AMOS

Advanced Maui Optical and Space Surveillance Technologies Conference

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IN OUR 10TH YEAR...

ABSTRACTS OF TECHNICAL PAPERS

Wailea Marriott Resort & Spa

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IRIDIUM/COSMOS COLLISION

ASTRODYNAMICS

IMAGING

TUTORIAL

SPACE SITUATIONAL AWARENESS

ORBITAL DEBRIS

NON-RESOLVED OBJECT CHARACTERIZATION

ADAPTIVE OPTICS

IYA FILM

ASTRONOMY

SPACE-BASED ASSETS

INSTRUMENTATION

ATMOSPHERICS/SPACE WEATHER

POSTER PRESENTATIONS

Analysis of the Prediction Characteristics for the Collision

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The Russian Space Surveillance System maintains an independent satellite catalog and has extensive experience in solving all the types of problems related to the observations of satellites, in particular the problems of collision prediction. For dealing with this important problem the Russian SSC uses the direct method that has been presented at the First European Conference on Space Debris. This algorithm looks for the intervals of dangerous approaches of all the pairs of cataloged satellites and evaluates the geometrical characteristics of each approach and the probability of collision. The rather sophisticated formula used for the calculation of collision probability includes the sizes of approaching satellites, correlation matrices of position determination, relative positions and velocities for the time of minimum distance.

This work presents and analyses rather accurate approximate relationship for the collision probability, explicitly demonstrating the influence of all the parameters. The results of the analysis lead to the conclusion that only satisfactory coincidence of real and calculated errors of position determination for the satellites for the time of approach provides conditions for making the best possible decision on the possibility of collision. The paper describes the measures undertaken in the catalog maintenance software, which provides this coincidence for the satellites with insignificant atmospheric drag.

What potential capabilities for collision prediction do the Russian sensors and the Space Surveillance Center maintaining the catalog have? The collision that happened above the Russian territory on February 10 of the year 2009 at 16. 46 UTC of the non-cooperable satellite Cosmos-2251 and the operational spacecraft Iridium-33 provided data for the answer to this question. This paper presents the results. We performed the analysis of the time dependence of the errors of the determination of the relative positions of the satellites for the time of their collision for all the updated by radar measurements orbits, starting from 10 days before the collision. It is shown that for the whole time interval the theoretical values of the errors are in satisfactory coincidence with their real values. The average level of the errors in the direction of the radius vector for the time of the collision are about 20-30 meters and for other directions are less than 500 meters. For the 10 days time span before the collision the collision probabilities are calculated. They increase in general from 10-5 in the beginning of the interval up to 10-4 in the end just prior to collision.

It is shown that in case of collision warning starting two days prior to collision with further updates for each update of the involved orbits the frequency of false alarm will be about 0.02 (once in 50 days).

The Spectrum of Satellite Breakup and Fragmentation

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The objective of this paper is to expose the spectrum of satellite breakup physics and is implications for debris production and observables.

Satellite response to the debris environment generally emphasizes small scale hypervelocity impact or the interaction of intense, coherent radiation with satellite surfaces or internals. There are empirical correlations of fragment size distributions based on arena tests and extremely rare observations of breakups in space. Klinkrad describes well research on material response to hypervelocity impact such as the ballistic limit for various materials and shielding walls. Smirnov, et. al., report well the phenomenology of breakups under the influence of nonuniform internal loading of monolithic bodies, such as pressurized tanks. They set forth the transformation of elastic energy into fragment kinetic energy. They establish a sound physical framework for bounding the number of fragments. We took advantage of these works in our previous papers.

There is not much research into the response of nonuniform structures to hypervelocity collisions with similarly massive and complex objects. This work generally employs complex hydrodynamic and finite element computation that is not well suited to real time, operational assessment of the consequences of such encounters. We hope to diminish the void between the extremes of microscopic impact and complex hydrocodes.

Our previous reports employed the framework established by Chobotov and Spencer, fundamentally equilibrium, Newtonian approach. We now explore the spectrum of interactions and debris evolutions possible with realistic combinations of these theories.

The spectrum encompasses Newtonian, semi-elastic energy and momentum transfer through little or no momentum exchange and from virtually all of the mass of the colliders being involved through fractional mass involvement. We observe that the more Newtonian outcomes do not agree well with sparse observations of the few collisions that have occurred in space at high relative velocities.
High speed images of collisions such as the Delta 183 intercept reveal that the objects appear to pass through each other, emerging as a collection of fragments that then disperse with diverse particular velocities under the influence of gravitation and other astrodynamic forces. We previously introduced the concept of partial involvement in which the portions of the colliders that do not make intimate contact tear off, retaining their parent momenta and subsequently fragmenting as elastic energy is released. We now conjecture that the duration of the collision is so short (fractional milliseconds) that stress waves cannot propagate within the involved portions either, and that the involved masses fragment inertially, each fragment inheriting the velocity of the parent object rather than the involved masses evolving about the vector sum of collider parent masses. We call this ghosting. We also observe that ghosted outcomes appear in aggregate to match much more closely observed outcomes, particularly that of the recent Iridium 33 Cosmos 2251 event.

We will discuss the range of outcomes we predict over the spectrum of interaction and fragmentation models. We will examine how the range of outcomes might affect fragment size, mass, and trajectory evolution, with implications for what might be observable and where the less observable fragments might reside.

Analysis and Implications of the Iridium 33/Cosmos 2251 Collision

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On 2009 February 10, Iridium 33--an operational US communications satellite in low-Earth orbit--was struck and destroyed by Cosmos 2251--a long-defunct Russian communications satellite. This is the first time since the dawn of the Space Age that two satellites have collided in orbit.

To better understand the circumstances of this event and the ramifications for avoiding similar events in the future, this paper provides a detailed analysis of the predictions leading up to the collision, using various data sources, and looks in detail at the collision, the evolution of the debris clouds, and the long-term implications for satellite operations.

The only publicly available system available to satellite operators for screening for close approaches, SOCRATES, did predict this close approach, but it certainly wasn't the closest approach predicted for the week of February 10. In fact, at the time of the collision, SOCRATES ranked this close approach 152 of the 11,428 within 5 km of any payload. A detailed breakdown is provided to help understand the limitations of screening for close approaches using the two-line orbital element sets. Information is also provided specifically for the Iridium constellation to provide an understanding of how these limitations affect decision making for satellite operators. Post-event analysis using high-accuracy orbital data sources will be presented to show how that information might have been used to prevent this collision, had it been available and used.

Analysis of the collision event, along with the distribution of the debris relative to the original orbits, will be presented to help develop an understanding of the geometry of the collision and the near-term evolution of the resulting debris clouds. Additional analysis will be presented to show the long-term evolution of the debris clouds, including orbital lifetimes, and estimate the increased risk for operations conducted by Iridium and other satellite operators in the low-Earth orbit environment.

The final portion of the paper will look at how collaborative efforts, such as the current Data Center operations supporting SOCRATES-GEO, might be used to reduce the overall risk of similar events in the future.

High Power Large Aperture Radar Observations of the Iridium-Kosmos Collision

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We present results from two beam park radar experiments conducted with the EISCAT Tromso and Svalbard radars on February 14th and 19th 2009 to survey the debris soon after the Iridium-Kosmos satellite collision. The resulting debris is clearly visible in both measurements. The results are compared to predictions by the ESA PROOF model and several pre-collision measurements conducted in December 2008.

Localized Density/Drag Prediction for Improved Onboard Orbit Propagation

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Since the development of Luigi G. Jacchia's first density model in 1970 (J70), atmospheric density modeling has steadily focused on large monolithic codes that provide global density coverage. The most recent instantiation of the global density model is the Jacchia-Bowman 2008 (JB08) model developed by Bruce Bowman of the Air Force Space Command. As the models have evolved and improved, their complexity has grown as well. Where the J70 model required 2 indices and various time averages to determine density, the JB08 model requires 5 indices to determine density. Due to computational complexity, the number of real-time inputs required, and limited forecasting abilities, these models are not well suited for onboard satellite orbit propagation.

In contrast to the global models, this paper proposes the development of a density prediction tool that is only concerned with the trajectory of a specific satellite. Since the orbital parameters of most low Earth orbiting satellites remain relatively constant in the short term, there is also minimal variation in the density profile observed by the satellite. Limiting the density model to a smaller orbit regime will also increase the ability to forecast the density along that orbital track. As a first step, this paper evaluates the feasibility of using a localized density prediction algorithm to generate the density profile that will be seen by satellite, allowing for high-accuracy orbit propagation with minimal or no input from the ground.

The algorithm evaluated in this paper is a simple Yule-Walker auto-regressive filter that, given previously measured density values, provides predictions on the upcoming density profile. This first approach requires zero information about the satellite's current orbit, but does require an onboard method for determining the current, local density. Though this aspect of the onboard system is not analyzed here, it is envisioned that this current, local density (or equivalently drag acceleration) would be calculated through onboard processing of GPS or accelerometer data.

Using the trajectory of the CHAMP satellite as a test case, various samples of CHAMP density data in the past (i.e. before a chosen epoch time) will be input to the filter, and the filter will in turn predict future" density values (i.e. beyond the chosen epoch time). The effectiveness of the filter will be assessed by comparing its predicted density values to true densities in the CHAMP database at those times. The two major design parameters to be investigated for the auto-regressive filter are the appropriate order of the filter and the past data sample (expressed in terms of both time span of the data and sampling interval). Results describe the prediction accuracy of the filter and length of time over which accuracy is maintained for various parameter settings.

Comparison of Different Algorithms of Orbit Determination Using Radar Measurements Acquired

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Efficient solution of the problem of warning of collisions between important spacecraft and other orbiting satellites requires expanding of the catalog of tracked satellites (currently comprising about 15,000 satellites) by an order of magnitude or more. This is a very difficult scientific and technical task. One of the major aspects is the creation of software tools capable of automatic maintenance of such a great catalog in real time. The amount of radar or optical measurements to be processed can reach millions, which is more than order of magnitude greater than the currently existing measurement fluxes.

It is known that the increase of the number of measurements by the order of magnitude results in at least two orders of magnitude increase of computational effort required by the procedures used for correlation of measurements with the catalog. This results in significant problems with processing the measurements in real time. The preliminary "compression" of measurement data acquired during one penetration of the radar's field of view will essentially (by the order of magnitude and more) reduce the requirements to the computers' capacity. The compression will happen in case all the single measurements (marks) acquired during one penetration will be replaced by the orbit generated using these measurements. Here we mean that a single radar measurement is the result of measuring radar parameters (range, azimuth, elevation angle and maybe range rate) by one pulse.

Traditionally for orbit determination by one penetration two types of techniques have been used – recurrent and joint processing. The recurrent procedures, convenient for the real time processing are usually based on generalized Kalman filter. The less convenient joint processing techniques are based on different modifications of least squares or least modules techniques. This work suggests and investigates a very simple algorithm combining the features of these two approaches and that is highly efficient for the considered task.

When the errors of single measurements are time correlated and also for all the cases when the statistical characteristics of the errors of single measurements are not known completely, the traditional techniques do not provide the guarantee estimate of the accuracy of acquired estimates. Now this limitation becomes important since the accurate evaluation of collision risk requires coincidence between the real and calculated values of the errors of orbit determination. Now we need the "guarantee" techniques of orbit determination, which along with the estimates of orbital parameters generate the guaranteed intervals or the errors for each of them. In addition, since the traditional techniques are efficient (for linear problem, non – correlated errors of measurements) the guarantee approach should not be less efficient than these methods.

The work formulates the general algorithm based on guarantee approach. It is characterized by significantly greater amount of calculations compared to traditional procedures. However, this san not be treated as a limitation since in the system maintaining the catalog and predicting collision hazard this algorithm is used much more rarely than the traditional technique. The work also presents a simple and elegant modification of the general guarantee approach procedure that has certain geometrical sense. The comparative analysis of this simplified algorithm with the least squares method is given as well. Mathematical simulation is used for investigation of comparative characteristics of different procedures. This is done under the assumption that the radar measures the local spherical coordinates of the satellite within the zone limited in range (not more than 3000-7000 km) and elevation angle (not more than 40°-60°) with errors of single measurements about tens of meters for the range and several angular minutes for angular coordinates.

Investigation of the Characteristics of the Algorithm of Primary Orbit Determination for LEO

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While processing of the radar information aimed at satellite catalog maintenance some measurements do not correlate with cataloged and tracked satellites. These non-correlated measurements participate in the detection (primary orbit determination) of new (not cataloged) satellites. The satellite is considered newly detected when it is missing in the catalog and the primary orbit determination on the basis of the non-correlated measurements provides the accuracy sufficient for reliable correlation of future measurements. We will call this the detection condition.

One non-correlated measurement in real conditions does not have enough accuracy and thus does not satisfy the detection condition. Two measurements separated by a revolution or more normally provides orbit determination with accuracy sufficient for selection of other measurements. However, it is not always possible to say with high probability (close to 1) that two measurements belong to one satellite. Three measurements for different revolutions, which are included into one orbit, have significantly higher chances to belong to one satellite. Thus the suggested detection (primary orbit determination) algorithm looks for three uncorrelated measurements in different revolutions for which we can determine the orbit inscribing them. The detection procedure based on search for the triplets is rather laborious. Thus only relatively high efficiency can be the reason for its practical implementation.

The work presents the detailed description of the suggested detection procedure based on the search for triplets of uncorrelated measurements (for radar measurements).

The break-ups of the tracked satellites provide the most difficult conditions for the operation of the detection algorithm and reveal explicitly its characteristics. The characteristics of time efficiency and reliability of the detected orbits are of maximum interest. Within this work we suggest to determine these characteristics using simulation of break-ups with further acquisition of measurements generated by the fragments. In particular, using simulation we can not only evaluate the characteristics of the algorithm but adjust its parameters for certain conditions: the orbit of the fragmented satellite, the features of the break-up, capabilities of detection radars etc.

We describe the algorithm performing the simulation of radar measurements produced by the fragments of the parent satellite. This algorithm accounts of the basic factors affecting the characteristics of time efficiency and reliability of the detection.

The catalog maintenance algorithm includes two major components detection and tracking. These are two processes permanently interacting with each other. This is actually in place for the processing of real radar data. The simulation must take this into account since one cannot obtain reliable characteristics of detection procedure simulating only this process. Thus we simulated both processes in their interaction.

The work presents the results of simulation for the simplest case of a break-up in near-circular orbit with insignificant atmospheric drag. The simulations show rather high efficiency. We demonstrate as well that the characteristics of time efficiency and reliability of determined orbits essentially depend on the density of the observed break-up fragments.

A Real Time Superresolution Image Enhancement Processor

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An image processor is discussed that combines many types of image enhancement onto a single compact electronics card. The current enhancements include bad pixel compensation, focal plane array non-uniformity correction, and several stages of contrast enhancement, feature sharpening, superresolution, and image motion stabilization. Though there are certainly better algorithms for particular applications, this mixture of algorithms reliably enables the system to substantially improve image quality for a large variety of sensors, platforms, and imaging geometries. The card design hosted an FPGA and microprocessor facilitated rapid development by allowing many complicated algorithm elements to be quickly coded in C, with the FPGA providing horsepower for simpler but more computationally intensive elements. Examples show the quality improvement gained by compensating for image degradations including camera motion, atmospheric turbulence induced blur, focal plane imperfections, camera pixel density, and noise.

Support-Based Digital and Optical Super-resolution in One and Two Dimensions

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A finite support of the object brightness distribution causes band-limited optical image data to contain information about that distribution at spatial frequencies above the optical band edge. Such information can be extracted from the image data, thus enabling optical superresolution (OSR). OSR attained in this way, as we shall show, is largely independent of the degree of detector undersampling, or digital sub-resolution. We shall present a unified Fisher-information-theoretic analysis of the processes of support-induced digital and optical superresolution of a sequence of sub-pixel-shifted low-resolution images in one (1D) and two (2D) spatial dimensions. We first express the object spatial spectrum as a linear superposition over its samples via a sampling type of expansion. This expansion captures quantitatively the extent of the coupling of information pertaining to superresolving (SR) frequency samples into the measurement band and thus into the image data. We then use the concept of Fisher information to determine the minimum error bounds on an unbiased estimation of these SR frequency samples, or equivalently the maximum possible fidelity of recovery of such information. The Fourier-domain sampling function is the usual sinc function in 1D, a direct product of two sinc functions for a 2D rectangular support, and closely related to the Fourier-Bessel function for a 2D circular support. We analyze these three cases in great detail with the help of FI and associated Cramer-Rao bounds under a variety of noise and other operating conditions. In this work we also verify a number of conclusions reached by previous researchers, including the extreme difficulty of obtaining even a modest frequency extrapolation with the help of support alone and a spatially-varying resolution improvement for bright sources.

