. Also, product of rotation matrix around heading direction to the transformation matrix from LL(local level) to gimbal coordinates can prevent LOS from swaying under aircraft heading disturbances. Even though aircraft suffers angular disturbance around heading direction, GPS/INS equipped on EO/IR can provide aircraft proceeding direction information in the form of linear velocity. Then comparison between the aircraft proceeding direction and heading information directly extracted from the GPS/INS produces amount of heading angular disturbance inflicting aircraft followed by the matrix calculation already mentioned just before. Simulation results show that the new scanning scheme ensures robust scanning under heading angular disturbances.

This paper describes the new scanning scheme along with overall but brief version of system formation of EO/IR, including introduction to the simulation package which enables us to verify and assess effectiveness of the scanning scheme.

8185-39, Poster Session

The design for embedded network infrared video monitoring system based on Linux OS

L. Liu, Nanjing Univ. of Science & Technology (China); C. Ning, ; X. Zhou, T. Pan, Nanjing Univ. of Science & Technology (China)

The video monitoring system could provide remote video information. It is convenient and intuitive, so it could be widely used in industrial, transportation, finance, teaching and other fields. With the development of computer and network technology, network video monitoring system will replace the traditional monitoring system and play an important role in many fields.

This paper describes the way to design an embedded network infrared video monitoring system based on Linux OS. Firstly, we make a comparison of the hardware solution between some regular monitoring systems, and then design the hardware system that we needed. Our hardware system uses the i.mx27 processor with the ARM9 core. Secondly, the software platform is introduced in this paper. The Linux operate system is applied in our software solution. According to the characteristic of Linux OS, we download uboot to the demo board, transplant the Linux kernel and jffs2 file system to the embedded system, and briefly compile and download drivers. Finally, the application software design process is introduced in the paper. The system can be used to encode the picture captured from infrared CCD, and then send the picture to another same embedded system to decode the picture, and finally display it on the LCD and achieve the goal of the infrared video's remote monitoring. As the infrared CCD would not be affect by the dim light, this monitoring system could be used all day long.

8185-20, Session 4

Remote sensing and field test capabilities at U.S. Army Dugway Proving Ground

J. T. Pearson, U.S. Army Dugway Proving Ground (United States); J. P. Herron, Space Dynamics Lab. (United States); M. S. Marshall, G. W. Lemire, U.S. Army Dugway Proving Ground (United States)

U.S. Army Dugway Proving Ground (DPG) is a major defense test range with the mission of testing chemical and biological defense systems and materials. DPG facilities include state-of-the-art laboratories, extensive test grids, controlled environment calibration facilities, and a variety of referee instruments for required test measurements. Among these referee instruments, DPG has built up a significant remote sensing capability for both chemical and biological detection. Technologies employed for remote sensing of chemicals

include passive scanning FTIR spectroscopy and open path active UV spectroscopy. Technologies used for remote sensing of biological and particulate materials are Raman-shifted eye-safe elastic backscatter Lidar and other non-eye-safe elastic backscatter Lidar systems. These systems provide referee data for bio-simulants, chemical simulants, toxic industrial chemicals (TICs), and toxic industrial materials (TIMs). DPG is also continuously improving its remote sensing capability through upgrading existing systems and development of new technologies and methods. In order to realize a successful large scale open-air test, each type of system requires calibration and characterization. DPG has developed specific controlled environment calibration facilities to meet this need. These facilities are the Joint Ambient Breeze Tunnel (JABT) which is used for bio-simulants, and the Active Standoff Chamber (ASC) which is used for chemical simulants. The JABT and ASC are open ended controlled environment tunnels. Each includes validation instrumentation to characterize a given simulant release within the tunnel. Standoff systems can be positioned at field test distances to collect data from the characterized simulant within the tunnel to calibrate sensitivity. Data from different types of systems can be easily correlated using this method, making later test data more meaningful. Once this is accomplished, DPG has a variety of large scale test grids available for field tests. Meteorological data is collected year round on these test grids to help predict the conditions for a desired test date. After and during testing, data from the various referee instruments is provided in a visual format to more easily draw conclusions on the results. This presentation provides an overview of DPG's standoff testing capabilities and facilities, as well as example data from different test and calibration scenarios.

8185-21, Session 4

SR 5000N IR spectroradiometer's new and enhanced tested performance: speed, FOV response uniformity, high dynamic range, and other measured parameters

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

In a previous paper we have presented the design and the expected performance of the latest generation visible/infrared spectroradiometric system for field use, called SR 5000N. Examples of significantly advanced performance are in compactness, field of view response uniformity, measurement speed, and interchangeability of configuration modules, such as fields of view size, wavelength range and detectors. In this paper we present the actual system performance after being tested in real life.

8185-22, Session 4

FSR: a field portable spectral reflectometer to measure ground targets from NIR to LWIR

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

ABB Bomem has recently designed a field-deployable reflectometer. The Full Spectrum Reflectometer (FSR) measures the diffuse reflectance of surfaces in the 0.7 µm to 13.5 µm spectral range. The spectral resolution is adjustable from 32 to 4 cm-1. The instrument is portable, battery-operated and designed for field usage in a single, lightweight and ruggedized package. In its simplest mode, the instrument is automated and can be operated by non-specialist personnel with minimal training.

The FSR has a laboratory mode to measure targets brought to the instrument in a sampling cup and a field mode with automated measurement sequence. To facilitate the measurement of various ground surfaces, the instrument is packaged in a three-point mount for easy target access and stability. One of the mount is the sampling port. The instrument has its own built-in NIR and LWIR infrared sources to illuminate the ground area to be measured. The instrument includes two built-in references for calibration: a Spectralon diffuser and an Infragold diffuser.

The first units were commissioned to build a spectral database of surfaces in various conditions (humidity, temperature, texture, mixing, etc.) and in the presence of interfering chemicals (oils, solvents, etc.) but the instrument can also serve other purposes such as the identification of unknown materials.

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

8185-23, Session 5

Automatic adjustment of difference of Gaussian (DOG) filter to improve OT-MACH filter performance for target-recognition applications

A. T. Alkandri, N. Bangalore, A. A. Gardezi, P. M. Birch, R. C. Young, C. R. Chatwin, Univ. of Sussex (United Kingdom)

A Wavelet-modified frequency domain Optimal Trade-off Maximum Average Correlation Height (OT-MACH) filter has been trained using 3D CAD models and tested on real target images acquired from a Forward Looking Infra Red (FLIR) sensor. The OT-MACH filter can be used to detect and discriminate predefined targets from a cluttered background. The FLIR sensor extends the filter's ability by increasing the range of detection by exploiting the heat signature differences between the target and the background. A Difference of Gaussians (DOG) based wavelet filter has been use to improve the OT-MACH filter discrimination ability and distortion tolerance. Choosing the right standard deviation values of the two Gaussians comprising the filter is critical. In this paper we present a new technique for auto adjustment of the DOG filter parameters driven by the expected target size. Tests were carried on images acquired by the Apache AH-64 helicopter mounted FLIR sensor, results showing an overall improvement in the recognition of target objects present within the IR images

8185-24, Session 5

Classification of small moving objects in atmospherically-degraded video

E. Chen, Y. Yitzhaky, Ben-Gurion Univ. of the Negev (Israel)

Automated outdoor video surveillance addresses observation of objects such as people and vehicles within a non-static environment, leading to a description of them and of their actions. Surveillance process may include moving object detection and tracking, object classification, human motion analysis, and activity understanding.

When imaging is performed through relatively long distance (one or two kilometers and above) additional difficulties occur which affect the performances of these tasks, since the captured video signals are likely to be degraded by the atmospheric path. The degradation sources that include turbulence and aerosols in the atmosphere cause mainly blur in the images. In video sequences spatiotemporal-varying distortions caused by turbulence become also meaningful. Both of these degradation sources may significantly reduce the ability of acquiring moving objects automatically in long-range imaging. Two main reasons for that are:

1) Since the objects in the video frames are distorted (blurred), the spatial and structural characteristics of the moving objects may be considerably changed, and thus be less informative for higher-level image processing operations such as classification of the objects into categories (such as human, human group, vehicles, animals, etc.).

2) The time-varying image shifts caused by the turbulence induce additional movements in the scene (temporal clutter), which may increase the false alarm (false detection) rate.

These effects become more and more significant as the imaging distance increases and as the sizes of the objects in the image are smaller.

This research aims to study and quantify the effects of these distortions on the ability to classify moving objects. The influence of the atmospheric path distortions on various object features was also examined for this purpose. Furthermore, we examined the effect

of image restoration (de-blurring) on classification performances. Although successful image restoration reduces the blur, it usually increases the noise and may increase the visible effects of the turbulence-induced random movement. Therefore, the influence of image restoration on object recognition and classification is not necessarily obvious. Previous research indicated that the geometrical features obtained after image restoration, better resemble the true properties of the objects. Both synthetic and real degraded videos were employed in this study.

The process of moving object classification may include preliminary stages of moving object detection, feature extraction and object tracking. In our case of long-distance imaging the motion detection process distinguishes moving regions from a dynamic background (using estimated-motion properties). In the feature extraction stage we examine a wide variety of object feature types such as geometrical, textural, invariant moments, and principal components representation. A feature-based object tracking is also used to eliminate false detections due to background movements such as those caused by turbulence. In the final classification stage we examine the effect of blurring on the classification with different types of features, through support vector machine (SVM) classifier.

Results show reduction of the separation of features is the classification process at higher imaging distance (blurrier images). Some improvement is usually achieved when images are restored using blind de-convolution, although image restoration does not improve the prior stage of moving object detection.

8185-25, Session 5

Morphological image processing-based algorithms for automated testing of thermal imagers

Z. Bomzon, E. Eschinasi, L. Brener, CI Systems (Israel) Ltd. (Israel)

Thermal imagers are often tested by analyzing images of targets with well-defined shapes such as squares, crosses, edges and 4-bars , that are projected onto the imager with a collimator. For instance, distortion can measured by projecting a known pattern of pinholes onto the camera, performing image analysis to find the positions of the centroids of the pinholes in the image, and comparing these positions to the expected location of the pinholes if no distortion were present.

There are two problems associated with many of the current algorithms used to test thermal imagers:

1. Many of the procedures require the user to define regions-of-interest within the image in which he expects to find the objects of interest (eg. pinholes) in the image. This process can be cumbersome, especially when multiple objects might be present in the image, in which case it is necessary to define multiple regions of interest

2. Many of the algorithms used for image analysis are sensitive to noise and therefore unstable in systems where the image quality is low. For instance, the system may not be able to identify pinholes if the image contrast is insufficient or varies across the image.

Morphological image processing is an area of image processing that has become a standard tool for imaging scientists. In morphological image analysis, the image is probed with structuring elements, and the manner in which the structuring element fits the within the image is measured. Hence, by using structuring elements that match well with shapes that are expected to appear in an image, it is possible to build robust routines for detecting these shapes, and eliminating noise and interference.

At CI-Systems we have developed a set of robust image analysis algorithms for measuring parameters such as distortion, Amplitude Modulation at Optimum Phase (AMOP) and boresiting of multi-sensor systems. The algorithms utilize morphological image processing to eliminate background and noise and automatically analyze the image to yield the desired measurement. They reduce user setup to a minimum and are robust to noise and interference. Here we present an overview of the procedures we have developed and demonstrate how they can be used to obtain fully automated testing of imaging systems.

8185-26, Session 5

Multi-frame underwater image restoration

A. V. Kanaev, W. W. Hou, S. Woods, U.S. Naval Research Lab. (United States)

Ability to image underwater is highly desired for scientific and military applications, including optical communications, submarine awareness, diver visibility, and mine detection. Underwater imaging is severely impaired by scattering and optical turbulence associated with refraction index fluctuations. This work introduces novel approach to restoration of degraded underwater imagery based on multi-frame correction technique developed for atmospheric distortions. The method represents synthesis of “lucky-region” fusion and optical flow based image warping. “Lucky-region” techniques relying on the presence of sharply focused fragments within degraded images are developed to compensate for imaging medium induced distortions typically found in atmosphere. However, the major differences between atmospheric and underwater imaging are the magnitudes of light scattering and refraction index fluctuations resulting in significantly stronger underwater image distortions. Thus, robust tracking of such distortions using, for example optical flow estimation, is necessary even under relatively benign underwater conditions. The particular implemented “lucky-region” algorithm computes image quality map for each image of the given frame set and subsequently mergers the best focused local regions into the single restored image according to anisotropic evolution equation. Optical flow estimation between the frames is used for warping distorted images with respect to restored image efficiently tracking and compensating for local feature movements between fused images. Developed multi-frame image restoration algorithm is applied to sets of images collected in laboratory under controlled conditions as well as field test data. Reliance of image restoration on sophistication of the optical flow algorithm is shown. Variable degrees of image degradation mitigation which manifest themselves as high spatial frequency content recovery are demonstrated depending on imaging conditions and ratio of typical image spatial frequency scale to typical degradation spatial frequency scale.

8185-27, Session 5

A new TBD-DP algorithm using multiple IR sensors to locate the target launch point

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

Moving target tracking in an IR image sequence under high clutter and noise power has been recently under intensive investigation, and the track-before-detect (TBD) technique based-on dynamic programming (DP) is known to be especially attractive in very low SNR environments ($\leq$3dB). In this paper we present a novel 3-dimensioanl (3D)- TBD-DP technique using multiple IR image sensors. Our approach, which does not require a separate image registration step, uses the pixel intensity values read off jointly from multiple image frames, to compute the merit function value required in the DP process. To overcome the computation burden related with the 3D-DP process, we also propose a novel technique that progressively changes the resolution or the level-of-detail (LOD) of the image. Our simulation results demonstrate that the proposed algorithm has good track detection performance with the computation load of less than an order of magnitude compared with the straight-forward 3D-DP, not employing the LOD technique

The proposed algorithm is described step-by-step below:

STEP 1. Initialization (Frame number k = 1). Initialize Merit function(1). Initialize Mapping function(1) used to map the most likely previous state. For all target parameters (i.e. position and velocity), tp_k = [x, y, z, v_x, v_y, v_z], Merit function(tp_1) = sum of measurements at projected pixel at each camera view coordinate; Mapping function(tp_1) = 0;

STEP 2. Recursion (2 $\leq$ Frame number k $\leq$ K). From the second frame to the last frame, for all target parameter, Merit function(tp_k) = maximum of merit function(k-1) + measurements at projected pixel at each camera view coordinate. Mapping function(tp_k) = argument of maximum of merit function(k-1).

STEP 3. Termination. Find the target parameter tp_K = {tp_K : merit function(tp_K) > threshold}

STEP 4. Backtracking. For each tp_k, k = K-1,...,2 ,1, tp_k = mapping function(tp_(k+1)).

This gives the estimated trajectory.

8185-28, Session 5

Aircraft recognition and tracking device

D. Filis, Research and Informatics Office (SAEP) (Greece); C. Renios, Consultant (Greece)

Air traffic control plays a vital role in today's world. That is because air security calls for a system that allows the user to have a visual contact with the target. Such objects may be either civil aircrafts facing communication problems, loss of control etc. during airport approach or fighter aircrafts not stating their intentions (friendly or not). Such a system can be implemented with the usage of the technology of aircraft recognition and tracking. This has various applications in all areas of air navigation, be they civil or military, spanning from air traffic control and regulation at civilian airports to anti-aircraft weapon handling and guidance for military purposes.

The system presented in this paper is an alternative implementation of identifying and tracking flying objects, which benefits from the optical spectrum by using an optical camera built into a servo motor (pan-tilt unit). More specifically, through the purpose-developed software, when a target (aircraft) enters the field of view of the camera, it is both detected and identified. Then the servo motor, being provided with data on target position and velocity, tracks the aircraft while it is in constant communication with the camera. All the features are so designed as to operate under real time conditions and they are accomplished with a number of algorithms, filters and controllers; Verification Filter, Validation Filter, Motion Detection and Target Position Filters, Servo Speed Controller, Target Position Predictor, Servo Movement Controller and others.

Simulations were also conducted to evaluate system's behavior and response, by relying on actual data of a real aircraft flight that were taken from a real scenario of a target being attacked. Coordinates of the aircraft in three dimensional space (3D) were taken, in which the complete simulation scenario in 3D form was designed. Then, flight paths from two (2) different angles of view were taken, so two (2) simulation scenarios were created. These angles were selected in such a way that it could be able the performance of the system to be examined; under conditions of variable aircraft size (first scenario) and under conditions of variable aircraft speed (second scenario). In both scenarios, it was assumed that an enemy aircraft is attacking a military airport within a six (6) second time window. Moreover, the positions of the original flight path were processed under scale in order these positions to fit in our camera's angle of view.

Finally, system analysis through real measurements was conducted and figures depicting Target Distance from the center of the system, Recognition Algorithm output signal and System output signal (for X-axis, Y-axis and for the whole system as well), were created.

In conclusion, this system enables the user to ascertain the condition of the aircraft and detect any possible external problems so as the necessary steps for guidance and assistance be taken (in case of applications for civil aircrafts); as well as to determine the aircraft's type, country of origin and its weapons, by mobilizing mechanisms of interception (in case of applications for fighter aircrafts).

8185-29, Session 5

3D target tracking in infrared imagery by SIFT-based distance histograms

R. Yan, Z. Cao, Huazhong Univ. of Science and Technology (China)

3D target tracking in forward-looking infrared (FLIR) image sequences taken from an airborne moving platform is an important issue. The given point located at the 3D target, such as its centroid, has to be accurately tracked in the application. However, it is difficult to maintain tracking accuracy due to abrupt image changes in illumination, scale, rotation, and object occlusions.

Recently, SIFT features are widely used in object tracking algorithms which has high tracking performance and accuracy due to its robust capability against rotation, scale change and occlusion. In spite of this, when it is used in tracking a huge 3D target in a FLIR image sequence such as a high building in complicated city background, the tracked point usually shifts away from the correct position as time increases. It arises because the original SIFT tracking algorithm uses the affine transformation model which is effective in one plane to describe changes between two image frames, while the tracked point in the vertical surface of the huge 3D target is not in the same plane as the background. The perspective transformation can not be adopted here to solve this problem either, since we lack the height information of SIFT keypoints in a 2D image and the camera poses. Under the circumstances, the tracking performance and accuracy for 3D target tracking will sharply decline.

In this paper, we propose a novel algorithm for 3D target tracking in FLIR image sequences taken from an airborne moving platform. Our approach uses SIFT keypoints detected in consecutive frames for the point correspondence. To overcome the problem that the tracking accuracy suffers from the affine transformation for a 3D target, the candidate position of the tracked point is firstly estimated by computing the affine transformation using local corresponding SIFT keypoints. Then the correct position of the tracked point is located by an optimal method. The Euclidean distances between a candidate tracked point and each SIFT keypoints in the neighborhood of the candidate point are calculated and are formed into a SIFT-based distance histogram. The distance histogram is defined a cost of associating each candidate point to a correct tracked point using the constraint based on the topology of each candidate tracked point with its surrounding SIFT keypoints. Minimization of the cost is formulated as a combinatorial optimization problem. As a result, 3D target tracking algorithm in infrared imagery by SIFT-based distance histograms is constructed.

Several image sequences including 250 frames each were tested to evaluate the proposed algorithm. For comparing, we also adopt another three tracking algorithms, original SIFT tracking algorithm, SIFT-based quadratic polynomial transformation tracking algorithm which is approximate to perspective transformation, and classical mean shift algorithm. Average value of tracking errors of the proposed algorithm is 2.39 pixels while it is 7.70, 5.52 and 12.04 on original SIFT tracking algorithm, SIFT-based quadratic polynomial transformation tracking algorithm and classical mean shift algorithm, respectively. It demonstrates that the proposed algorithm efficiently improves the tracking performance and accuracy for 3D target tracking.

8185-30, Session 5

Multi-band infrared image for object discrimination based on Gabor tensor filter

Y. Zhao, Northwestern Polytechnical Univ. (China)

Dim or stealth targets discrimination in heavy clutter backgrounds is very useful for infrared search and track systems. However, there is not enough discriminate information in traditional panchromatic infrared images, which makes it very difficult to detect and identify these targets in practical applications. Multispectral infrared imaging techniques exploit the differences between the targets and the background's infrared signature in different wavelength to improve the discrimination performance. These differences should be sued fully in discrimination process, but the correlativity between spatial and spectrum is destroyed when the images are vectorized in traditional methods. The motivation behind designing a tensor discrimination method is to handle the multispectral image as a whole in order to improve the discrimination performance of the traditional method. In this paper, we proposed a tensor Quadratic Correlation filter model, which generalizes the traditional Quadratic Correlation filter. The tensor Quadratic Correlation filter approach is adopted to take into account both spatial and spectral information simultaneously. The 3-mode product between tensor and filter matrix is given for Quadratic Correlation filter. This method doesn't destroy the original spatial structure of multispectral images. By considering the spatial and spectral information in the filter, the probability of discrimination is improved. And an improved multi-way filter for multispectral tensor is performed before tensor Quadratic Correlation filter. The experimental results of ROC curves indicate that our algorithm is effective to improve detection performance of targets in clutter background. And the multispectral images acquired at 8-9 μm , 9-10 μm , 10-11 μm , 11-12 μm , and 8-14 μm were tested in the experiment. We also show

that this novel approach is extremely efficient in applications by using tensor model for multispectral IR image processing.

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8186A-01, Session 1

Laser vibrometry

P. Lutzmann, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

No abstract available

8186A-02, Session 1

New approaches of 3D range-gated imaging in scattering environments

M. Laurenzis, F. Christnacher, E. Bacher, N. Metzger, S. Schertzer, Institut Franco-Allemand de Recherches de Saint-Louis (France); T. Scholz, Technical Ctr. for Ships and Naval Weapons (Germany)

In this contribution we discuss the application of range gated imaging for 3D image acquisition in scattering environments. This work is placed in the context of range gated imaging for the vision through atmosphere with different types of aerosols (like fog, smoke) and for the vision in submarine applications. In the presence of scattering media the image quality i.e. the resolution of different spatial frequencies is reduced due to contribution of scattered light to the imaging process. The amount of scattered light which is recorded depends on the scattering material as well as on the reflectance conditions in the observed scene. Further, an impact of scattered light on the depth resolution can be observed in our investigations. We realized a detailed analysis of the impact of the scattered light on the imaging process and analyzed its influence on the 3D image reconstruction. We studied range gated imaging in our fog tunnel as well as under water. Further, we developed new strategies to avoid degradation of 3D image information and we realized 3D imaging under degraded conditions with high depth accuracy. Due to our results it is possible to enlarge the 3D imaging range in scattering environments.

8186A-03, Session 1

Investigation of the image coding method for 3D range-gated imaging

M. Laurenzis, E. Bacher, S. Schertzer, F. Christnacher, Institut Franco-Allemand de Recherches de Saint-Louis (France)

In this contribution we discuss the method of image coding by multiple exposures of range gated images. This new 3D imaging method is based on the super-resolution depth mapping method where the specific shape of range-gated depth intensity profiles is used to determine the depth of scene from a few images. Using certain multiple exposure sequences it is possible to realize an intensity coding of the depth of scene within a few images. This intensity coding can be used to enlarge the depth mapping range under conservation of the high depth accuracy of the super-resolution method. For the first time we developed a theoretical three state model to give a precise prediction of the number of permutations which can be used for image coding process. With the new 3D imaging method the depth mapping range of range gated imaging increases exponentially with the number of utilized images. Further, we realized for the first time an image coding sequence for 3 range-gated images to enlarge the depth mapping range by a factor of 12. We demonstrate 3D imaging from three images in a range of 460 m to 1000 m using a laser pulse width of 300 ns. In the discussion of our results we recognized that due to the impact of noise, a linking error can be observed during the encoding of the intensity images. This encoding error is critical and leads to enormous errors in the calculation of the depth of scene. But by the application of effective noise reduction strategies and the use of a threshold value to tolerance drift of intensity levels it is possible to reduce this error. Here, we gave detailed analysis of this problem and gave concrete recommendations to develop effective error reduction strategies. All in all, it is shown that the image coding method is a powerful tool for 3D range gated imaging with high depth accuracy.

8186A-04, Session 1

See around the corner using active imaging

O. Steinvall, Swedish Defence Research Agency (Sweden)

This paper investigates the prospects of “seeing around the corner” using active imaging. A monostatic active imaging system offers interesting capabilities in the presence of glossy reflecting objects. Examples of such surfaces are windows in buildings and cars, calm water, signs and vehicle surfaces. During daylight it might well be possible to use mirrorlike reflection by the naked eye or a CCD camera for non-line of sight imaging. However the advantage with active imaging is that one controls the illumination. This will not only allow for low light and night utilization but also for use in cases where the sun or other interfering lights limit the non-line of sight imaging possibility. The range resolution obtained by time gating will reduce disturbing direct reflections and allow simultaneous view in several directions using range discrimination.

Measurements and theoretical considerations in this report support the idea of using laser to “see around the corner”. Examples of images and reflectivity measurements will be presented together with performance examples of potential system applications.

8186A-05, Session 1

Performance evaluation of systems for laser illumination through the atmosphere with adverse condition

H. Laurent, N. Rivière, C. Romain, ONERA (France)

Using laser imaging systems to represent 3-D scene becomes a referent prospective technology in the areas of guidance and navigation. Measurement with high spatial resolution for significant range can be achieved, even in degraded visibility conditions such as the Brown-White Out, rain, fog, sandstorms ... Moreover, this technology is well suited for assisted perception tasks (access to 3D information) and obstacle detection (telemetry of small objects). It is very complementary to conventional enhanced vision systems such as Forward Looking Infrared (FLIR) and millimeter wave radar to provide images of land in environments with limited visibility. It also offers a 3D mapping of land or a single location in relation to the environment, which means alone or coupled with others, can realign and secure real-time database of information used such in a synthetic vision system (SVS).

The objective of the work is to assess the impact of degraded visibility conditions on the laser radiometric propagation. For that, Monte Carlo MC Codes will be used to obtain spatial and temporal evolutions of the laser propagation.