This work attempts to clarify a number of foundational issues about digital and optical superresolution from an estimation-theoretic viewpoint, particularly the essential role of prior knowledge and the enormous difficulty in achieving any significant bandwidth extension in an unbiased reconstruction. We shall also present our preliminary results on a general computational approach for addressing arbitrarily complicated support geometries in our FI-based analysis.

Preconditioning MFBD and the Local Minimum Trap

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Obtaining high resolution images of space objects from ground based telescopes involves using a combination of sophisticated hardware and computational post processing techniques. An important, and often highly effective, computational post processing tool used at AMOS is multi-frame blind deconvolution (MFBD) for image restoration.

One difficulty with using MFBD algorithms is that the nonlinear inverse problem they are designed to solve may have many local minima. Standard optimization methods that use the gradient to search for a minimum (e.g., the conjugate gradient method) may get trapped in a local minimum, resulting in a less than optimal restored image. One approach to get around this difficulty is to run the algorithm several times with different initial guesses, which then results (hopefully) in computing several different local minima. A pseudo global minimum is then found by determining the best of these local minima. There are several disadvantages to this approach, including the extensive cost for large scale problems.

In this paper we consider an alternative, computationally less expensive approach, based on preconditioning. Preconditioning is used widely in science and engineering to accelerate convergence of iterative optimization methods, but it is usually applied to convex problems that have only one local minimum. However, recently it has been observed that for a nonlinear inverse problem arising in inverse scattering that preconditioning can have the dual advantage of improving the rate of convergence and reducing the problem of becoming trapped in local minima. We investigate adapting this approach to MFBD. The most effective approaches are designed using information specific to the application, so we consider several schemes appropriate for use in MFBD algorithms, and for imaging of space objects.

A Statistical Information Based Analysis of a Compressive Imaging System

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Recent advances in optics and instrumentation have dramatically increased the amount of data, both spatial and spectral, that can be obtained about a target scene. The volume of the acquired data can and, in fact, often does far exceed the amount of intrinsic information present in the scene. In such cases, the large volume of data alone can impede the analysis and extraction of relevant information about the scene. One approach to overcoming this impedance mismatch between the volume of data and intrinsic information in the scene the data are supposed to convey is compressive sensing.

Compressive sensing exploits the fact that most signals of interest, such as image scenes, possess natural correlations in their physical structure. These correlations, which can occur spatially as well as spectrally, can suggest a more natural sparse basis for compressing and representing the scene than standard pixels or voxels. A compressive sensing system attempts to acquire and encode the scene in this sparse basis, while preserving all relevant information in the scene.

One criterion for assessing the content, acquisition, and processing of information in the image scene is Shannon information. This metric describes fundamental limits on encoding and reliably transmitting information about a source, such as an image scene. In this framework, successful encoding of the image requires an optimal choice of a sparse basis, while losses of information during transmission occur due to a finite system response and measurement noise. An information source can be represented by a certain class of image scenes, .e.g. those that have a common morphology. The ability to associate the recorded image with the correct member of the class that produced the image depends on the amount of Shannon information in the acquired data. In this manner, one can analyze the performance of a compressive imaging system for a specific class or ensemble of image scenes.

We present such an information-based analysis of a compressive imaging system based on a new highly efficient and robust method that enables us to evaluate statistical entropies. Our method is based on the notion of density of states (DOS), which plays a major role in statistical mechanics by allowing one to express macroscopic thermal averages in terms of the number of configuration states of a system for a certain energy level. Instead of computing the number of states at a certain energy level, however, we compute the number of possible configurations (states) of a particular image scene that correspond to a certain probability value. This allows us to compute the probability for each possible state, or configuration, of the scene being imaged.

We assess the performance of a single pixel compressive imaging system based on the amount of information encoded and transmitted in parameters that characterize the information in the scene. Amongst many examples, we study the problem of faint companion detection. Here, we show how information in the recorded images depends on the choice of basis for representing the scene and the amount of measurement noise. The noise creates confusion when associating a recorded image with the correct member of the ensemble that produced the image. We show that multiple measurements enable one to mitigate this confusion noise.

Speckle Imaging with a Partitioned Aperture: Laboratory Results

Brandoch Calef

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Speckle imaging is a class of techniques for imaging through atmospheric turbulence by collecting and processing a large number of short-exposure frames. In severe conditions, when the diameter of the telescope is much larger than the characteristic scale of atmospheric fluctuations, the reconstructed image is dominated by "turbulence noise" caused by redundant baselines in the pupil. In earlier work, it was shown that this noise could be dramatically reduced by partitioning the telescope aperture and combining the bispectra of all the subapertures. We will describe an experimental investigation of this technique and show results from a laboratory study.

Enhancing Image Processing Performance for PCID in a Heterogeneous Network of Multi-code Processors

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The Physically-Constrained Iterative Deconvolution (PCID) image deblurring code is being ported to heterogeneous networks of multi-core systems, including Intel Xeons and IBM Cell Broadband Engines. This paper reports results from experiments using the JAWS supercomputer at MHPCC (60 TFLOPS of dual-dual Xeon nodes linked with Infiniband) and the Cell Cluster at AFRL in Rome, NY. The Cell Cluster has 52 TFLOPS of Playstation 3 (PS3) nodes with IBM Cell Broadband Engine multi-cores and 15 dual-quad Xeon head nodes. The interconnect fabric includes Infiniband, 10 Gigabit Ethernet and 1 Gigabit Ethernet to each of the 336 PS3s. The results compare approaches to parallelizing FFT executions across the Xeons and the Cell's Synergistic Processing Elements (SPEs) for frame-level image processing. The experiments included Intel's Performance Primitives and Math Kernel Library, FFTW3.2, and Carnegie Mellon's SPIRAL.

Optimization of FFTs in the PCID code led to a decrease in relative processing time for FFTs. Profiling PCID version 6.2, about one year ago, showed the 13 functions that accounted for the highest percentage of processing were all FFT processing functions. They accounted for over 88% of processing time in one run on Xeons. FFT optimizations led to improvement in the current PCID version 8.0. A recent profile showed that only two of the 19 functions with the highest processing time were FFT processing functions. Timing measurements showed that FFT processing for PCID version 8.0 has been reduced to less than 19% of overall processing time. We are working toward a goal of scaling to 200-400 cores per job (1-2 imagery frames/core). Running a pair of cores on each set of frames reduces latency by implementing parallel FFT processing. Our current results show scaling well out to 100 pairs of cores. These results support the next higher level of parallelism in PCID, where groups of several hundred frames each producing one resolved image are sent to cliques of several hundred cores in a round robin fashion.

Current efforts toward further performance enhancement for PCID are shifting toward using the Playstations in conjunction with the Xeons to take advantage of outstanding price/performance as well as the Flops/Watt cost advantage. We are fine-tuning the PCID parallization strategy to balance processing over Xeons and Cell BEs to find an optimal partitioning of PCID over the heterogeneous processors. A high performance information management system that exploits native Infiniband multicast is used to improve latency among the head nodes. Using a publication/subscription oriented information management system to implement a unified communications platform makes runs on large HPCs with thousands of intercommunicating cores more flexible and more fault tolerant. It features a loose coupling of publishers to subscribers through intervening brokers. We are also working on enhancing performance for both Xeons and Cell BEs, buy moving selected operations to single precision. Techniques for adapting the code to single precision and performance results are reported.

First Polarimetric Images of Boosting Rocket Exhaust Plumes

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We report video-rate imaging polarimetry observations of boosting rocket exhaust plumes obtained with the Lockheed Martin ATC Simultaneous Stokes Imaging Polarimeter (SSIP). The unique design of the SSIP, mounted to a tracking telescope, allowed us to acquire rocket plume imaging polarimetry over a period of minutes for each of three launches, observing the plume phenomenology at a variety of altitudes and aspect angles. Our data includes image polarimetry of solid and liquid rocket exhaust plumes and mixing of the two exhaust flow fields. We also present multi-spectral image data, showing for the first time distinct shock structures in the plumes at two wavelengths.

Beyond Diffraction Limited Seeing Through Polarization Diversity

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Dim-object detection and characterization of geosynchronous satellites is one of the Air Force's primary concerns in Space Situational Awareness (SSA). Space-to-Space imaging satellites are costly and require medium to long time scales for useful data collection. Telescope imaging is a more economical solution and can be employed in a much shorter period of time. Atmospheric seeing and the diffraction limit of the optical systems impede our efforts to get the resolutions needed for SSA.

The Light collected from satellites and other man-made objects tend to be highly polarized but, distant and/or small objects have low photo-counts in short exposure imagery. Recently, it has been shown that short exposure images of objects that possess spatial polarization diversity can be restored with resolutions as high as twice the diffraction-limit. Also, recent work in blind deconvolution of long exposure imagery and simultaneous estimation of the atmospheric seeing parameter have produced significantly improved image reconstruction, reducing the need for adaptive optics where they are not practical. The goal of this paper is to combine polarization diversity imaging with blind deconvolution of long exposure imagery to produce a new algorithm that gains the benefits of both methods. Simulated long exposure image data was used to test the new algorithm. The results show that resolution beyond the limit imposed by atmospheric seeing are possible when the object being imaged possesses spatial polarization diversity.

Improving the Detection of Near Earth Objects for Ground Based Telescopes

Anthony O'Dell

U.S. Air Force

Congress has mandated the detection of 90 percent of 140 meter diameter and larger Near Earth Objects (NEOs). While a dedicated satellite would be the preferred method of detection, ground-based telescopes are the current detection technology available. With current detection techniques, 140 meter diameter NEOs at 1 astronomical unit or more away from Earth are difficult to detect. In order to increase their detection, the methods of data collection and data analysis must be addressed.

Detection of NEOs, to include but not limited to asteroids, comets, and satellites, using ground-based telescopes with Nyquist sampling and a matched filter for point source objects are investigated as a image processing method to increase detection rates. Computer simulations for a 1 meter diameter telescope with a 128-by-128 charge coupled device (CCD), one second integration, and a 20.7 visual magnitude point source object within the CCD field of view (FOV) were computed using MatLab code. The simulation results for Nyquist sampling with cross-correlation of a point spread function (PSF) and a threshold detector are compared to Rayleigh sampling with a threshold detector. For accurate PSF calculations, atmospheric seeing measurements at the time of data collection are necessary, so various atmosphere seeing values, from 10 cm to 20 cm, are simulated and compared. Nyquist sampling with PSF cross-correlation and a threshold detector is found to be an improvement over Rayleigh sampling with a threshold detector for atmospheric seeing parameters of 10 cm to 20 cm for all simulations. The improvement over Rayleigh sampling is increased as the atmospheric seeing becomes worse. The affects of incorrect measurement of the seeing parameter are also simulated and analyzed.

Simulations for the NEO in varying locations within the CCD pixel FOV are computed and analyzed. Nyquist sampling with PSF cross-correlation is an improvement over Rayleigh sampling for all locations with the improvement increasing as distance from the CCD FOV center is increased.

Computer simulations show that Nyquist sampling with PSF cross-correlation outperforms Rayleigh sampling regardless of position within the CCD pixel FOV and for all atmospheric seeing parameters between 10 and 20 cm in detection of point source objects at a telescopes limiting visual magnitude.

AMOS Site Capabilities Tutorial

Captain Bryan Little

Air Force Research Laboratory

The Maui Space Surveillance Complex (MSSC), located at the summit of Haleakala, is a national resource providing support to various government agencies and the scientific community. The tutorial summarizes MSSC systems, capabilities, and support procedures and includes a description of the telescopes and sensors. It will also include a brief overview of the Maui High Performance Computing Center (MHPCC).

Enhanced Algorithms for EO/IR Electronic Stabilization, Clutter Suppression, and Track-Before-Detect for Multiple Low Observable Targets

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The paper describes the development and evaluation of a suite of advanced algorithms which provide significantly-improved capabilities for finding, fixing, and tracking multiple ballistic and flying low observable objects in highly stressing cluttered environments. The algorithms have been developed for use in satellite-based staring and scanning optical surveillance suites for applications including theatre and intercontinental ballistic missile early warning, trajectory prediction, and multi-sensor track handoff for midcourse discrimination and intercept. The functions performed by the algorithms include electronic sensor motion compensation providing sub-pixel stabilization (to 1/100 of a pixel), as well as advanced temporal-spatial clutter estimation and suppression to below sensor noise levels, followed by statistical background modeling and Bayesian multiple-target track-before-detect filtering. The multiple-target tracking is performed in physical world coordinates to allow for multi-sensor fusion, trajectory prediction, and intercept. Output of detected object cues and data visualization are also provided.

The algorithms are designed to handle a wide variety of real-world challenges. Imaged scenes may be highly complex and infinitely varied — the scene background may contain significant celestial, earth limb, or terrestrial clutter. For example, when viewing combined earth limb and terrestrial scenes, a combination of stationary and non-stationary clutter may be present, including cloud formations, varying atmospheric transmittance and reflectance of sunlight and other celestial light sources, aurora, glint off sea surfaces, and varied natural and man-made terrain features. The targets of interest may also appear to be dim, relative to the scene background, rendering much of the existing deployed software useless for optical target detection and tracking. Additionally, it may be necessary to detect and track a large number of objects in the threat cloud, and these objects may not always be resolvable in individual data frames.

In the present paper, the performance of the developed algorithms is demonstrated using real-world data containing resident space objects observed from the MSX platform, with backgrounds varying from celestial to combined celestial and earth limb, with instances of extremely bright aurora clutter. Simulation results are also presented for parameterized variations in signal-to-clutter levels (down to 1/1000) and signal-to-noise levels (down to 1/6) for simulated targets against real-world terrestrial clutter backgrounds. We also discuss algorithm processing requirements and C++ software processing capabilities from our on-going MDA- and AFRL-sponsored development of an image processing toolkit (iPTK). In the current effort, the iPTK is being developed to a Technology Readiness Level (TRL) of 6 by mid-2010, in preparation for possible integration with STSS-like, SBIRS high-like and SBSS-like surveillance suites.

Commercial and Foreign Entities (CFE) Pilot Program Status Update and Way-Ahead

Charles Spillar

HQ U.S. Air Force Space Command

Air Force Space Command's CFE pilot program will enable USSTRATCOM to securely exchange SSA information with commercial and foreign space partners. The pilot program will deliver a basic Conjunction Assessment service to the JSpOC by Oct 09; capability to provide additional advanced services will be delivered via the Joint Space Operations Center Mission System acquisition strategy. An initial capability will be used to identify Doctrine, Organization, Training, Materiel, Leadership, Personnel and Facilities requirements that must be addressed prior to fielding the basic capability 1 Oct 09.

Space Surveillance Network Sensor Development, Modification, and Sustainment Programs

Richard Colarco

L-3 Communications

The paper and presentation will cover status of and plans for sensor development, modification, and sustainment programs supporting the Space Surveillance Network, including: Space Based Space Surveillance early orbit operations Space Surveillance Telescope development and expected performance FPS-85 radar service life extension program Haystack Ultra-Wideband Satellite Imaging Radar modification and expected performance improvement Space Fence development the future of GLOBUS II SSA Environmental Monitoring development Self-Awareness SSA development.

Probabilistic Evidential Reasoning with Symbolic Argumentation for Space Situation Awareness

Joe Gorman, Glenn Takata

Charles River Analytics

A number of research efforts have investigated approaches and technologies to improve space situation awareness (SSA). Prior research included investigation of probabilistic methods using structured models such as Bayesian belief networks. Such approaches have a firm foundation in evidential reasoning and are believed to have considerable prudential for reasoning about situations of interest in space. However, building the necessary models and specifying the quantitative probabilities linking nodes is a non-trivial effort. Probabilistic models necessitate the estimation of probabilities that relate events. However, situations of interest r are rare events and a lack of relevant observations makes it challenging to validate probabilistic models. Research in the elicitation of probabilities has shown that even domain experts cannot generate valid mathematical relationships between abstract entities that form probabilistic models. The complexity of probabilistic models that realistically describe situations of interest exacerbates the challenge of defining the required probabilities. Data driven machine learning approaches have been used to address this problem in other domains. However, the lack of exemplars of events of interest limits the applicability of data driven machine learning to modeling space situations of interest. The result is an increased reliance on elicited knowledge. Technologies are needed that simplify the process of model construction and that can take advantage of multiple information sources to provide SSA. This paper describes an approach, based on Toulmin's theory of argumentation, which provides an intuitive representation that can be used to create and exercise models of space situations. These models are then supplied to a fusion component that uses the Dempster-Shafer theory of belief propagation to estimate confidences for the characterization of these situations of interest.

Analysis of Situation in GEO Protected Region

Vladimir Agapov[1], Igor Molotov[1], Zakhary Khutorovsky[2]

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Protected GEO region is defined by boundaries in inclination (-15 deg & +15 deg) and orbit radius (+- 200 km with respect to true GEO height). There are nearly 380 operational satellites with orbits inside of this zone. In addition, there are more than 200 catalogued large objects with orbits completely inside of the protected zone or crossing it. Research made by the ISON network revealed several hundreds of new previously unknown objects in GEO region with orbits crossing the protected zone. Thus we already have significant amount of accurate information about real population of artificial objects in the most valuable part of GEO space. Based on information obtained by the ISON network we will describe up to the date situation with distribution of GEO objects inside the protected zone. Groups of operational satellites owned by different operators and working in close proximity will be characterized with examples constructed on the base of real measurement data. Uncontrolled objects (both large and small) crossing GEO protected region will be classified by long term evolution peculiarities. Special case of objects with high area-to-mass ratio will be discusses. Importance of more comprehensive deterministic study of the GEO protected region will be shown in our paper.

Faint Deep Space Debris Observations with ISON Optical Network

Igor Molotov, Vladimir Agapov

Keldysh Institute of Applied Mathematics, RAS

New cooperation for global monitoring of space objects at high orbits, International Scientific Optical Network (ISON), is appeared under auspices of the Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences. ISON provides the observations of faint deep space debris in cooperation with team of the Astronomical Institute of the University of Bern (AIUB) since 2004. It is jointly discovered already about 500 faint space debris fragments at high orbits and almost 200 of them are continuously tracked with ISON. Presence of space debris clouds created in earlier suspected fragmentations of GEO objects is proved by long deterministic observations of individual members of the clouds. For the first time, a large amount of data on long time intervals is obtained for objects with high area-to-mass ratio (AMR).

Till present, the uncatalogued faint deep debris are discovering mainly with Teide ESA OGS telescope and Crimean observatory in Nauchny, while object tracking is providing by cooperation of the 0.5-2.6-m class telescopes including Zimmerwald, Gissar, Mondy, Abastumany, Arkhyz, Mayaki, Andrushivka and Terskol.

During 2009 it is planned to join several telescopes with large field of view (1.3 – 2.3 degree) in Ussuriysk, Krasnojarsk, Mondy, Nauchniy, Andrushivka, Abastumani, Mayaki and Kitab into semi-automatic network in order to try to establish the faint debris quasi continuous orbit maintenance. It is planned to use survey mode for this purpose as it is adjusted now for brighter GEO objects with ISON survey subsystem of 22-cm telescopes.

Along with sensors development, it is elaborated and tested a few survey modes and algorithm permitting to find correlation between short arc tracks of non-correlated objects in order to discovery of new objects and to establish their orbits.

Analysis of Orbit Prediction Sensitivity to Thermal Emissions Acceleration Modeling for High Area-to-mass Ratio Objects

Thomas Kelecy[1], Moriba Jah[2]

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High area-to-mass ratio (A/m) inactive resident space objects (RSOs) in the geosynchronous orbit (GEO) regime pose a hazard to active GEO RSOs. The combination of solar radiation pressure (SRP) and solar and lunar gravitational perturbations causes perturbations in the orbits of these RSOs. The high A/m nature of these RSOs results in greater sensitivity to SRP forces resulting in the perturbation of mean motion, inclination and eccentricity. The subsequent drift with respect to the Earth, combined with time varying orientation with respect to the sun and transitions into and out of Earth's shadow, results in many of these RSOs being "lost" after initial acquisition as they transition through periods of days to weeks out of view of observing sites. This work examines the sensitivity of the prediction accuracies to inadequate modeling of the thermal emissions component of the SRP acceleration in the force models. The simplest models treat the thermal emission term either implicitly, or as a term that is a function of a fixed surface temperature and area. In reality, the temperature can vary with time for inert objects (e.g. orbital debris) transitioning in to and out of Earth shadow. Additionally, the orientation dynamics result in thermal acceleration components that vary relative to the inertial reference frame, and in general, have components orthogonal to the sun-object line. The prediction uncertainties associated with thermal modeling, orientation dynamics and materials uncertainties are examined in terms of the SRP acceleration perturbations for a range of representative high A/m object characteristics. Results indicate that significant prediction errors result from inadequate accounting for the thermal emissions component when compared to the standard SRP models used. These errors need to be addressed in the orbit determination and prediction to allow for more accurate re-acquisition and tracking.

Photometric Studies of GEO Debris

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The photometric signature of a debris object can be useful in determining what the physical characteristics of a piece of debris are. We report on optical observations in multiple filters of debris at geosynchronous Earth orbit (GEO).

Our sample is taken from GEO objects discovered in a survey with the University of Michigans 0.6-m aperture Schmidt telescope MODEST (for Michigan Orbital DEbris Survey Telescope), and then followed up in real-time with the Cerro Tololo Inter-American Observatory (CTIO) 0.9-m for orbits and photometry. Our goal is to determine 6 parameter orbits and measure colors for all objects fainter than R = 15th magnitude that are discovered in the MODEST survey. At this magnitude the distribution of observed angular rates changes significantly from that of brighter objects.

There are two objectives:

1. Estimate the orbital distribution of objects selected on the basis of two observational criteria: brightness (magnitude) and angular rates.

2. Obtain magnitudes and colors in standard astronomical filters (BVRI) for comparison with reflectance spectra of likely spacecraft materials. What is the faint debris likely to be?

In this paper we report on the photometric results.

For a sample of 50 objects, more than 90 calibrated sequences of R-B-V-I-R magnitudes have been obtained with the CTIO 0.9-m. For objects that do not show large brightness variations, the colors are largely redder than solar in both B-R and R-I. The width of the color distribution may be intrinsic to the nature of the surfaces, but also could be that we are seeing irregularly shaped objects and measuring the colors at different times with just one telescope.

For a smaller sample of objects we have observed with synchronized CCD cameras on the two telescopes. The CTIO 0.9-m observes in B, and MODEST in R. The CCD cameras are electronically linked together so that the start time and duration of observations are the same to better than 50 milliseconds. Thus the B-R color is a true measure of the surface of the debris piece facing the telescopes for that observation. Any change in color reflects a real change in the debris surface.

We will compare our observations with models and laboratory measurements of selected surfaces. This work is supported by NASAs Orbital Debris Program Office, Johnson Space Center, and Houston, Texas, USA.

Reflectance Spectra of Space Debris in GEO

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The space debris environment in the Geostationary Earth Orbit (GEO) region is mostly investigated by means of optical surveys. Such surveys revealed a considerable amount of debris in the size range of 10 centimeter to one meter. Some of these debris exhibit particularly high area-to-mass ratios as derived from the evolution of their orbits. In order to understand the nature and eventually the origin of these objects, observations allowing to derive physical characteristics like size, shape and material are required. Information on the shape and the attitude motion of a debris piece may be obtained by photometric light curves. The most promising technique to investigate the surface material properties is reflectance spectroscopy. This paper discusses preliminary results obtained from spectrometric observations of space debris in GEO. The observations were acquired at the 1-meter ESA Space Debris Telescope (ESASDT) on Tenerife with a low-resolution spectrograph in the wavelength range of 450-960 nm. The target objects were space debris of different types with brightness as small as magnitude 15. Some simple-shaped, intact 'calibration objects' with known surface materials like the MSG-2 satellites were also observed. The spectra show shape variations expected to be caused by the different physical properties of the objects. The determination of the possible materials is still in a preliminary phase. Limitations of the acquisition process of the spectra and the subsequent analysis are discussed. Future steps planned for a better characterization of the debris from the observed data are briefly outlined.

An Assessment of GEO Orbital Debris Photometric Properties Derived from Laboratory-Based Measurements

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Optical observations of orbital debris offer insights that differ from radar measurements (specifically the size parameter and wavelength regime). For example, time-dependent photometric data yield lightcurves in multiple bandpasses that aid in material identification and possible periodic orientations. This data can also be used to help identify shapes and optical properties at multiple phase angles. Capitalizing on optical data products and applying them to generate a more complete understanding of orbital space objects, is a key objective of NASA's Optical Measurement Program, and a primary driver for creation of the Optical Measurements Center (OMC). The OMC attempts to emulate space-based illumination conditions using equipment and techniques that parallel telescopic observations and source-target-sensor orientations. The OMC uses a 300 Watt Xenon arc lamp as a solar simulator, a CCD camera with Johnson/Bessel colored filters, and a robotic arm to orientate/rotate objects to simulate an objects orbit/rotational period. A high-resolution, high bandwidth (350nm-2500nm) Analytical Spectral Devices (ASD) spectrometer is also employed to baseline various material types.

Since observation of GEO targets are generally restricted to the optical regime (due to radar range limitations), analysis of their properties is tailored to those revealed by optical data products. In this connection, much attention has been directed towards understanding the lightcurves of orbital debris with high area-to-mass (A/m) ratios (> 0.9 m2/kg). A small population of GEO debris was recently identified, which exhibits the properties of high A/m objects, such as variable eccentricities and inclinations – a dynamical characteristic generally resulting from varying solar radiation pressure on high A/m objects. Materials such as multi-layered insulation (MLI) and solar panels are two examples of materials with high area-to mass ratios. Lightcurves for such objects can vary greatly (even for the same object under different illumination conditions). For example, specular reflections from multiple facets of the target surface (e.g. Mylar or Aluminized Kapton) can lead to erratic, orientation-dependent lightcurves.

This paper will investigate published color photometric data for a series of orbital debris targets and compare it to the empirical photometric measurements generated in the OMC. The specific materials investigated (known to exist in GEO) are: an intact piece of MLI, separated layers of MLI, and multiple solar cells materials. Using the data acquired over specific rotational angles through different filters (B, V, R, I), a color index is acquired (B-R, R-I). As a secondary check, the spectrometer is used to define color indexes for the same material. Using these values and their associated lightcurves, this laboratory data is compared to observational data obtained on the 1m telescope of the Astronomical Institute of the University of Bern (AUIB) and the 0.9 m Small and Moderate Aperture Research Telescope System (SMARTS) telescope at Cerro Tololo Inter-American Observatory (CTIO). We will present laboratory generated lightcurves with color indexes of the high A/m materials alongside telescopic data of targets with high A/m values. We will discuss the relationship of laboratory to telescope data in the context of classification of GEO debris objects.

Photometry of Rotating Regular N-sided Prisms for Arbitrary Solar Phase Angles

Keith Knox

Boeing LTS

The rotation rates of asteroids can be determined by analyzing the periodic frequencies of time-varying photometric signatures from unresolved images of the asteroid. Due to the random nature of the asteroid, in terms of shape and albedo, a unique period can be determined. Because the various sides of an asteroid are different, the smallest repeat cycle of the photometric curve is directly related to the rotation rate of the asteroid.

When this method is applied to spin-stabilized satellites, an ambiguity arises. Spin-stabilized satellites are often constructed in the shape of a cylindrical regular polygon. Unless the various sides of the satellite have different albedos or otherwise reflect the light differently, the period of the rotation of the satellite will be an integral multiple of the smallest period in the signature. In other words, the rotational period of the satellite will be N times bigger than the smallest period in the signature, where N is the number of identical sides on the satellite. With this ambiguity, one has to know a priori the number of sides on the satellite to measure the rotation rate. This talk will present an analysis of the photometric signatures of a diffuse, rotating cylindrical regular polygon for an arbitrary phase angle, i.e. the angle between the illumination source and the observer. The analysis will show that the modulation of the periodic signal is a function of the number of sides on the cylindrical polygon. The modulation of the periodic curve is defined as the difference between the maximum and minimum values divided by the sum of the maximum and minimum values.

Photometric signatures of actual satellites in orbit are complicated and will not be adequately represented by a diffuse regular polygon model, but this analysis does provide insight into the problem of the multiple-side satellite rotation rate ambiguity.

Signature Intensity Derivative and its Application to Resident Space Object Typing

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A key feature of resident space object (RSO) photometric signatures is change in their brightness and color with time. It has been discovered that because of the illumination angle dependency of this temporal nature, time alone is insufficient to characterize the intrinsic nature of change in signature brightness. In this paper, we present a derivation of how the first derivative of the photometric intensity as a function of phase angle is related to the normalized reflectance spectra of the materials contained in the RSO signature. It is shown for the case of the geosynchronous orbit satellite and the results of a test case in this orbit regime are presented. We discuss the implications on existing characterization algorithms and its potential for the development of new algorithms that process the photometric signatures. Finally, we discuss the insights obtained by this analysis on photometric data collection techniques.

Catalog of Brightness Curves for Geo Space Debris

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Institute for Precision Instrument Engineering

Catalog of brightness curves for space debris (SD) in Geostationary Earth Orbits (GEO) was created using long-term optical observations. These observations were carried out mainly at the Kosmoten" optical station located at the Northern Caucasus. The catalog contains about 3000 brightness curves of 820 different GEO SD. The overwhelming majority of brightness curves belong to GEO SD catalogued by NORAD, and there are several tens of curves obtained on uncorrelated GEO SD. The catalog consists of two parts: 1) text files of raw data and 2) image of brightness curves plotted using the raw data. For each object all images and files of raw data contain a complete description of observation conditions: azimuths and elevations, start and completion time of observations, scanning frequency, Sun position characteristics, phase angle, angular distance to the Earth shadow and vector of orbital elements. Additionally, the presented images include the results of preliminary analysis of derived curves: classification (active inactive payload R/B debris), typical period of brightness variation, set of Fourier spectral components etc. Current analysis of catalog data allows an unambiguous segregation of the observed objects into four main groups: active payloads, inactive payloads, boosters and fragments. An analysis of temporal evolution of brightness curves for the same space object, as well as for a set of objects of the same group, allows to make important conclusions about the behavior of a space object in the orbit: features of transition into inactive state, activity shown in a passive state, fragmentation process, etc. Besides, an analysis of time series for brightness curves for the same object allows to determine not only the periodicity of its motion around the center of mass but also to calculate the vector of angular momentum and to reveal the features of construction and shape of a space object. At present the catalog is steadily extended and towards to the end of October, 2009 will include the brightness curves of almost all catalogued GEO SD.

A Survey of Geosynchronous Satellite Glints

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Artificial satellites have characteristic diffuse reflected-light signatures as they are illuminated at varying phase angles by the Sun and are viewed at differing orientations by an observer. At times of favorable alignment between the satellite, observer and Sun, specular reflection off of relatively flat surfaces, such as solar panels, can cause brief increases in reflected light of several hundred times that of the nominal diffuse signature. Such events are commonly referred to as "glints". In the case of geosynchronous satellites, favorable glint alignments are due to changes in the Sun-Vehicle-Observer angle which are primarily due to the apparent motion of the Sun as the observer-satellite vector remains nearly stationary. These occur near in time to the vernal and autumnal equinoxes. While the most favorable geosynchronous satellite glint alignments are precluded by the fact that the satellites are at that time most likely to be in Earth shadow, observations of several glints have been reported in the literature. While such studies note the peak brightnesses, durations, and phase angles of individual glints, to our knowledge, no extended study of geosynchronous glint characteristics exists. Beginning with the autumnal equinox glint season of 2007 we have built on our earlier studies using the U.S. Naval Observatory, Flagstaff Station 40-inch Ritchey telescope to provide near-real-time astrometric and photometric information for use by the Navy Prototype Optical Interferometer (NPOI) team in its efforts to obtain interferometric fringes of geosynchronous satellites during a glint episode. The combined observations culminated in successful fringe measurements of DirecTV-9S during the vernal equinox 2008 and 2009 seasons (see Armstrong, et al. 2009, this conference). For our 40-inch telescope observations we used an LN2-cooled 2048x2048 CCD with standard R-band and H-alpha photometric filters, covering an area of the sky of approximately 22x22 arcmin with each integration. Observations

typically were initiated well before a predicted potential glint and continued through the glint occurrence (if any) for our secondary goal of estimating peak glint brightnesses. As we were using photometric equipment, took care to obtain photometric calibrations, and were fortunate to have observed on several photometric nights, we have calibrated, time-resolved observations of numerous glint episodes, dominated by the GE2/GE4/DTV4S/DTV9S constellation. In particular, we will discuss systematic differences between glints from different satellites, comparison of glints from the same satellite during different epochs, and the time evolution of glints from DirecTV-9S during the 2009 vernal equinox observing season.