Using our model of performance (MATLIS 4D see. Proc. SPIE 7835, 78350A (2010)) adapted to the degraded conditions issued from the literature or derived from the results of MC modelling, we will study the responses and performance of 3D imaging generic systems (with scanning or 3D focal plane array) on simplified application scenarios.

8186A-06, Session 2

Signal processing for imaging and mapping ladars

C. A. Grönwall, G. Tolt, Swedish Defence Research Agency (Sweden)

The new generation laser-based 3D imaging sensors enable data collection at video rate. This opens up for real-time data analysis but also set demands on the signal processing. In this paper the possibilities and challenges with this new data type are discussed. We present examples of signal processing that are attractive to perform in real-time, with applications in target detection, tracking and mapping. The commonly used focal plane array based detectors produces range estimates that vary with the target's surface reflectance and our experience is that the built-in signal processing may not compensate for that. We propose a simple adjustment that can be used even if some sensor parameters are not known. The cost for the higher data rate is, compared to scanning laser radar systems, lower range accuracy. By gathering range information from several frames the geometrical information of the target can still be achieved. We present an approach of how range data can be used to remove foreground clutter in front of a target. We also illustrate how range data enables target classification in near real-time and that the results can be approved if several frames are co-registered.

8186A-07, Session 2

3D reconstruction from a monocular vision system for unmanned ground vehicles

R. C. Tompkins, Y. Diskin, M. Youssef, V. K. Asari, Univ. of Dayton (United States)

We present a real time 3D reconstruction technique designed to support an autonomously navigated unmanned ground vehicle (UGV). The algorithm presented focuses on the 3D reconstruction of a scene, with color and surface information, using only a single moving camera and a simple 3-DOF orientation sensor. The proposed method uses the information from the orientation sensor to more accurately calculate camera location using visual cues. This precise positioning information enables the reconstruction of a robust 3D model particularly suitable for autonomous navigation and mapping tasks.

After the preprocessing tasks of video stabilization and enhancement, the first algorithmic step is (1) SURF Extraction, wherein we locate stable feature points within each frame using the Speeded-Up Robust Features (SURF). Next, in the (2) Feature Tracking step, every feature in the current frame is matched with the most similar feature in the preceding frames. The (3) Disparity Map is formed by mapping all the disparities of these features between two consecutive frames such that disparities of objects far away are significantly smaller than objects close to the camera plane. The (4) Depth map represents the depth as a function of feature disparity, camera movement and focal length. Since depth alone does not provide information about a point's position in 3D space, (5) Point Localization uses the camera's field of view specification to calculate the point's horizontal and vertical coordinates. Each tracked and localized feature point is then displayed in this 3-dimensional (6) Point Cloud, including color information which is obtained by analyzing the regions around each feature in the input images. To minimize error, only points that can be tracked continuously through a window of several frames are used in the reconstruction. This (7) Point Registration process assembles point positions to form multiple video segments into a single, dense point cloud. The registration process will identify repeating points that will be used to confirm the new UGV position. (8) Position Calculation estimates speed and position by registering and analyzing changes in previously calculated 3D points. Each point carries an (x,y,z) coordinate as well as an RGB component to indicate the feature's color from the original video frame. Finally, a (9) Texturization step improves the 3D scene by incorporating textures and reflections onto detected surfaces.

An autonomous navigation control system utilizes the resulting visually reconstructed scene, centered at the current camera location, to either register its position with a location in a known 3D model, or for obstacle avoidance and area exploration while mapping an unknown environment. The suitability of the reconstruction for mapping tasks can be evaluated using ground-truth measurements of actual objects. The accuracy of the reconstruction for navigation within a known environment can be measured by first establishing the location of the known model and the UGV using GPS, and then comparing that location within the model to the location calculated by registering the reconstructed scene to the known model. We can then use this distance measure, evaluated in a testing set of several environments, as a quantitative accuracy metric.

8186A-08, Session 2

Waveform analysis for airborne and terrestrial laser scanning

A. Ullrich, M. Pfennigbauer, RIEGL Laser Measurement Systems GmbH (Austria)

Scanning LIDAR instruments based on time-of-flight measurement with short laser pulses provide highly accurate 3D information in applications like airborne laser scanning, mobile laser scanning and terrestrial laser scanning. Target range is derived from the time elapsed between emission of the laser pulse and reception of the echo signal originating from the reflection of the laser pulse by a target. Originally such instruments were based on analogue signal processing schemes for echo signal detection and discrimination. The introduction of so-called full waveform systems to the market, digitizing the echo signals and carrying out all the necessary signal processing tasks in the digital domain represented a significant leap in technology. The presentation gives an overview on the development and achievements in the commercial use of echo digitization and waveform analysis. It will also address the specific advantages of the technique compared to conventional (discrete) signal processing and attempts to differentiate the somewhat vague term of full waveform.

8186A-09, Session 2

Resolving range ambiguities in high-repetition rate airborne lidar applications

P. Rieger, A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria)

Correctly determining a measurement range in LIDAR instruments based on time-of-flight measurements on laser pulses requires the allocation of each received echo pulse to its causative emitted laser pulse. Without further precautions this definite allocation is only given under certain conditions constraining the usability of range finders and laser scanners with very high measurement rates. Losing the unambiguousness of ranges in high repetition systems is well known in RADAR and has been coined by the term "multiple time around" (MTA) decades in the past. However fundamental differences in scanning LIDAR to RADAR with respect to MTA processing allow new approaches when dealing with range ambiguities in LIDAR. The paper presents known and novel techniques avoiding or even resolving range ambiguities without any further user interaction required. Such techniques may base upon measures affecting hardware (e.g. spatial multiplexing or modulation of consecutive laser pulses), software (e.g. assumptions about the true measurement range based on a rough DTM) or both hard- and software in order to achieve a high probability of correctly resolved range ambiguities. Furthermore a comparison of different approaches is given, discussing their specific (dis-) advantages and their current status of implementation.

8186A-10, Session 2

Multiple object tracking based on the partition of the bipartite graph

P. V. Babayan, B. A. Alpatov, Ryazan State Radio Technical Univ. (Russian Federation)

In this work an algorithm of the tracking of the set of moving objects is described. An object tracking is defined here as an estimation of the trajectories of all objects in the scene. The important features of the concerned task are crossings of object trajectories and temporary

screenings of the objects by the parts of the background. It is a significant task for the transport monitoring and surveillance machine vision systems. Sometimes the objects are lost and their trajectory estimations are tangled because of the situations of screenings and trajectory crossings. The proposed algorithm performs the recognition of these situations and this helps to increase the performance of the object tracking.

The source data for the proposed tracking algorithm is a list of the parameters of the binary regions extracted from each image from video sequence. It is supposed that this list was previously obtained on the extraction step, performed by a thresholding or a background subtraction algorithm. The main idea of the considered tracking algorithm is to build a bipartite graph that describes an object moving. This graph is built on each frame of an image sequence. The vertices of the graph belong to the extracted binary regions and to the objects detected in the past. Each weight of the edge of the graph is the correspondence measure between the adjacent region and object. These measures are calculated based on the parameters such as size and center coordinates. After that the recourse procedure is used to partition the graph into connected graphs of five types, corresponding to several situations: detection of a new object, object missing, merging of the objects into one region, division of the region and a “simple” object tracking. During the partition some edges of the source graph are excluded. These graphs are used to form a new list of the objects. The parameters of the objects are filtered using the Kalman filtering and the objects are excluded from the list if they are lost for a long time. If the objects are merged, their parameters are stored. This helps to remember the object trajectories in the future, when the region is divided. When an object is detected an unique number is assigned to it. This number allows to identify an object in each image of the sequence and to build a trajectory of its moving. There is a modification of this algorithm that gives a priority to the selected object. The priority increases the time of the tracking for this object. This is helpful for using in close circuit control systems.

The experimental research was performed on a set of image sequences obtained during observations of aerial and ground objects. The objects was extracted by the background subtraction algorithm. The performance measure of the algorithm was the time of the true tracking. The algorithm shows a good tracking performance for both ground and aerial environments. Despite of the recourse property of the algorithm, it has a good computational effectiveness for using in real-time object tracking systems.

8186A-11, Session 3

SNIPOD: an EDA multisensor study for sniper detection

G. Fournier, G. Piau, Y. Duval, EADS France (France); O. Steinvall, L. J. Sjöqvist, I. G. Renhorn, L. Carlsson, H. Habberstad, D. Lindgren, Swedish Defence Research Agency (Sweden); D. Bank, EADS Deutschland GmbH (Germany); M. Kastek, R. Dulski, P. Trzaskawka, Military Univ. of Technology (Poland); R. Otterlei, Snipos AS (Norway); F. Pierre, R. Grasser, C. Jacquelard, CILAS (France)

Under the call “Collective Survivability” of the Defense R&T Joint Investment Program on Force Protection within European Defence Agency (EDA) a multisensor project on sniper detection has been carried out. EADS France Innovation Works was the main contractor and the project title was “Sniper Positioning and Detection” (SNIPOD).

In order to improve the current capabilities, the SNIPOD project has tackled the limitations of up-to-date systems, mainly acoustic and laser-based solutions, investigated complementary promising or upstream technologies, developed signature databases and explored multisensor monitoring and data fusion techniques.

During the project, several technologies have been studied to enable detection both before and after shot. These technologies include thermal IR and passive SWIR for the detection of the sniper body and the muzzle flash. Different types of laser sensors have been studied for pre-shot detection by sight detection. Acoustics has been investigated for the detection of both the muzzle blast and the shock wave. A radar has been used to detect the flying bullet and derive the bullet trajectory. An investigation of potential new technologies (high range resolution laser radar and Doppler laser, THz, seismic, geophones, UV sensors) has also been done in parallel to experimental work.

The project has involved several laboratory and field trials demonstrating both each individual sensor capability as well as the data fusion improvement. Some examples from these experiments will be presented together with the recommendations to EDA and Contributing Member States for future developments.

8186A-12, Session 3

Multisensor configurations for early sniper detection

D. Lindgren, Swedish Defence Research Agency (Sweden); D. Bank, EADS Deutschland GmbH (Germany); L. Carlsson, Swedish Defence Research Agency (Sweden); R. Dulski, Military Univ. of Technology (Poland); Y. Duval, G. Fournier, EADS France (France); R. Grasser, CILAS (France); H. Habberstad, Swedish Defence Research Agency (Sweden); C. Jacquelard, CILAS (France); M. Kastek, Military Univ. of Technology (Poland); R. Otterlei, Snipos AS (Norway); G. Piau, EADS France (France); F. Pierre, CILAS (France); I. G. Renhorn, L. J. Sjöqvist, O. Steinvall, Swedish Defence Research Agency (Sweden); P. Trzaskawka, Military Univ. of Technology (Poland)

This contribution reports some of the fusion results from the EDA SNIPOD project, where different multi-sensor configurations for sniper detection and localization have been studied.

A project aim has been to cover the whole time line from sniper transport and establishment to shot. To do so, combinations of different optical sensors with and without laser illumination have been evaluated, as well as acoustic arrays and solid state projectile radar. From a system point of view, it is assumed that all (or possibly a cost-effective subset of) the sensors are integrated on a compact and mobile platform. A sensor fusion node collects detections and background statistics from the sensors and employs hypothesis testing and multi-sensor estimation programs to produce unified and reliable sniper alarms and accurate sniper localizations. Operator interfaces that connect to the fusion node should be able to support both sniper countermeasures and the guidance of personnel to safety. Although the integrated platform has not been actually built, sensors have been evaluated at common field trials and by using simulations.

The envisioned system is fully automatic, and through the fusion node, the operators are given, in a sense, the best situational picture, considering available sensor data at any time. Beside the mentioned sensors, the fusion node also utilizes terrain models, weather data and ballistic models of various granularities. Today, not all sensor techniques in the study are mature enough to provide automatic detection, however.

In conclusion, all the studied sensors contribute to improved sniper detection capabilities at the system level, although a cost/benefit trade off in many cases would result in a system with perhaps two or three sensors. Today, the acoustic sensor is due to its maturity probably one of them, although the projectile radar may be an interesting alternative post-shot sensor in the future, with potentially better capabilities to detect sub-sonic projectiles. Flash detectors are also interesting post-shot sensors with good signal-to-noise ratio even over long distances, but compared to the acoustics, they are today rather expensive. Optical systems with laser illumination capabilities are very potent when it comes to discover scopes and sniper bodies over large distances, and is of course a candidate for pre-shot sensing. This type of systems is today commercially available, and the algorithms for automatic detection are still developed and improved. The sniper body heat may be clearly visible in the infra red spectra using IR sensors, although automatic detectors are rather prone to false alarms from persons that are not snipers or from animals. Regardless of which sensors that are used in the system, the fusion node unifies the sensor data to reduce the operator load, and also combines sensor data to reduce the false alarm rate and to improve the sniper localization accuracy.

8186A-13, Session 3

MR-i, high-speed dual-cameras hyperspectral imaging FTS

F. M. Prel, L. M. Moreau, S. Lantagne, C. B. Roy, C. A. Vallieres, L. E. Lévesque, ABB Analytical Measurement (Canada)

From scientific research to deployable operational solutions, Fourier-Transform Infrared (FT-IR) spectroradiometry is widely used for the development and enhancement of military and research applications. These techniques include targets IR signature characterization, development of advanced camouflage techniques, aircraft engine's plumes monitoring, meteorological sounding and atmospheric composition analysis such as detection and identification of chemical threats. Imaging FT-IR spectrometers have the capability of generating 3D images composed of multiple spectra associated with every pixel of the mapped scene. That data allow for accurate spatial characterization of target's signature by resolving spatially the spectral characteristics of the observed scenes.

MR-i is the most recent addition to the MR product line series and generates spectral data cubes in the MWIR and LWIR. The instrument is designed to acquire the spectral signature of various scenes with high temporal, spatial and spectral resolution. The four port architecture of the interferometer brings modularity and upgradeability since the two output ports of the instrument can be populated with different combinations of detectors (imaging or not). For instance to measure over a broad spectral range from 1.3 to 13 µm, one output port can be equipped with a LWIR camera while the other port is equipped with a MWIR camera. Both ports can be equipped with cameras serving the same spectral range but set at different sensitivity levels in order to increase the measurement dynamic range and avoid saturation of bright parts of the scene while simultaneously obtaining good measurement of the faintest parts of the scene. Various telescope options are available for the input port.

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

8186A-14, Session 3

Image-based systems for space surveillance: from images to collision avoidance

M. Pyanet, B. Martin, N. Fau, S. Vial, EADS Astrium (France); C. Chalte, P. Beraud, P. Fuss, R. Le Goff, SODERN (France)

In many spatial systems, image is a core technology to fulfil the mission requirements. Depending on the application, the needs and the constraints are different and imaging systems can offer a large variety of configurations in terms of wavelength, resolution, field-of-view, focal length or sensitivity. Adequate image processing algorithms allow the extraction of the needed information and the interpretation of images.

As a prime contractor for many major civil or military projects, Astrium ST is very involved in the proposition, development and realization of new image-based techniques and systems for space-related purposes. Among the different applications, space surveillance is a major stake for the future of space transportation. Indeed, studies show that the number of debris in orbit is exponentially growing and the already existing population of small and medium debris is a concrete threat to operational satellites. This paper presents Astrium ST activities regarding space surveillance for space situational awareness (SSA) and space traffic management (STM). Among other possible SSA architectures, the relevance of a ground-based optical station network is investigated. The objective is to detect and track space debris and maintain an exhaustive and accurate catalogue up-to-date in order to assess collision risk for satellites and space vehicles. The system is composed of different type of optical stations dedicated to specific functions (survey, passive tracking, active tracking), distributed around the globe. To support these investigations, two in-house operational breadboards were implemented and are operated for survey and tracking purposes.

This paper focuses on Astrium ST end-to-end optical-based survey concept. For the detection of new debris, a network of wide field of view survey stations is considered: those stations are able to detect small objects and associated image processing (detection and tracking) allow a preliminary restitution of their orbit.

8186A-15, Session 4

Polarimetric wavelet fractal remote sensing principles for space materials

G. C. Giakos, The Univ. of Akron (United States); R. H. Picard, P. D. Dao, P. N. Crabtree, P. J. McNicholl, Air Force Research Lab. (United States)

A new remote sensing approach based on polarimetric wavelet fractal detection principles will be introduced and the Mueller matrix formalism will be defined, aimed at enhancing the detection, identification, characterization, and discrimination of unresolved space objects at different aspect angles. The design principles of a multifunctional liquid crystal monostatic polarimetric ladar will be introduced and related to operating conditions and system performance metrics. Backscattered polarimetric signal contributions from different space materials will be studied and analyzed using correlation coefficients and wavelets combined with fractals. The depolarization, diattenuation, and retardance of the materials will be estimated using Mueller matrix decomposition for different aspect angles.

The advantages of the presented system are multiple. First, the multifunctional system is well suited for situations where polarimetric BRDF and a linear response are needed over a wide dynamic range, such as under wide variation of signal levels or under different aspect angles. The polarimetric wavelet fractal principles would enhance the capabilities of the ladar to provide not only enhanced characterization and discrimination of the object but also would provide complementary information regarding the object orientation (aspect angle) with respect to the observer. Second, the monostatic polarimetric ladar could be easily reconfigured to operate either in a single-point-detection mode enabling BRDF measurement with enhanced small-angle scattering detection capabilities or in a multiple-point-detection format enabling texture (bidirectional texture function or BTF) measurements, which include the spatial "micro-scale" variation of the BRDF.

8186A-16, Session 4

4D active imaging systems to perform the strategic surveillance of an aircraft environment in bad weather conditions

N. Rivière, H. Laurent, C. Romain, ONERA (France)

Onera, the French Aerospace Lab, develops and models active imaging systems to better understand the relevant physical phenomena impacting on their performances. As a consequence, efforts have been done both on the propagation of a pulse through the atmosphere (scintillation and turbulence effects) and, on target geometries and their surface properties (radiometric and speckle effects). But these imaging systems must operate at night in all ambient illuminations and weather conditions in order to perform the strategic surveillance of the environment for various worldwide operations or to perform the enhanced navigation of an aircraft. Onera has implemented a code for 4D laser imaging systems considering temporal laser backscattered intensity (full wave form). As we aim to image a scene even in the presence of rain, snow, fog or haze, Onera introduces such meteorological effects in this numerical model and compares the simulated point-cloud with measurements provided by commercial imaging systems.

8186A-17, Session 4

Shipborne hydrographic laser scanning

M. Pfennigbauer, P. Rieger, RIEGL Laser Measurement Systems GmbH (Austria); M. Schaich, ArcTron GmbH (Germany)

Applications like hydro-archeology, hydrobiology, or hydraulic engineering sometimes require accurate surveying of submerged areas with point densities usually only achieved with mobile or terrestrial laser scanning. For navigable waterbodies, hydrographic laser scanning from a floating platform represents a viable solution. RIEGL's new hydrographic laser scanning platform VQ-820-G with its exceptionally high measurement rate of up to 110,000 net measurements per second and narrow laser footprint is optimally suited for such applications. We present results from a measurement campaign surveying prehistoric lake dwellings at the Bodensee in Germany. While the aim of typical hydrographic laser scanning applications is to roughly acquire the ground's shape and structure, in this case it was tried to determine the exact position, shape, and attitude of the remainders of the piles. The special requirements with respect to mission planning and data processing are discussed and the performance of the laser scanner is assessed.

8186A-18, Session 4

Remote optical timing system for cycling

F. Culfaz, A. G. McCarthy, H. McArdle, L. Laycock, BAE Systems (United Kingdom); P. Barratt, English Institute of Sport (United Kingdom); M. Parker, British Cycling (United Kingdom); S. Rose, McLaren Applied Technologies (United Kingdom)

A remote laser timing system has been developed for use by the British Cycling team. Five optical Timing Gate Units (TGU) have been installed around the track at the Manchester Velodrome. Each TGU can identify and monitor multiple cyclists during training sessions. Lap and split times can be measured as well as the speeds of individual cyclists passing each gate. The system allows coaches to concentrate on observing the cyclists' technique rather than manually capturing their times. It has resulted in more effective and efficient training sessions that have helped cyclists improve their performance.

In operation, a custom, lightweight and unobtrusive retro-reflective tag is attached to each cycle. These tags have been designed to provide timing reference points as well as a unique ID code. They are interrogated by an eye-safe laser incorporated into each gate. The dimensions and trajectory of the infra-red beam are such that it can accommodate variations in cycle position and inclination across the track. The receiver optics within each gate has been designed to maximise the collection of retro-reflected signal, whilst rejecting background light from within the Velodrome. Following detection, the signal is digitised and buffered; the latter enables the threshold levels to be optimised prior to extracting ID, timing and speed information. Data from the five TGUs are sent to a Central Control Unit (CCU) for processing. A custom GUI has been developed to display the data.

This paper will describe the design issues encountered, and the detailed optical and signal processing solutions. Example results obtained from training sessions will be presented.

8186A-19, Session 5

Damage reconstruction in gas pipelines by remote impact measurement

O. A. Olugboji, Newcastle Univ. (United Kingdom)

Third party damage to petroleum pipelines can be catastrophic if undetected. This damage results in financial losses, environmental pollution and frequent loss of life as a result of explosion. Therefore damage detection and location methods will play a key role in the overall integrity management of a pipeline system.

This work presents the development and testing of a mathematical technique for reconstructing the pressure pulse caused by it from measurements made remotely. When an impulsive event occurs along a pipeline, the pressure pulse propagates in both directions and can be detected and measured by sensors located at different positions along the pipeline. From these measurements the location of the event can be determined and its form reconstructed.

Technique for reconstructing the pulse at it source from the distorted pulses measured were developed using the theory of inverse methods. The theoretical work was validated by experiments using a simulated pipeline.

The experimental work was carried out using an experimental test rig comprising a flexible hose pipe 23 m long and 19 mm diameter with four pressure sensors distributed along the pipe and connected to a data acquisition system.

The technique was tested for both static and flowing air in the pipe, and was found to give good results.

8186A-20, Session 5

Hardware implementation of fuzzy logic for image stabilization

E. Koohestani, Safir Informatics (Iran, Islamic Republic of)

The most important issue in the image stabilization case is to purpose a real-time strategy to achieve the global motion of the whole image. We designed an applicable method to extract the sub-image motions from the detected edge intensity of nine areas thanks to a general convolution algorithm. After that, an innovative tagging criterion helps us to validate the possibility of the correctness of the extracted motion in every windows by considering a variance between sub-convolutions. This criterion gave a meaningful instrument to score the validity of the nine motions in a fuzzy environment to make a globally average motion. Next, the desired motions should suppress by a trained filter and then artificial effect should be smoothed . The hardware and purposed software can be employed in tracking systems properly because of the very managed calculated overhead on a CPU from TriMedia family.

8186A-21, Session 5

A novel technique for accurate velocity measurement using LFM radar

C. Ma, X. Xu, BeiHang Univ. (China)

With the development of wideband radar systems, high-power instrumentation radars for research in space objects detection, tracking and classification have achieved great success. Using of various decoys is an important countermeasure for ballistic missiles. Decoys could be quite sophisticated and complex, but they all conform to the basic requirements of being light in weight compared with a warhead. Thus the fundamental approach to warhead identification is to discern space objects on the basis of motion, size, and shape differences caused by weight constraints.

For this purpose, different techniques have previously been proposed for velocity measurement and compensation using stepped frequency waveforms. Son proposed the phase difference method for object motion compensation of stepped frequency Inverse Synthetic Aperture Radar (ISAR) signature. Alternatively, it should be possible to determine the motion parameter via phase slope measurement for complicated objects. Welsh developed a point scattering model for the frequency response of moving objects using a linear frequency modulated (LFM) radar. Jin studied the wideband radar signatures of a midcourse ballistic target and pointed out that the point scattering model is a simple approximation model. Previous researches have demonstrated that the simulation of the wideband radar signatures based on the ideal points scattering model or geometrical theory of diffraction(GTD) model has limitations as below: (1) Ignorance of the aspect angle changes in the scattering centers; (2) No reflections on correspondent range walk of the scattering centers according to the aspect angle changes.

In this work, we present a novel method for estimating the velocity of a high speed object from its LFM radar signatures based on phase slope analysis. A high fidelity semi-physical wideband radar signature model for dynamic space objects is established where the electromagnetic scattering calculation model and LFM radar signal model are integrated. This method utilizes the phase slope of the

received intermediate frequency signals from the object to estimate the object's kinematic parameters and does not require Fourier processing. Constant false alarm rate (CFAR) filtering is subsequently exploited to enhance the accuracy of the velocity measurement. Then polynomial fitting is incorporated to the proposed method to reduce the estimation errors and improve the robustness. Numerical results demonstrate that the phase slope measurement method yields a unique and accurate estimation for an actual object rather than point scatterers.

8186A-25, Session 5

Results of ACTIM, an EDA study on spectral laser imaging

D. Hamoir, L. Hespel, Y. Boucher, ONERA (France); O. Steinvall, J. Ahlberg, H. Larsson, D. Letalick, Swedish Defence Research Agency (Sweden); E. Repasi, P. Lutzmann, G. Ritt, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

This paper details the main scientific results from the EDA OB study ACTIM. The aim of the study was to investigate the potential of laser imaging, with emphasis on spectral laser imaging, in view of helping the EDA participating Members States (pMS) in forming a common understanding on the research and technology priorities in this area. The work included a literature survey, the identification of the most promising military applications, system analyses for selected applications, a roadmap and recommendations.

Laser imaging, thanks to the quasi-monostatic, short-pulse active illumination allows observing smaller targets at longer ranges, seeing through adverse atmospheric conditions (rain, fog, smoke...), penetrating through obscurants (foliage, camouflage, glass windows, curtains...) and keeping seeing when passive visible or thermal imaging loose contrast (shadows, thermal inversion). When 3D, it is also well suited to producing numerical terrain models, to detecting geometrical changes and to performing robust target identification. Current laser imaging and mapping systems are mostly based on a single-, fixed-frequency laser, generally in the near infrared and often in the so-called eye-safe region (1.5µm).