Comparison of Neural Networks and Tabular Nearest Neighbor Encoding for Hyperspectral Signature Classification in Unresolved Object Detection

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Accurate and computationally efficient spectral signature classification is a crucial step in the nonimaging detection and recognition of spaceborne objects. In classical hyperspectral recognition applications using linear mixing models, signature classification accuracy depends on accurate spectral endmember discrimination [1]. If the endmembers cannot be classified correctly, then the signatures cannot be classified correctly, and object recognition from hyperspectral data will be inaccurate. In practice, the number of endmembers accurately classified often depends linearly on the number of inputs. This can lead to potentially severe classification errors in the presence of noise or densely interleaved signatures. In this paper, we present an comparison of emerging technologies for nonimaging spectral signature classfication based on a highly accurate, efficient search engine called Tabular Nearest Neighbor Encoding (TNE) [3,4] and a neural network technology called Morphological Neural Networks (MNNs) [5]. Based on prior results, TNE can optimize its classifier performance to track input nonergodicities, as well as yield measures of confidence or caution for evaluation of classification results. Unlike neural networks, TNE does not have a hidden intermediate data structure (e.g., the neural net weight matrix). Instead, TNE generates and exploits a user-accessible data structure called the agreement map (AM), which can be manipulated by Boolean logic operations to effect accurate classifier refinement algorithms. The open architecture and programmability of TNE's agreement map processing allows a TNE programmer or user to determine classification accuracy, as well as characterize in detail the signatures for which TNE did not obtain classification matches, and why such mis-matches occurred. In this study, we will compare TNE and MNN based endmember classification, using performance metrics such as probability of correct classification (Pd) and rate of false detections (Rfa). As proof of principle, we analyze classification of multiple closely spaced signatures from a NASA database of space material signatures. Additional analysis pertains to computational complexity and noise sensitivity, which are superior to Bayesian techniques based on classical neural networks.

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Space Object Characterization Using Time-Frequency Analysis of Multispectral Measurements from the Magdalena Ridge Observatory

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The interactions between the surface materials and the body dynamics complicate the characterization of space objects from their optical signatures. One method for decoupling these two effects on the observed signature is to obtain simultaneous measurements using multiple spectral filter bands. The advantage of this approach is that it provides spectral resolution between the filter bands to identify the different materials based on their optical properties as a function of wavelength and temporal resolution between samples to identify the periodic, quasi-periodic, and transient fluctuations characteristic of the object motions, including attitude control, maneuvers, and station-keeping. We have developed algorithms to extract and to analyze light curve data from unresolved resident space objects (RSO) collected at the Magdalena Ridge Observatory (MRO) using the Multi Lens Array (MLA) camera coupled to the 2.4-m telescope. The MLA camera produces 16 spectrally-filtered and temporally synchronous sub-images ranging from 414 nm to 845 nm. We have developed a filter band calibration using a set of stellar observations to remove the atmospheric refraction and absorption effects and differences in the optical paths across the different filter bands using catalogued spectrophotometric data. We apply wavelet analysis to the RSO optical signature light curves to obtain the time-frequency characteristics of the signal for each band. This information allows us to obtain information about the body motions as a function of time. We next attempt to correlate these characteristics across the different MLA filter bands to derive constraints on the types of surface materials. In this presentation, we will present results from several case studies to demonstrate the effectiveness of our approach and to provide guidance on the effectiveness of different spectral bands for space object characterization.

Micro-Facet Scattering Model for Pulse Polarization Ranging

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Determining the shape, material and orientation of nano-sats (satellites too small to image from the ground) requires new sensing approaches. Pulse Polarization Ranging (PPR) is one such approach that uses the polarization and shape characteristics of laser pulses reflected from satellites to determine satellite shape, orientation and material. We use an innovative approach to relate PPR measurements to actual satellite characteristics (shape, material and orientation), requiring that we have an accurate physical and dynamical model of the satellite. In particular, to determine the polarization characteristics (depolarization, birefringence, diattenuation) of the reflected pulses we need an accurate model of light scattering from real (complex) surfaces. To do this, we have extended the micro-facet model of Ashikhmin et al. to include retro-reflection and multiple scattering effects. In this presentation, we describe the scattering model and its efficient implementation using graphical processing units (GPUs).

Wide-Field Image Compensation with Multiple Laser Guide Stars

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We report closed-loop results obtained from an adaptive optics system with multiple laser guide beacons. The system is mounted on the 6.5 m MMT telescope in Arizona, and is designed to explore advanced altitude-conjugated techniques for wide-field image compensation. Five beacons are made by Rayleigh scattering of laser beams at 532 nm integrated over a range from 20 to 29 km by dynamic refocus of the telescope optics. The return light is analyzed by a unique Shack-Hartmann sensor that places all five beacons on a single detector, with electronic shuttering to implement the beacon range gate. The wavefront sensor divides the 6.5 m telescope pupil into 60 subapertures, and wavefront correction is applied with the telescope's unique deformable secondary mirror. The system has now begun operations as a tool for astronomical science, in a mode in which the boundary-layer turbulence, close to the telescope, is compensated. Image quality of 0.2-0.3 arcsec is routinely delivered in the near infrared bands from 1.2 to 2.5 microns over a field of view of 2 arcmin. Although it does not reach the diffraction limit, this represents a 3 to 4-fold improvement in resolution over the natural seeing, and a field of view an order of magnitude larger than conventional adaptive optics systems deliver. In this paper we present performance metrics including images of the core of a globular cluster where correction is almost uniform across the full field, and preliminary results from the first scientific program to take advantage of the system.

Predicting Photon Returns of Sodium Guide Stars for Different Laser Technologies

Edward Kibblewhite

University of Chicago

We have written a detailed Monte Carlo code to determine the photon return from the sodium layer for different types of laser. The code captures the effects of magnetic field, radiation pressure, collision lifetime distribution and spin-exchange relaxation time on the multi-level sodium atom for CW and pulsed laser formats. We compare these results with those obtained from the Optical Bloch equations for a two level atom and from experimental data, where available. We discuss the effect of saturation and optimal pulse and spectral format of lasers for different applications.

Holographic Adaptive Optics

Geoff Andersen

USAF Academy

For the last two decades adaptive optics has been used as a technique for correcting imaging applications and directed energy/laser targeting and laser communications systems affected by atmospheric turbulence. Typically these systems are bulky and limited to <10 kHz due to large computing overhead and limited photon efficiencies. Moreover most use zonal wavefront sensors which cannot easily handle extreme scintillation or unexpected obscuration of a pre-set aperture. Here we present a compact, lightweight adaptive optics system with the potential to operate at speeds of MHz. The system utilizes a hologram to perform an all-optical wavefront analysis that removes the need for any computer. Finally, the sensing is made on a modal basis so it is largely insensitive to scintillation and obscuration. We have constructed a prototype device and will present experimental results from our research.

The holographic adaptive optics system begins with the creation of a multiplexed hologram. This hologram is created by recording the maximum and minimum response functions of every actuator in the deformable mirror against a unique focused reference beam. When a wavefront of some arbitrary phase is incident on the processed hologram, a number of focal spots are created – one pair for each actuator in the DM. The absolute phase error at each particular actuator location is simply related to the ratio of the intensity of each pair of spots. In this way we can use an array of photodetectors to give a direct readout of phase error without the need for any calculations.

The advantages of holographic adaptive optics are many. To begin with, the measurement of phase error is made all optically, so the wavefront sensor directly controls the actuators in the DM without any computers. Using fast, photon counting photodetectors allows for closed loop correction limited only by the speed of the deformable mirror which in the case of MEMS devices can be 100 kHz or more. All this can be achieved in an extremely compact and lightweight package making it perfectly suited to applications such as UAV surveillance imagery and free space optical communications systems. Lastly, since the correction is made on a modal basis instead of zonal, it is virtually insensitive to scintillation and obscuration.

Hawaiian Starlight: Sharing the Beauty of the Hawaiian Skies

Jean-Charles Cuillandre

Canada-France-Hawaii Telescope Corp.

The summit of Mauna Kea (14,000 feet) offers the best viewing of the Cosmos in the northern hemisphere, and the film "Hawaiian Starlight" delivers a pure esthetic experience from the mountain into the Universe.

Seven years in the making, this cinematic symphony reveals the spectacular beauty of the mountain and its connection to the Cosmos through the magical influence of time-lapse cinematography scored exclusively (no narration) with the awe-inspiring, critically acclaimed, Halo music by Martin O'Donnell and Michael Salvatori. Daytime and nighttime landscapes and skyscapes alternate with stunning true color images of the Universe captured by an observatory on Mauna Kea, all free of any computer generated imagery.

An extended segment of the film will be presented at the Advanced Maui Optical and Space Surveillance Technologies Conference to celebrate the international year of Astronomy 2009, a global effort initiated by the IAU (International Astronomical Union) and UNESCO (United Nations Educational, Scientific and Cultural Organization) to help the citizens of the world rediscover their place in the Universe through the day- and night-time sky, and thereby engage a personal sense of wonder and discovery. Hawaiian Starlight is true to this commitment. The inspiration and technology of the film will be shortly presented by the film's director.

Planning Ahead for Asteroid Hazard Mitigation, Phase 1: Parameter Space Exploration and Scenario Modeling

Catherine S. Plesko[1], Robert P. Weaver[1], R. Ryan C. Clement[1], Paul A. Bradley[1], Walter F. Huebner[2]

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The mitigation of impact hazards resulting from Earth-approaching asteroids and comets has received much attention in the popular press. However, many questions remain about the near-term and long-term feasibility and appropriate application of all proposed methods. Recent and ongoing ground and space-based observations of small solar system body composition and dynamics have revolutionized our understanding of these bodies (e.g., Ryan (2000), Fujiwara et al. (2006), and Jedicke et al. (2006)). Ongoing increases in computing power and algorithm sophistication make it possible to calculate the response of these inhomogeneous objects to proposed mitigation techniques.

Here we present the first phase of a comprehensive hazard mitigation planning effort undertaken by Southwest Research Institute and Los Alamos National Laboratory. We begin by reviewing the parameter space of the objects physical and chemical composition and trajectory. We then use the radiation hydrocode RAGE (Gittings et al. 2008), Monte Carlo N-Particle (MCNP) radiation transport (see Clement et al., this conference), and N-body dynamics codes to explore the effects these variations in object properties have on the coupling of energy into the object from a variety of mitigation techniques, including deflection and disruption by nuclear and conventional munitions, and a kinetic impactor.

Preliminary results for models of the deflection of a 100 m basalt sphere by a 100 kt nuclear burst (Bradley et al., LPSC 2009) are encouraging. A 40 cm/s velocity away from the burst is imparted to the objects center of mass without disruption. Further results will be presented at the meeting.

Rotation Rates of Recently Discovered Small Near-Earth Asteroids

William Ryan, Eileen V. Ryan

New Mexico Institute of Mining and Technology

As part of an effort to obtain astrometric data on newly discovered Near-Earth Asteroids (NEAs) using the Magdalena Ridge Observatory s (MRO) 2.4-meter telescope, a program has also been implemented to obtain physical characterization information on some of the smallest objects in the asteroid population. Characterization studies that determine physical properties such as spin rates and orientations, shapes, material type and internal structure/strength are important for properly addressing and mitigating any potential threats from dangerous Earth-crossing objects. The rotation rate of an object can imply essential information about its internal composition (via deduction of strength boundary limits) and degree of fracture, and thereby its collisional history. In particular, the discovery of asteroids having sub-hour rotation periods is highly indicative of a non-negligible tensile strength. Previously, extensive work had been done to acquire rotation rates for asteroids greater than 200 meters in diameter, and although progress has been made extending this database to the less than 200 meter size-range, the data are still lacking. Therefore, our research has been focused toward collecting lightcurves of objects primarily smaller than 200 meters which have allowed the determination of rotation rates.

Rotation rates derived from the lightcurves collected to date indicate that the asteroids studied in this small size regime exhibit both slow (hours) and fast (minutes) rotation periods. With respect to superfast rotators, one object in our database of special note is asteroid 2009 BF2 (approximately 27 meters in diameter) which is the second fastest rotator yet discovered, with a rotation period of about 58 seconds

(2008 HJ is the fastest rotator at 42.7 seconds). Additionally, our survey has collected three lightcurves for objects with absolute magnitudes H > 22 that have been observed to be rotating more slowly (greater than 7 hours) than the presumed strengthless body limit. Asteroid 2008 UP100 exhibits an amplitude of ~1.2 magnitudes or greater even after correcting to zero phase. Recent modeling of rubble pile structures by Harris et al. (2008) indicates that this borders on or exceeds the elongation limit of a slowly rotating strengthless object, implying the possible existence of tensile strength. We expect that the continued photometric observation of faint NEA targets-of-opportunity will increase our current sample and ultimately result in a better understanding of the structure of these small bodies.

Impact Hazard Mitigation: Understanding the Effects of Nuclear Explosive Outputs on Comets and Asteroids

Ryan Clement

Los Alamos National Laboratory

The NASA 2007 white paper “Near-Earth Object Survey and Deflection Analysis of Alternatives” affirms deflection as the safest and most effective means of potentially hazardous object (PHO) impact prevention. It also calls for further studies of object deflection. In principle, deflection of a PHO may be accomplished by using kinetic impactors, chemical explosives, gravity tractors, solar sails, or nuclear munitions. Of the sudden impulse options, nuclear munitions are by far the most efficient in terms of yield-per-unit-mass launched and are technically mature. However, there are still significant questions about the response of a comet or asteroid to a nuclear burst. Recent and ongoing observational and experimental work is revolutionizing our understanding of the physical and chemical properties of these bodies (e.g., Ryan (2000), Fujiwara et al. (2006), and Jedicke et al. (2006)). The combination of this improved understanding of small solar-system bodies combined with current state-of-the-art modeling and simulation capabilities, which have also improved dramatically in recent years, allow for a science-based, comprehensive study of PHO mitigation techniques. Here we present an examination of the effects of radiation from a nuclear explosion on potentially hazardous asteroids and comets through Monte Carlo N-Particle code (MCNP) simulation techniques.

MCNP is a general-purpose particle transport code commonly used to model neutron, photon, and electron transport for medical physics, reactor design and safety, accelerator target and detector design, and a variety of other applications including modeling the propagation of epithermal neutrons through the Martian regolith (Prettyman 2002). It is a massively parallel code that can conduct simulations in 1–3 dimensions, complicated geometries, and with extremely powerful variance reduction techniques. It uses current nuclear cross section data, where available, and fills in the gaps with analytical models where data are not available. MCNP has undergone extensive verification and validation and is considered the gold-standard for particle transport. (Forrest B. Brown, et al., "MCNP Version 5," Trans. Am. Nucl. Soc., 87, 273, November 2002.) Additionally, a new simulation capability using MCNP has become available to this collaboration. The first results of this new capability will also be presented.

In particular, we will show results of neutron and gamma-ray energy deposition and flux as a function of material depth, composition, density, geometry, and distance from the source (nuclear burst). We will also discuss the benefits and shortcomings of linear Monte Carlo. Finally, we will set the stage for the correct usage and limitations of these results in coupled radiation-hydrodynamic calculations (see Plesko et al, this conference).

Asteroid Detection with the Pan-STARRS Moving Object Processing System

Robert Jedicke, Larry Denneau, Mikael Granvik, Richard Wainscoat

University of Hawaii, Institute for Astronomy

We will present the first asteroid and comet discoveries by the Pan-STARRS prototype telescope (PS1) using the Moving Object Processing System (MOPS). The MOPS was designed to be capable of detecting fast moving objects whizzing by the Earth as well as those moving as slowly as the fastest proper motion stars. We will discuss the design of the MOPS and its efficiency, accuracy, and reliability as determined from long term realistic simulations with synthetically generated objects in the presence of false detections. Our simulations with a synthetic but realistic NEO population indicate that PS1 will discover more of these hazardous objects in its 3.5 year mission than all existing surveys have identified since asteroids were first discovered more than 200 years ago. In particular, we will show that PS1 has a high efficiency for discovering objects that will actually impact the Earth in the next 100 years.

Proper Motions from the Pan-STARRS PS1 Survey

David Monet[1], PS1 Team[2]

[1]U. S. Naval Observatory, [2]UH Institute for Astronomy

Preliminary studies of the PS1 astrometric capabilities have been presented at previous AMOS Technical Conferences. As of the 2009 AMOS deadline, PS1 is scheduled to go into routine survey operations in May 2009. Hence, large amounts of data should be available by the time of the conference, and detailed astrometric studies and results will be done on as much of the data as possible. All preliminary work suggests that with four months of epoch difference, proper motions as small as 0.1 arcsecond per year should be easily detectable.

The Pan-STARRS Project: The Next Generation of Survey Astronomy Has Arrived

William Burgett, Nick Kaiser

University of Hawaii, Institute for Astronomy

The University of Hawaii Institute for Astronomy is developing a large optical synoptic survey telescope system: the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). This talk summarizes the Pan-STARRS science goals, the distributed aperture design approach, and the overall project development plan. The overview description of the Pan-STARRS system design comprises the telescope, camera, observing control infrastructure, image processing, image analysis, and archiving of the science data products. The development plan includes the Pan-STARRS PS1 system that will begin its survey mission in mid-2009 as well as the next phases of the project.

A New Method for Collimating and Aligning a Very Wide Field Telescope

Nick Kaiser, Dr. Jeff Morgan

University of Hawaii, Institute for Astronomy

The Pan-STARRS PS1 telescope is an alt-az system with two mirrors and three corrector lenses. In order to be able to deliver sub-arcsecond image quality over its very wide field of view (3 deg diameter), the optical elements need to be centered to a precision better than of order 100 microns, and their tilts need be controlled to within 15 arcseconds. Control of the optics configuration is accomplished by static adjustment of the corrector lenses and camera with respect to the instrument rotator, and by real-time active control of the 5 degrees of freedom for both primary and secondary mirrors. In addition, the pneumatic primary mirror support system allows real-time fine control of the mirror figure to correct for astigmatism, tri-foil and other low order aberrations. We have developed software that analyzes shapes of out-of-focus images found across the focal plane and decomposes these into signal-to-noise eigenmodes that allow a determination of any misalignment of the telescope optics, which can then be corrected. We show how this technique has been applied with considerable success to collimate and align the PS1 telescope.

The Pan-STARRS Gigapixel Camera

John Tonry, Peter Onaka

University of Hawaii, Institute for Astronomy

The Pan-STARRS1 gigapixel camera (GPC1) comprises 1.4 billion pixels and has been operating without significant problem for nearly two years. We will report on the performance of its detectors, the controllers we built for it, the infrastructure necessary to support such a large system, and the software we have written to help out the science mission. We are in the process of building a second camera (GPC2) for the second Pan-STARRS telescope (PS2), and we will discuss the challenges involved, including lessons learned from GPC1, and lay out what we think are the timescales and risks are for replication of this system.

Applied Reachability for Space Situational Awareness and Safety in Spacecraft Proximity Operations

Marcus Holzinger, Daniel Scheeres

University of Colorado at Boulder

Several existing and emerging applications of Space Situational Awareness (SSA) relate directly to spacecraft Rendezvous, Proximity Operations, and Docking (RPOD) and Formation / Cluster Flight (FCF). When multiple Resident Space Ob jects (RSOs) are in vicinity of one another with appreciable periods between observations, correlating new RSO tracks to previously known objects becomes a non-trivial problem. A particularly difficult sub-problem is seen when long breaks in observations are coupled with continuous, low- thrust maneuvers. Reachability theory, directly related to optimal control theory, can compute contiguous reachability sets for known or estimated control authority and can support such RSO search and correlation efforts in both ground and on-board settings. Reachability analysis can also directly estimate the minimum control authority of a given RSO. For RPOD and FCF applications, emerging mission concepts such as fractionation drastically increase system complexity of on-board autonomous fault management systems. Reachability theory, as applied to SSA in RPOD and FCF applications, can involve correlation of nearby RSO observations, control authority estimation, and sensor track re-acquisition. Additional uses of reachability analysis are formation reconfiguration, worst-case passive safety, and propulsion failure modes such as a ‘stuck’ thruster.

Existing reachability theory is applied to RPOD and FCF regimes. An optimal control policy is developed to maximize the reachability set and optimal control law discontinuities (switching) are examined. The Clohessy-Wiltshire linearized equations of motion are normalized to accentuate relative control authority for spacecraft propulsion systems at both Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO). Several examples with traditional and low thrust propulsion systems in LEO and GEO are explored to illustrate the effects of relative control authority on the time-varying reachability set surface. Both monopropellant spacecraft at LEO and Hall thruster spacecraft at GEO are shown to be strongly actuated while Hall thruster spacecraft at LEO are found to be weakly actuated. Weaknesses with the current implementation are discussed and future numerical improvements and analytical efforts are discussed.

Telescope Spectrophotometric and Absolute Flux Calibration, and National Security Applications, Using CALIPSO Satellite LIDAR, and Future Wavelength-Tunable Systems

Justin Albert[1], William Burgett[2], Jason Rhodes[3], James Battat[4]

[1]University of Victoria, [2]University of Hawaii, [3]NASA JPL, [4]MIT

At AMOS 2006 we proposed a tunable laser-based satellite-mounted spectrophotometric and absolute flux calibration system, to be utilized by ground- and space-based telescopes, for precision calibration of ground-based telescope photometry and flux. Since then, we have performed a campaign of observations of the 532 nm pulsed laser aboard the CALIPSO satellite (launched Apr. 2006), using a portable network of cameras and NIST-calibrated photodiodes, to test the precision of this method of measuring atmospheric extinction. This technique has astrophysical applications including reducing a major systematic uncertainty (absolute photometry) on cosmological parameter measurement using type Ia supernovae, as well as in upcoming photometric red shift surveys measuring growth of large scale structure in the Universe. In addition, upcoming systems potentially have broad utility for defense and national security applications such as ground target illumination and space communication. We will report on our measurements using our observations of the CALIPSO laser, and discuss future directions and applications. For further details please see http://www.arxiv.org/abs/astro-ph/0604339 and http://www8.nationalacademies.org/astro2010/DetailFileDisplay.aspx?id=546.

Operationally Responsive Space Launch for Space Situational Awareness Missions

Thomas Freeman

Launch Test Squadron, SMC/SDTW

The United States Space Situational Awareness capability continues to be a key element in obtaining and maintaining the high ground in space. Space Situational Awareness satellites are critical enablers for integrated air, ground and sea operations, and play an essential role in fighting and winning conflicts. The United States leads the world space community in spacecraft payload systems from the component level into spacecraft and in the development of constellations of spacecraft. This position is founded upon continued government investment in research and development in space technology, which is clearly reflected in the Space Situational Awareness capabilities and the longevity of these missions.

In the area of launch systems that support Space Situational Awareness, despite the recent development of small launch vehicles, the United States launch capability is dominated by unresponsive and relatively expensive launchers in the Expandable, Expendable Launch Vehicles (EELV). The EELV systems require an average of six to eight months from positioning on the launch table until liftoff. Access to space requires maintaining a robust space transportation capability, founded on a rigorous industrial and technology base.

To assure access to space, the United States directed Air Force Space Command to develop the capability for operationally responsive access to space and use of space to support national security, including the ability to provide critical space capabilities in the event of a failure of launch or on-orbit capabilities. Under the Air Force Policy Directive, the Air Force will establish, organize, employ, and sustain space forces necessary to execute the mission and functions assigned including rapid response to the National Command Authorities and the conduct of military operations across the spectrum of conflict. Air Force Space Command executes the majority of spacelift operations for DoD satellites and other government and commercial agencies. The Command researched and identified a course of action that has maximized operationally responsive space for Low-Earth-Orbit Space Situational Awareness assets.

On 1 Aug 06, Air Force Space Command activated the Space Development and Test Wing (SDTW) to perform development, test and evaluation of Air Force space systems and to execute advanced space deployment and demonstration projects to exploit new concepts and technologies, and rapidly migrate capabilities to the warfighter. The SDTW charged the Launch Test Squadron (LTS) to develop the operationally responsive spacelift capability for Low-Earth-Orbit Space Situational Awareness assets. The LTS created and executed a space enterprise strategy to place small payloads (1500 pounds), at low cost (less than $28M to $30M per launch), repeatable and rapidly into 100 - 255 nautical miles orbits. In doing so, the squadron provides scalable launch support services including program management support, engineering support, payload integration, and post-test evaluation for space systems.

The Air Force, through the SDTW/LTS, will continue to evolve as the spacelift execution arm for Space Situational Awareness by creating small, less-expensive, repeatable and operationally responsive space launch capability.

AFRL's Demonstration and Science Experiments (DSX) Mission

Mark Scherbarth[1], Aaron Adler[2], Durand Smith[2], Val Loretti[3], Janet Stuart[4]

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The Air Force Research Laboratory (AFRL) Space Vehicles Directorate has developed the Demonstration and Science Experiments (DSX) mission to research technologies needed to significantly advance Department of Defense (DoD) capabilities to operate spacecraft in the harsh radiation environment of medium-earth orbits (MEO). The ability to operate effectively in the MEO environment significantly increases the DoDs capability to field space systems that provide persistent global targeting-grade space surveillance and reconnaissance, high-speed satellite-based communication, lower-cost GPS navigation, and protection from space weather and environmental effects on a responsive satellite platform. The three DSX physics-based research/experiment areas are: 1. Wave Particle Interaction Experiment (WPIx): Researching the physics of very-low-frequency (VLF) electro-magnetic wave transmissions through the ionosphere and in the magnetosphere and characterizing the feasibility of natural and man-made VLF waves to reduce and precipitate space radiation; 2. Space Weather Experiment (SWx): Characterizing, mapping, and modeling the space radiation environment in MEO, an orbital regime attractive for future DoD, Civil, and Commercial missions; 3. Space Environmental Effects (SFx): Researching and characterizing the MEO space weather effects on spacecraft electronics and materials. Collectively, thirteen individual payloads are synergized together from these three research areas and integrated onto a single platform (DSX) which provides a low-cost opportunity for AFRL due to their common requirements. All three groups of experiments require a 3-axis stabilized spacecraft bus (but no propulsion), a suite of radiation sensors, and extended duration in a low inclination, elliptical, MEO orbit. DSX will be launch ready in summer 2010 for a likely launch co-manifest with an operational DoD satellite on an EELV (evolved expendable launch vehicle).

Stratospheric Observatory for Infrared Astronomy (SOFIA): Infrared Sensor Development and Science Capabilities

Joel Nelson[1], Martin Ruzek[2]

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a unique airborne observatory designed to operate in the lower stratosphere to altitudes as high as 45,000 feet and above 99.8 percent of Earths obscuring atmospheric water vapor. SOFIA's capabilities enable science and observations that will complement and extend past, present and future infrared (IR) telescopes in wavelength range, angular and spectral resolution, and observing flexibility. The joint U.S. and German SOFIA project to develop and operate a 2.5-meter infrared airborne telescope in a Boeing 747-SP is nearing readiness for for open door flights and demonstration of early science results. Flying in the stratosphere, SOFIA allows observations throughout the infrared and submillimeter region. The SOFIA instrument complement includes broadband imagers, moderate resolution spectrographs capable of resolving broad features due to dust and large molecules, and high resolution spectrometers suitable for kinematic studies of molecular and atomic gas lines at high resolution. First science flights will begin in early 2010.

A great strength of SOFIA is the enormous breadth of its capabilities and the flexibility with which those capabilities can be modified and improved to take advantage of advances in infrared technology. This paper and presentation will highlight the following points: A 2.5-meter effective-diameter optical-quality telescope for diffraction-limited imaging beyond 25 micrometers, giving the sharpest view of the sky provided by any current or developmental IR telescope operating in the 30-60 micrometers region; Wavelength coverage from 0.3 micrometers to 1.6 mm and high resolution spectroscopy (R to 105) at wavelengths between 5 and 150 micrometers; An 8 arcmin FOV allowing use of very large detector arrays; Ready observer access to science instruments which can be serviced in flight and changed between flights; A low-risk ability to incorporate new science-enabling instrument technologies and to create a whole "new" observatory several times during the lifetime of the facility; Opportunity for continuous training of instrumentalists to develop and test the next generation of instrumentation for both suborbital and space applications; Mobility, which allows access to the entire sky and a vastly increased number of stellar occultation events; Unique opportunities for educators and journalists to participate first-hand in exciting astronomical observations.

The mid- and far-IR wavelength regions are key to studying the dusty universe. SOFIA science emphasizes four major themes: Star and planet formation; the interstellar medium of the Milky Way; Galaxies and the galactic center; and Planetary science. These capabilities will enable a wide range of science investigations over SOFIA's 20-year operational lifetime. This paper will address SOFIA's nine first-light science instruments, capabilities, and development.

Geo Satellite Imaging at the Naval Prototype Optical Interferometer (NPOI)

Sergio Restaino

Naval Research Laboratory

We report the interferometric detection of an earth-orbiting artificial satellite using optical interferometry. We targeted four geosynchronous communications satellites with the Navy Prototype Optical Interferometer (NPOI) near Flagstaff, AZ, and obtained interferometric fringes on one of them, DIRECTV-9S. We used an east-west 15.9-meter baseline of the NPOI and took data in 16 spectral channels covering the 500-850 nm wavelength range. Observations took place during the "glint season" of 28 February to 3 March 2008 and then again from 26 February to 4 March 2009, when the geometry of the solar panel arrays and the Sun's position creates glints as bright as 2nd magnitude for a few minutes each night. Subsequent analysis shows that the fringe amplitudes are consistent with a size scale of the glinting area of less than 2 meters (50 nanoradians at GEO) in an east-west direction. This work shows that interferometric detection of satellites at visual wavelengths is possible, and suggests that a multi-baseline interferometer array tailored to the angular size and brightness of geosynchronous satellites could lead to images of these satellites.

SAM, The Starfire Optical Range Atmospheric Monitor

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The Starfire Optical Range has developed an atmospheric turbulence monitor (Starfire Atmospheric Monitor, or SAM), which uses wave front distortions to measure the Fried parameter, the Greenwood parameter and scintillation parameter simultaneously. SAM differs from Differential Image Motion Monitor (DIMM) instruments in that it measures the atmosphere with a Shack Hartman wavefront sensor. Shack Hartman wavefront sensors have been used to monitor the atmosphere in the past; however SAM enables these measurements to be made with a dedicated instrument that can sample at higher spatial frequencies than most adaptive optics systems. Compared to DIMM instruments, rapid statistically accurate measurements of the Fried parameter (r0) can be made with SAM because it measures and calculates many differential tilts simultaneously. Furthermore, because SAM utilizes a 4-by-4 set of detector elements for each subaperture instead of a quad cell it can measure r0 values down to 1cm.

This paper provides a basic overview and operation of the instrument. We discuss the construction of SAM including the telescope, optics, camera, and electronics. We then will discuss the data reduction and calculation of the Fried parameter (r0) from differential tilt data. The basic capabilities of SAM, including day/night operation, limiting star magnitudes, and the validation of SAM will also be discussed. We present initial measurements of r0 measured by SAM. Finally, we discuss other measurements SAM will be able to make.