On the other hand great progress has recently occurred in passive multi- and hyper-spectral imaging with applications ranging from environmental monitoring and geology to mapping, military surveillance, and reconnaissance. Data bases on spectral signatures allow the possibility to discriminate between different materials in the scene. Present multi- and hyper-spectral sensors generally operate in the visible and short wavelength

region (0.4-2.5 µm) and rely on the solar radiation. The measured radiance in the sensor is however difficult to relate to spectral reflectance units due to the dependence on a number of external sources and phenomena such as e.g. solar angle, clouds, shadows, atmospheric scattering or extinction. These variations increase the uncertainty to derive reflectance spectra and to relate these to data bases for material identification.

An active spectral imaging will largely overcome these difficulties by offering a complete control of the illumination. In addition, it will bring all the advantages already sought when using single-frequency active imaging: night and low-light operation, penetration, access to polarization information and to high-resolution 3D information. Hence fusing the knowledge of ladar and passive spectral imaging will result in new capabilities in the field of EO-sensing.

Based on the answers of the pMS experts, we have identified three main application areas and classes of systems for active imaging in general, and for spectral active imaging in particular: (1) long range observation for identification / classification, (2) mid-range mapping for reconnaissance, (3) shorter range perception and warning for autonomous and aided navigation.

We present the system analyses that have been performed for confirming the interests, limitations and requirements of spectral active imaging in these three prioritized applications.

8186A-22, Session 6

The top down design flow of a-Si:H photodiodes with multivariate methods of analysis

C. Merfort, K. Seibel, A. Bablich, K. Watty, M. Böhm, Univ. Siegen (Germany)

A fast and reliable detection of potentially dangerous substances has become very important in ensuring civilian safety in the recent past. Modern security systems could be considerably more effective if objects could be properly characterized and identified. For instance, chemical tests are used to identify samples of any whitish powder that is suspected to be dangerous or illegal. These chemical tests are conducted very quickly. However, they are relatively expensive. Well established methods of optical characterization offer a good alternative. The different interactions of light with the sample constitute the basis of an optical characterization, as discussed in [1]. The need for low cost and disposable devices has driven the development of intelligent photodiodes, especially a-Si:H multispectral photodiodes. These MS-diodes were first manufactured by Rieve et al. in 2000 [2] and exhibit excellent photosensitive qualities related to the dynamic range and the spectral sensivity. In addition to these a-Si:H diodes developed at the IMT exists an inestimable wealth of different sensor approaches optimized for different applications, each with different characteristics of the spectral response. Our aim of reengineering is to develop the best match for the spectral response adjustment. Unfortunately, it is not sufficient to optimize the spectral response only. The complete measurement setup for surface inspection consists of several components that depend on a variety of parameters. The relevant parameters for the reengineering process are the light source, the homogeneity of the samples, the spectral response, the scattered light or noise, the drift of the wavelength, the financial costs and the complexity of the setup.

The top down design flow starts with the calculation of the photocurrent for more than 20 different combinations of light sources, real and simulated spectral responses and whitish powder samples. With these calculations, the influence of the parameters on the color reproduction could be determined. Due to the fact that the photocurrent is equivalent to the three color matching functions X, Y and Z. The next step was to apply a factor analysis to this multivariate data set. The variable binding on two factors leads to a clear decrease in the complexity. The result after the factor analysis can be represented in a 2-D scattergram. Each of the coordinate axes represents one of the two factor values profitability and color reproduction. A negative factor value represents a below average result in all measurements. A positive factor value indicates an extremely good result. The optimum combination of radiation and spectral response is found at the point of intersection of the factor values in the first quadrant.

It is expected that the use of colorimetric values in the field of security would considerably simplify and accelerate the identification of potentially dangerous substances.

[1] C. Merfort, K. Seibel, A. Bablich, K. Watty, M. Böhm, "Continuous Tunable Optical Detectors with a-Si:H Bias Sensitive Photodiodes", presented at the Materials Research Society (MRS) Fall Meeting, Boston, USA, November 28-03, 2010, Paper Number AA17.3

[2] P. Rieve, "Spektralselektive optoelektronische Sensoren auf der Basis amorphen Siliziums, PhD Thesis, (University of Siegen, 2000)

8186A-23, Session 6

Near-infrared power LED for emerging security and defence applications

J. Heerlein, M. Behringer, C. Jaeger, OSRAM Opto Semiconductors GmbH (Germany)

High-power near-Infrared LED (IRED) are gaining more and more interest in a large variety of commercial, industrial and military applications.

IRED are based on InAlGaAs semiconductor structures which cover a spectral range of 780 to 1100 nm. This wavelength range is supposed to be not visible to the human eye. But, depending on the radiant

intensity and wavelength, a reddish glow is still evident. Therefore, in covert applications longer wavelength of 940 nm to 980 nm are preferred due to the much lower sensitivity of the human eye compared to 850 nm. On the other hand at around 850 nm the spectral sensitivity of CMOS or CCD camera or other silicon based photo detectors is at its maximum. We present the latest developments in high power IRED in the quest for more than 1 W from a single 1mm² die.

New emerging applications arise at the horizon and ask for more infrared (IR) power, specific wavelengths and more optical design freedom. Closed-circuit television (CCTV) with IR is used for border control whereas independent of the light situation video pictures must be of good contrast and good resolution. Active near infrared (NIR) night vision systems are being used in various military applications. In all those applications an IR sensitive camera is combined with IR illumination. Further applications using NIR light sources are infrared beacons and tactical lights.

In addition to sole illumination purposes, IRED are also being used for optical data communication due to their fast modulation capabilities (> 100 MHz) compared to other light sources. In all those applications the average optical output power is an important figure of merit.

Classical IRED are bulk emitters, radiating the infrared light in all directions. Due to the reflections at the interface semiconductor - air and related strong light absorption in the semiconductor, the overall electro-optical efficiency is limited to just less than 10%. We present new semiconductor technologies such as Thinfilm structures and in combination the Nanostack principle. Thinfilm structures contain internal reflectors to direct the light to the top surface. Also, the absorption within the thin layer structure is significantly reduced. The Nanostack is a vertical stack of epitaxial grown pn-junctions (electrical series connection) leading to a multiplication of optical power for a given operating current (Fig. 1). These technologies combined, result in record high efficiencies of more than 30% and optical output power / total flux of about 1 W at 1 A from a 1 mm2 die.

Such high optical power is under DC conditions often limited by the power dissipation. Therefore, a low thermal resistance of the package is essential to remove the heat from the pn-junction where the light is generated. New housings with metal core boards or ceramic base are being developed for high power IRED. With such assemblies' low thermal resistances of typically 6.5 K/W for a single 1 mm2 die are realized. Therefore, a DC operation at 1A leads to only moderate heating and operation even at elevated ambient temperature is possible. A further power extension can be achieved with multichip devices which reach optical output power of several Watts.

In summary we are going to present novel technologies for power IRED, give examples and describe their technical capabilities.

8186A-24, Session 6

Interference fiber ring perimeter with FFT analysis

V. Va?inek, J. Vitasek, S. Hejduk, J. Bocheza, J. Látal, P. Koudelka, Technical Univ. of Ostrava (Czech Republic)

Mach-Zehnder interferometers belong to the most sensitive devices for measurements of small changes at optical paths within optical fibers. It means that it is possible to measure both refractive index changes and length changes. According to their lay-out many quantities can be measured. Their great advantage is that they are insensitive on ageing component, from which they are composed of. It is in virtue of herewith, that there are evaluated no changes in optical signal intensity but number interference fringes. For monitoring of dynamical changes of optical paths it is necessary to analyze the changes of interference pattern. The best way of doing this is the usage of FFT. We have used Mach-Zehnder interferometer with PM fiber and PM couplers. Panda PM fibers have been used for interferometer design. Fibers were excited with stable DFB laser at the wavelength of 1550 nm. PM couplers have been optimized for the same wavelength. The length of both interferometer arms was 6 m and it was terminated with optical receiver containing InGaAs PIN photodiode. The photodiode output has been connected to a measuring card module. A part of card module is the supporting SW for signal analysis. The sampling frequency per channel has been 200 kHz. The reference fiber of the interferometer was protected from external influences; the measuring fiber has been fixed to a wooden slab. A movement of persons over the slab was monitored, signal processed with FFT and frequency spectra were evaluated. They rose owing to dynamic changes of interferometric pattern. The results reflect that the individual subjects passing through slab embody characteristic frequency spectra, which are individual for particular persons. The scope of measuring frequencies proceeded from zero to 10 kHz. We have tested the stability of frequency response, amplitude frequency spectra for walking people. We were trying to evaluate the false signal coming from animals, balls impacts, noises from talking people, etc. These experiments were performed on the series of 20 repeated events. The evaluation of experiments displayed that the dispersion of measured values is lower than 2%. We compared these values with previous experiments proceeded with conventional fibers and couplers. The results obtained for PM devices embodied outstanding improvement, typically over 40%.

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8187-01, Session 1

Recent advances with laser DEW

D. D. Seeley, High Energy Laser Joint Technology Office (United States)

No abstract available

8187-02, Session 1

Overview and plans for High Power Laser Conference

H. Ackermann, High Energy Laser Joint Technology Office (United States)

No abstract available

8187-03, Session 1

High power solid state laser and solid state laser testbed experiment

M. Lavan, U.S. Army Space and Missile Defense Command (United States)

No abstract available

8187-04, Session 1

High energy laser test demonstrator

M. Lavan, U.S. Army Space and Missile Defense Command (United States)

No abstract available

8187-05, Session 2

Cryo thin disc laser

T. C. Newell, Air Force Research Lab. (United States)

No abstract available

8187-06, Session 2

Diode pumped alkali lasers

B. V. Zhdanov, R. J. Knize, U.S. Air Force Academy (United States)

Diode pumped alkali vapor lasers, which are under extensive development during the past years, attract a growing interest because of their potential to achieve high power in a high quality beam that is very desirable for various important applications in science, technology and national security areas. These lasers have a number of positive features as compared to other high power lasers (chemical, solid state, fiber lasers) and do not have many of the undesirable features and problems existing in other high power laser systems.

Historically, an optically pumped alkali (potassium) vapor laser was the first laser proposed by A.L. Schawlow and C.H. Townes in 1958, but was not experimentally demonstrated at that time. In the next 45 years, many experiments with alkali vapors were performed that demonstrated stimulated emission, gain and amplified spontaneous emission. However, the real interest to alkali vapor lasers appeared after the first demonstration in 2003 of a really efficient lasing in Rb vapor optically pumped by Ti:Sapphire laser. This interest was stimulated by a possibility of using efficient diode lasers for pumping of alkali vapors that promised very high total wall plug efficiency. Alkali lasers have very high quantum efficiency: 95.3% for Cs, 98.1% for Rb and 99.6% for K as compared to 76% for a 1.06 μm Nd: YAG laser. This is very important not only for increasing the overall laser efficiency, but also for minimizing heating problems, because the energy defect is usually converted into heat released into the gain medium. Gaseous gain medium - a very important feature that allows generate laser beams with excellent spatial quality and diffraction limited divergence. In addition, it helps to reduce thermal problems existing, for example, in solid state lasers, as the gas gain medium can be flowed to remove heat. Alkali lasers can be scaled to higher powers by simple increasing the volume of a gain medium and number of pump sources. And this does not lead to the high light intensity inside the gain medium, like in fiber lasers. The latter means that nonlinear optical effects and optical damage will probably not be limiting factors for alkali lasers. Operating wavelengths of alkali lasers lie within an atmospheric transmission window. They do not use hazardous materials and can be constructed in a closed cell, eliminating the need for vacuum pumping and discharge of chemicals. All these properties and features of alkali lasers show that they can be an alternative to the most developed and successful high power laser systems and even exceed them in many parameters.

In this paper we present a review of the most important achievements in alkali lasers research and development and discuss some problems existing in this field.

8187-07, Session 3

Basic research high-peak power OPO

C. Radzewicz, Univ. of Warsaw (Poland)

No abstract available

8187-08, Session 3

Guiding electric discharge by combined nanosecond and femtosecond pulses

A. A. Ionin, P.N. Lebedev Physical Institute (Russian Federation)

No abstract available

8187-28, Session 3

Single-mode high-power narrow line-width fiber amplifiers

J. Edgecumbe, J. Galipeau, D. Björk, C. Wang, K. Wang, S. Christensen, I. Majid, K. Tankala, Nufern (United States)

The amplification of narrow line-width signals to high power using fiber amplifiers is hindered by the onset of non-linear effects in the fiber - most significantly Stimulated Brillouin Scattering (SBS). The threshold power for the onset of SBS is directly dependent upon the fiber core effective area. This leads to the use of so-called Large Mode Area (LMA) fiber designs. Recently it has been observed at multiple laboratories that these fibers, which support the propagation of a few transverse modes, can lead to beam instability and mode coupling at high power. This limits the output beam quality of the fiber amplifier or laser. We discuss recent results of amplifier designs with near diffraction limited output at greater than 1600W with input line-widths near 10GHz.

8187-09, Session 4

Recent progress in quantum cascade lasers

E. L. Normand, Cascade Technologies Ltd. (United Kingdom)

No abstract available

8187-10, Session 4

Coherent monolithic Quantum Cascade Laser µ-stripes array

M. Carras, G. De Naurois, B. Simozrag, O. Patard, F. Alexandre, X. Marcadet, Alcatel-Thales III-V Lab. (France)

In order to increase the output power of laser diodes while keeping a good far field quality, phase array are a good candidate. We have achieved the fabrication of a monolithic quantum cascade lasers phase array at =8.4µm. The device consists in parallel Quantum Cascade Laser (QCL) waveguides, buried into InP:Fe and phase-locked by evanescent coupling. This micro-structured QCL is a key solution to solve both problems of high temperature elevation and multimodal emission when creating large area lasers. Indeed, QCLs cannot work at room temperature in continuous wave in a simple braod waveguide configuration. The spacing between µ-stripes with InP:Fe enhance lateral thermal extraction. Optical supermodes can be controlled though the array period, chosen inferior to the optical wavelength.

The active layer has been etched by inductively coupled plasma (ICP). Semi-insulating InP:Fe was then selectively regrown by metal organic vapour phase epitaxy (MOVPE) for optical confinement, thermal extraction and electrical insulation purposes (Fig 1.a). Then, InP:Si upper cladding was overgrown with metallic layer deposited on the top (Fig 1.b). Dimensions of the µ-stripes are 2µm large each, constant spacing between 1 µm and 8 µm, and number of emitters up to 16 µ-stripes

Lasers were measured in pulse mode operation at room temperature. Dual-lobes farfield pattern was obtained with lobes narrowing with the array size (i.e. stripes number). Comparaison with a finite element method (FEM) numerical simulation of the 16 µ-stripes array is shown (Fig 2), which accurately depicts the signature of the pure anti-symmetrical supermode. Nearfield image (Fig2 inset) has been taken from a Quantum Well Infrared Photodetector (QWIP) for 8 µ-stripes. It presents a sinus envelope predicted by a supermode emission. Efficient beam combining has been obtained at more than 80% where multi µ-stripes power is compared to the single µ-stripe.

8187-11, Session 4

Coherent combining of quantum-cascade lasers with a binary phase grating

G. Bloom, C. Larat, E. Lallier, G. Lehoucq, S. Bansropun, M. L. Lee-Bouhours, B. Loiseaux, Thales Research & Technology (France); M. Carras, X. Marcadet, Alcatel-Thales III-V Lab. (France); G. Lucas-Leclin, P. Georges, Lab. Charles Fabry (France)

There is an increasing need for powerful sources in the mid-infrared with a good beam quality for DIRCM applications. The quantum cascade laser (QCL) is a promising solution for optical countermeasures. But the maximum power achievable under continuous regime (CW) operation at room temperature is now limited by the heating of the active region. In order to circumvent this limitation, an external beam combining technique can advantageously be applied to deliver the power of several QCL while keeping the beam quality of a single emitter. We have already developed a Michelson type cavity to coherently combine two QCL and have demonstrated a combining efficiency of 85% with a good beam quality. To combine more emitters we used an external cavity with a 1 to 5 beamsplitter. This paper presents the first demonstration of coherent beam addition of five QCL in an external cavity in CW regime.

The five QCL used, made of standard InGaAs/AlInAs active regions emitting at 4.5 µm, have their output facets anti-reflection (AR) coated (R < 2%) to facilitate the phase locking in external cavity. The combining of these five emitters is achieved by a binary phase grating or Dammann grating (DG). The binary phase profile is optimized so that the grating is able to separate an incident beam at 4.5 µm into five beams of equal intensities with a good splitting efficiency. The optimized profile is fabricated in GaAs with UV optical lithography and ICP (Inductively Coupled Plasma) etching. The grating is then AR coated on both the etched facet and the rear one. An experimental splitting efficiency of ~ 75% is obtained along with a good uniformity between the five central orders intensities.

The coherent combining process in an external cavity with a DG can be easily explained. Since a laser tends to oscillate on the mode with the lowest threshold, the external cavity will ensure phase locking between the different lasers and will select the right relative phases so that there are constructive interferences at the common output end (corresponding to the 0th order of the DG). This self-organization process is totally passive since it is based on loss minimization in the external cavity.

A combining efficiency of ~ 60% is measured corresponding to an output power of 250 mW in CW regime at room temperature along with an output beam quality close to the one of an individual QCL. Thus, the laser emission of the external cavity has an increased spatial brightness in comparison with a single emitter.

The current power limitation is mainly due to the loss of 25% introduced by the DG. More power should be obtained using a more efficient beamsplitter such as multilevel phase gratings or continuous phase gratings.

In this paper, the coherent combining of five QCLs in a 5-arms external cavity with a Dammann grating was demonstrated in continuous regime. This method is shown to increase the brightness of QCLs and is thus an efficient solution for the power scaling of these components.

8187-12, Session 4

High power, military ruggedized QCL-based laser systems

E. B. Takeuchi, W. B. Chapman, D. Caffey, D. Arnone, A. Priest, M. Pushkarsky, M. Young, T. Day, Daylight Solutions Inc. (United States)

Multi-watt, multi-wavelength laser systems based upon quantum cascade laser (QCL) technology have been demonstrated to satisfy environmental ruggedization criteria for military applications. Daylight's modular design approach provides integrators with the ability to optimize their system performance, while providing advanced capabilities. Daylight will review the technical performance of commercially available laser modules and systems, as well as discuss several different system embodiments that have been demonstrated to meet military requirements.

8187-13, Session 5

Progress with OPO based systems for mid-IR generation

E. Lippert, Norwegian Defence Research Establishment (Norway)

No abstract available

8187-14, Session 5

Development on ceramic host materials

J. S. Sanghera, U.S. Naval Research Lab. (United States)

No abstract available

8187-15, Session 5

Compact efficient mid-infrared laser source: OP-GaAs OPO pumped by Ho:YAG laser

A. Hildenbrand, C. Kieleck, M. Eichhorn, Institut Franco-Allemand de Recherches de Saint-Louis (France); E. Lallier, D. Faye, A. Grisard, Thales Research & Technology (France); B. P. Gérard, Alcatel-Thales III-V Lab. (France)

Due to a wide transparency range (0.9-17 µm), a low absorption loss (0.01 cm-1), and a laser damage threshold comparable to ZGP crystals (2 J/cm2), combined with excellent nonlinear, thermal and mechanical properties, quasi-phase-matched orientation-patterned gallium arsenide (OP-GaAs) crystals are well adapted for efficient mid-infrared optical parametric oscillator (OPO).

The paper discusses the best results obtained, to our knowledge, with an OP-GaAs OPO pumped by a Q-switched 2.09 µm Ho:YAG laser. The compact (33 x 48 cm) high-repetition rate source developed allows to achieve 4.0 W of average output power in the 3-5 µm range at 40 kHz repetition rate with a 45 % slope efficiency and a very good beam quality ($M^2 < 1.8$). 6.4 W were obtained at 70 kHz with a 51 % slope efficiency, and 7.7 W at 100 kHz with a 46 % slope efficiency. At 40 and 70 kHz, an optical damage occurred at a fluence of 1.9 and 1.5 J/cm² respectively. The performances are limited by the OP-GaAs crystal thickness.

8187-16, Session 6

Spectroscopic methods for detection of impurities

Y. Y. Kalisky, Nuclear Research Ctr. Negev (Israel)

No abstract available

8187-17, Session 6

Role of single photon detection in pulse laser-based optical navigation

J. Blazej, I. Prochazka, Czech Technical Univ. in Prague (Czech Republic)

We are reporting on research, development, and operational results of the photon counting detectors that are being developed in our lab for ground laser ranging and space missions related to laser ranging, optical navigation or precise time transfer by laser pulses. The detector is based on silicon avalanche photodiode operated in a special mode with single photon detection capability in optical wavelength region. Routinely used wavelength is 532 nm, but any below 1.2 microns can be used. The detection chip is controlled by a dedicated circuit. The circuit allows biasing and active quenching of detection structure. The bias is controlled by optional external gate. The ground version of detector is optimized for an precision time tagging of an incoming laser pulse in order of several picoseconds and for high dynamical range of incoming optical signal. The space versions of detectors are optimized for an on-board detection and precision time tagging of an incoming laser pulse. The photon counting approach advantages will be discussed for several time of flight application mainly in order to reduce the systematic biases as much as possible. The optical receiver concept and experiment results in satellite laser ranging and laser time transfer will be presented focused on result overlapping to other optical techniques. Some new application and instrumentation to provide one-way ranging over planetary distances will be discussed.

8187-18, Session 6

Infrared laser irradiation breadboard: dazzling sensitivity analysis of a HgCdTe focal plane array

A. Durécu, P. Bourdon, D. Fleury, D. Goular, C. Planchat, S. Rommeluère, O. Vasseur, ONERA (France)

Nowadays, imaging systems are everywhere. More and more consumer electronics products are equipped with low-cost visible cameras for video grabbing purpose. Many civilian and military applications like video monitoring, target detection or identification rely on the use of high-resolution visible to near-infrared cameras. Even thermal sensors (infrared cameras) that used to be very expensive devices, are becoming more and more common with the development of uncooled focal plane arrays. Similarly, laser sources have evolved towards lower cost and higher power, and the risk of imaging system disturbance due to laser dazzling effects can no more be ignored.

Very few studies of focal-plane-array sensitivity to laser blooming can be found in the open literature, most of these papers offering qualitative results rather than quantitative ones. A more comprehensive understanding of the physical phenomena leading to the dazzling effects is a necessary step on the way to quantify them more accurately and design more resilient sensors.

In this paper we present an experimental bench which has been developed specifically to perform dazzling experiments on mid-infrared focal plane arrays. This dedicated bench delivers an intense laser spot on the focal planes with accurate control of spot diameter, power, location and pulse time sequence. Wavelength and beam direction are kept within the sensor bandwidth and field-of-view.

The main elements of this experimental bench are described i.e. the laser sources, the optical focusing set-up, the power control device and the opto-electronic synchronization subsystem.

With this breadboard, dazzling experiments are conducted on a HgCdTe focal plane. The main parameters affecting dazzling phenomena are varied: laser spot size and position, laser pulse energy level, pulse sequence length and delay and sensor's integration time.

Finally first hints on the quantitative assessment approach of these dazzling effects are proposed.

8187-29, Session 6

Recent advances in helicopter self-protection technology

K. A. Sarkady, U.S. Naval Research Lab. (United States)

Current systems used to protect rotary wing aircraft against IR guided threats are heavy, costly, and some have reliability issues. These characteristics make it difficult to install laser based directed infrared countermeasures systems on small helicopters. Several system concepts and components including missile warning detectors, pointers, lasers, fiber, and processors will be described and discussed. Recent flight test results of a light weight IRCM system will be discussed along with several technology growth paths for self protection components.

8187-19, Session 7

Turbulence effects in a horizontal propagation path close to ground: implications for optics detection

L. J. Sjöqvist, L. Allard, O. K. Gustafsson, M. Henriksson, M. Pettersson, Swedish Defence Research Agency (Sweden)

Atmospheric turbulence effects close to ground may affect the performance of laser based systems severely. The variations in the refractive index along the propagation path cause effects such as beam wander, intensity fluctuations (scintillations) and beam broadening. Typical geometries of interest for optics detection include nearly horizontal propagation paths close to the ground and

up to kilometre distance to the target. The scintillations and beam wander affect the performance in terms of detection probability and false alarm rate. Of interest is to study the influence of turbulence in optics detection applications. In a field trial atmospheric turbulence effects along a 1 kilometre horizontal propagation path were studied using a diode laser with a rectangular beam profile operating at 0.8 micrometer wavelength. Single-path beam characteristics were registered and analysed using five photodetectors arranged in horizontal and vertical direction. The turbulence strength along the path was determined using a scintillometer and single-point ultrasonic anemometers. Strong scintillation effects were observed as a function of the turbulence strength and amplitude characteristics were fitted to model distributions. In addition to the single-path analysis double-path measurements were carried out on different targets. Experimental results are compared with existing theoretical turbulence laser beam propagation models. The results show that influence from scintillations needs to be considered when predicting performance in optics detection applications.

8187-20, Session 7

Time-correlated single-photon counting laser radar in turbulence

M. Henriksson, L. J. Sjöqvist, Swedish Defence Research Agency (Sweden)

A time-correlated single-photon counting (TCSPC) laser radar system can be used for range profiling of objects with high time resolution and dynamic range. A system setup is described and daytime outdoor measurements over distances up to 1 km are presented. The system has 114 ps full width half maximum system response, indicating a Rayleigh criterion resolution of two surfaces separated by 17 mm and much better with more advanced signal processing methods. The high dynamic range and time resolution allows measurement of distances between different optical surfaces in objects such as optical sights. The system thus has a potential use to classify objects and remove false alarms in an optics detection system. Effects of atmospheric turbulence and background radiation in daytime conditions are analyzed. A method for determining the scintillation index in noisy data using the temporal autocorrelation is described. System performance calculations based on measured data indicate that the performance necessary to detect characteristic features of optical sights and other retroreflecting objects may be found in reasonable dwell times well below 100 ms.