Novel All Digital Ring Cavity Locking Servo for FASOR-X

Jeffrey Baker[1], David Gallant[1], Arthur Lucero[1], Harold Miller[2], Jonathon Stohs[2]

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We plan to use this servo in the new 50W 589-nm sodium guidestar laser to be installed in the AMOS facility in July 2010. Though the basic design is unchanged from the successful Hillman/Denman design, numerous improvements are being implemented in order to bring the device even further out of the lab and into the field. The basic building block of the Hillman/Denman design are two low noise master oscillators that are injected into higher power slave oscillators that are locked to the frequencies of the master oscillator cavities. In the previous system a traditional analog Pound-Drever-Hall (PDH) loop was employed to provide the frequency locking. Analog servos work well, in general, but robust locking for a complex set of multiply-interconnected PDH servos in the guidestar source challenges existing analog approaches. One of the significant changes demonstrated thus far is the implementation of an all-digital servo using only COTS components and a fast CISC processing architecture for orchestrating the basic PDH loops active within system. Compared to the traditionally used analog servo loops, an all-digital servo is a not only an orders-of-magnitude simpler servo loop to implement but the control loop can be modified by merely changing the computer code. Field conditions are often different from laboratory conditions, requiring subtle algorithm changes, and physical accessibility in the field is generally limited and difficult. Remotely implemented, trimmer-less and solderless servo upgrades are a much welcomed improvement in the field installed guidestar system. Also, OEM replacement of usual benchtop components saves considerable space and weight as well in the locking system. We will report on the details of the servo system and recent experimental results locking a master-slave laser oscillator system using the all-digital Pound-Drever-Hall loop.

Science Objectives and Commissioning of the Magdalena Ridge Observatory Interferometer

Charles Cormier[1], Dr. Van Romero[1], Dr. Michelle Creech-Eakman[1], Dr. Dave Westpfahl[1], Dr. Sergio Restaino[2], Dr. David Buscher[3]

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The Magdalena Ridge Observatory Interferometer (MROI) is the most ambitious optical interferometer project in the world today. First funded in 2000, the project has gained significant momentum in the last few years, and is working closely with our collaborators from the University of Cambridge. We have recently completed and begun outfitting the Ridge beam combining facilities and have telescopes and optics under construction. When completed, MROI will include 10 movable telescopes operating over 7.5 to 340m baselines and wavelengths (0.6-2.4 microns) that will allow astronomers to produce sub-milliarcsecond images of a large variety of astrophysical targets. I will present our overall completed design and recent progress, our timeline to first light, and the significant technical and scientific milestones anticipated as we are entering our commissioning. First light and inception of commissioning are expected in 2010.

Validation of Optical Turbulence Simulations from a Numerical Weather Prediction Model in Support of Adaptive Optics Design

Randall Alliss, Billy Felton

Northrop Grumman - TASC

Optical turbulence (OT) acts to distort light in the atmosphere, degrading imagery from large astronomical telescopes and possibly reducing data quality of air to air laser communication links. Some of the degradation due to turbulence can be corrected by adaptive optics. However, the severity of optical turbulence, and thus the amount of correction required, is largely dependent upon the turbulence at the location of interest. Therefore, it is vital to understand the climatology of optical turbulence at such locations. In many cases, it is impractical and expensive to setup instrumentation to characterize the climatology of OT, so simulations become a less expensive and convenient alternative.

The strength of OT is characterized by the refractive index structure function Cn2, which in turn is used to calculate atmospheric seeing parameters. While attempts have been made to characterize Cn2 using empirical models, Cn2 can be calculated more directly from Numerical Weather Prediction (NWP) simulations using pressure, temperature, thermal stability, vertical wind shear, turbulent Prandtl number, and turbulence kinetic energy (TKE). In this work we use the Weather Research and Forecast (WRF) NWP model to generate Cn2 climatologies in the planetary boundary layer and free atmosphere, allowing for both point-to-point and ground-to-space seeing estimates of the Fried Coherence length (ro) and other seeing parameters. Simulations are performed using the Maui High Performance Computing Centers Jaws cluster.

The WRF model is configured to run at 1km horizontal resolution over a domain covering the islands of Maui and the Big Island. The vertical resolution varies from 25 meters in the boundary layer to 500 meters in the stratosphere. The model top is 20 km. We are interested in the variations in Cn2 and the Fried Coherence Length (ro) between the summits of Haleakala and Mauna Loa. Over six months of simulations have been performed over this area. Simulations indicate that the vast lava fields which characterize the Big Island to the shoreline have a large impact on turbulence generation. The same turbulence characteristics are also present in the simulations on the Southeastern face of Haleakala. Turbulence is greatest during the daytime when the lava fields produce tremendous heat fluxes. Good agreement is found when the WRF simulations are compared to in situ data taken from the Advanced Technology Solar Telescope (ATST) Site Survey Working Group at the Mees Solar Observatory on Haleakala. The ATST used a solar DIMM instrument; therefore comparisons were limited to daytime. Both the WRF simulations and ATST showed ro values bottoming out in the 3-4 cm range during daytime. Analysis of the horizontal path between Haleakala and Mauna Loa show minimum ro dropping below 1 cm during the peak heating of the day. We are awaiting horizontal observations of Cn2 to become available to continue the validation exercises. Results of these analyses are assisting communication engineers in developing state of the art adaptive optic designs. Detailed results of this study will be presented at the conference.

Preliminary Results to Support Evidence of Thermospheric Contraction

Arrun Saunders, Graham G. Swinerd, Hugh G. Lewis

University of Southampton

Atmospheric density has an important influence in predicting the positions of satellites in low Earth orbit. For long-term predictions of satellite ephemerides, any density trend in the thermosphere would be a valuable input, not only to satellite operators, but also to studies of the future low Earth orbit environment in terms of space debris. A secular thermospheric density trend has not yet been definitively proven but predictions by Ramesh and Roble [1], along with evidence by Emmert et al. [2], strongly suggest the existence of such a phenomenon. With the ultimate goal of deriving a long-term empirical model of thermospheric cooling and contraction, the primary focus of this paper is to present preliminary results obtained to support the existing evidence for such a thermospheric contraction.

There are many ways of determining atmospheric density, but inferring thermospheric density from satellite drag data is a relatively cost-effective way of gathering in-situ measurements. Given an initial satellite orbit, one approach is to use an orbital propagator to predict the satellite's state at some time ahead and then to compare that state with Two-Line Element (TLE) data at the same epoch. The difference between the semi-major axis of the satellite from the initial orbit and that after the orbit propagation is then integrated to obtain an estimate of global average density. This is the approach adopted in our new work, using a bespoke, orbital propagator that includes perturbations due to atmospheric drag, gravitational anomalies, luni-solar gravity effects and solar radiation pressure. The methods used to derive precise estimates of the ballistic coefficient of each satellite for use in the propagator are outlined, as this information is not contained explicitly in the TLE sets. In validation of the orbital propagator used in this study, Saunders et al. [3] ran simulations to predict satellite re-entry dates with satisfactory results. Now, historical satellite data from the past 50 years have been used to infer thermospheric density values over the same period. A comparison of these values with those derived from an empirical standard atmospheric model, the US NRLMSISE-00 (Naval Research Laboratory's Mass Spectrometry and Incoherent Scatter Radar up to the Exobase, released in the year 2000), is the method by which the long-term trend is established. More recent atmospheric models have not been used due to their requirement concerning atmospheric state indices (e.g. the Disturbance Storm Time index used with the latest Jacchia-Bowman models) which are not available for the complete historical time period.

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Improving Laser-Guide Star AO Observations via Mesospheric Sodium Enhancement

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Innovative Technology Systems (ITS)

The use of modern Adaptive Optics (AO) systems allows large telescopes to approach diffraction limited seeing. This technique can improve the imaging resolution of a large telescope by more than an order of magnitude. Such a capability provides real improvement in ground-based space situational awareness (SSA) observations.

The drawback to current adaptive optics systems is that they only improve resolution over small imaging regions, sometimes as small as a few tens of arc seconds. Such small imaging regions limit the availability of suitable guide stars, which in turn limits the availability and duty cycle of an AO system. This limitation has led to the development of systems for producing artificial guide stars, which can be created along a line of sight coincident with that of the telescope. The most commonly used artificial guide stars are created by tuning a laser to the frequency of the Sodium D1/D2 line complex, and exciting sodium atoms in the Earth's mesosphere.

The mesospheric sodium layer is exceptionally rarified, and has densities that vary diurnally, seasonally, and geographically. Our investigation centers on the use of sounding rockets to deliver substantial quantities of atomic sodium to the mesospheric layer. This direct enhancement of the sodium layer could increase the number of nights that laser-guide star AO observations could be performed, as well as increasing guide star brightness. These improvements should yield better AO wavefront correction and faster imaging frame rates. For the SSA application, these improvements will lead to more and better imaging opportunities.

We will present a basic overview of the relevant mesospheric dynamics, with emphasis on sodium dwell times and replenishment rates. We will present several possible mechanisms for delivery and deployment of atomic sodium in the mesosphere, and demonstrate the trade-offs in their use. We will present a possible concept of operation for notional delivery systems. Finally, we will discuss the cost-effectiveness of this approach in relation to the expected improvement in performance for typical laser-guide star AO systems.

JSpOC Cognitive Task Analysis

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This paper will overview a Cognitive Task Analysis (CTA) of the tasks accomplished by space operators in the Combat Operations Division (COD) of the Joint Space Operations Center (JSpOC). The methodology used to collect data will be presented. The work was performed in support of the AFRL Space Situation Awareness Fusion Intelligent Research Environment (SAFIRE) effort. SAFIRE is a multi-directorate program led by Air Force Research Laboratory (AFRL), Space Vehicles Directorate (AFRL/RV) and supporting Future Long Term Challenge 2.6.5. It is designed to address research areas identified from completion of a Core Process 3 effort for Joint Space Operations Center (JSpOC). The report is intended to be a resource for those developing capability in support of SAFIRE, the Joint Functional Component Command (JFCC) Space Integrated Prototype (JSIP) User-Defined Operating Picture (UDOP), and other related projects. The report is under distribution restriction; our purpose here is to expose its existence to a wider audience so that qualified individuals may access it.

The report contains descriptions of the organization, its most salient products, tools, and cognitive tasks. Tasks reported are derived from the data collected and presented at multiple levels of abstraction. Recommendations for leveraging the findings of the report are presented. The report contains a number of appendices that amplify the methodology, provide background or context support, and includes references in support of cognitive task methodology. In a broad sense, the CTA is intended to be the foundation for relevant, usable capability in support of space warfighters. It presents, at an unclassified level, introductory material to familiarize inquirers with the work of the COD; this is embedded in a description of the broader context of the other divisions of the JSpOC. It does NOT provide guidance for the development of Tactics, Techniques, and Procedures (TT&Ps) in the development of JSpOC processes. However, the TT&Ps are a part of the structure of work, and are, therefore, a factor in developing future capability.

The authors gratefully acknowledge the cooperation and assistance from the warfighters at the JSpOC as well as the personnel of the JSpOC Capabilities Integration Office (JCIO). Their input to the process created the value of this effort.

Simulations of Optical Interferometric Imaging of Geo-Stationary Satellites

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The emerging field of optical interferometery will enable imaging of geo-stationary satellites at a height of 36,000 meter with a resolution of less than 1 meter. The current generation of optical interferometers has baselines up to 300 meters, which is a factor 100 larger than a 3 meter single dish telescope. Since the spatial resolution scales with wavelength over lambda, the increase in baseline translates directly in an increase in resolving power to see smaller details.

The Magdalena Ridge Observatory Interferometer (MROI) will be a 10 element optical interferometer. Each telescope will have a 1.4 meter primary mirror and the maximum distance within the array is close to 400 meters. MROI is currently under construction in the heart of New Mexico and is designed to meet a dual purpose: provide imaging capabilities for space situational awareness, and to provide science capabilities to astronomers. This paper is specifically aimed to demonstrate the capabilities of MROI for imaging geostationary satellites.

We have performed simulations of the performance of MROI to image geostationary satellites. These simulations start with a real image of a satellite and a model which uses simple geometric shapes to best represent the real image. This model is fed to a simulator that takes into account the interferometer array configuration and computes the observables using estimates of the errors in the observations and due to the intervening atmosphere. For an imaging interferometer these are the visibilities and closures phases for each available baseline. Finally we use exiting imaging reconstruction algorithms to compute a reconstructed image.

To complete the paper with present a discussion on the limitations of these simulations and optical interferometry in general, but will also point to specific issues of interest to the community that these simulations have identified.

A separate paper will be presented by the MRO program office that provides an overview of the status of the MRO project.

Application of MODTRAN® for Planetary Atmospheres to Jupiter and Titan

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Spectral Sciences, Inc.

At last year's AMOS conference we described the application of a version of MODTRAN® for radiative transfer in planetary atmospheres to Saturn. The initial application was to Neptune. We have demonstrated good agreement with remotely obtained spectral data from the near UV through the far IR for both planets. This year, we describe upgrades to the model and demonstrate its application to Jupiter and Titan. Comparisons will be made to spectra from many different sources, including, for example, the Cassini-Huygens probe that landed on Titan. Some of the model upgrades include extending the spectral data bases to higher temperatures and adding new aerosol and haze models.

AFRL Advanced Electric Lasers Branch - Construction and Upgrade of a 50-watt Facility-Class Sodium Guidestar Pump Laser

Timothy Bronder[1], Harold Miller[2], Jonathan Stohs[2], Chunte Lu[2], Jeffrey Baker[3], Art Lucero[3]

[1]Air Force Research Laboratory, [2]AFRL/RDLAS, [3]AFRL/RDLAS (Boeing)

The development of a reliable and effective laser source for pumping mesospheric sodium to generate an artificial guidestar has been well documented. From the early achievements with 589nm high-power dye lasers at the Keck and Lick observatories to the ground-breaking 50W CW FASOR (Frequency Addition Source of Optical Radiation) Guidestar at the Air Forces Starfire Optical Range (SOR), there has been intense interest in this technology from both the academic and military communities. Beginning in the fall of 2008, the Air Force Research Laboratorys Advanced Electric Lasers Branch began a project to build, test, verify and deliver an upgraded version of the SOR FASOR for use at the AF Maui Optical Station (AMOS) in the summer of 2010. This FASOR will be similar in design to the existing SOR device and produce 50W of diffraction limited, linearly polarized narrow linewidth 589nm light by combining the output of two injection-locked Nd:YAG ring lasers (operating at 1064nm and 1319nm) using resonant sum-frequency generation in a lithium triborate crystal (LBO). The upgraded features will include modularized sub-components, embedded control electronics, and a simplified cooling system.

The first portion of this upgrade project is to reconstruct the current SOR FASOR components and include improved methods of regulating the gain modules of the two injection lasers. In parallel with this effort, the technical plans for the modularization and re-packaging of the FASOR will be finalized and coordinated with the staff at Maui. This presentation will summarize the result of these efforts to date and provide updates on the AMOS FASOR status. Additionally, plans for 'next-generation' FASOR upgrades for both SOR and AMOS will also be discussed.

Experimental Investigation of Image De-Aliasing Algorithm Performance

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U.S. Air Force Research Lab

Various image de-aliasing algorithms and techniques have been developed to improve the resolution of sensor-aliased images captured with an under sampled point spread function. In the literature these types of algorithms are sometimes included under the broad umbrella of superresolution. Image restoration is a more appropriate categorization for this work because we aim to restore image resolution lost due to sensor aliasing, but only up to the limit imposed by diffraction. Specifically, the work presented here is focused on image de-aliasing using microscanning. Much of the previous work in this area demonstrates improvement by using simulated imagery, or using imagery obtained where the sub pixel shifts are unknown and must be estimated. This paper takes an experimental approach to investigate performance for both the visible and long-wave infrared (LWIR) regions. Two linear translation stages are used to provide two-axis camera control via RS-232 interface. The translation stages use stepper motors, but also include a microstepping capability which allows discrete steps of approximately 0.1 microns. However, there are several types of position error associated with these devices. Therefore, the microstepping error is investigated and partially quantified prior to performing microscan image capture and processing. We also consider the impact of less than 100% fill factor on algorithm performance.