8187-21, Session 7

Statistical characteristics of the laser field speckle structure registered in a focal plane of receiving objective

Y. A. Rezunkov, NIIKI OEP (Russian Federation)

Lasers are often used for an active location of low Earth orbit geodesic satellites [1] when the technique of active illumination and registration of the reflected laser radiation is applied. But the laser radiation can sufficiently disturb optical images being recorded by photodetectors of the satellite optical systems. At that one should be mentioned that the scattered laser field has spectacular statistical characteristics [2].

To exclude an influence of the scattered laser radiation on an operation capability of geodesic satellites, main statistical characteristics of the registered laser fields in a plane of receiver optics are to be studied. It is known [3] that the speckles sizes and intensity of the laser radiation depend on both laser characteristics (wavelength, spatial and temporal coherent length) and spatio-power characteristics of recording matrix photo detectors.

In the paper, the statistical characteristics of the laser fields recorded experimentally by using an InSb type of matrix detectors are examined for various illumination conditions of the receiver optical system. Theoretical analysis of the speckled images is based on determination of such field's characteristics as the dispersion and covariance of registered signals and on their dependences on the illumination conditions including the radiation coherence length and illuminating angle.

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2. G.I. Kozin, A.P. Kuznetcov. Spatial coherence and intensity of reflected laser radiation. Quantum Electronics, Vol. 28, No 12, 1998

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8187-22, Session 7

Optical techniques: using coarse and detailed scans for the preventive acquisition of fingerprints with chromatic white-light sensors

M. Hildebrandt, J. Dittmann, Otto-von-Guericke-Univ. Magdeburg (Germany); C. Vielhauer, Fachhochschule Brandenburg (Germany)

The preventive application of automated latent fingerprint acquisition devices can enhance the "Homeland Defence", e.g. by improving the border security. Here, contact-less optical acquisition techniques for the capture of traces are subject to research; chromatic white light sensors employed in contact-less surface measurement devices allow for multi-mode operation using coarse or detailed scans. The presence of potential fingerprints (Regions-of-Interest) could be detected using fast coarse scans. In our experiments we use a FRT MircoProf 200 CWL 600 contact-less surface measurement device to perform exemplary scans. Those scans are acquired with resolutions lower than 250ppi (more than 100 micron between two measured points). Such resolutions do not allow for a reliable extraction of minutia features from fingerprint patterns. Hence, no verification or identification of the fingerprint is possible using coarse scans. Thus, they are privacy preserving.

However, coarse scans allow for a fast detection of potential latent fingerprints as Regions-of-Interest. Those regions can be acquired in detail using much higher resolutions (up to 12500-25000ppi, dot distance of 1-2 micron).

We improve the approach of Hildebrandt et al. for the detection and acquisition of fingerprints on various surfaces that might be relevant within the border control of luggage and freight. In their approach, the fingerprints are automatically located on smooth non-absorbing surfaces by applying a modified variance-based approach on the data acquired with coarse scans. Afterwards, Hildebrandt et al. capture the fingerprints within those Regions-of-Interest by detailed scans. Furthermore, the authors show first results for the age determination of the latent fingerprints. In their approach, a theory of the evaporation of water within the first hours is introduced and supported by a logarithmic short-term aging curve. Hildebrandt et al. suggest the separation of overlapping fingerprints as the last step of the automatic manipulation detection and evidence gathering.

We show extended approaches towards the detection and acquisition of latent fingerprints to reduce the surface material dependency. Additionally, we analyse the impact of potential influences, such as condensing humidity or dust, which might interfere with the investigation. The main purpose for our suggested approach is the secure and reliable non-destructive contact-less optical acquisition and investigation of Regions-of-Interest that are likely to contain fingerprints that allow for further investigations. This is especially important if the original traces might be destroyed or altered during other investigations, e.g. by drug sniffer dogs or explosive detection dogs.

8187-23, Session 8

Infrared decoy and obscurant modelling and simulation for ship protection

B. Butters, E. Nicholls, R. H. Walmsley, Chemring Countermeasures Ltd. (United Kingdom)

Imaging seekers used in modern Anti Ship Missiles (ASMs) use a variety of counter countermeasure (CCM) techniques including guard gates and aspect ratio assessment in order to counter the use of IR decoys. In order to improve the performance of EO/

IR countermeasures and to avoid triggering the ASM CCMs it is necessary to accurately place and configure the deployment of decoys. The capability and capacity of the decoy launcher is therefore crucial in this regard where every wind vector across the ship and threat direction has to be catered for. Ideally the deployed countermeasures will not interfere with the lines of sight of the ship's EO/IR sensors.

Modelling and simulation of naval EO/IR countermeasure scenarios is therefore extremely complex. Over recent years Chemring have developed a Navier Stokes hot smoke model to represent the diffusion, advection and thermal buoyancy of an IR decoy. Effects such as the thermal buoyancy of the IR smoke and its extinction properties also affect the performance of any co-located chaff or other obscurant material. Therefore modelling of the full range of countermeasure materials used in ASM engagements has evolved to a common grid based system to accommodate these effects.

Deployment of the countermeasures requires the development of algorithms based on multi-dimensional solvers to control the countermeasure launch and burst sequence from a launcher that is trainable in azimuth and elevation. The launcher model incorporates realistic azimuth and elevation rates and the engineering constraints on azimuth and elevation arcs of fire. The countermeasure munitions include electronic fusing controlled by the launcher algorithm.

The paper describes the basis of the countermeasure, threat. launcher and ship models used and typical simulation outcomes against generic imaging ASM seekers that use shape discrimination or a guard gate trigger.

Some of the issues regarding decoy placement in different wind conditions and threat aspect are commented on. The paper develops on publications by other authors with regard to the required model fidelity and the importance of the decoy position.

8187-24, Session 8

Signature modelling and radiometric rendering equations in infrared scene simulation systems

C. J. Willers, Council for Scientific and Industrial Research (South Africa); M. Willers, Denel Dynamics (South Africa); N. Sanders, Rochester Institute of Technology (United States); F. D. Lapierre, Royal Belgian Military Academy (Belgium)

The development and optimisation of modern infrared systems necessitates the use of simulation systems to create radiometric realistic representations (e.g. images) of infrared scenes. Such simulation systems are used in signature prediction, the development of surveillance and missile sensors, signal/image processing algorithm development and aircraft self-protection countermeasure system development and evaluation.

Even the most cursory investigation reveals a multitude of factors affecting the infrared signatures of real world objects. Factors such as spectral emissivity, spatial/volumetric radiance distribution, specular reflection, reflected direct sunlight, reflected ambient light, atmospheric degradation and more, all affect the presentation of an object's instantaneous signature. The signature is furthermore dynamically varying as a result of internal and external influences on the object, resulting from the heat balance comprising insolation, internal heat sources, aerodynamic heating (airborne objects), conduction, convection and radiation. In order to accurately render the object's signature in a computer simulation, the rendering equations must therefore account for all the elements of the signature.

In this overview paper, the signature models, rendering equations and application frameworks of three infrared simulation systems are reviewed and compared. The paper first considers the problem of infrared scene simulation in a framework for simulation validation. This approach provides concise definitions and a convenient context for considering signature models and subsequent computer implementation. The primary radiometric requirements for an infrared scene simulator are presented next.

The signature models and rendering equations implemented in OSMOSIS (Belgian Royal Military Academy), DIRSIG (Rochester Institute of Technology,) and SIMIS/OSSIM (CSIR & Denel Dynamics) are reviewed. In spite of these three simulation systems' different application focus areas, their underlying physics-based approach is similar. The commonalities and differences between the different systems are investigated, in the context of their somewhat different application areas.

The application of an infrared scene simulation system towards the development of imaging missiles and missile countermeasures are briefly described.

Flowing from the review of the available models and equations, recommendations are made to further enhance and improve the signature models and rendering equations in infrared scene simulators.

1. INTRODUCTION

2. IMAGE SIMULATION VALIDATION FRAMEWORK

2.1 Qualification, Verification and Validation

2.2 Infrared Simulation Validation in Practice

3. SUMMARY REQUIREMENTS FOR SIGNATURE RENDERING

4. THE DIRSIG SIMULATION SYSTEM

4.1 Target Applications

4.2 Models and Equations

4.3 Implementation Summary

5. THE OSMOSIS SIMULATION SYSTEM

5.1 Target Applications

5.2 Models and Equations

5.3 Implementation Summary

6. THE OSSIM/SIMIS SIMULATION SYSTEM

6.1 Target Applications

6.2 Models and Equations

6.3 Implementation Summary

7. APPLICATIONS IN MISSILE AND COUNTERMEASURE DEVELOPMENT

7.1 Infrared Scene Simulation in Imaging Missile Development

7.2 Infrared Scene Simulation in Missile Countermeasure Development

8. CONCLUSION

8.1 Review

8.2 Recommendations

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8187-25, Session 8

Modelling a man-portable air-defence (MANPAD) system with a conical scan two-colour infrared (IR) seeker

J. Jackman, M. A. Richardson, Cranfield Univ. (United Kingdom); B. Butters, R. H. Walmsley, Chemring Countermeasures Ltd. (United Kingdom); P. W. Yuen, D. B. James, Cranfield Univ. (United Kingdom)

The use of flares against 1st and 2nd generation Man-Portable Air-Defence (MANPAD) systems proved to be very effective. This naturally led to the development of counter-countermeasures (CCM) that could be incorporated into the MANPADs infrared (IR) seeker. One possible CCM is two-colour where the seeker detects in two separate IR bands. It is designed to exploit the different spectral characteristics of the target and flare. In this paper we describe the modelling process of a two-colour conical scan (conscan) IR seeker using CounterSim, a missile engagement and countermeasure simulation software tool developed by Chemring Countermeasures Ltd. It starts by explaining the signal processing needed to be able to reject the flare and track the target. The MANPAD model is then used in an engagement with a transport aircraft model. Flares are first deployed reactively from different dispensers then fired throughout an engagement to investigate the effect of flare release time and the viability of pre-emptive countermeasures.

8187-26, Session 8

Feature-based tracking algorithms for imaging infrared anti-ship missile seekers

G. J. Gray, M. A. Richardson, N. Aouf, Cranfield Univ. (United Kingdom); B. Butters, R. H. Walmsley, E. Nicholls, Chemring Countermeasures Ltd. (United Kingdom)

Infrared guided missiles represent a significant threat to naval surface combatants. As a result, ship self defence against heat seeking anti-ship missiles is an area of ongoing interest and research. Off-board decoy systems, such as flares, can be effective in denying or delaying an infrared missile's acquisition of the target, however, as technologies advance, the missile threat will continue to become smarter and more capable. Reticle based seekers with a single infrared detector have given way to seekers incorporating focal plane array detectors, which produce complete images of their field of view. Because of this, it is possible to include sophisticated image processing based counter-countermeasure techniques to reject decoys and home in on the target.

In order to develop effective countermeasures to imaging infrared seekers, it is necessary to perform simulations of ship-decoy-missile engagement scenarios using high fidelity missile models. CounterSim is a countermeasure simulation environment developed by Chemring Countermeasures Ltd., which provides the ability to perform detailed infrared (as well as radar) guided missile engagement scenarios for air, land and sea targets, in order to test the effectiveness of off-board countermeasures. Reticle and image based models of infrared seekers are available in the CounterSim environment. The facility also exists for the user to define the seeker's tracking algorithm graphically within CounterSim, as well as via a scripting interface to Matlab. Using this interface, this paper will consider a number of different tracking algorithms for imaging infrared missiles, based on image processing and computer vision techniques which are available in the literature.

Tracking algorithms which use object features such as Fourier Descriptors, Moment Invariants and other shape discriminants will be considered. In addition to these geometrical and contour based features, a seeker using interest points generated by the Scale Invariant Feature Transform to track objects will be examined. The effectiveness of flares as protection for a naval vessel, in simulations against these seeker models will be investigated.

8187-27, Session 8

The new optimization method of actively Q-switched quasi-three-level lasers

J. K. Jabczynski, L. Gorajek, M. Kaskow, J. Kwiatkowski, W. Zendzian, Military Univ. of Technology (Poland)

The Q-switched, quasi - three level lasers (QTL) play the important role of efficient pumping sources or main transmitter sources in the majority of optical infrared countermeasures systems. Two laser pumping schemes are typical for such type of lasers: direct, resonant pumping into upper laser level (e.g. Ho doped gain media pumped at 1.9 um wavelength) and indirect pumping with fast relaxation to the upper laser level (e.g. Tm doped media pumped by the laser diodes operating at 0.79 um wavelength). In both cases the lower laser level is partly populated, which causes the significant impact on the performance of QTL laser. The aim of work is to develop efficient theoretical tool enabling analysis and optimization of such type lasers. The model is valid for end-pumped systems for wide class of partially coherent, optical pumping sources (starting from the fundamental mode fiber lasers up to high power multimode laser diode bars). The model consists of two parts: pumping part and Q-switched part, which can be separated in a case of active Q-switching regime. For the pumping of QTL gain medium the semi-analytical model was developed, enabling the calculations for final average occupation of upper laser level for given pump power and duration, spatial pump beam profile, spectroscopy, length and dopant level of gain medium. The both scheme of pumping, moreover ground-state-depletion, up-conversion parasitic relaxation and temperature effects were considered in the model. The new approach for optimization of CW regime of QTL lasers was developed to optimize the Q-switched lasers operating with high repetition rates. For pumping durations comparable to laser upper level lifetimes, the optimization procedure based on Lagrange multiplier technique was developed. The simple analytical formula for effective pump duration to achieve the quasi-stationary inversion for given pump power density and up-conversion parameter was derived. The model enables the optimization of gain medium length and absorbance, average pump area and out-coupling losses for wide class of QTL lasers. The results of modeling were compared with experiments carried out for 2 cases: laser diode pumped Q-switched Tm:YLF laser and Q-switched Ho:YAG laser resonantly pumped by Tm-fiber laser. Moreover, the theoretical analysis and optimization procedure was performed for the laser system consisted of Master Oscillator and Power Amplifier based on Ho:YLF crystals pumped by the same, high power 120-W Tm fiber laser beam.

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8188-01, Session 1

Investigation of security related fully polarimetric signatures of radiometer measurements at W band

S. Dill, M. Peichl, D. Rudolf, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The actual and continuous threat by international terrorism and the increasing number of terroristic attacks raise the danger to the public and create a new and more complex dimension of threat. This evolution must and can only be combat by the application of new counter-measures like advanced imaging technologies for wide-area surveillance and the detection of concealed dangerous objects, in order to protect the human population and sensitive and important infrastructures. The observation of a variety of security critical premises, borders, and maritime coastal areas for instance attracts the increasing attention of companies, institutions, and authorities. Hence there is a strong demand on wide-field-of-view imaging for intruder detection under all adverse ambient conditions. Furthermore the imaging of persons for security purposes is of increasing interest particularly for airline and other transportation services or public events with large crowds. Therefore personnel inspection with respect to weapons and explosives becomes an important mean.

Passive microwave remote sensing allows a daytime independent non-destructive observation and examination of the objects of interest under nearly all weather conditions without artificial exposure of persons and observation areas, hence fully avoiding health risks. The penetration capability of microwaves provides the detection of objects through atmospheric obstacles like bad weather, fog or dust, vapour and smoke, as well as through thin non-metallic materials and clothing. For the latter the detection of hidden objects like weapons, explosives, and contraband is possible by monitoring dielectric anomalies. Furthermore the acquisition of polarimetric object characteristics can increase the detection capability by gathering complementary object information. Based on the physical principles of microwave radiometry, images have a quasi-optical appearance simplifying the image interpretation for the operator. In addition, the sensor operation is inherently passive and covert.

The recent development and construction of a fully-polarimetric W-band receiver at DLR allows the acquisition of a new dimension of information compared to former imaging capabilities. As presented on earlier conferences some interesting features can be detected analyzing polarimetric signatures. The new receiver can be installed on various imaging systems used by DLR over the years. In continuation of previous work this paper will discuss further imaging results recorded recently from security relevant scenarios. In particular, the occurrence and the peculiarities of observed polarimetric phenomena will be introduced and discussed.

8188-02, Session 1

Reducing the acquisition time in a single-sensor passive-millimetre wave (PMMW) imaging system utilizing compressive sensing

J. Nogueira-Nine, Sony Deutschland GmbH (Germany); R. Stirling-Gallacher, Sony Deutschland GmbH (United States)

Single sensor passive millimetre-wave (PMMW) imaging systems typically suffer from long acquisition times, which inhibit their utilization in security applications (i.e. weapon concealed detection systems) where real time operation is required. This is inherent to the physical principle behind the system, where the achievable temperature resolution and the integration time are inversely proportional. The longer the sensor can collect (and integrate) energy radiated by the scene at each position, the finer the temperature resolution becomes. Reducing the integration time without degrading the temperature resolution can be achieved by increasing the bandwidth of the radiometer, but this is possible only up to certain limits.

Solutions based on multi-sensor implementations, where each pixel in the scene is imaged with a dedicated radiometer, have the shortest possible imaging time, determined only by the integration time of one pixel. But multi-sensor imagers are expensive and difficult to implement and to calibrate. Single pixel imagers use a radiometer mounted to a motor or utilise an electronic beam steering antenna, which scans the scene in two dimensions. Here the scanning time is very long and any motor movement adds additional acquisition time.

To reduce the acquisition time we propose to utilise in such single pixel imagers the recent theory of compressive sensing, which establishes that, under special conditions, it is possible to recover a signal of size N, from a reduced number of samples M, where M<<N. These special conditions are: (1) the signal has to be sparse in some domain other than the acquisition one and, (2) the restricted isometry property (RIP), which is satisfied when the representation and the measurement matrices are incoherent.

The images considered here are piecewise smooth and therefore they can be sparsely represented in the transformed total variation domain, hence (1) is valid. The signal measurement takes place in the space domain, so the easiest way to ensure incoherent measurements that satisfies (2), is to acquire the samples randomly across the field of view (FOV) of the scene. However, a random sampling of the scene makes only practical sense for electronic steered beam approaches, and not for motor based ones.

This paper therefore proposes sparse trajectories for a motor based radiometer, designed to achieve a random-like effect with a level of incoherence high enough to successfully recover the image using compressive sensing. Another proposed alternative samples all the pixels in the FOV of the scene, but for each pixel, the integration time is randomly selected from a pool of discrete possible values. The radiometric image is then reconstructed by combining the images obtained from the individual application of compressive sensing to each group of pixels having the same integration time.

For demonstration purposes, a single pixel PMMW imaging simulator has been implemented in Matlab/Simulink, including a configurable radiometric scene generator. The paper presents results from simulated radiometric scenes at 140GHz acquired with the proposed sparse trajectories and recovered using compressive sensing. They show that savings in acquisition time between 50-70% are possible while maintaining the required temperature resolution.

8188-03, Session 1

First results of a high-power, narrow linewidth, dual-color IR laser for the testing of electro-optic based THz spectrometers

D. J. Burdette, C. Blaga, C. Roedig, E. Grabisna, A. Mooney, L. Mosbacker, Traycer Diagnostic Systems, Inc. (United States)

Traycer Diagnostic System has developed a dual-color, continuous wave (CW), double Littman-Metcalf infrared laser that is high power (3 - 15 W), widely tunable (1025 nm -1035 nm), with linewidths on the order of 1 MHz. This infrared laser will be used as a test module to characterize various CW non-linear electro-optic crystals for the generation of THz radiation. As a proof of principle test, this IR laser has been used as the pumping source for a lithium niobate crystal coupled to a silicon prism output coupler. Quantitative results of the output power, bandwidth, signal-to-noise ratio, and THz spectral resolution for this novel spectrometer will be presented.

8188-04, Session 1

First measurements of the 22-GHz Technology Strategy Board (TSB) aperture synthesis passive millimetre wave imager

N. A. Salmon, QinetiQ Ltd. (United Kingdom)

First results from the 32-channel, 22 GHz aperture synthesis imaging system are presented. The system uses a compact array of 32 antenna elements inside a 10 cm diameter array, making the Rayleigh distance for array at 1.5 m. With a gain of 9 dBi the imager has a half angle field of view 35▮. The receiver modules comprise of RF amplifiers, a heterodyne mixers using a local oscillator at 9.4 GHz, and IF amplifiers with a centre frequency of 3.71 GHz and a bandwidth of 300 MHz. The receiver modules are long and narrow to allow this compact configuration, the total antenna-receiver module having a volume of ~15 litres. Signals in the IF bandwidth are cross-correlated and accumulated using a Virtex 5 FPGA based processor, which occupies a volume of 37 litres and weighs 18 kg. Measured receive noise temperatures are in the region of 500 K. Measurements are presented demonstrating the field of view, susceptibility to aliasing, the spatial resolution and the ability to image simple outdoor scenes in far field and indoor scenes in the near field.

8188-05, Session 2

Design of a distributed aperture millimeter-wave imaging system for “see-through” imaging in rotary craft induced degraded visual environments

R. D. Martin, C. A. Schuetz, T. E. Dillon, D. Mackrides, Phase Sensitive Innovations, Inc. (United States); S. Shi, D. W. Prather, Univ. of Delaware (United States)

The demand for all-weather, day-night imaging systems has been spurred by calls for persistent surveillance in security and defense applications, and increased safety in military aviation, such as carrier landings in fog and helicopter landings in sand and dust. To meet these demands requires systems that offer robust imaging capabilities. Whereas visible and infrared systems can provide high resolution imagery in a small-sized package, they are hindered by atmospheric obscurants, such as cloud cover, fog, smoke, rain, sand, and dust storms. Millimeter wavelengths, on the other hand, are not and passive millimeter wave imaging may be one method to reduce, or perhaps even eliminate, the impact of low visibility atmospheric conditions. One primary obstacle to imaging in this spectrum is the aperture size required to achieve the resolution typically desired in surveillance applications, which impacts the volume of the imager. To overcome this limitation, we present a pupil plane, distributed aperture imager whose aperture can be increased without increasing imager volume. Such an imager is achieved by up-converting via phase modulation the millimeter wave radiation to optical wavelengths and detecting the millimeter wave image optically. Thus, since the scale of the image forming elements is fixed, the volume of the imager is not proportional to the cube of the aperture diameter as is the case for a focal plane imager. The advantages of such a system for brownout mitigation and the performance of a 30 element aperiodic system will be discussed.

8188-06, Session 2

Design and performance of a full-Stokes millimeter-wave polarimeter utilizing optical up conversion

J. Wilson, Univ. of Delaware (United States); C. A. Schuetz, R. D. Martin, T. E. Dillon, Phase Sensitive Innovations, Inc. (United States); M. Murakowski, Univ. of Delaware (United States); P. Yao, Phase Sensitive Innovations, Inc. (United States); D. W. Prather, Univ. of Delaware (United States)

Imagers in the millimeter-wave (mmW) spectrum are advantageous due to their ability to operate passively and in adverse weather conditions. Many dielectric materials are highly transmissive at mmW wavelengths such as certain types of clothing and some plastics which can be useful for security screening. The polarization properties of received radiation can include additional information beyond unpolarized measurements. Certain targets can have unique polarization signatures which can aid in the identification of targets. The ability to record full-Stokes information allows a variety of techniques to be applied to mmW imagery such as polarization difference imaging. Several mmW full-stokes polarimeters have already been created and data from these sensors are available in the literature.

Optical up-conversion is an approach to detecting mmW radiation. An electo-optic phase modulator is used to create side bands on a carrier frequency from a laser operating at a telecom frequency. The amplitude of the side band is proportional to the received mmW energy and by stripping away the carrier frequency a photodiode can be used to detect the amplitude of the sideband. Passive mmW sensors have been constructed which are based on optical up-conversion approaches but have been limited to the detection of one or two linear polarization states. The design of a general fully polarimetric mmW imager has been discussed in the literature but no such sensor has previously been created. In this paper, results are presented from a fully-polarimetric mmW imager which is based on optical up-conversion. A division of time approach is used to extract the Stokes parameters from multiple measurements. This approach is scalable to distributed aperture type systems which can have smaller sizes and lower weights versus focal plane array systems. A phase control loop is utilized to compensate for random phases introduced into the optical fibers by vibrations and thermal fluctuations. Two electro-optic phase modulators are used to up-convert two orthogonal linear polarization states to optical wavelengths. The DC bias of one of the phase modulators is used to control the phase through one of the channels. By creating a series of different known phase shifts between the two polarization channels and using a linear polarizer at the backend, the detected intensity will vary with the Stokes parameters.

The measured performance of the sensor will be compared to previous sensors which were not capable of full-Stokes detection. The tradeoff between the signal to noise ratio and the number of detected stokes parameters will be discussed for a variety of polarimetric schemes which can be applied to this type of sensor.

8188-07, Session 2

Minimising the costs aperture synthesis passive millimetre wave imaging systems

N. A. Salmon, QinetiQ Ltd. (United Kingdom)

The high costs of millimetre wave technology are a considerable obstacle to the development of passive imagers and the case for aperture synthesis systems is no exception. A review is presented of the methodology and technologies which can be used to cut the costs of developing passive millimetre wave aperture synthesis demonstrator systems. By keeping the reception frequencies low and sourcing components from low cost commercial sources, demonstrators with tens to hundreds of channels can be afforded. Technologies investigated are commercial satellite receivers, high-speed digital technologies (field programmable gate arrays and graphics processor units) and wide-bandwidth personal computer data acquisition and processing systems.

8188-08, Session 3

Standoff imaging of a masked human face using a 670 GHz high-resolution radar

J. A. Kjellgren, J. Svedin, Swedish Defence Research Agency (Sweden); K. B. Cooper, Jet Propulsion Lab. (United States)

This paper presents an exploratory attempt to use high-resolution radar measurements for face identification in forensic applications.

An imaging radar system developed by JPL [1] was used to measure a human face at 670 GHz. Frontal views of the face were measured both with and without a ski mask at a range of 25 m. The realized spatial resolution was roughly 1 cm in all three dimensions. The frame time was 23 s.

The surfaces of the ski mask and the face were detected by using the two dominating reflections from amplitude data.

Various methods for visualization of these surfaces were evaluated. As the radar bandwidth, 26 GHz, only corresponds to a roughly 4% relative bandwidth, it was clear that speckle severely limited the use of the amplitude data, which thus was omitted.

In some parts of the face, comparing visualized radar images of the masked and the unmasked face, discrepancies were observed. There are mainly two reasons for this; Firstly, the limited spatial resolution does not allow a complete discrimination between the surface of the skin and the mask. Secondly, the tight mask deforms the face to a certain degree. The latter poses a fundamental problem to handle in a potential identification process.

The possible use of radar-based measurements for forensic applications depends upon the accuracy of the data in relation to the variation within the population of interest.

The accuracy of the radar data was estimated by performing a highly accurate face measurement using a stereoscopic optical system, which was used as a reference.

The possibility to use radar data to determine certain face distance measures between well- defined face landmarks, typically used for anthropometric statistics [2], was next explored. Examples of such measures are face length, frontal breadth and interpupillary distance.

The observed measurements for an individual may be used to classify the individual as belonging to a smaller subset of the total population. The average relative size of such a subset depends upon the ratio between the standard deviations of a radar measurement and the standard deviations of the measures for the total population. The size of the subset can be reduced by averaging repeated measurements and by using different measurements taking their correlation into account.

The radar system used in this paper seems to provide information sufficient to exclude a subject from suspicion. It is believed that a system for identification must provide significantly more information. It should be pointed out, however, that the measurement distance of 25 m is higher than typical for our application in mind.

[1] K. B. Cooper, R. J. Dengler, N. Llombart, T. Bryllert, A. Skalare, I. Mehdi, and P. H. Siegel, “Penetrating 3-D Imaging at 4- and 25-m Range Using a Submillimeter-Wave Radar,” IEEE Trancactions on microwave theory and techniques, vol. 56, pp. 2771-2778, 2008.

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8188-09, Session 3

Super resolution and optical properties of THz double line array based on Glow Discharge Detector (GDD) pixel

A. Abramovich, Ariel Univ. Ctr. of Samaria (Israel); N. S. Kopeika, Ben-Gurion Univ. of the Negev (Israel); D. Rozban, Ariel Univ. Ctr. of Samaria (Israel) and Ben-Gurion Univ. of the Negev (Israel); A. Levanon, Ben-Gurion Univ. of the Negev (Israel); A. Akram, Ariel Univ. Ctr. of Samaria (Israel) and Ben-Gurion Univ. of the Negev (Israel); H. Joseph, O. Yadid-Pecht, A. Belenky, Ben-Gurion Univ. of the Negev (Israel)

The properties of terahertz (THz) radiation are well known. They penetrate well most non-conducting media; there are no known biological hazards, and atmospheric attenuation and scattering is lower than visual and IR radiation. Thus THz imaging is very attractive for homeland security, biological, space, and industrial applications

Recently we have found experimentally that inexpensive miniature neon indicator lamp Glow Discharge Detectors (GDD) can be used as THz detectors. Based on the GDD we designed, constructed, and experimentally tested a 8X8 GDD array. In order to improve the performance and the resolution of the THz images a larger array is required. In this work we use a special double line 2X18 moving array detector. This enables us to employ the scanning method in order to get 36X36 pixel THz images. Furthermore, using this double line array it will be possible to employ super resolution methods. Optical properties such as optical transfer function and measurement of point spread function are presented.

8188-10, Session 3

First results of an 80 x 64 pixel, broadband, real-time THz imager

D. J. Burdette, Traycer Diagnostic Systems, Inc. (United States); P. Fay, Univ. of Notre Dame (United States); K. Sertel, G. C. Trichopoulos, K. Topalli, The Ohio State Univ. (United States); Z. Zhang, Univ. of Notre Dame (United States); L. Mosbacker, Traycer Diagnostic Systems, Inc. (United States)

The widespread adoption of THz sensing applications has been hindered by the lack of a real-time, broad-band, cost-effective THz camera with sufficient sensitivity to enable applications in markets as diverse as security, non-destructive evaluation, and biomedical imaging. In order to fill this technological gap, large format 2D focal plane arrays (FPAs) with highly sensitive detection elements must be developed that can be easily integrated with CMOS circuits. Traycer Diagnostic Systems has filled this technological gap with the development of an 80 x 64 pixel array of InGaAs heterostructure backward diodes (HBDs) monolithically integrated to broadband (500 GHz - 900 GHz) antennas. The excellent diode output voltage response allows for the direct coupling of the FPA to CMOS electronics without the need for low noise amplifiers which make the construction of 2D arrays difficult. A technique has been developed to directly flip-chip Traycer’s FPA to a voltage-mode readout integrated circuit (ROIC) provided by New Imaging Technologies to readout the data at video rates (30 Hz). This merger of the Traycer’s high sensitivity THz FPA with New Imaging Technologies ROIC allows for broadband, real-time THz image acquisition necessary for large scale THz application development. Noise power and responsivity measurements will be presented.

8188-11, Session 3

Active THz imaging system to measure water content evolution in leaves

D. Etayo, J. C. Iriarte, I. Palacios, I. Ederra, R. Gonzalo, Univ. Pública de Navarra (Spain)

Quality control systems in industry can benefit from the new possibilities offered by THz frequency range. THz imaging systems can complement actual quality control systems and at the same time offer new information about products, improving quality and reducing costs. In this case we have implemented and imaging system to control the evolution of water content in leaves. THz frequencies are sensitive to water content in leaves. Therefore, THz leaves images vary depending on the water content in leaves. In this paper, the evolution of the water content in a leaf in 48 hours can be clearly seen in THz while in the visible region the leaf has no change.

THz waves are sensitive to water content in objects. Therefore quite a lot of systems can benefit from this sensitivity to measure water content or water content evolution. For instance, agriculture sector could minimize irrigation costs and at the same time optimize crops production, by knowing the humidity or the plant. Works have been done showing water content measurements in plants. The work presented in this paper shows the water content evolution of leaves

in the range from 0.14 THz to 0.22 THz. Different images of the same leaf have been taken with 48 hours of difference to measure the evolution of water content in the leaf. Transmission and reflection parameters have been measured obtaining frequency and time domain information. The evolution of a leaf in a 48 hours time period measured in transmission has been compared with the visible images before the measurements and after 48 hours. In the visible region the leaf is still green after 48 hours of cutting. Therefore, no appreciable change can be seen in the visible image. However, in the THz image more than 5dB variation can be seen due to the loss of water in the leaf.

As a conclusion, it can be said that imaging in active THz technology can be used to measure the evolution of water content in leafs while no change is appreciable in the visible region. Agriculture quality control systems could benefit from this technology.

8188-12, Session 3

Active millimeter wave imaging system for material analysis and object detection

C. Zech, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany) and Karlsruher Institut für Technologie (Germany); A. Hülsmann, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); I. Kallfass, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany) and Karlsruher Institut für Technologie (Germany); A. Tessmann, A. Leuther, M. Schlechtweg, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); O. Ambacher, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany) and Albert-Ludwigs-Univ. Freiburg (Germany)

The use of millimeter waves for imaging purposes is becoming increasingly important, as millimeter waves can penetrate most clothing and packaging materials, so that the detector has not to be brought into physical contact with the object. This will offer a view to the subjacent content of e.g. packets or bags without the need to open them, whereby packaging and content won't be damaged. Nowadays X-rays are used, but as millimeter waves are not such high-energetic as X-rays, they are less harmful for the human health. In this paper we report an active millimeter wave imaging tomograph for material analysis and object detection purposes. The system is build using our in-house W-band components. The object is illuminated with low-power millimeter waves in the frequency range between 89 and 96 GHz; mirrors are used to guide and focus the beam. The object is moved through the focus point to scan the object pixel by pixel. Depending on the actual material some parts of the waves are reflected, the other parts penetrate the object. A single-antenna FMCW-radar is used for illumination and measurement of the material-specific reflected power, a second receiver is used to measure the transmitted wave. All information are calculated into amplitude and phase images by a computer algorithm. The system can be used for security, such as detecting concealed weapons, explosives or contrabands at airports and other safety areas, or quality assurance applications, e.g. during production to detect defects or trace entrapped gases. Some imaging results will be presented in this paper.

8188-13, Session 4

Development and characterization of LiNbO3 electro-optic phase modulator at 170 GHz for mmw imaging system

J. Macario, P. Yao, Univ. of Delaware (United States); C. A. Schuetz, Phase Sensitive Innovations, Inc. (United States); S. Shi, D. W. Prather, Univ. of Delaware (United States)

Lithium niobate modulators have been for years the devices of choice for the telecommunication market due to their high modulation rate and robustness. Matching RF and optical velocities has been the most critical factor that limited this technology to 40 Gb/s since the early 2000's. However, recent interest in millimeter-wave imaging, which requires good resolution images for object recognition and therefore large bandwidth, has led to significant progress in modulator's design and fabrication techniques. 100 GHz modulation bandwidth has been reported.

Recently, our group has developed a high-sensitivity mmW imaging system based on optical upconversion. In such a system, native millimeter-wave radiation of objects is first collected by a broadband horn antenna, which feed the millimeter-wave signal to a coplanar waveguide on a lithium niobate electro-optic phase modulator. The power of mmW is then transferred to the sidebands of an optical carrier due to phase modulation. The overall performance of the passive imaging system is highly dependent on the conversion efficiency of the modulator, as well as the wavelength of the operating millimeter-wave. Performances of our imaging system and of our modulator at 95 GHz have already been reported. However, in order to increase the resolution of the system, the modulation frequency also has to be increased. Therefore, we have started to develop and characterize our modulator at higher frequency up to 170 GHz.

In this paper, modulator design and fabrication techniques are presented, supported by experimental measurements of optical response. We demonstrate optical upconversion up to 170 GHz by achieving RF and optical index matching combined with substrate modes elimination and low dielectric and conduction losses. The RF index is matched to the optical group velocity at 2.19 through CPW ridged structure and silicon dioxide layer deposition. Accurate index matching is obtained by controlling the thickness and the topology of the silicon dioxide layer. Substrate modes are eliminated by thinning the lithium niobate substrate down to less than 120 µm and micro-machining grooves underneath the RF electrode on the backside of the substrate. Moreover, a fiber-modulator-fiber optical bonding process offering insertion loss of 3 dB has been developed to ensure good optical upconversion efficiency. We have applied the phase modulator to our millimeter-wave imaging system and obtained high quality mmW images in W-band.

8188-14, Session 4

260GHz SiGe BiCMOS manufacturing process platform for mmWave applications

A. Kar-Roy, E. J. Preisler, G. Talor, Jr., Z. Yan, R. Booth, J. Zheng, S. Chaudhry, D. Howard, M. Racanelli, TowerJazz (United States)

TowerJazz offers a high volume commercial 0.18um silicon germanium (SiGe) BiCMOS technology platform. In this paper we will report on the highest speed process available to date in this platform, SBC18H3. The SBC18H3 process integrates a 240GHz FT / 270GHz FMAX SiGe heterojunction bipolar transistor on a 1.8V/3.3V dual gate oxide CMOS process. The new SiGe HBT exhibits a minimum noise figure of less than 2dB at 40GHz and consumes nearly 3x less power to achieve the same power gain at 77GHz as compared with the previous SBC18 generation device. Integration and characteristics of other millimeter-wave enabling devices such as p-i-n diodes, Schottky diodes, small-area precision metal-insulator-metal (MIM) capacitors, metal-oxide-semiconductor (MOS) varactors and high-Q resistors which have been characterized out to >50GHz and will also be presented. Enhanced design enablement tools for millimeter-wave applications such as a transmission line toolbox, accurate modeling for scalable active and passive devices, and design-for-manufacturing capabilities will also be discussed. Ongoing work to achieve SiGe HBT device with FMAX > 300GHz within the highly manufacturable SBC18 platform will also be discussed. Applications of the SBC18H3 process for > 50GHz millimeter-wave circuits used in the areas of optical networking, wireless communications, automotive and phased-array radar and THz imaging will also be presented.

8188-15, Session 4

Type-II InAs/GaInSb superlattices for terahertz range photodetectors

M. A. Patrashin, I. Hosako, National Institute of Information and Communications Technology (Japan)

We have designed InAs/Ga0.6In0.4Sb superlattices (SL) for terahertz range photodetectors. Depending on the thicknesses of the InAs and

Ga0.6In0.4Sb layers, the SL energy gap Eg can be adjusted between 8-25 meV, which corresponds to a cut-off frequency from 2 to 6 THz. Different designs were numerically evaluated by using the eight-band k-p model. The calculations show that the SL energy gap is highly sensitive to fluctuations in layer thicknesses, and that variations of the thicknesses from the design parameters should be kept below one monolayer (ML).

A 40-period strained InAs/Ga0.6In0.4Sb SL with an alternating InSb(1ML) or GaAs (1ML) interfaces have been grown by a molecular beam epitaxy on GaSb substrate; the target bandgap Eg was 9meV. The SL samples were characterized by X-ray diffraction (XRD), atomic force microscopy (AFM), photoluminescence (PL) and absorption measurements. Despite a large lattice mismatch of 0.4%, a good structural and surface quality was confirmed by the XRD and AFM measurements. The surface roughness is 0.22 nm.

8188-16, Session 4

MEMS-microfabricated folded waveguide circuit for THz TWT

Y. Wang, Z. Chen, Y. Gao, Z. Shi, China Academy of Engineering Physics (China)

Envisioned applications of THz radiation, such as high-rate communications, radar, remote sensing and biological research, require high power, reliable, compact, efficient and relatively inexpensive sources. Micro-machined Vacuum Electron Devices, i.e. micro-VEDs represent a promising solution. The folded waveguide traveling-wave tube (TWT) is one of the most practical and promising terahertz-range sources because of its tremendous advantages. A major challenge in realizing folded waveguide TWT is the fabrication of the folded waveguide circuit. Recently, there have been intensive efforts to employ LIGA technology and deep reactive ion etching (DRIE) to fabricate the folded waveguide circuit. However, The LIGA technology is expensive and it need more time to fabricate the mask. DRIE technology is a process for silicon. The silicon structures serve as a mold itself for generating metallic structures, or must be metalized. UV-LIGA using SU-8 photoresist is another alternative technology for fabricating the folded waveguide circuit. It can gain high high-aspect ratio structure, vertical sidewalls and all-metal structure, and it is inexpensive and timesaving. In this paper, we fabricated the folded waveguide circuit for the 220GHz folded waveguide TWT using the UV-LIGA technology. The folded waveguide circuit is formed by E-plane bends rectangular serpentine waveguide and the beam tunnel hole in the broad wall of the rectangular waveguide. We design a folded waveguide circuit for the 220GHz folded waveguide TWT. The cold characteristics including dispersion relation and interaction impedance are analyzed using HFSS. Preliminary simulations for the 50 periods folded waveguide circuit is predicted by CST PARTICLE STUDIO. Simulations show that the nonlinear gain is 14 dB at 220 GHz where beam voltage and current are 20.6 kV and 15 mA, respectively. The parameters were not selected from an optimized set, and further optimizations are under investigation. Here, the folded waveguide circuit with a rectangular beam tunnel was fabricated by UV-LIGA technology. Firstly, a 200μm thick SU-8 photoresist is spun on the Cu substrate. This photoresist layer is exposed and developed to define the circuit geometry without a beam tunnel. Cu is electroplated around the SU-8 mold forming the folded waveguide. Then polishing the surface using CMP, the second SU-8 layer is spun on the substrate. After exposed and developed SU-8 photoresist, another layer of Cu is electroplated for forming a beam tunnel. Then the planarization is followed by polishing, and SU-8 photoresist is eliminated. By aligned bonding of two mirrored cell, then we get the folded waveguide circuit. Optimization of the UV-LIGA processing to achieve the desired dimensional tolerances is in process. And the optimization of structure parameters of the folded waveguide circuit will also be discussed.

8188-17, Session 5

Resolution capability comparison of infrared and terahertz imagers

L. Marchese, F. Châteauneuf, É. Savard, L. Le Noc, M. Bolduc, D. G. Dufour, M. Terroux, INO (Canada); D. Tang, Dept. of National Defence (Canada); A. Bergeron, INO (Canada)

Infrared and terahertz are two imaging technologies that differ fundamentally in numerous aspects. Infrared imaging is

an efficient passive technology whereas terahertz technology is an active technology requiring some kind of illumination to be efficient. What's more, the detectors are also different and yield differences in the fundamental physics when integrated in a complete system. One of these differences lies in the size of the detectors. Infrared detectors are typically larger than the infrared wavelengths whereas terahertz detectors are typically much smaller than the wavelength of illumination. This results in different constraints when designing these systems, constraints that are imposed by the resolution capabilities of the system.

In the past INO has developed an infrared imaging camera core of 1024x768 pixels and tested some microscanning devices to improve its sampling frequency and ultimately its resolution. INO has also engineered detectors and camera cores specifically designed for active terahertz imaging with smaller dimensions (160x120 pixels). In this paper the evaluation of the resolution capabilities of a terahertz imager at the pixel level is performed. The resolution capabilities for the THz are evaluated in the sub-wavelength range, which is not actually possible in the infrared wavebands. Based on this evaluation, the comparison between the resolution limits of infrared detectors and the terahertz detectors at the pixel level is performed highlighting the differences between the wavebands and their impact on system design.

8188-18, Session 5

Enhanced terahertz imaging system performance analysis and design tool for concealed weapon identification

S. R. Murrill, U.S. Army Research Lab. (United States); C. C. Franck, CACI Technologies, Inc. (United States); R. L. Espinola, U.S. Army Night Vision and Electronic Sensors Directorate (United States); D. T. Petkie, Wright State Univ. (United States); F. C. De Lucia, The Ohio State Univ. (United States); E. L. Jacobs, The Univ. of Memphis (United States)

The U.S. Army Research Laboratory (ARL) and the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) have developed a terahertz-band imaging system performance model/tool for detection and identification of concealed weaponry. The details of the 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 (Brugge). An advanced version of the base model that accounts for both 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, and for the impact of target and background thermal emission, was reported on at the 2007 SPIE Defense and Security Symposium (Orlando). This paper will provide a comprehensive review of an enhanced, user-friendly, Windows-executable, terahertz-band imaging system performance analysis and design tool that now includes additional features such as a MODTRAN-based atmospheric attenuation calculator and advanced system architecture configuration inputs that allow for straightforward performance analysis of active or passive systems based on scanning (single- or line-array detector element(s)) or staring (focal-plane-array detector elements) imaging architectures. This newly enhanced THz imaging system design tool is an extension of the advanced THz imaging system performance model that was developed under the Defense Advanced Research Project Agency's (DARPA) Terahertz Imaging Focal-Plane Technology (TIFT) program. This paper will also provide example system component

(active-illumination source and detector) trade-study analyses using the new features of this user-friendly THz imaging system performance analysis and design tool.

8188-19, Session 5

New superresolution ranging technique for FMCW radar systems

M. Testar, R. Stirling-Gallacher, Sony Deutschland GmbH (Germany)

Range resolution enhancement techniques, or so called super-resolution ranging techniques, are a significant breakthrough in short-range radar imaging. Improving range resolution in a robust stable manner enables a target to be peeled in finer layers.

For a radar system using the frequency modulated continuous wave (FMCW) technique and traditional frequency domain detection for reception; the range resolution (ΔR) is limited by the bandwidth of the wave transmitted (B) and the speed of propagation (c), $\Delta R = 2c / B$. Therefore super-resolution ranging technique can relax the RF specifications of a radar system. Directly, due to the reduction of the bandwidth used as some range resolution can be recovered with post-processing. Additionally, the agility requirements of the transmitter are relaxed proportionally with the reduction of the frequency excursion needed, which indirectly leads to improvements in phase noise of the transmitter and waveform linearity. Therefore super-resolution ranging techniques have clear implications on performance improvement and cost reduction in FMCW radar systems.

The two main families of techniques which allow range resolution enhancement in FMCW radar systems are autoregressive modeling and time-domain eigenvalue decomposition. The time domain eigenvalue decomposition is often the favored choice in most applications. In this paper we first present a comparison of known state of the art super-resolution ranging techniques for FMCW radar. Multiple key performance characteristics are evaluated for the different techniques including minimum distance between targets in order to be distinguished, absolute positioning accuracy and stability in low SNR environments. The evaluation is based on statistical simulations and real measured data from a radar set-up. The radar set-up consists of a commercial FMCW radar at 94 GHz and a baseband platform developed for this purpose.

The result of the evaluation shows that state of the art techniques have poor stability at low SNR levels. Additionally we show that as the distance between closely spaced targets is reduced, the relative positioning error keeps reasonably stable but the error in absolute positioning increases rapidly. As a result of these findings a new adaptive super-resolution ranging technique is proposed, with the objective to improve the performance in terms of the identified issues. This new method is based on eigenvalue decomposition techniques and adapts its computational requirements to the detection environment. The presented results from both simulations and real measurements show that the method proposed can yield an improved range resolution of up to 15 times compared to traditional frequency domain processing, in high SNR environments. Furthermore, the robustness and stability of the results in low SNR (<20 dB) and additionally the absolute positioning error in comparison to the evaluated known range super-resolution techniques are improved.

8188-20, Session 5

Millimetre radar threat level evaluation at stand off ranges

S. W. Hamer, N. Bowring, D. Andrews, Manchester Metropolitan University (United Kingdom); N. Rezgui,

MiRTLE (Millimetre Radar Threat Level Evaluation) is a W-band (75 - 110 GHz) mm-wave polarimetric RADAR system is demonstrated for the detection of threat objects concealed under clothing upon the human body at stand-off ranges of up to 25 metres. The system implements Stepped Frequency Continuous Wave RADAR with low cost components to deliver a compact, UWB, high resolution (~ 1 cm) RADAR system capable of detecting, resolving and discriminating a wide spectrum of threat items concealed on the human body. Threat detection is autonomously rendered by application of a neural network to the scattered time domain polarimetric radar return, the system may be taught to alarm or reject certain classes of objects; allowing for highly specific through to broad spectrum threat detection. The authors present ROC and confusion matrices for some simple envisaged threat scenarios.

8188-21, Session 5

Comparison of Schemes for Active Sub-millimeter Wave Imaging

O. Furxhi, E. L. Jacobs, The Univ. of Memphis (United States)

Various schemes for active imaging require different allocations of source power and can result in different overall signal to noise ratios. At the University of Memphis we have developed an image-plane scanning device used with a single pixel detector to form video rate images of the scene. Imaging with this device requires flood illumination of the scene. Because sub-millimeter wave sources typically produce low power, it is a common belief that flood illumination results in low detected signal power and therefore low signal to noise ratios (SNR) at the detector. In this work we quantify the SNR at the detector for our system and compare it to conventional imaging systems, conjugate point imaging systems, and focal plane array imaging. Unlike the other two systems, imaging with our device requires an additional pixel formation step; therefore, the SNR at the detector is not the per-pixel SNR. We present the limits of the per-pixel SNR and discuss its dependence on various device components.

8188-22, Session 5

Explosives characterization in terahertz range

I. Maestrojuan Biurrun, D. Etayo, I. Palacios, J. C. Iriarte, I. Ederra, R. Gonzalo, Univ. Pública de Navarra (Spain)

Terahertz frequency range is one of the most promising frequency range at present due to, mainly, the huge amount of potential applications. It is well known that terahertz systems are becoming popular due to its capability of forming images both in good and bad meteorological conditions and even through clothes. This possibility of seeing under low visibility conditions would blind other technologies working at visible range or infrared.

Some applications that might be of interest are medicine (detection of skin cancer, tooth decay, etc), defense and security (weapon and hidden explosives detection, gas detection, etc), in viticulture (to control the state of the vineyard), the alimentary sector, space and aeronautic, industrial sector (quality control), passive tomography, and even thought protein research for the pharmaceutical industry.

A characterization of different explosives is going to be realized in this paper. This characterization will be done utilizing two different methods. First of all a system with a capacity of measuring from 20 GHz to 4 THz fed by a laser source will be used. With this system it will be possible to calculate the refractive index, the absorbance and other important parameters of the explosive samples. This system has two measuring capabilities one of them is using a pellet and the other one is using two external headstocks.

Secondly, a cuasi-optical system will be employed. This system will be formed by four elliptical mirrors that will allow measuring the Scattering parameters from 40 to 220 GHz.

With this study it will be possible to characterize some of the most common used explosives, i.e., gun explosive, gunpowder mine, pent, TNT, etc, and it will allow to determine their peculiarities in order to get a future imaging system that allow detecting in the security and defense sectors.

8188-23, Poster Session

Feature extraction techniques to reduce dimensionality of the acquired THz spectra response

R. Ryniec, M. Szustakowski, Military Univ. of Technology (Poland)

Recently, there has been a significant interest in employing Terahertz (THz) technology, spectroscopy and imaging for standoff detection applications. One of the prime motivations for this interest is that target compounds such as explosives, and bio/chemical weapons have characteristic THz spectra that can be used to identify these compounds.The increased interest is due to the potential use of terahertz (THz) detection and imaging concealed weapons, explosives, chemical and biological agents. The THz technique is based on the use of THz electromagnetic waves to spectroscopically detect and identify compounds through their characteristic transmission or reflectivity spectra in the THz range.To developtechnologies utilizing THz waves, one needs to first understand theinteraction between THz waves and materials.The terahertz spectrum of the explosives can be measure using a conventional Fourier transform infraredspectroscopy and by terahertz pulse spectroscopy in transmission and reflection modes. Under realistic circumstances, a target threat material will be concealed in a package, under clothing, sand, soil etc.For the optical constants around the resonance region, due to strong absorption, it is necessary to have a proper data analysis method to distinguish the various contributions to the experimental data, so that one can accurately model the absorption pattern therefore the optical constants. For practical applications such as security screening, reflection measurement is necessary due to the high absorption coefficients of explosives. These can be extracted from TDS reflection measurement. Practical security systems required methods of identifying threat materials from their spectral features both for reason of operational convenience and speed. Automatic pattern matching techniques and classifiers can be employed. In this paper we discuss the applications of Short Time Fourier Transform and image processing with pattern recognition to the automatic identification of materials.