For the visible region we use a CMOS camera and a resolution target to generate a contrast transfer function (CTF) for both the raw and microscanned images. This allows modulation transfer function (MTF) estimation, which gives a more complete and quantitative description of performance as opposed to simply estimating the limiting resolution and/or visual inspection. The difference between the MTF curves for the raw and microscanned images will be explored as a means to describe performance as a function of spatial frequency. Finally, our goal is to also demonstrate algorithm performance in the LWIR region using a microbolometer camera. Current state-of-the-art microbolometers have a pixel pitch of approximately 25 microns, and therefore de-aliasing algorithms are of particular interest for these cameras. Although microbolometers do not provide the best performance in terms of detectivity and are limited to video frame rates, these sensors are important for some applications because they are compact and can operate uncooled.

Ultra-Wide Field of View Stereoscope for Low Earth Orbits Surveillance

Octavian Cristea, Paul Dolea

BITNET CCSS

Optical detection of LEO objects with unknown orbital parameters is problematic. In a wide area search mission, an optical sensor collects frames of data on consecutive directions in order to find objects in its range of detection. Taking into account that a LEO object is fast moving on the sky and the visibility window is very small (the sky is clear, the sensor is in the Earth’s shadow and the object is above the horizon and illuminated), and taking into account a typical surveillance sensor FOV of less than one degree, the probability to detect unknown objects is very small. Another limitation is that accurate determination of the target’s position requires correlation of data from more than one passive sensor (a single passive sensor suffers from an inability to get unambiguous range data, even against fairly deterministic tracks such as satellites).

This paper examines the setup of a ground-based stereoscopic imager which can detect LEO objects and provide data regarding their orbits. In its minimal configuration, the stereoscope consists of a pair of (COTS) large aperture ultra-wide FOV lenses, backed with a high-quality CCD. While an ultra-wide FOV camera raises problems related to the detection magnitude and orbit estimation accuracy, such a camera significantly increases the probability of unknown objects detection.

The stereoscopes base-line is of the order of tens of Km, a compromise between simultaneous detection of low altitude objects from two locations and triangulation accuracy. Each camera continuously images the night sky and sends captured images to a local computer for off-line data processing. Each computer has a GPS card for pair cameras synchronization and it is connected to internet through a Ku band VSAT.

Geometric calibration of the image is made automatically, by matching captured stars in the image with an astronomical catalogue of stars. Making interpolation between these reference points, the computer attaches astronomical coordinates to each pixel of the sky image. This way, many errors due to light propagation through the atmosphere or f-Theta distortion can be corrected.

The recovery of orbital depth is made by correlating matching feature points from pairs of simultaneous images. Since any pair of captured images practically contains the same star field, another application of the stereoscope is to produce 3D images of the night sky with LEO objects floating in front of the star field.

This project is in the concept development phase and it is based on a research cooperation agreement between BITNET CCSS, the Technical University of Cluj and the Astronomical Observatory of Cluj.

A Lunar Laser Ranging Retroreflector for the 21st Century

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Over the past forty years, Lunar Laser Ranging (LLR) to the Apollo Cube Corner (CCR) Retroreflector arrays has supplied almost all of the significant tests of General Relativity. The LLR program has evaluated the PPN parameters and addressed, for example, the possible change in the gravitational constant and the properties of the self-energy of the gravitational field. In addition, LLR has provided significant information on the composition and origin of the moon. These arrays are the only experiment of the Apollo program that are still in operation. Initially the Apollo Lunar Arrays contributed a negligible portion of the error budget used to achieve these results. Over the decades, the performance of ground stations has greatly upgraded so that the ranging accuracy has improved by more than two orders of magnitude, i.e., a factor of 140. Now, after forty years, because of the lunar librations the existing Apollo retroreflector arrays contribute significant fraction of the limiting errors in the range measurements. The University of Maryland, as the Principal Investigator for the original Apollo arrays, is now proposing a new approach to the Lunar Laser CCR array technology. The investigation of this new technology, with Professor Currie as Principal Investigator, is currently being supported by two NASA programs and, in part, also by INFN/LNF. Thus after the proposed installation on the next Lunar landing, the new arrays will support ranging observations that are a factor 100 more accurate than the current Apollo LLRRAs, from the centimeter level to the micron level. The new fundamental physics and the lunar physics that this new LLRRA can provide will be described. In the design of the new array, there are three major challenges: 1) Validate that the specifications of the CCR required for the new array, with are significantly beyond the properties of current CCRs, can indeed be achieved. 2) Address the thermal and optical effects of the absorption of solar radiation within the CCR, reduce the transfer of heat from the hot housing to the CCR and 3) Define a method of emplacing the CCR package on the lunar surface such that the relation between the optical center of the array and the center of mass of the moon remains stable over the lunar day/night cycle. The design approach, the computer simulations using Thermal Desktop, Code V and locally developed IDL software, and the results of the thermal vacuum testing conducted at the INFN/LNF's SCF facility at Frascati, Italy of the new array will also be presented. For example, the new lunar CCR housing has been built at INFN/LNF. The innovations in the LLRRA-21 with respect to the Apollo LLRR Arrays and current satellite retroreflector packages will be described. The new requirements for ground stations will be briefly addressed. This new concept for the LLRRA-21 is being considered for the NASA Manned Lunar Landings, for the NASA Anchor Nodes for the International Lunar Network and for the proposed Italian Space Agency's MAGIA lunar orbiter mission.

Analytical Modeling of Space-Based Thermal Imaging Systems

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Dynetics, Inc.

We describe an analytical approach for modeling space-based thermal imaging systems as would be used for viewing resident space objects (RSOs) such as debris. The approach addresses key parameters for staring IR focal-plane arrays such as dark current and residual spatial noise. Another critical consideration is the target signature which is specified using the radiant intensity corresponding to the spectral band of the imaging system. An empirical method for determining appropriate signature values is preferred due to the uncertainty of modeling the thermal properties of space objects. To address this, the analytical modeling is extended to address a ground-located thermal imaging system such as would be used for measuring the radiant intensity of the space object. Notional sensor parameters will be given based on a simplified operational concept to demonstrate the modeling method. The sensor parameters include optical parameters and features of the data processing system such as frame integration. Additional design parameters include optical characteristics such as aperture diameter, focal ratio, and temperature, camera characteristics such as integration time, dark current and spatial noise, and system characteristics such as pointing accuracy and platform stabilization.

Comparing Speckle Imaging Methods

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Speckle imaging techniques have been evolving since the fundamental idea was presented almost 40 years ago;(1) the critical insight demonstrated how moments of the Fourier transform of an ensemble of short exposures contain information out to the diffraction limit. Many variations on the theme have been implemented, but in all cases, an ensemble of short-exposure images is collected and then post-processed to restore the object. In this presentation, we will compare speckle imaging reconstruction results for several speckle imaging approaches. In particular, we will compare and contrast four methods: 1) Knox-Thompson, using a hidden phase-finder in the object spectrum phase reconstruction ;(2,3) 2) Knox-Thompson, using a phasor-based phase reconstruction; 3) Bispectrum, using only two bispectrum planes and a phasor-based phase reconstruction;(4) 4) Bispectrum, using four bispectrum planes and a phasor-based phase reconstruction. In each application of the four approaches, we first calculate the modulus of the object spectrum using a Wiener-Helstrom filter to remove the speckle transfer function. The methods then differ in their object spectrum phase reconstructions.

The first method solves two-dimensional difference equations for the phase using the method described in Reference 3. There, we demonstrate that the object spectrum phase can be decomposed into a regular, single-valued function determined by the divergence of the phase gradient, as well as a multi-valued function determined by the circulation of the phase gradient; this second function has been called the "hidden phase." The standard least-squares solution to the two-dimensional difference equations always misses this hidden phase. Reference 3 develops a solution method that gives both the regular and hidden parts of the object spectrum phase.

The next three methods all use phasor-based phase reconstruction algorithms. Here, we develop “least-squares” motivated iterative improvement algorithms that rapidly converge to the least-squares-best two-dimensional phasor array for the object spectrum.

In our applications, we will implement all four methods on a simple binary star object at both moderate and low photon-per-frame light levels. Then, we will apply the four methods to several complex extended objects, once again varying the photons per frame. In the simulations, we will assume that the only

aberrations are those introduced by atmospheric turbulence setting the ratio of the telescope diameter, D, to the Fried Parameter, r0, greater than or equal to ten.(5) In addition, we assume only photon noise in the short exposures while neglecting other noise sources. We will present numerous results, describing the strengths and weaknesses of each of the four methods applied to both simple and extended objects.

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Militarily Critical Technology Program

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Institute for Defense Analyses

The Militarily Critical Technology Program (MCTP) creates two technology lists: Militarily Critical Technology List (MCTL), which is focused on protecting US technology, and Developing Science and Technology List (DSTL). There are 20 different technology areas; two in particular are discussed in this poster paper, Space Systems Technologies and Lasers & Optics Technologies. The authors are the Technology Working Group chairs for Space Systems (Jim Doherty) and Lasers & Optics (Ray Wick), both from Institute for Defense Analyses (IDA), and also IDAs task leader for the MCTP (Paul Sellers).

The AO PSF from Keck and Gemini

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From a continuing program to derive asteroids’ triaxial ellipsoid sizes and rotational poles on the world’s largest telescopes with adaptive optics (AO), we have accumulated many images of the point spread functions (PSF) produced by AO. Although not required to reduce observations of asteroid images, these PSF observations are interesting in their own right as indicators of the quality of the AO performance. In particular, the Keck 10 m telescope AO PSF is oversampled, which allows results to be obtained for relatively smaller asteroids as compared to the Gemini 8 m telescope. Furthermore, there appears to be residual motion in the Gemini AO system, which impacts its performance. We will report the simple analytic descriptions of the PSF from these two telescopes, and discuss the limitations with respect to asteroid observations.

Performance Constraints on the MCS Superresolution Algorithm

Michael Egan

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In previous work we have demonstrated the ability of the algorithm developed by Magain, Courbin, and Sohy (MCS, ApJ 2008) to resolve point sources and filamentary extended sources that have positions closer than the traditional 1.22D/? diffraction limit of an optical system. The efficacy of the technique depends on a number of factors, including the signal to noise ratio (SNR) of the sources, the blackness" of the overall image, knowledge of the original system point spread function, etc. In this paper we will explore the effect of each of these parameters on the results of the algorithm to determine the point at which positions and amplitudes of sources reconstructed using the MCS algorithm become unreliable. Results from simulated data will be presented, as well as reconstructions of astronomical imagery from the Midcourse Space Experiment that will be compared with the higher resolution “truth” data from the Spitzer Space Telescope.

Comparison of Different Methods of Ephemeris Retrival for Correlation of Observations

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Surveys searching for unknown space debris objects gain so called tracklets, short series of astrometric positions spanning an interval of a few minutes. These tracklets do not yet allow determining a full six parameter orbit. The observed positions and velocities are compared on one hand with ephemerides generated from the two line elements of the external DISCOS catalogue, and on the other hand with ephemerides generated from an internally maintained orbit catalogue. Two different ways to generate ephemerides from TLEs are compared in terms off consistency. Position and velocity errors assessed from correlating observations with ephemerides stemming from the DISCOS catalogue are compared with the errors assessed from correlating observations with the internal orbit catalogue. The different error values are discussed. Understanding the differences between predicted and observed positions of objects is also relevant in the context of space situation awareness and collision avoidance.

Optimizing Site Locations for Determining Shape from Photometric Light Curves

Dan Fulcoly, Katharine Kalamaroff, Francis Chun

USAFA

When a satellite is either too small or too far away to visually resolve its physical details, other techniques must be used to characterize and describe them. One promising method is photometry - analyzing how the reflected light from a satellite varies as a function of time or phase angle. By plotting the range-normalized photometry versus the solar phase angle of the space object over several passes, we hope to see a characteristic shape that is indicative of a certain shape or attitude. The ultimate goal is be able to extract the exact shape and attitude of a known or unknown space object from its photometric curves. This is known as the inverse problem, and it is incredibly complex due to the large solution space containing all satellite orbits, shapes, materials, and attitudes. One way to enhance the analysis of such a problem is to get more information, and in our case this information will come from different telescope locations and multiple passes of the same satellite. Due to the complexity of the problem, this paper will be a case study limited to certain aspects of the analysis. The question we ask is "Given a certain scenario (orbit, engagement, shape, material, attitude, etc.) and central location (e.g. AEOS), what is the optimal arrangement of four deployable telescopes for determining the shape of the satellite? Certain shapes have a characteristic magnitude-phase angle distribution, especially in its lower boundary which is independent of satellite material and driven primarily by diffusive reflection. The optimum arrangement will be determined by how much of the phase angle coverage is met to determine the lower boundary of magnitude-phase angle distribution. We will discretize the area surrounding the central site and examine how much of the data is required to determine the satellite shape. Some constraints might be required, such as keeping one telescope in each quadrant or requiring there be a certain distance between satellites, to ensure that the optimal arrangement is not a trivial one (i.e. four telescopes at the same location).

ALL-ON-ALL CONJUNCTION ASSESSMENT: Methods for Automating and Minimizing the Computation Time

Robert Hall, Matthew Berry, Vince Coppola, James Woodburn

AGI

The challenge of ensuring safety of flight not only for manned missions but also for active satellite payloads has received international attention and heightened priority since the Iridium / Cosmos collision on 10 Feb 2009. The operational need of performing robust conjunction assessments on a larger set of primary satellites and secondary space objects is upon us. This paper presents a process that has been implemented demonstrating a unique approach for performing All-On-All conjunction assessment on the entire space catalog. The process implemented provides an achievable, realistic capability to address the reality of a growing debris environment in space. A robust conjunction assessment process and capability is a foundational element in ensuring safety of flight and ultimately achieving robust Space Situational Awareness (SSA).

In general, the determination of the times when two space objects are close together is rather straight forward to understand, implement, and apply. However, hardware and software performance quickly becomes a consideration when attempting to perform this determination over an extended analysis period for every possible pair of objects from the entire space catalog. For a catalog of 12,000 objects, almost 72 million pairs must be evaluated.

An innovative approach has been applied to the challenge of conjunction assessment. The process developed and implemented uses an approach handling the propagation aspect and dividing the problem up in parallel chunks. The parallel approach provided the opportunity to leverage multiple processors available on a desktop PC. Additionally, a unique implementation for computationally performing the conjunction assessment is used to achieve the conjunction assessment. This implementation leverages a set of three filters, originally designed by Hoots et al1, now available in our approach to be used with a special perturbations version of the space catalog.

This approach has produced robust conjunction assessment results in terms of computational performance, automation, and capability, making full catalog propagation and conjunction assessment available within very short times. The authors will discuss and present the detailed approach and results for performing conjunction assessment including All-on-All assessments.

Accurate Radiometric Calibration using Mechanically-Shuttered CCD Systems

Doyle Hall, Dennis Liang

Boeing LTS Maui

Acquiring accurate radiometric measurements is an essential part of characterizing non-resolvable satellites. For instance, temporal photometric signatures provide information on characteristic size, reflectance, and stability, spin rate, etc., and with more detailed analysis, shape and attitude. Multi-color photometric measurements provide information on material composition and the effects of space weathering. Thermal infrared radiometry provides gray-body temperatures and emissivity properties. Many of these methods rely on accurate radiometric calibration. For CCD systems, the calibration process generally entails removing bias and dark signals from the raw frames, dividing by a flat-field frame to account for non-uniformities, and applying a sensitivity factor to convert the remaining signal into photon-flux or energy-flux units. However, when using mechanically-shuttered camera systems, another effect must be accounted for to obtain accurately calibrated data: the finite time required for the mechanical shutter to open and close. Measurements for both two-bladed and iris mechanical shutters indicate that neglecting this effect can lead to calibration errors of 10% or more in short-duration exposures. We present methods for measuring this effect, either in a laboratory setting or with the instrument mounted on a telescope, and the additional steps required to calibrate CCD data.