8188-24, Poster Session

Low-cost THz heterodyne detection by miniature neon indicator lamp glow discharge detector

H. Joseph, N. S. Kopeika, A. Abramovich, A. Akram, A. Levanon, D. Rozban, Ben-Gurion Univ. of the Negev (Israel)

Terahertz (THz) radiation or millimeter wavelength detection and imaging don't have to be expensive. A miniature neon indicator lamp costing about 50 cents acting as a Glow Discharge Detector (GDD) is excellent as a low cost THz detector, but not as the most sensitive detector on the market. Experimental results show that a GDD can work as heterodyne detector, which improves the sensitivity. The experimental results show that sensitivity of heterodyne detection is improved by two orders of magnitude as compared to direct detection. We show here a proof of concept at low frequencies. In this work we compare the performance of GDDs in direct detection to the performance of GDDs in heterodyne detection at 10 GHz and at 300GHz with a low power source.

8188-25, Poster Session

A Fourier transform spectrometer design for measurement of broadband THz radiation

X. Lin, Beijing Institute of Space Mechanics and Electricity (China); J. Zhang, Shanghai Institute of Applied Physics (China); F. Zhou, Beijing Institute of Space Mechanics and Electricity (China); Z. Dai, Shanghai Institute of Applied Physics (China)

Intense, coherent, polarized THz radiation can be derived from relativistic f-sec electron bunches. At the Shanghai Institute of Applied Physics THz Research Centre, such radiation is generated in the form of coherent transition radiation (CTR), coherent synchrotron radiation (CSR) and coherent undulator radiation (CUR) at wave length from 50μm up to mm waves by a femtosecond accelerator facility.

To measure the frequency spectrum of the THz radiation, a modified Michelson interferometer was employed. The interferometer consists of a beam splitter, a fixed mirror and a movable mirror. The beam splitter is made from 2-μm-thick nitrocellulose and come with a metallic coating, providing consistent 30% reflection and 30% transmission over a very wide bandwidth. To obtain a better resolution, we use hollow retroreflectors as reflect mirrors, the most important advantage of the hollow retroreflector is the fact that it can return the light along a path that is parallel to that of the incident light, as a result, the resolution of modified interferometer is 1 or two orders of magnitude than normal Michelson interferometer which uses flat mirror as reflect mirror. We measured the THz radiation spectrum properties which is produced by femtosecond accelerator.

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8189A-01, Session 1

Proximal and point detection of contaminated surfaces using Raman spectroscopy

J. A. Guicheteau, S. D. Christesen, U.S. Army Edgewood Chemical Biological Ctr. (United States); A. Tripathi, SAIC (United States); E. D. Emmons, P. G. Wilcox, D. K. Emge, U.S. Army Edgewood Chemical Biological Ctr. (United States); I. Pardoe, EXCET, Inc. (United States); A. W. Fountain III, U.S. Army Edgewood Chemical Biological Ctr. (United States)

We are actively investigating the use of Raman spectroscopy for the proximal standoff detection of chemicals and explosive materials on surfaces; including fingerprints for forensics attribution. These studies include Raman Chemical Imaging of contaminated fingerprints and testing and analysis of commercial handheld or portable instruments operating in the near IR and specifically developed UV Raman instruments for on-the-move reconnaissance of chemical contamination. As part of these efforts, we have measured the Raman cross sections of chemical agents, toxic industrial chemicals, and explosives from the UV to NIR. We have also measured and modeled the effect of interrogation angle on the Raman return from droplets on man-made surfaces. Realistic droplet distributions have been modeled and tested against variations in surface scan patterns and laser spot size for determining the optimum scan characteristics for detection of relevant surface contaminations.

8189A-02, Session 1

Discrimination of new and aged post-blast explosives residues

A. Elfving, D. Menning, H. G. Önnerud, E. Holmgren, M. Brantlind, U. Hedebrant, H. Östmark, R. Karlsson, Swedish Defence Research Agency (Sweden)

One of the top priorities for armed forces is to counter IEDs. These types of explosives can be fabricated from both military and home made explosives and they are an ever evolving threat with thousands of attacks every year. In order to develop optical stand-off and point detection capabilities it is important to understand the chemical signature of the IED-threat and how it evolves with time and environment. In many cases, explosives are placed in an environment already contaminated with post-blast residues. Consequently, it is of interest to study the signature differences between aged and unaged post-blast residues and non-blasted IEDs.

The present work presents the post-blast compounds dependency on thermal and UV light ageing. Several explosives have been studied, such as C4 and ANFO, and the results have been compared with those from non-detonated pure explosives. The analysis has so far been conducted using either liquid or gas chromatography coupled to mass spectrometry (LC/GC-MS) or ultraviolet and LC conductivity measurements. Results from stand-off Raman spectroscopy measurements on corresponding samples will also be presented.

In the C4 post-blast residues, RDX, HMX, PETN and adipates have been detected. The results show that the UV light ageing of post-blast materials adsorbed onto sand will not to any significant extent degrade RDX without the addition of water to the ageing. Hydration of the sand will cause the amounts of RDX to decrease with a contemporary increase in the amounts of other compounds. The first analyses indicate that highly polar compounds are formed.

Pure RDX, PETN, TNT and tetryl have been subjected to UV light ageing. After 24 hours of ageing, the analysis showed that TNT and tetryl degraded significantly. RDX and PETN were stable and no degradation products were found. Additional two weeks of ageing indicated a further degradation process for TNT and tetryl, while RDX and PETN were still not degraded. Supplementary experiments were carried out to study the impact of water together with UV light. After additional 12 days of ageing the results reveal that the degradation accelerates in the presence of water. In the RDX sample, some new compounds appeared that have not yet been identified. PETN seems to be stable even in the presence of water.

Analysis of water extracts from non aged C4 post-blast residues has shown that there is nitrite and nitrate present. After 20 weeks of ageing in UV light (sequential addition of water the last 6 weeks), the concentration of nitrite has decreased to a concentration below the detection limit. On the other hand, the concentration of nitrate increased about three times. However, thermal ageing of the C4 post-blast sand indicate that there is no ageing up to 65 degC. In addition, the samples will be optically analysed using stand-off imaging Raman spectroscopy at a detection distance of about 10 meters.

This work has clearly indicated that there is a high potential to discriminate newly placed IEDs in environments contaminated with post-blast explosives residues.

8189A-03, Session 1

Stand-off Raman spectroscopy: qualitative and quantitative analysis

B. Zachhuber, C. Gasser, B. Lendl, Technische Univ. Wien (Austria)

A pulsed stand-off Raman system has been built and optimised for the qualitative and quantitative analysis of inorganic and organic samples including explosives. The system consists of a frequency doubled Q-switched Nd:YAG laser (532nm, 10Hz, 4.4ns pulse length), aligned coaxially with a 6 Schmidt-Cassegrain telescope for collection of Raman scattered light. The telescope was coupled via a fibre optic bundle to an Acton standard series SP-2750 spectrograph with a PI-MAX 1024RB intensified CCD camera equipped with a 500-ps gating option for detection. Gating proved to be essential for achieving high signal-to-noise ratios in the recorded stand-off Raman spectra. In some cases, gating also allowed suppression of disturbing fluorescence signals. For the first time, quantitative analysis of stand-off Raman spectra was performed using both univariate and multivariate methods of data analysis. To correct for possible variation in instrumental parameters, the nitrogen band of ambient air was used as an internal standard. For the univariate method, stand off Raman spectra obtained at a distance of 9 m on sodium chloride pellets containing varying amounts of ammonium nitrate (0-100%) were used. For the multivariate quantification of ternary xylene mixtures (0-100%), stand-off spectra at a distance of 5m were used. The univariate calibration of ammonium nitrate yielded R2 values of 0.992, and the multivariate quantitative analysis yielded root mean square errors of prediction of 2.26%, 1.97% and 1.07% for o-, m- and p-xylene, respectively. Stand-off Raman spectra obtained at a distance of 10 m yielded a detection limit of 174µg for NaClO3.

8189A-04, Session 1

Raman database considerations for near-infrared systems

B. M. Kunkel, Y. Su, R. G. Tonkyn, E. G. Stephan, A. G. Joly, J. C. Birnbaum, K. H. Jarman, T. J. Johnson, Pacific Northwest National Lab. (United States)

As Raman spectroscopy evolves, questions arise as to the portability of Raman data: dispersive versus Fourier transform, wavelength calibration, intensity calibration, and frequency of the excitation laser.

If a reference data set is truly portable it obviates the time-consuming and expensive process of re-recording instrument-specific spectral libraries. One reference data set may not be portable to all systems, such as a near-infrared database used for a surface-probing Raman system that employs an ultraviolet laser: certain Raman modes may be enhanced differently. However, most of the modern portable and at-line systems use near-infrared (NIR) excitation lasers, and many of these are close in wavelength. In the NIR there is greatly reduced resonance enhancement, fluorescence or other interfering phenomena. We have thus investigated the possibility of porting reference data from one NIR system to another. Specifically, we have constructed a reference library of >100 sundry compounds and common materials using a 1064 nm laser system, and evaluated the ability to identify the same compounds whose experimental spectra were recorded using a second system equipped with a 785 nm laser. Preliminary results show a very good success rate at identification, including in those few cases where for the 785 nm data baseline correction was needed due to fluorescence.

8189A-05, Session 2

Broad band tunable external cavity quantum cascade laser system for stand off detection of explosives

F. Fuchs, S. Hugger, Q. K. Yang, M. Kinzer, W. Bronner, R. Lösch, R. Aidam, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); K. A. Degreif, S. Rademacher, Fraunhofer-Institut für Physikalische Messtechnik (Germany); F. H. Schnürer, W. Schweikert, Fraunhofer-Institut für Chemische Technologie (Germany)

Due to the terrorist threat there is a strong demand for reliable tools for CBRNE detection. Especially the trace detection of explosives is in the focus of interest. As many chemical compounds of interest exhibit their characteristic “fingerprint” absorption bands in the mid-infrared spectral range, spectroscopic sensing is an attractive approach towards the detection of hazardous substances. Since the spectral structures are very broad, a source with broad spectral tunability is mandatory.

Quantum cascade (QC) lasers, since their first demonstration in 1994, have been established as high power coherent light sources in the mid-infrared of the electromagnetic spectrum with attractive features such as freely designable emission wavelength, continuous wave and high temperature operation. For example, the realization of the hetero-cascading design by combining active gain regions centered at different emission wavelengths enables very broad spectral tuning.

Within the collaborative project IRLDEX, funded by the German Federal Ministry of Education and Research, a mobile system has been developed that can detect traces of explosives on surfaces using hyperspectral IR-image analysis. On the hardware side, the key component of the system is a external cavity quantum cascade laser (EC-QCL) with a wide tunable range around 300 cm-1

The imaging laser system is used for stand-off detection of traces of explosives. Traces of TNT, PETN, RDX, HMDT, FOX12, ANFO, SEMTEX, PHX, and TATP as well as various non-hazardous substances such as flour or skin cream on different substrate-materials were analyzed by illuminating them with the EC-QC laser and collecting the diffusely backscattered light. By tuning the EC-QCL across the characteristic absorption spectra we were able to detect these explosives with excellent discrimination against other non-hazardous substances. For medium distances (< 3 m) trace concentrations down to the range of some 10 µg/cm2 can be detected. For higher material concentrations we could demonstrate detection distance up to 28 m.

The work is funded under the programme “Research of Civil Security” by the German Federal Ministry of Education and Research (BMBF), contract number FKZ 13N4543.

Keywords: stand-off detection, remote sensing, tunable infrared laser, quantum cascade laser, external cavity laser, explosives, CBRNE detection

Figures

Fig. 1. Left: Tuning range of external cavity quantum cascade laser system optimized for explosive detection. Right: IR-Absorbance Spectra of typical explosives. The tuning range of two different QCL designs is indicated.

Fig. 2. Mobile demonstrator system for stand off detection of surface traces of explosives.

Fig. 3 Left: Diffusely backscattered laser illumination of auto body sheet with traces of various explosives. Hyperspectral illumination was performed at 1272 cm-1, 1287 cm-1, 1297 cm-1, and 1366 cm-1 , respectively. Right: Visible photograph of test sample.

8189A-06, Session 2

The microfluidic bioagent autonomous networked detector (M-BAND): an update

M. A. Northrup, Microfluidic Systems, Inc. (United States)

The microfluidic - bioagent autonomous networked detector (M-BAND) - an update

Abstract: The BioWatch program is currently operating urban bioaerosol monitors in many cities through out the US. The importance of having such an early warning system for a biological attack is a key objective of homeland security. However due to the high cost of the human labor and desire for broader agent coverage with faster times from collection to results there is a need to install autonomously operating systems. The Microfluidic Bioagent Networked Detector (M-BAND) developed by Microfluidic Systems for the Department of Homeland Security, runs autonomously for up to 30 days, continuously analyzing air samples for the detection of bacteria, viruses, and toxins with results in as little as two hours. Results from individual instruments are reported via a secure wireless network in real time to give an accurate and up to date status for fielded instruments in aggregate. Designed for either outdoor or indoor environments, the M-BAND will operate from - 25 to 125 ºF. The M-BAND utilizes the industry-standard TaqMan® Real-Time PCR with an end-point read and toxin immunoassays which are well-established in the diagnostics field for optimal specificity and sensitivity. Designed with a high level of operational flexibility, M-BAND can be remotely set to detect for DNA-based pathogens alone, with or without either RNA-based organisms or toxins, or for all three types of pathogens simultaneously at remotely programmable intervals. Air collection rates of 400L/min have been achieved providing 10 mL of concentrated fluidic sample to the detection system. Sample processing time includes: 60 minutes lysis and purification and a thermal cycling rate of 1.2 min/cycle. The typical time for combined sample processing and detection is 120 min assuming 50 thermal cycles. Toxin analysis time is 40 min. The pathogen detection assays currently implemented include 5 bacteria including spores, viruses, toxins, and an internal bacterial positive control. The highest degree of specificity is provided by multiple gene targets per organism via a 17-plex multiplex TaqMan® PCR, and chemiluminescence-based immunoassay toxin detection.

8189A-07, Session 2

Infrared signatures to discriminate viability of autoclaved bacillus spores

M. D. W. Schneider, N. B. Valentine, T. J. Johnson, Pacific Northwest National Lab. (United States)

Optical methods can offer good sensitivity for detecting small amounts of chemicals and biologicals, and as these methods mature, are some of the only techniques that can offer true standoff detection. For detection of biologicals, determining the viability is clearly important: Certain species of gram-positive bacteria are capable of forming endospores, specialized structures that arise when living conditions become unfavorable or little growth medium is available, being resistant to many chemicals as well as changes in heat or pH. Such spores can remain dormant from months to years until more favorable conditions arise, resulting in germination back to the vegetative state. This characteristic of bacterial spores allows for contamination of a surface (e.g. food or medical equipment) even after sterilization. Bacterial spores have also been used as biological weapons, as in the case with B. anthracis. Thus, rapid analysis to determine a spore’s vitality in a given environment or after attempts to sterilize a given environment is crucial. The increasing availability of portable spectrometers may provide a key to such rapid onsite analysis. The present study was designed to determine whether infrared spectroscopy may be used to differentiate between viable vs. dead B.

subtilis and B. atrophaeus spores. Preliminary results show that the reproducible differences in the IR signatures can be used to identify viable vs. autoclaved (dead) B. subtilis and B. atrophaeus bacterial spores.

8189A-08, Session 2

Assessment of UV and IR spectroscopic gas analysis for the detection of CWAs and other health impacting chemicals

S. G. Johnson, Thales Research & Technology (UK) Ltd. (United Kingdom) and Cranfield Univ. (United Kingdom); J. F. Hassard, Imperial College London (United Kingdom)

This abstract outlines the approach taken to the research on the utility of UV and IR Spectroscopy to CWA detection.

Initial Literature review

An initial survey of literature established previous studies conducted by DSTL and Edgewood on the UV spectra of CWA species. Additionally literature was reviewed to assess the benefits and shortfall of UV and IR technologies. This established the domain for the task of extending from UV only in to optical and IR. UV and IR measure the same gas species at different wavelength range with UV involving electronic transitions of the valence electrons, while IR involving molecular vibrations and rotations without electronic transition. Both result in an absorption spectrum. This information is useful for matching the capabilities of UV and IR absorption to increase the throughput of both measurements.

1 http://

UV/Deep UV evaluation

UV Spectra were obtained for target threat species. It should also be noted that predictions of performance were limited by many of the historic tests being in the liquid phase. This has the effect of smoothing out the differentials where present in the gas phase, and in some gases it is impossible to determine what the exact gas-phase absorption cross-sections will look like

Differential Path approach

The benefits of a differential path approach were reviewed and methods to best apply this technique were tested - with particular application in dynamic selection of sensitivity.

Infrared Integrations approach

The application of FT-IR spectrometry was then compared against the UV capability to see what shortfall were addressed and any expected improvements in sensitivity.

Performance predictions

Based of this work a series of predictions were made as to the performance of the system at detection and quantification, prior to testing.

UV/Deep UV testing against CWA/TICs at TNO

TNO was selected as an independent test house, both to obtain gas phase spectra and then also to test the system performance

UV/Deep UV testing against Industrial Chemicals at NPL

Concurrently testing was taking place at NPL looking at linearity and potentially PPT sensitivity.

Once this was successfully concluded, testing was conducted to prove the concept of using the same cell for UV and IR which led to the construction and initial lab testing of the UV-IR system.

8189A-09, Session 2

Optical sensing solutions for defence and security application

J. D. Dougherty, J. Lane, D. Fish, Ocean Thin Films, Inc. (United States); J. M. Eichenholz, N. J. Barnett, D. Creasey, Ocean Optics, Inc. (United States); N. C. Shand, Defence Science and Technology Lab. (United Kingdom)

Ocean Optics and Ocean Thin Films have co-developed a suit of miniature spectroscopic instrumentation to solve many of the detection challenges faced in defence and security. The presentation highlights the technological problems and bespoke solutions developed for successful deployment of multispectral imaging, multi analyte vapour detection, novel optical filters and linear CCD detectors for real life applications

8189A-10, Session 3

Detection for security applications utilising quantum cascade lasers: research, technology and operations

E. L. Normand, D. Chana, M. T. McCulloch, Cascade Technologies Ltd. (United Kingdom)

The Quantum Cascade Laser (QCL) is a nascent semiconductor laser light source technology with the potential to revolutionise the use of the IR electromagnetic band for solving detection problems. QCL sources are ideally suited to material detection problems which require: high speed data acquisition and analysis; multi-material capabilities; high sensitivity; high accuracy; and environmental robustness. As a result the technology has already been successfully deployed in a number of industrial gas detection and monitoring applications by Cascade Technologies and its characteristics have motivated Cascade to develop a technology applications programme for solving problems associated with the detection of illicit substances for the security and defence sectors.

In addition to addressing technical issues, it is argued here that the development of a viable security technology must involve careful consideration of operational and regulatory constraints and requirements, even at very early/conceptual stages. Whilst more challenging, optimising technology with consideration of this wider parameter space has numerous benefits.

In order to address the above Cascade Technologies has implemented a strategy for its Security and Defence business Unit that iteratively develops Concepts of Operations (ConOps) as an integral component in all its product development activities. An overview of recent novel developments utilising QCLs is presented, with the development of a novel passenger screening portal for aviation security - in collaboration with Morpho as a technology partner and BAA as an operational partner - serving as an example. Finally, a discussion on current cutting-edge research in QCL sources is presented, illustrating how an understanding of future security requirements is being used to motivate and shape laboratory based research activity.

8189A-11, Session 3

Spatially offset Raman spectroscopy (SORS) for through-barrier chemical and explosive detection

A. Frisby, L. Lee, R. J. Hopkins, Defence Science and Technology Lab. (United Kingdom)

The capability to detect toxic chemicals and explosive materials through a wide range of container types has a variety of applications, including liquids screening in airports. Conventional Raman spectroscopy is commonly used for chemical detection, but can cause an intense spectral response by scattering and/or fluorescence from the container. Such a response can reduce the effectiveness of the technique for content analysis by swamping any Raman signatures that are present.

By producing two spectra containing different contributions from the container and the contents, spatially offset Raman spectroscopy (SORS) allows a contents spectrum to be obtained even through fluorescing containers. This innovative technique is capable of a truly through-barrier detection capability for a range of opaque non-metallic containers. In this paper, the use of SORS for through-barrier detection is introduced, and its use with a range of analytes and container materials evaluated. The potential advantages of using a longer wavelength (1064nm) incident laser to reduce sample fluorescence are also explored, focussing in particular on mixtures of fluorescing and scattering materials.

8189A-12, Session 3

Spatially offset Raman spectroscopy for liquid screening

P. W. Loeffen, G. T. Maskall, S. Bonthron, M. Bloomfield, Cobalt Light Systems Ltd. (United Kingdom); P. Matousek, Cobalt Light Systems Ltd. (United Kingdom) and Central Laser Facility (United Kingdom)

Recently Spatially Offset Raman Spectroscopy (SORS) has been discussed as a novel method for the screening of liquids and gels (LAGs) at airports and for other security applications. SORS is an optical spectroscopic method which enables the precise chemical identification of substances from a reference threat list and, due to the rich spectral information, has an inherently high probability of detection and low false alarm rate. The method is generally capable of screening substances inside non-metallic containers such as plastic and glass. In contrast to conventional backscatter Raman, SORS is typically successful through opaque plastic and coloured glass, which are often challenging for conventional backscatter Raman. SORS is performed in just a few seconds by shining a laser light onto the container and then measuring the Raman signal at the excitation point but also at one or more offset positions. Each measurement has different relative orthogonal contributions from the container and contents Raman spectra, so that, with no prior knowledge, the spectra of both the container and contents can be extracted - either by scaled subtraction or via multivariate statistical methods. In this presentation, the latest results will be described from a prototype SORS device designed for aviation security and the advantages and limitations of SORS will be discussed. This project is funded under the Innovative Research Call in Explosives and Weapons Detection (2010) initiative, a cross-government programme sponsored by a number of government departments and agencies under the CONTEST strategy.

8189A-13, Session 3

Tip-based nanolithography for the nanofabrication of sensors and advanced optical structures

R. J. Stokes, Univ. of Strathclyde (United Kingdom) and Nanoink Inc. (United States)

Advances in Tip-based nanolithography and nanofabrication methods will be presented in the context of advanced optical structures. Examples will centre on the use of molecular ‘inks’ to rapidly generate nanoscale structures in Si and Au with dimensions from 20 to 500 nm. This highlights potential applications in meta-materials, optical coatings or for the development of advanced focal plane arrays. Parrallel deposition methods allow structures to be fabricated over large areas. The use of so-termed ‘liquid inks’ allow the depositions of a very wide range of materials (such as optical polymers) with dimensions of 100 nm to several microns. Advances in liquid inks also allow the fuctionalisation of existing biosensor devices with multiple receptor materials (such as DNA, antibodies and proteins) with unique precision.

8189A-14, Session 4

BioSense/SR-BioSpectra: demonstrations of wide-area/early warning for bio-aerosol threats: overall program description and early T&E results

J. Simard, B. Sylvie, P. Lahaie, P. Mathieu, G. A. Roy, D. Nadeau, J. E. McFee, S. Rowsell, J. Ho, Defence Research and Development Canada (Canada); N. Ho, F. Babin, D. Cantin, INO (Canada); J. H. Robinson, S. Wood, J. Hsu, P. Findlay, MacDonald, Dettwiler and Associates Ltd. (Canada)

Threats associated with bioaerosol weapons have been around for several decades and have been mostly associated with terrorist activities or rogue nations. Up to the turn of the millennium, defense concepts against such menaces relied mainly on point or in-situ detection technologies. Over the last 10 years, important efforts have been deployed by multiple countries to supplement the limited spatial covertness of (or network of) point bio-detectors using Lidar technology. The addition of such technology makes possible to detect within seconds suspect aerosol clouds over area of multiple tens of square kilometers and tracks their trajectories. These additional capabilities are paramount in directing presumptive ID missions, mapping hazardous areas, establishing efficient counter-measures and supporting subsequent forensic investigations. In order to develop such capabilities, Defense Research and Development Canada (DRDC) and the Chemical, Biological, Radiological-Nuclear, and Explosives Research and Technology Initiative (CRTI) have supported two major technology demonstration projects based on spectrally resolved Laser Induced Fluorescence (LIF) Lidar: BioSense, aiming wide open space defense military missions, and SR-BioSpectra, aiming networked enclosed or semi-enclosed short range wide space surveillance common in defense and public security missions. First, this article reviews briefly the modeling behind these demonstration projects. Second, the Lidar adapted and the lab-size bioaerosol LIF chambers (BSL1), developed to challenge the constructed systems and to accelerate populating the library of spectral LIF properties of bioaerosols and interferents of interests, respectively, are described. Then, the most recent T&E results obtained with SR-BioSpectra and BioSense (BioSense starting the demonstration phase of the project by April 2011) are reported. Finally, a brief discussion stating the ways ahead for a complete defense suite is provided.

8189A-15, Session 4

iCATSI: multi-pixel imaging differential spectroradiometer for standoff detection and quantification of chemical threats

F. M. Prel, L. M. Moreau, ABB Analytical Measurement (Canada); H. Lavoie, F. Bouffard, J. Thériault, Defence Research and Development Canada (Canada); C. A. Vallieres, C. B. Roy, ABB Analytical Measurement (Canada); D. Dubé, Defence Research and Development Canada (Canada)

Homeland security and first responders are often faced with safety situations involving the identification of unknown volatile chemicals. Examples include industrial fires, chemical warfare, industrial leak, etc. The Improved Compact ATmospheric Sounding Interferometer (iCATSI) sensor has been developed to investigate the standoff detection and identification of toxic industrial chemicals (TICs), chemical warfare agents (CWA) and other chemicals.

iCATSI is a combination of the CATSI instrument, a standoff differential FTIR optimised for the characterization of chemicals and the MR-i, the hyperspectral imaging spectroradiometer of ABB Bomem based on the proven MR spectroradiometers. The instrument is equipped with a dual-input telescope to perform optical background subtraction. The resulting signal is the difference between the spectral radiance entering each input port. With that method, the signal from the background is automatically removed from the signal of the target of interest. The iCATSI sensor is able to detect, spectrally resolve and identify 5 meters plumes up to 5 km range. The instrument is capable of sensing in the VLWIR (cut-off near 14 µm) to support research related to standoff chemical detection. In one of its configurations, iCATSI produces three 24 x 16 spectral images per second from 5.5 to 14 µm at a spectral resolution of 16 cm-1. In another configuration, iCATSI produces from two to four spectral images per second of 256 x 256 pixels from 8 to 13 µm with the same spectral resolution.

Overview of the capabilities of the instrument and results from tests and field trials will be presented.

8189A-16, Session 4

Remote detection of liquid surface contamination by imaging infrared spectroscopy: measurements and modelling

S. Sabbah, J. Eichmann, R. Braun, R. Harig, Bruker Sigma GmbH (Germany); C. R. Howle, Defence Science and Technology Lab. (United Kingdom)

Previous studies showed that imaging infrared spectrometry allows remote detection and identification of traces of potentially hazardous liquid surface contaminants. Because the spectra depend on the liquid (composition and thickness), the background material, and on the illumination of the surface, a comprehensive radiative transfer model has been developed and applied to calculate synthetic spectra which are used to approximate measured spectra; these simulated spectra are compared to experimentally acquired data. The model requires spectra of the complex refractive indices of the liquids. These spectra were calculated by applying the Kramers-Kronig relations to spectra of the linear absorption coefficient, which are contained in commonly available spectral libraries. As the agreement between measured and modelled spectra of liquids on different surfaces is excellent, the results confirm the validity of the model.

8189A-17, Session 4

Hazardous liquid detection using active hyperspectral imaging

C. R. Howle, A. J. S. McIntosh, Defence Science and Technology Lab. (United Kingdom); D. J. M. Stothard, M. H. Dunn, Univ. of St. Andrews (United Kingdom); G. Robertson, W. Miller, G. P. A. Malcolm, G. T. Maker, M Squared Lasers Ltd. (United Kingdom)

The ability to remotely locate and identify potential liquid hazards is desirable in a variety of civilian and military applications. Candidate technologies to satisfy these requirements include the fusion of imaging and optical spectroscopy. Hence, a novel system based on IR negative contrast imaging (NCI) is presented. The NCI system is based on an OPO laser comprising a periodically-poled LiNbO3 (PPLN) crystal of fanned grating design that operates in both the shortwave and midwave IR spectral regions (1.5 - 1.8 µm and 2.6 - 3.8 µm, respectively). Wavelength tuning is achieved by translating the PPLN crystal within the 1064 nm pump beam. System size and complexity are minimised by the use of InGaAs/InSb single element detectors and the intracavity OPO design. Images are composed by raster scanning the monochromatic beam over the scene of interest; the reflection and/or absorption of the incident radiation by target chemicals and their surrounding environment provide a method for spatial location of the hazard. The NCI has been employed to detect liquid chemical warfare agents on a variety of surfaces at ranges of 5 - 10 m and results of these laboratory investigations are presented here.

8189A-18, Session 5

Efficiency of the detection of explosive using the spectral dynamics analysis of reflected signal

V. A. Trofimov, S. A. Varentsova, Lomonosov Moscow State Univ. (Russian Federation); M. Szustakowski, N. Palka, T. Trzcinski, Military Univ. of Technology (Poland)

We investigate the efficiency of detection of explosive hidden under various substances. The detection occurs using the spectral dynamics analysis of reflected THz signal. The main difficulty concludes in multi-reflection of THz wave from substance which is used to pack the explosive. In some cases this substance can be opaque for THz radiation. We consider the interation of THz pulse with substance under the falling of THz wave at various angle in respect to the sample. In this case we can get more information about explosive in comparison with the case of normal falling of THz wave. Hence, the probability of detection increases.

8189A-19, Session 5

Screening mail for powders using terahertz technology

M. C. Kemp, Iconal Technology Ltd. (United Kingdom)

Following the 2001 Anthrax letter attacks in the USA, there has been a continuing interest in techniques that can detect or identify so-called 'white powder' concealed in envelopes. Electromagnetic waves in the terahertz frequency range (wavelengths 100-500 µm) penetrate paper and have short enough wavelengths to provide good resolution images; some materials also have spectroscopic signatures in the terahertz. We report on an experimental study into the use of terahertz imaging and spectroscopy for mail screening. Spectroscopic signatures of target powders were measured and, using a specially designed test rig, a number of imaging methods based on reflection, transmission and scattering were investigated.

It was found that, contrary to some previous reports, bacterial spores do not appear to have any strong spectroscopic signature which would enable them to be identified. Imaging techniques based on reflection imaging and scattering are ineffective in this application, due to the similarities in optical properties between powders of interest and paper. Transmission imaging using time-of-flight of terahertz pulses, however, was found to be a very simple and sensitive method of detecting small quantities (25 mg) of powder even in quite thick envelopes. An initial feasibility study indicates that this method could be used as the basis of a practical mail screening system.

8189A-20, Session 5

Possible way for increasing the quality of imaging from THz passive device

V. A. Trofimov, V. V. Trofimov, Lomonosov Moscow State Univ. (Russian Federation); C. Zhang, C. Deng, Y. Zhao, Capital Normal Univ. (China)

We investigate and find a possible way for the improvement of a quality of imaging which is getting from passive THz receiver. With this aim we apply various frequency filters and transform of spectrum to get the clear imaging of boundaries of samples. We find the liquid explosive, knife, pistol and metal plate hidden under clothes. The treatment of imaging from passive THz device is made by computer. The performance of such treatment is less than 1 second.

8189A-21, Session 5

An immuno-based surface plasmon resonance biosensor for ephedrine detection

S. D'Auria, A. Varriale, Consiglio Nazionale delle Ricerche (Italy); A. Secchi, D. Massimiliano, L. Pierno, A. M. Fiorello, SELEX Sistemi Integrati S.p.A. (Italy)

Ephedrine is the major alkaloid isolated from different species of Ephedra sinica, the oldest medicinal herb used in Chinese traditional medicine. It is also a major precursor for synthetic drugs such as amphetamine. Ephedrine is a sympathomimetic agonist at both α- and β-adrenergic receptors and displays an indirect sympathetic activation, in that it enhances the release of norepinephrine from the sympathetic neurons. This basic pharmacological mechanism seems to account for most of ephedrine's therapeutic efficacy, as well as its most prominent adverse effects.

For twenty years ephedrine has been a crucial chemical precursor for the illicit production of methamphetamine and its related drugs. Its conversion into this class of compounds is relatively simple, cheap and with a high yield . Therefore, the abuse of amphetamine and methamphetamine may be associated with ephedrine.

A ready and sensitive detection is the most prudent means to prevent the entry of ephedrine into illegal commerce. Currently conventional analytical methods of detection involve chromatographic analyses, such as HPLC, GC and more recently, techniques such as LC/MS and GC/MS, that are time consuming and expensive to analyze.

In this work we describe the realization of an easy approach to sense the presence of ephedrine based on the use of antibodies anti-ephedrine and surface plasmon resonance (SPR) methodology. In particular, we describe the synthesis of an ephedrine derivative and its immobilization to a CM5 chip as well as the production of antibodies that specifically recognize ephedrine molecules present in environment.

8189A-22, Session 5

Two secure facilities for Egyptian nuclear weapons

A. E. El Mohamed, Consultant (Egypt)

Egyptian Nuclear weapons states have developed dedicated safe and secure facilities for nuclear warhead and bombs assembly and disassembly operations .These facilities are critical elements of material nuclear weapons infrastructures .Their broad operational responsibilities include the production of new warheads, the dismantlement of retired warheads ,warhead modernization and refurbishment, stockpile surveillance and component testing ,production of trainers, and modification of stockpiled warheads for flight-testing purposes such as an operation involving replacement of fissile components with inert materials and telemetry systems .The facility is defined as a nuclear warhead assembly/disassembly plant ,If it conducts the operations of assembly/disassembly of nuclear explosive packages (NEP),an assembly containing high explosive (HE),components and fissile materials, and/or final mechanical assembly of warheads (Bombs). As such operations involve staging and handling of fissile materials components and assemblies including NEPs and fully assembled warheads , The facility's states could be defined as "Shutdown" or "Converted" .If it no longer works with intact nuclear weapons or subassemblies containing fissile materials.

In this second paper ,I will complete my first paper that published the SPIE2010 and I discuss and present the main secure facilities for Egyptian nuclear warheads and bombs and the major monitoring options for former warhead assembly/disassembly facilities that could be used in combination with each other ,and show some cases of nuclear forensic investigations

8189A-32, Session 5

Near infrared transmission through clothing: applications in sensing and screening

D. Hutchins, A. Saleem, C. Canal, L. A. J. Davis, The Univ. of Warwick (United Kingdom)

Experiments have been performed to demonstrate that near infrared (NIR) transmission through a wide range of clothing materials is possible. Studies have shown that the characteristics of NIR transmission are affected by both the type of fibre used, and the weave pattern. A series of experiments has indicated that NIR transmission is also dependent on other variables such as fabric porosity and dye colour. This work has used both an integrating sphere to measure total through-transmission intensity, and scanned detectors to look at spatial scattering and diffraction effects,. Wavelength-dependant spectroscopy has also been used. It is shown that, in many cases, transmission coefficients are sufficiently high that imaging and spectroscopy of objects hidden behind clothing samples should be possible. However, while transmission through clothing at NIR wavelengths in the 750-1,700 nm range is often more effective than in the visible or IR regions, the fabrics themselves will modify the transmitted signal in terms of spatial effects, intensity and spectral content. The conclusions that can be drawn from our measurements will be discussed, and an explanation given on the mechanisms by which the transmission characteristics are is modified by fabric structure.

The paper will then describe the possible use of near infrared signals to identify objects that are hidden behind clothing layers. This can be done using spectroscopy. It is important, however, to distinguish the various contributions that exist within the backscattered signal. It would be expected that the clothing, any container, and the back reflecting surface will all have an influence, in addition to the wavelength-dependent absorption within the unknown chemical. A set of careful laboratory experiments have demonstrated that transmission through a set of different clothing fabrics does modify the spectral content of signals, but that the spectrum of a particular chemical can still be identified, provided certain steps are taken. These involve a set of careful calibration measurements, and the use of processing techniques for the retrieval of data. It will be shown that this is possible for both granular solids and selected liquids.

A discussion will be presented on how these measurements can be used to predict the likely effectiveness of a personal screening technique based on backscattered NIR signals.

8189A-24, Session 6

Colour invariant target recognition in multiple camera CCTV surveillance

U. Soori, P. W. Yuen, I. Ibrahim, A. Tsitiridis, T. Chen, K. Hong, D. B. James, M. A. Richardson, Cranfield Univ. (United Kingdom)

Targets recognition in crowded scene has been a popular, and at the same time a very difficult topic, in computer vision surveillance applications. To identify targets such as people from low resolution CCTV video footage has been a daunting task. It is because the most important useable signature for target discriminations will be the colours of what they wear and very unfortunately, the colours can be seen quite differently dependent on illumination conditions and view angles. Conventional colour constancy models, such as the Retinex theory, have been found not able to retrieve the intrinsic spectral signature when it is applied on its own. Furthermore, the parameterisation of any Retinex base algorithm has been an absolutely non-trivial task. The purpose of this work is to high light the pros and cons of various Retinex based algorithms, and to compare the result with respected to the proposed physics based approach using luminance information. All results will be discussed in the context of the colour opponent features commonly adopted in colour machine vision work.

8189A-25, Session 6

User-assisted visual search and tracking across distributed multi-camera networks

Y. Raja, S. Gong, T. Xiang, Vision Semantics Ltd. (United Kingdom)

Human CCTV operators face several challenges in their task which can lead to missed events, people or associations. These include: (a) data overload in distributed multi-camera environments with large numbers of video feeds needing to be monitored simultaneously; (b) short attention span leading to loss of concentration at potentially crucial moments; (c) limited knowledge of what to look for such as potentially useful but unknown associations between people; and (d) lack of access to non-visual contextual intelligence to aid search such as the environment-specific regular movement patterns of people. Developing a system to aid human operators and alleviate such burdens requires addressing the problem of automatic re-identification of people across disjoint camera views, a matching task made difficult by factors such as lighting, viewpoint and pose changes and for which absolute scoring approaches are not best suited. Accordingly, we describe a distributed multi-camera tracking system to visually aid human operators in associating people and objects effectively over multiple disjoint camera views in a large public space. Given a user-selected target, the system searches video data to obtain a ranked list of potential matches. The system comprises three key novel components over previous approaches: (1) the use of the RankSVM variant of support vector machines as a measure of relative ranking rather than absolute scoring to avoid the need for absolute classification of matches; (2) multi-camera behaviour profiling characterising the space-time movement patterns of people as higher-level knowledge

to reduce the search space and increase the chance of finding correct matches; and (3) human-assisted data mining in the form of feedback cycles to interactively guide search and in the process recover missing detections and discover previously unknown associations. We provide an extensive evaluation of the effectiveness of the system as compared to existing approaches on industry-standard i-LIDS multi-camera data under varying i-LIDS classified levels of activity. This evaluation shows that: (a) our methods improve on existing methods in finding correct matches in the top 5 ranks of query results by 84% and in the top 20 by 35%; (b) the use of behavioural profiling improves the recognition rate in the top 20 ranks by 175% over using appearance alone; and (c) the human-assisted search feature results in 90% on average of the top 10 ranks for a query being correct after only three short feedback cycles, enabling an efficient reconstruction of a person's movements through the multi-camera environment.

8189A-26, Session 6

Application of speed enhanced spatial domain correlation filters for real-time security monitoring

A. A. Gardezi, A. Alkandri, N. B. Manjunathamurthy, P. M. Birch, R. C. Young, C. R. Chatwin, Univ. of Sussex (United Kingdom)

A speed enhanced space variant correlation filer which has been designed to be invariant to change in orientation and scale of the target object but also to be spatially variant, i.e. the filter function becoming dependant on local clutter conditions within the image. The speed enhancement of the designed filter is due to the use of optimization techniques employing low-pass filtering to restrict kernel movement within regions of interest. The detection and subsequent identification capability of the two-stage process has been evaluated in highly cluttered backgrounds using both visible and thermal imagery acquired from public and defence domains along with associated training data sets for target detection and classification. In this paper a series of tests have been conducted in multiple scenarios relating to situations that pose a security threat and a performance matrix comprised of peak-to-correlation energy (PCE) and peak-to-side lobe ratio (PSR) measurements of the correlation output has been calculated to allow the definition of a recognition criterion. The acquired performance matrix has been used to create a range of ratios for the evaluation of the quality of detection within a given scenario. A feasible hardware implementation has also been discussed in this paper for potential use in security applications relating to real time surveillance employing the proposed two-stage process.

8189A-27, Session 7

Machine-assisted verification of latent fingerprints: first results for nondestructive contact-less optical acquisition techniques with a CWL sensor

M. Hildebrandt, S. Kiltz, J. Dittmann, C. Vielhauer, Otto-von-Guericke-Univ. Magdeburg (Germany)

The non-destructive contact-less optical acquisition of latent fingerprints with chromatic white light sensors allows for gathering high-resolution images of traces from crime scenes. Used especially in forensics, this application can assist performing an identification of people and can employ methods and techniques also applied in biometrics.

Using the contact-less surface measurement device FRT MicroProf 200 CWL 600 to acquire fingerprints, depending on the original pattern and the surface, even pores on the ridge-lines are visible.

An automated extraction of features and an automated verification of fingerprints from different sources using pattern recognition approaches, such as non-destructively acquired latent fingerprints or exemplar fingerprints from Automated Fingerprint Identification System (AFIS) databases, might enhance the investigation process and allows for the utilisation of biometrics for security applications. Therefore, it is necessary to determine potential error rates for each utilised approach to assess its particular reliability. However, the performance of identification techniques for latent fingerprints is not evaluated within this paper. Jain et al. reported in On Matching Latent Fingerprints" that the rank-20 identification (with 20 potential candidates for one sample) of latent and rolled exemplar fingerprints has an accuracy of 93.4%. However, the utilised reference data includes a rolled fingerprint for each latent fingerprint. It is likely, that the particular results for latent fingerprints without a reference sample are much worse because 20 wrong candidates are likely to be presented.

The automated extraction of fingerprint features from latent fingerprints acquired with the non-destructive contact-less optical chromatic white light sensor has not been evaluated before. Our goal is to show first results towards the feature extraction and matching performance for verification purposes by determining the potential error rate using algorithms and processing for pattern recognition. Our exemplary chosen test set includes 30 fingerprints from 5 people. We evaluate various approaches, including the NIST Biometric Image Software (NBIS). Here, we concentrate on the detection of layer 2 features (minutia points). We show the influence of different acquisition resolutions for the latent fingerprints onto the minutia detection performance. Additionally, we discuss and evaluate pre-processing techniques that reduce the error rates. Here, a minutia detection performance of 88-97% could be achieved depending on the quality of the latent fingerprint. Subsequently, we evaluate the matching performance towards the automatic verification of latent fingerprints. The particular acquisition resolution influences the verification performance significantly; however, our first results show positive tendencies. Future work should include pores (layer 3 fingerprint features) for the matching of latent fingerprints, too.

8189A-28, Session 7

A first framework for the development of age determination schemes for latent biometric fingerprint traces using a chromatic white light

(CWL) sensor

R. Merkel, J. Dittmann, S. Kiltz, C. Vielhauer, Otto-von-Guericke-Univ. Magdeburg (Germany)

The identification of criminals or terrorists using latent fingerprint traces is a common technique in forensic investigations. Especially on coins, which are touched with a high frequency, many fingerprint traces reside. However, on such surfaces touched by many people, it is often easy to claim that the fingerprint trace was left prior to a certain incident or even after the incident took place. Therefore, it is of high interest to determine the age of a fingerprint trace, meaning the time which has passed since the trace was left on the coin. So far, no satisfactory technique for the determination of such fingerprint age has been developed. With the upcoming use of optical, non-invasive image sensor technology, new chances might arise for solving this challenge.

In this paper, we want to evaluate aging effects of latent fingerprint traces left on copper coins. We use the FRT-MicroProf 200 CWL 600 contact-less optical 3D surface measurement device based on a Chromatic White Light (CWL) sensor, which can acquire high-resolution intensity and 3D-topography images of a surface with a lateral resolution of up to 1µm. We use this optical sensor device to scan 10 different latent fingerprint traces on copper coins with a lateral resolution of 5µm and an area of 10x10mm in periodical intervals over several months. We show, that after only one week, corrosion artefacts might appear, which are growing in size and number for several weeks. To the high-resolution biometric fingerprint images acquired by such optical sensor technology, we apply pattern recognition techniques, such as normalisation, median filtering, Laplace filtering, connected components labelling and binarisation and fuse the captured intensity and 3D-topography images to extract and evaluate the number and size of such corrosion-artefacts, appearing mainly at areas on the ridge lines where pores were present.

We visualise and evaluate the experimental progression of the growth and amount of such corrosion artefacts in relation to the time passed. Our results show that the rate of growth as well as the amount of artefacts seem to progress in a logistic sigmoid form. We furthermore approximate a mathematical aging function to describe the aging process of latent fingerprint traces left on copper coins. Based on the

resulting aging-curve, we discuss how such a mathematical function might be used to determine the age of fingerprint traces.

8189A-30, Session 7

Separation and sequence detection of overlapped fingerprints: experiments and first results

R. Kärgel, S. Giebel, M. Leich, J. Dittmann, Otto-von-Guericke-Univ. Magdeburg (Germany)

Latent fingerprints provide vital information in modern crime scene investigation since they allow for identification of suspects based on well-known techniques from the field of biometrics. On frequently touched surfaces these fingerprints may overlap which poses a major problem for forensic analysis. In order to make the fingerprints available for analysis, they have to be separated. An additional estimation of the number of overlapping fingerprints and the sequence in which they were left can help to reconstruct the progression of events. Advances in both tasks can considerably improve solving crimes and are the subject of this work.

Current approaches to fingerprint separation do either provide only few implementation details, may require manual marking of each fingerprint and the overlapping area, or introduce constraints on ridge line orientations. Often these methods are only evaluated with idealized or even synthetic fingerprints. The method presented here does not include any of these limitations and has been exemplary tested with real latent fingerprints, which have been acquired with a contact-less surface measurement device equipped with a chromatic white light sensor.

In our first experiment towards the separation of overlapped fingerprints we focus on blind source separation, which is a well-known approach in pattern recognition. The method has been applied previously to the separation of overlapped texts and involves a maximum a posteriori estimation of the single fingerprints and the mixing coefficients, computed by an expectation-maximization algorithm.

The test set consists of fingerprints of two persons on two materials - hard disk drive platters and coins. Each test sample contains exactly two fingerprints from either the first or the second person or both. Five different timespans between these two marks have been examined immediately, after one day, after three days, after one week and after two weeks - summing up to a total of 30 test samples.

All samples are acquired with the non-destructive chromatic white light surface measurement device FRT MicroProf 200 equipped with a CWL 600 sensor that produces both an image of the intensity of the light the material reflects and a topographical image depicting height differences.

Since forensic investigations typically rely on manual assessment of acquired fingerprints by forensic experts, a subjective scale ranging from 0 to 8 was used to rate the test results.

Our results indicate that the chosen method can separate overlapped fingerprints, which exhibit strong differences in contrast since one of these samples has been separated satisfyingly with a score of 7. Sequence estimation is currently subject of ongoing research; the full paper contains results for subjective assessment of the quality of different intuitively selected sequence features.

8189A-31, Poster Session

Through-barrier detection of explosive components for security screening applications

L. Lee, R. J. Hopkins, A. Frisby, R. Mansson, Defence Science and Technology Lab. (United Kingdom)

The detection of materials through containers is a vital capability for security screening applications at high risk locations, such as airports and checkpoints. Current detection procedures require suspect containers to be opened and the contents sampled, which is laborious and potentially hazardous to the operator. The capability to detect through-barrier would overcome these issues.

Spatially Offset Raman Spectroscopy (SORS) is an innovative spectroscopic technique that avoids fluorescence interference and strong Raman scatter from containers. This novel approach enables non-invasive detection of hazardous and benign materials through a range of container materials, including coloured glass and opaque coloured plastics.

The ability of SORS to detect explosive components and benign materials through a range of glass and plastic containers was investigated by applying two different analysis methods to the resultant data. The acquired SORS spectra were compared to reference Raman signatures from a test set. Furthermore, the potential reduction in sample fluorescence achieved using a longer excitation wavelength was investigated by comparing conventional Raman signatures of the explosive components and benign materials acquired at 785 nm and 1064 nm. For some fluorescent samples, Raman spectral features that were not present at 785 nm were revealed at 1064 nm.

Conference 8189B: Optical Materials in Defence Systems Technology

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8189B-43, Session 8

Second-order nonlinear optics of silicon nitride films and gratings

M. Kauranen, R. Kumar, S. Kumar, T. Ning, H. Pietarinen, G. Genty, O. Hyvärinen, J. Simonen, Tampere Univ. of Technology (Finland); T. Kaplas, Univ. of Eastern Finland (Finland)

Metamaterials are artificial materials with designed optical properties. They often consist of periodic arrays of metal nanoparticles on a dielectric substrate. The main effort in this field has been on materials at the effective medium limit, where the array period is much smaller than wavelength. A typical period, however, is a few 100 nm, which allows light to couple diffractively into the substrate. In this paper, we review our work that takes advantage of such resonance-domain effects in enhancing and tailoring nonlinear properties of such nanoscale materials. In all cases, the nonlinear process is second-harmonic generation (SHG).

The first example consists of anisotropic, L-shaped metal nanoparticles ordered in a two-dimensional array on a substrate. The array period is sub-wavelength for the plasmonic resonance wavelengths of the particles. We then vary the mutual orientation of the particles in order to modify the symmetry and dichroic properties of the structures. Most importantly, we find that the SHG responses of two samples that have similar orientational particle distribution vary by more than an order of magnitude depending on the detailed particle ordering. The results are explained by long-range coupling between the particles, which becomes possible because the changes in particle ordering double the structural period and thus open diffraction orders.

The second example consists of dielectric resonant waveguide gratings (RWG). We have investigated both silicon dioxide-titanium dioxide and silicon nitride structures. RWGs have sub-wavelength periods and they consist of a surface waveguide and a surface grating that diffracts light both into and out of the waveguide mode at the resonant angle of incidence. Such resonances lead to strong local fields within the structure, which can enhance nonlinear processes. For both material systems, we find that SHG is enhanced by three orders of magnitude compared to a flat reference surface of the same material. However, for silicon nitride even the reference signal was significantly higher than for a typical dielectric surface.

8189B-46, Session 8

The substituted [2.2]paracyclophanes as versatile platform for a design of new optical materials

L. N. Puntus, Institute of Radio Engineering and Electronics (Russian Federation); E. V. Sergeeva, K. A. Lyssenko, A.N. Nesmeyanov Institute of Organoelement Compounds (Russian Federation); I. Pekareva, Institute of Radio Engineering and Electronics (Russian Federation); F. Kajzar, Univ. d'Angers (France)

From a fundamental standpoint, [2.2]paracyclophanes (PCP) is composed of two benzene rings covalently fixed in a face-to-face geometry by ethano bridges. The presence of rigid framework and two parallel aromatic rings in [2.2]paracyclophanes facilitate the synthesis of chiral molecules (planar chirality) while the introduction of various substituents can easily change the optical characteristics of these molecules. In one's turn the extremely sharp emission lines of the lanthanide ions (Ln) and high luminescence quantum yield make the lanthanide complexes the perfect candidates for the different applications in the fields of electronics and photonics. Thus in order to fully utilize the benefits of the lanthanide ions and substituted PCP a series of lanthanide complexes containing [2.2]paracyclophane core will be designed, synthesized and characterized for linear and nonlinear optical properties. The complexes designed exhibit strong photoluminescence owing to effective sensitization of the Ln3+ ion luminescence upon the excitation in both UV and visible regions.

8189B-47, Session 8

Chromophores design for optical power limiting at telecommunications wavelength

C. Andraud, Ecole Normale Supérieure de Lyon (France)

No abstract available

8189B-40, Session 9

Photo-induced deformation of azobenzene elastomers: theory and simulations

M. Saphiannikova Grenzer, V. P. Toshchevikov, Leibniz-Institut für Polymerforschung Dresdene e.V. (Germany); J. Ilnytskyi, Institute for Condensed Matter Physics (Ukraine); G. Heinrich, Leibniz-Institut für Polymerforschung Dresdene e.V. (Germany)

Photoresponsive elastomers functionalized with azobenzene chromophores have been extensively explored recently as smart materials which are able to change their shape and volume in response to light. Since the light stimulus can be controlled rapidly, precisely and remotely, azobenzene elastomers have a fascinating potential for nano- and micro-technologies serving as artificial muscles, sensors, microrobots and micropumps [1-2].

Here, we present a microscopic theory of photo-induced deformation of azobenzene elastomers under uniform illumination with linearly polarized light. The theory is based on the statistical approach developed recently [3] for uncrosslinked azobenzene polymers built from short rigid oligomers with azobenzene chromophores in side chains. According to this approach, the photo-induced mechanical stress originates from the orientation anisotropy of azobenzene oligomers caused by the preferable reorientation of the azobenzene chromophores perpendicular to the electric vector of the light. In the present work, the theory [3] is extended to the case of azobenzene elastomers by taking the chain structure of network strands explicitly into account. We consider different orientation distributions of chromophores around the main chains which are determined by the potentials of internal rotations of spacers and by their length. The light-induced changes in orientation anisotropy of chromophores are described by an effective orientation potential, the strength of which is a linear function of the light intensity.

We show that, similar to the uncrosslinked azobenzene polymers, the photomechanic behaviour of azobenzene elastomers is very sensitive to their chemical structure. Azobenzene elastomers can demonstrate uniaxial contraction / expansion along the polarization vector of the light, if the chromophores have preferable orientation parallel / perpendicular, respectively, to the main chains. For some chemical structures, elongation of a sample displays a non-monotonic behaviour with the light intensity and can even change its sign (a stretched sample starts to be uniaxially compressed).

The orientation mechanism of photo-induced deformation has been verified in recent molecular dynamics simulations on two model side-chain azobenzene polymers [4]. The first one has a stiff main chain and a short spacer, while the second one has a flexible main chain and a long spacer. Both models demonstrate a noticeable deformation under homogeneous illumination with the sign of deformation depending on the molecular architecture. Results of computer simulations and the analytical theory are in a good qualitative agreement.

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8189B-41, Session 9

Use of nonscanning coherence radar for distance measurement

D. Ulieru, SITEX 45 (Romania); F. N. Pistritu, National Institute for Research and Development in Microtechnologies (Romania)

An interferometer without moving parts is processed for measurement of distances to, or distance differences between diffuse surfaces. The interferometer which is a variation of the nonscaning white light interferometer, utilizes the limited coherence of the light sources. The light is divided by a beam splitter and reflected from two surfaces, one references and one object surface. After recombination it is spatially filtred. A distance differences couses a delay between the reflections. The delay can be measured with the nonscanning with light interferometer by finding the positions of the correlation peaks. Since thee are no moving parts, the interferometer can be used to measure rapidly moving objects e.g. by recording the interference pattern with a streak camera or a high speed video camera. Because of the spatial filtering a medium powder light source is needed (at least 100mV or more) in order to have enough light intensity to be recorded by the COD sensor. Selection of a suitable grating angle and coherence length of the light sources can increase the measurement range as well as sensitivity and accuracy. The readable accuracy for a smooth surface showed be of the some order as for the coherence radar i.e. in the micrometer range. The maximum range which in the experiments performed here was about 2 mm, may also be interested by multiple reflections. In this way the range can be expanded by a factor of 100 or more depending on the COD array used. These figures can for example be compared with those reached using white light channeled spectrum interferometry.

8189B-42, Session 9

Chalcogenide and Germanium hybrid optics

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

When choosing a material to design infrared optics, an optical designer has to decide which material properties are most important to what they are trying to achieve. Factors include; cost, optical performance, index of material, sensor format, manufacturability, mechanical mounting and others. This paper will present an optical design that is made for a 640x480, 17µm sensor and is athermalized by using the material properties of Chalcogenide glass and Germanium (Ge). The optical design will be a 3-element f1.0 optic with an EFL of 20mm at 10µm. It consists of two Ge spherical lenses and a middle Chalcogenide aspheric element. By using Ge and Chalcogenide, this design utilizes the high index of Ge and combines it with the lower dn/dt of Chalcogenide glass to provide an athermalized design without the use of additional electro-optical thermal compensators inside the assembly. This study will start from the optical design process and explain the mechanical and optical properties of the design, then show the manufacturing process of molding an aspheric Chalcogenide element. After the three elements are manufactured, they will be assembled and tested throughout the temperature range of -40 to 85°C to compare optical performance to design expectations. Ultimately, this paper will show that a high performance, athermalized optical assembly is possible to manufacture at a lower cost with the use of combining different infrared materials that allow for spherical Ge lenses and only one aspherical Chalcogenide element which can be produced in higher volumes at lower costs through glass molding technology.

8189B-44, Session 9

Hyperspectral polarized and angular measurements for laser imaging and target characterization

C. Romain, N. Rivière, H. Laurent, ONERA (France)

Recent developments in laser-imaging and remote sensing require a comprehensive optical characterization of man-made targets. Reflectivity measurements of materials are valuable information for target classification and identification. Onera, the French Aerospace Lab, has developed a new optical instrument to measure hyperspectral polarized BRDF using a Supercontinuum “white” laser. We measured BRDF of various targets to build a large optical properties database for defence, security and industrial needs. Hyperspectral measurements provide relevant information to simulate actual and future laser-imaging devices. Apart from imaging applications, our instrument is used to retrieve microphysical properties (particle size distribution, optical thickness, absorption) of various scattering media for defence or industrial prospective applications.

8189B-45, Session 9

A platform for nanosensors

A. Attias, A. Colas, D. Kreher, F. Mathevet, Univ. Pierre et Marie Curie (France); F. Charra, Commissariat à l’Énergie Atomique (France)

In view of the demanding forthcoming applications in nanotechnology (nanosensors) for defence systems, it is of prime interest to create functions out of the plane and fully exploit the room above the substrate. Accessing the third dimension is so a mandatory step for nanooptics/electronics. Here we introduce the Janus-like 3D tecton concept. It consists of a dual-functionalized unit presenting two faces linked by a rigid spacer: one face (A) is designed for steering 2D self-assembly, the other one (B) is a functional molecule. The objective is to take advantage of the in-plane self assembling of building blocks lying on face A to control the positioning of out-off plane active unit B, linked to the base. Here we present nanosensors where (i) the A face self-assemble on a substrate leading to a nanoporous network, and (i) the functional molecule is a photoswitchable chromophore able to control the immobilization/release of guest molecules into/out of the cavities.

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8189C-50, Session 10

Fundamental and practical problems of QKD security

H. P. Yuen, Northwestern Univ. (United States)

There have been persistent claims in the literature that quantum key distribution (QKD), in particular the single-photon BB84 protocol, has been proved unconditionally secure not only in principle [1] but also for various concrete realizations [2]. The criterion of the attacker Eve's mutual information on the generated key K has been employed in most theoretical and all experimental work, which has been shown to be somewhat inadequate [3], and even very inadequate [4], against known-plaintext attacks (KPA) from Eve with quantum memory when K is used in the common one-time pad format. The unconditional security claim is thereby solely supported by the claim via a trace-distance criterion d which is interpreted [5] to be the probability of K being different from a uniform key with respect to Eve.

In [6] we have shown that d does not have such a meaning at all, thus the whole QKD unconditional security foundation has been removed. There is simply no security proof against KPA on K. It is further pointed out in [6] that security against KPA is an essential requirement of an unconditional security proof. In fact, if one just considers the raw security [6] of K, conventional symmetric-key expansion such as a keyed pseudo-random number generator would yield far better quantitative security than that of K obtained from any concrete QKD system. This is a proper comparison because a shared secret key is needed for creating the public channel in BB84. What is thus sorely missing is a proof of information-theoretic "semantic security" [7], for both raw security and "composition security" [1] against at least KPA.

In addition to the above basic points, this paper also shows how Eve's optimal probability of estimating K determines the number of semantically secure bits that can be generated regardless of what privacy amplification is employed. The severeness of this constraint is illustrated in specific numerical examples involving concrete QKD systems that have been experimentally developed with properly quantified security [2].

A further more practical problem of model completeness in QKD security analysis was brought out by the "Norway attack" [8] that completely undermines the security of known experimental QKD schemes. It will be shown that such attacks are totally inapplicable to the KCQ approach to quantum cryptography [9], even at the single-photon level.

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8189C-51, Session 10

Quantitative analysis of quantum noise masking in quantum stream cipher by intensity modulation operating at G-bit/sec-data rate

T. Iwakoshi, F. Futami, O. Hirota, Tamagawa Univ. (Japan)

An emergent subject in the modern cryptography is to realize a physical cipher with provable security operating at G bit/sec data rate under certain physical condition. Especially the defense data center communication is a concrete application .The quantum stream cipher by Yuen protocol so called Y-00 is a candidate of such a cipher [1,2]. It has the following feature. The transmitter sends the binary information data by one of many bases consisting of two coherent state signals, where a basis is selected randomly by the pseudo random number generator (PRNG) with the short secret key. The legitimate receiver with the same PRNG can directly observe the binary information signal without error, but the attacker without key is forced to observe the multi level signals and the receiver is extremely degraded by the quantum noise in the signal measurement. This corresponds to the random cipher that the ciphertext of simple mathematical cipher by PRNG is randomized by quantum noise [3] and it gives a masking effect against the attacker's security analysis [4]. If the masking is perfect in the context of hiding whole ciphertext, the cipher clearly has the unconditional security or information theoretic security. But in general the masking effect is very small in presently realizable schemes. An inquiry of realization methods of a perfect masking is a future problem. So to clarify the quantitative security property for the realizable such a random cipher is our concern because of the sense of the practice.

The primitive parameters of the security for such a cipher are the degree of the randomization and masking by quantum noise to the ciphertext of the attacker. This paper clarifies the masking effect for the Y-00 encryption system implemented by the intensity modulation, and shows the fact that this type may provide the greatest masking effect even if the attacker employs the universal heterodyne measurement, while the coherent modulation without the additional randomization can have the masking effect of one photon corresponding to the field vacuum noise. Following the quantitative analysis of the masking, we will show how to ensure the sufficient masking effect in our experimental encryption system with 4096 signal levels operating at 2.5 Gbit/sec data rate.

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8189C-52, Session 10

Quantum cryptography and authentication with low key consumption

A. Abidin, Linköping Univ. (Sweden); C. Pacher, T. Lorünser, Austrian Research Ctrs. GmbH - ARC (Austria); J. Larsson, Linköping Univ. (Sweden); M. Peev, Austrian Research Ctrs. GmbH - ARC (Austria)

Quantum Key Distribution (QKD - also referred to as Quantum Cryptography) is a technique for secret key agreement.

It has been shown that QKD rigged with Information-Theoretic Secure (ITS) authentication (using secret key) of the classical messages transmitted during the key distribution protocol is also ITS.

Note, QKD without any authentication can trivially be broken by man-in-the-middle attacks.

Here, we study an authentication method that was originally proposed because of its low key consumption; a two-step authentication that uses a publicly known hash function, followed by a secret strongly universal-2 hash function, which is exchanged each round.

This two-step authentication is not information-theoretically secure but it was argued that nevertheless it does not compromise the security of QKD. In the current contribution we study intrinsic weaknesses of this approach under the common assumption that the QKD adversary has access to unlimited resources including quantum memories. We consider several implementations of Quantum Cryptographic protocols that use such authentication and demonstrate various attacks that fully or partially extract the secret key, some of them relying on moderate computing power alone. Even including the final key from the protocol in the authentication does not rule out the possibility of these attacks.

Outline of the attacks: (i) Eve intercepts messages transmitted between Alice and Bob, (ii) Eve determines corresponding messages such that they collide with the authentic message under the public hash function (therefore also with the composed hash function), and in addition modify the final key that Alice and Bob generate such that Eve has complete or partial knowledge of it. Depending on the protocol variants (e.g. immediate vs. delayed authentication) the different attacks which we study address sifting, error correction, confirmation, and privacy amplication or only some steps. In some instances there is a price: introducing errors in the system, but these errors are few enough so that subsequent protocol steps can handle them. To rectify the situation, we propose a countermeasure that, while not information-theoretically secure, restores the need for very large computing power for the attack to work. Finally, we specify conditions that must be satisfied by the two-step authentication in order to restore information-theoretic security.

8189C-53, Session 10

Finite-key analysis of the six-state protocol with photon number resolution detectors

S. Abruzzo, H. Kampermann, S. Bratzik, M. Mertz, D. Bruss, Heinrich-Heine-Univ. Düsseldorf (Germany)

Quantum key distribution aims at the creation of a secret key between two authorized parties. Among the discrete-variable protocols, the six-state protocol [1] can tolerate more noise than the BB84 protocol, which was the first proposed QKD protocol. Some of the security proofs developed so far analyzed the six-state protocol only in an idealized setting, i.e. with ideal single-photon sources, a perfect quantum channel and ideal detectors[2]. In realistic scenarios, photon sources could produce multi-photon signals which cannot be described by qubits anymore, so infinite-dimensional operators have to be considered. Moreover channels are imperfect because there are losses during the transmission of the signal. Finally detectors are imperfect because double clicks and dark counts are possible.

Besides experimental imperfections, there are also approximations made in the security proofs. Many proofs that consider experimental issues are developed in the asymptotic case, where the sifted key tends to infinity and the protocol has a negligible probability of failure. The few proofs that analyzed the finite correction to the key length for the six-state protocol are developed only in the idealized scenario. With this work we want to contribute to closing this gap by extending the finite-key analysis also the to scenario with imperfect devices. We adopt the information-theoretical model presented in [3] and we extend the multi-photon analysis given in [4] to the finite case.

For what concerns the experimental set-up, we study the scenario where there is an untrusted source placed between Alice and Bob and photon number resolving detectors are used for having access to the photon number statistics of the incoming signals.

As an application we calculate key-rate for the setting where the source produces entangled photon pairs via parametric down-conversion and the losses in the channel depend on the distance.

In agreement with other works considering finite-key corrections, we find that the difference between the asymptotic case and the finite case is not negligible and it should be considered in any experimental situation.

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8189C-54, Session 11

Single photon detection for high bit rate quantum communication

J. Dynes, Z. Yuan, A. Sharpe, A. Shields, Toshiba Research Europe Ltd. (United Kingdom)

Quantum communication, in particular, quantum key distribution (QKD) is moving ever closer to real world implementation. However, for successful QKD system deployment, the QKD system components must be robustly designed and feature highly reliable operation. In this paper we focus on one important aspect of any quantum communication system: the single photon detector. In particular our interest is centered upon the InGaAs avalanche photodiode (APD) single photon detector operating in a self-differencing (SD) mode. Such a detector features high clock frequencies of up to 3GHz, high photon count rates as well as detection efficiencies approaching 20% with low afterpulsing. We show successful operation of a high bit rate QKD system using this SD-APD technology in a real world fiber network.

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A parallel, event-driven software approach for quantum key

G. E. Brittelle, Boeing-SVS, Inc. (United States)

The BB84 Quantum Key Distribution (QKD) protocol, developed by Charles Bennett and Gilles Brassard in 1984, provides a method of securely communicating a private key from one party to another for use in one-time pad encryption. The BB84 protocol stack is a four-stage process consisting of sifting, error detection and correction, information reconciliation, and privacy amplification. The implementation of this stack for a high key-rate QKD system is a computationally intensive process where overall system performance is governed by the efficient management of high-rate data streams, the storage associated with the distance between the two communicating parties, and the performance of the information reconciliation and privacy amplification algorithms. Many current QKD systems implement the sifting algorithm as well as the generation and management of the high-speed quantum data streams in custom hardware designed to manage the computational demands of high-performance QKD systems. This paper presents a software-based implementation of the BB84 protocol for a high-speed QKD system using robust, commercially available components.

Modern computer architectures have made it possible to achieve cluster-like performance in a professional workstation without the data locality issues associated with a distributed system. Cache-coherent Non-Uniform Memory Access (NUMA) systems integrate each processer with dedicated local memory, dramatically decreasing access time and improving overall system performance. The QKD system presented here leverages the optimal performance of the NUMA architecture to implement QKD in a parallel context, or PQKD84 for Parallel-QKD-BB84. The PQKD84 system software is a collection of independent software modules responding to system events and communicating through a common high-speed shared-memory interface. A PQKD84 executive module manages the operation of each system module. Each system module (task) is assigned to a specific processor enabling parallel execution without requiring interaction with an operating system scheduler. The implementation of high-performance, commercially available hardware is abstracted away and system hardware appears as a system software module. A Curtiss-Wright Serial Front Panel Data Port (sFPDP) card implements a low-latency, high-speed serial communica¬tions protocol providing a sustained 2.5 Gbps (Giga-bits per second) link to manage the high-rate classical channel data streams. A teraflop-class general-purpose graphics processing unit (GPGPU) provides the engine for the error detection and correction algorithm.

This paper demonstrates a parallel implementation of the BB84 protocol in a high-speed QKD system using robust, commercially available components. Additionally, the NUMA-based system architecture and hardware interfaces allow the system to scale linearly and is highly suitable for practical implementations.

8189C-56, Session 11

A high brightness source of polarization entangled photons

F. O. Steinlechner, ICFO - Instituto de Ciencias Fotónicas (Spain); P. Trojek, qutools GmbH (Germany) and Ludwig-Maximilians-Univ. München (Germany) and Max-Planck-Institut für Quantenoptik (Germany); M. Jofre, A. Gardelein, ICFO - Instituto de Ciencias Fotónicas (Spain); H. Weinfurter, Ludwig-Maximilians-Univ. München (Germany) and Max-Planck-Institut für Quantenoptik (Germany); V. Pruneri, ICFO - Instituto de Ciencias Fotónicas (Spain) and ICREA-Institució Catalana de Recerca i Estudis Avançats (Spain)

Summary

We present a simple but highly efficient source of polarization entangled photons based on SPDC in bulk PPKTP. Utilizing the highest available nonlinear coefficient in a type 0 collinear configuration, as well as an optimized geometry of the setup, we expect to exceed the brightness achieved in current schemes by at least an order of magnitude.

Motivation

While the use of polarization entangled photons is currently mostly limited to quantum optics laboratories, a commercial implementation of communication protocols utilizing entangled photons may well be possible in the foreseeable future. Many obstacles must be overcome in the pursuit of a global scale quantum optical communication network; one of these is the engineering of sources of entangled photons with sufficient brightness and entanglement visibility.

Entangled photon source

We report on our progress in engineering a compact, high brightness source of polarization entangled photons centered around 810 nm. Our approach is based on collinear non-degenerate down-conversion emission,from crossed type-0 crystals, as demonstrated in [1]. With respect to [1], utilizing beta-BaB2O4 (BBO), we make use of periodically poled KTiOPO4 (PPKTP). The proposed crossed crystal geometry allows accessing the largest nonlinear coefficient in PPKTP which is almost an order of magnitude larger than that utilized in previous schemes, such as the type II Sagnac configuration [2]. We consider the options of both multimode (free running) laser diode and single frequency pumping and discuss the consequences for spectrum and achievable brightness. Using 2x12mm crossed PPKTP crystals and single frequency laser pumping, brightness and visibility in excess of 5 MHz/mW and 95% respectively, have already been achieved, whereby these values were directly measured, and not inferred after correction for losses and correction for accidental coincidence counts.

Finally, by combining the larger interaction length of 2x20mm PPKTP crystals with an optimally designed geometric setup, we expect to further improve upon these values and achieve unprecedented brightness, especially valuable to long distance quantum communication links in fiber and free-space.

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8189C-57, Session 11

Free-space quantum key distribution with spatial modes of the optical field

M. T. Gruneisen, Air Force Research Lab. (United States); R. C. Dymale, Boeing-SVS, Inc. (United States); K. E. Stoltenberg, Air Force Research Lab. (United States)

In terrestrial quantum key distribution (QKD) systems, optical fibers can provide efficient coupling between the QKD transmitter and receiver. For applications involving air- and space-based platforms, the optical channel will necessarily be established through free space where absorption, scattering, atmospheric turbulence, and diffraction can lead to significant optical losses that directly impact quantum bit rates in single-photon protocols. Unconfined propagation through free space however also creates the opportunity to increase the capacity of the quantum channel by utilizing spatial modes of the optical field for multi-channel and multi-level encoding of photons. Exploiting spatial modes for QKD, as an alternative or addition to polarization encoding, requires new techniques for encoding, multiplexing, de-multiplexing, and performing projective measurements on single photons according to the amplitude and phase characteristics of the wave function.

In this presentation, principles of holography are considered as a means of generating the spatial modes of the mutually unbiased bases in a multi-dimensional Hilbert space and performing projective measurements on photons associated with these modes. Computer-generated holography (CGH) with high-resolution spatial light modulators is considered as a means of generating the amplitude and phase modulation associated with these modes and volume holography is considered as a means of performing projective measurements and de-multiplexing optical channels defined by spatial modes. Physical optics analysis quantifying the performance limits of both thin and thick phase holograms will be presented and compared to experimental results. Phase-only modes are generated modulo 2pi with a liquid-crystal (LC) phase modulator. The amplitude and phase modulations required for mutually unbiased bases states are generated via CGH with a single LC phase modulator. Projective measurements are performed with volume holograms prepared in photo-thermo-refractive glass and photorefractive lithium niobate.

8189C-58, Session 12

Quantum key distribution from a space-based platform

R. Ursin, Univ. Wien, Institute for Quantum Optics and Quantum Information (Austria)

In a modern information based society secure communication is of utmost importance. An overnight breakthrough in mathematics or computer science could make current electronic money transfer encryption methods instantaneously vulnerable. This is because the security of classical cryptography relies on the computational difficulty of certain mathematical functions. Hence, classical cryptography can neither provide any indication of eavesdropping nor guarantee absolute security.

Modern quantum cryptography, often also called quantum key distribution (QKD), provides both as it is based on theoretical and experimental proven laws of nature. However, with present fiber and detector technology terrestrial quantum communication is limited to within some 100 of kilometers, well within the radius a single person can travel within a reasonable time. A very convenient way to extend the distance for quantum communication between earth based parties is the use of optical free-space links to and from satellites. This will enable to perform quantum communication over distances currently not accessible via fibers and is thus expected to be of high technological impact in the future. The possibility to distribute an absolute secure key between globally separated communication parties makes such a system highly marketable.

Within various feasibility studies and experimental tests for adopting the concepts of fundamental quantum physics and quantum communications to a space infrastructure it was shown on a 144km terrestrial free-space channel that, with state-of-the-art technologies, quantum communication to and from satellite are possible. I will present in my talk, the basic principles of QKD, its implementation using various protocols and recent results from ESA funded studies within this field will be described.

8189C-59, Session 12

Performances of the SwissQuantum network over 21 months

D. Stucki, M. Legré, L. Monat, S. Robyr, P. Trinkler, G. Ribordy, id Quantique SA (Switzerland); R. Thew, N. Walenta, N. Gisin, Univ. of Geneva (Switzerland); F. Buntschu, D. Perroud, G. Litzistorf, Univ. of Applied Sciences Western Switzerland (Switzerland); S. Ventura, P. Junod, Ecole d'Ingénieurs du Canton de Vaud (Switzerland)

In this paper, we present the architecture and results of the SwissQuantum network. This three-nodes triangular quantum network was running from March 2009 to January 2011 in the Geneva metropolitan area. The three trusted nodes were located at the University of Geneva (Unige), the CERN and the University of Applied Sciences Western Switzerland (hepia). This quantum network was composed of three layers: a quantum layer, a key management layer, and an application layer.

The three point-to-point Quantum Key Distribution (QKD) links of the quantum layer were implemented with customized versions of IDQ commercial QKD device. They relied on the plug and play protocol. This protocol in a go&return scheme allows to auto-compensate the fluctuations of the polarization in the fiber between two nodes. The quantum bit error rate and the secret rate were rather stable over the full period. The long running time allows us to make some statistics and we register some fluctuation between day and night for example. The only problems on the quantum layer were the consequences of external problems: air conditioning failure in one of the node rooms; power outage. This testbed allowed us to demonstrate the robustness and the reliability of quantum key distribution over almost two years in a field environment.

The key management layer is the interface between the quantum layer and the application layer. Indeed, QKD is limited to a strict configuration: point-to-point link with a limited distance. The key management layer allows both to implement features which make the quantum layer more reliable, and to increase the number of application configurations which are compatible with QKD technology. Link aggregation can for example be used to increase the bandwidth and availability of a link between two nodes thanks to multiple network paths between these two nodes. In the SwissQuantum network, the connection between CERN and Unige had higher priority than the other links. For these connections, keys were thus exchanged along two paths. Dual key agreement was also implemented in the key management layer. It consists in combining one key exchanged with QKD and one exchanged with a conventional public key agreement technique.

The application layer was composed of three different cryptographic services. The connection exchanged between CERN and Unige were encrypted with commercial 10 Gbps Ethernet layer 2 encryptors. Two prototypes were tested on the link Unige - Hepia. One pair of 2Gps fiber channel layer 2 cryptographic devices which performed not only encryption but also authentication. The second prototype was based on IPsec layer 3 encryption.

The successful operation of the SwissQuantum network over more 21 months shows that QKD is mature enough for integration in secure telecommunication networks. The total operation time exceeded 45'000 hours and more than 800 million keys were exchanged.