Forensic Reconstructions of the Chinese ASAT Test and the Iridium

Johannes Hacker

Emergent Space

Several recent breakup events have significantly worsened the orbital debris environment in low earth orbit (LEO). China's anti-satellite (ASAT) test of January 2007, in which the Chinese military destroyed a decommissioned weather satellite called Fengyun-1C (FY-1C) generated an additional 2378 objects in the Space Surveillance Network (SSN) catalog. Approximately an additional 400 objects larger than 5 cm are being tracked but have yet to be cataloged. In addition, the National Aeronautics and Space Administration (NASA) Orbital Debris Program Office (ODPO) [1] estimates the total number of FY-1C debris objects larger than 1 cm to be greater than 150,000. Kelso [2] estimates that 79% of the cataloged debris pieces will still be in orbit a century after the incident. Another major debris generating event was the break-up of Breeze-M, a Proton 4th stage that failed to reach GEO. It exploded on February 19, 2007; generating over 1000 new debris pieces in the SSN catalog at a 495 x 14,705 km orbit with a 51.5 degree inclination. [3] The recent collision of Iridium 33 and Cosmos 2251 promises to result in as many if not more additional debris pieces added to the SSN catalog as the destruction of FY-1C. As of April 10, 2009 - mere weeks after the collision - an additional 822 pieces of debris have been added to the SSN catalog. 536 of these pieces are from Cosmos 2251 and 244 are from Iridium 33. It took just over a year for the SSN to add all of the current FY-1C debris pieces to the catalog.

Satellite breakups due to explosions have been modeled based upon empirical data in the past. But empirical data on breakups caused by hypervelocity impact have only become available due to recent unfortunate events.

A first order forensic reconstruction of the Iridium 33 / Cosmos 2251 collision similar to one previously conducted [4] on FY-1C is presented. This reconstruction is based upon backward propagation of TLE's to the impact point, and generating a three dimensional velocity distribution of the debris pieces. This backward propagation was a simple analytic propagation which considered only a J2 gravity model and accounted for atmospheric drag by assuming a linear change in semi-major axis.

In addition, a higher order reconstruction for both events will be presented. Methods of determining ballistic coefficient data from TLE data [5] will be applied. Higher order reconstructions of the FY-1C and the Iridium 33 / Cosmos 2251 breakup events will be presented.

[1] Orbital Debris Quarterly News, Volume 13, Issue 1, January 2009, page 2. (http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv13i1.pdf)
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[3] Orbital Debris Quarterly News, Volume 11, Issue 2, April 2007, page 3.
[4] Hacker, Johannes M., "A First Order Forensic Analysis of China's Recent Anti-Satellite Test", AAS/AIAA Astrodynamics Specialist Conference, Mackinac Island, MI, August 23, 2003.
[5] Cefola, P. J., Proulx, R. J., Nazarenko, A. I., and Yurasov, V. S., "Atmospheric Density Correction Using Two Line Element Sets as the Observational Data", AIAA/AAS Astrodynamics Specialist Conference, Big Sky, MO, August 2003.

Scaling up of the Iris AO Segmented DM Technology for Atmospheric Correction

Michael Helmbrecht, Min He, Carl Kempf, Patrick Rhodes

Iris AO, Inc.

Adaptive-optical correction of atmospheric turbulence requires deformable mirrors with hundreds to thousands of actuators. Since May of 2008, Iris AO has been developing microelectromechanical systems (MEMS) fabrication processes to support the manufacture of 500-3000 actuator DMs. The DM technology is based on a proven, commercially available, 111-actuator, 37-piston/tip/tilt segment DM. This poster will present an overview of the MEMS design and will discuss challenges in scaling to DMs to thousands of actuators. It will show development progress towards building a 489-actuator, 163-PTT-segment DM. Finally, it will show preliminary results of a 925-segment actuator array.

Price-Based Information Routing in Complex Satellite Networks for Space-Based Situational Awareness

Islam Hussein, Jingkai Su, Yue Wang, Alexander Wyglinski

Worcester Polytechnic Institute

Future space-based situational awareness and space surveillance systems are envisioned to include a large array of satellites that seek to cooperatively achieve full awareness over given space and terrestrial domains. Given the complexity of the communication network architecture of such a system, in this paper we build on the system architecture that was proposed by the presenting author in the 2008 AMOS conference and propose an efficient, adaptable and scalable price-based routing and bandwidth allocation algorithm for the generation, routing and delivery of surveillance information in distributed wireless satellite networks. Due to the potentially large deployments of these satellites, the access points employed in a centralized network control scheme would easily be overwhelmed due to lack of spectral bandwidth, synchronization issues, and multiple access coordination. Alternatively, decentralized schemes could facilitate the flow and transference of information between data gatherers and data collectors via mechanisms such as (multi-hop) routing, allocation of spectral bandwidths per relaying node, and coordination between adjacent nodes.

Although there are numerous techniques and concepts focusing on the network operations, control, and management of sensor networks, existing solution approaches require the use of information for routing, allocation, and decision-making that may not be readily available to the satellites in a timely fashion. This is especially true in the literature on price-based routing, where the approach is almost always game theoretic or relies on optimization techniques. Instead of seeking such techniques, in this paper we present algorithms that will (1) be energy-aware, (2) be highly adaptable and responsive to demands and seek delivery of information to desired nodes despite the fact that the source and destination are not globally known, (3) be secure, (4) be efficient in allocating bandwidth, (5) be decentralized and allow for node autonomy, and (6) be useful in aiding satellite motion and orientation control for improved performance.

Advanced Sciences and Technology Research for Astrodynamics

Moriba Jah

Air Force Research Laboratory

The Advanced Sciences and Technology Research Institute for Astrodynamics (ASTRIA) has been created as a research endeavor that focuses all astrodynamics R&D within the Air Force Research Laboratory (AFRL). ASTRIA is mainly a consortium of academic partners brought together to bear on the nation's challenges as related to astrodynamics sciences and technologies. An overview of ASTRIA is presented as well as examples of several research efforts that are relevant to data/track association, UCT/cross-tagging mitigation, and attitude recovery from light curve data.

Simulations of Non-resolved, Infrared Imaging of Satellites

Kevin Jim, Kawailehua Kuluhiwa, Basil Scott, Russell Knox, James Frith, Brooke Gibson

Oceanit

Simulations of near-infrared, non-resolved imaging of earth-orbiting satellites during nighttime and daytime were created to consider the feasibility of such observations. By using the atmospheric radiative transfer code MODTRAN (MODerate resolution atmospheric TRANsmission), we incorporate site-specific mean weather conditions for several possible locations. In general, the dominant effect to be modeled is the sky radiance, which has a strong dependence upon the solar angle and the nature of the distribution of aerosols. Other significant effects included in the model are telescope design, camera design, and detector selection. The simulations are used in turn to predict the signal to noise ratio (SNR) in standard astronomical filter bands for several test cases of satellite-sun-observer geometries. The SNR model is then used to devise a method to design an optimal filter band for these observations.

Advanced Photosensors for Laser Beacon Adaptive Optics on the Starfire Optical Range 3.5 M Telescope

Robert Johnson, Dennis Montera

Air Force Research Laboratory's Directed Energy Directorate, Kirtland Air Force Base, N.M.

Adaptive optics systems can measure and correct high-order aberrations using an artificial laser beacon without the need for a relatively bright object near the object being imaged. Several types of photosensors, each with different performance requirements, are required to operate an adaptive optics system. Wavefront sensing requires sensors with a few hundred pixels, which make a few thousand images per second. Tracking or tilt measurement requires less than 10 pixels, but must be read several thousand times per second to measure atmospheric tilt and telescope mount jitter. Finally, imaging or science sensors require upwards of a million pixels, but typically make less than 30 images per second. All of these sensors require low read noise, high pixel digitization rates, and wide dynamic range. In this paper, I discuss the sensors we have developed and plan to use for the adaptive optics upgrade to the Starfire Optical Range (SOR) 3.5 m telescope. I discuss how improvements in sensor performance impact the capability of the adaptive optics system and, ultimately, the quality of the science images.

A New Undergraduate Course on the Physics of SSA

Maj Thomas Jost, Dr. Michael Dearborn, Dr. Francis Chun, Dr. Geoff McHarg

USAF Academy Physics Dept

As documented in the National Defense Authorization Act for fiscal year 2010, space situational awareness (SSA) is a high priority for the DoD and intelligence community. A fundamental understanding of the technical issues involved with SSA requires knowledge in many different scientific areas. The mission of the United States Air Force Academy (USAFA) is to educate, train, and inspire men and women to become officers of character motivated to lead the United States Air Force in service to our Nation. The physics department is implementing the USAFA mission and the need for technically competent officers in SSA through a comprehensive SSA Initiative. As part of the Initiative, we are developing a course to provide junior or senior cadets with the scientific background necessary to understand the challenges associated with SSA missions and systems. This presentation introduces the planned course objectives and includes a discussion of topics to be covered. Examples of topics include, optically resolved imaging, radiometry and photometry, radar detection and tracking, orbital prediction, debris and collision avoidance, detection of proximity operations and modeling and simulation tools. Cadets will have hands-on opportunities to collect metrics of a designated object using Academy assets such as the 41 cm telescope. Cadets will convert telescope gimbal angles into an orbital data. Cadets will synthesize what they learned in the course by completing the semester with a final project where the collected data is merged with a notional scenario to present a mock decision briefing. This class will be open to cadets of any academic major, since the intent is to prepare officers with basic technical competence in SSA applications. This is critical since graduates of the Academy become commissioned officers in the military and serve in a large variety of leadership positions – from the researcher to the warfighter. Since we are currently developing the course, the SSA community will be invited to send online feedback to USAFA physics department faculty and to participate by providing materials that may be integrated into course.

The Space Elevator, Orbital Debris, and Space Situational Awareness

Jason Kent

USAF

With the construction of a space elevator, the need for accurate, high resolution space debris tracking will dramatically increase. The safe operation of the elevator will depend on greater space situational awareness as well as a solid orbital debris mitigation plan.

The Space Elevator is a carbon nanotube (CNT) tether 1 meter wide and 100K km long stretching from the surface of the Earth out to geosynchronous orbit (GEO) and beyond to a counterweight. The mass of the 800 ton tether is balanced at the center point at GEO, centripetal force balances out the structure. Earths gravity pulls the earth-side tether to the surface while the counterweight serves to pull outward. The space elevator is an elegant solution to the question of how to provide cheap, reliable access to space. For all its technical achievement, a space elevator would be useless if debris threatens its safe operation.

The space elevators tether design gives it a very small cross section at any altitude. But, the sheer length and relative fragility of the structure mean space debris which intersect its path could prove catastrophic. A hit with significant force could, at a minimum, damage the tether. At worst, the tether would be snapped with the subsequent loss of some or the entire tether.

Safe operation of the elevator dictates the need for orbital debris mitigation techniques. Four approaches in this arena are: improved Space Situational Awareness (SSA), debris removal, elevator maneuverability, and the use of multiple tethers.

This paper will explore the needs of SSA for space elevator operations. The basic need to detect and track items of 1 cm or larger is needed to ensure the space elevator can operate safely. This requirement presents a problem to today's tracking system and means that, in conjunction with developing the space elevator, the nation needs to vastly improve its SSA infrastructure.

This paper will also include a survey of current debris mitigation plans and recommend the most useful plans in the age of the space elevator – these debris removal techniques can be used to benefit not only the space elevator but other orbital assets as well. The three general categories include: returning objects to Earth, deorbiting for destruction in the Earth's atmosphere, and moving debris to a new orbit (e.g. junkyard or for reuse as part of a counterweight for one of the space elevator tethers – recycling in orbit!).

Elevator maneuvering would be dependent on the quality of SSA and the reaction which this knowledge allowed. Techniques for moving an elevator will be explored.

Finally, this paper will briefly look at the use of multiple tethers in conjunction with improved SSA, debris mitigation, and elevator maneuvering.

The space elevator is a concept which could revolutionize how man gets to space and enable the use of space on a scale which has only been imagined the minds of science fiction writers. Orbital debris offers a significant hazard to the safe operation and survival of the tether. Plans involving improved SSA, debris mitigation, elevator maneuverability, and use of multiple tethers can all be implemented to ensure the space elevator a key component of mankind's future in space.

Key Words: Space Elevator, Carbon Nanotubes, CNT, Space Situational Awareness, Orbital Debris, Tether

Development of a New Type Sensor for In-Situ Space Debris Measurement

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Space debris environment models are used for debris impact risk assessments for spacecraft. The comparison of representative models revealed that there is large difference in the flux value of the size range from a hundred micrometers to several millimeters. The uncertainty of models is caused by the lack of measurement data. Although the large size objects (larger than several cm) can be detected by grand based observations, and small size debris (smaller than hundred micrometers) is measured by spacecraft surface inspections, the size range of hundred micrometers to several millimeters cannot be detected by ground observations and cannot get enough data from spacecraft surface inspections. On the other hand, importance of measurement of these large particles has been increased especially in the engineering viewpoints (e.g. space system design and operations). The in-situ measurement data are useful for; 1) verifications of space debris environment models, 2) verifications of space debris environment evolution models, 3) real time detection and evaluation of the influences on space environment by unexpected events, such as explosions on an orbit (ex. ASAT (Anti-Satellite Test) and satellites collisions). Authors have been developing the in-situ measurement sensor to detect dust particles ranging from a hundred micrometers to several millimeters. Since spatial density of this size range of debris is low, the sensor must have a large detection area, while the sensor is required to be low in mass, low in power, robust, and low in telemetry requirements. The sensor consists of multitudes of thin and conductive strips which are formed with fine pitch on a thin film of nonconductive material. A dust particle impact is detected when one or more strips are severed by the impact hole. It is simple to produce and use and requires almost no calibration as it is essentially a digital system. Features of the sensor are; 1) Simple mechanism, 2) High reliability (sensing ability), 3) Flexible configuration, 4) Measurement of change of the usable area of a sensor is possible correctly, 5) Low weight, low power and low cost, 6) Excellent extendability for measure additional parameters (the impact location, the impact velocity and direction of the particle). Authors report the sensor development, hypervelocity impact experiments on the preliminary models of the sensor, and mission plans which use the sensors.

Space Object Radiometric Modeling for Hardbody Signature Database Generation

Bernie Klem, Dave Swann

United States Air Force Arnold Engineering Development Center, Advanced Missile Signature Center

Recent advances in spacecraft health monitoring have resulted in successful applications of photometry and light curve analysis to quantify measurable changes to the spacecraft by passive means. Subtle changes in degradation of spacecraft material properties, reorientation of central body attitude, and slight misalignment of major signature producing components (extended solar panels) are often detected under non optimized viewing conditions. It is beneficial to the observer / analyst to understand the fundamental optical signature variability associated with these detection and identification processes.

This presentation captures the fundamental observable variations of representative convex surfaces that may exist in the surround for which the subtle change processes need to be detected. The key surface parameters include shape, orientation, altitude, surface - sensor - light source scenario, and material reflection characteristics. Specifically, the talk summarizes radiant intensity patterns as a function of prioritized key parameters as generated from moderate – to - high fidelity simulations. The intent is to provide the analyst with an information - base capability to select the observation – sensing scenario that has an increased likelihood of successfully monitoring changes to the spacecraft.

The focus of the paper is to present a graphical database summary of typical meter - size convex surfaces that include a right circular cylinder, a right circular conical frustum, a right circular cone, and a thin circular disk. These objects are modeled in their major in - plane and out - of - plane orientations with respect to the sun and the earth, while situated at a low earth orbit (LEO) and a geostationary earth orbit (GEO) altitude location. Results are presented for broad visible spectral band observations as the sensor performs a complete “walk - around” of the objects in the solar and solar - perpendicular planes to capture the diffuse and specular reflection signature characteristics resulting from both the direct sun and the earth albedo. Results are also presented for the cases where the space objects experience complete tumbling motion in these planes while being observed from a fixed sensor location. A partial database has already been generated demonstrating the complexity of the earth albedo diffuse and specular glint patterns for LEO altitude surfaces.

Continuous engagement with conference participants in the poster session is anticipated to provide a discussion agenda for expansion of the presented topics to include such areas as: (1) simultaneous multiple color sensing, (2) introducing hi fidelity spectral material property simulation capability to the database, and (3) developing infrared observable features into the sensing and status identification algorithms.

Observation of Light Curves of Space Objects

Hirohisa Kurosaki[1], Toshifumi Yanagisawa[2], Atsushi Nakajima[2]

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Geosynchronous orbit and low earth orbit have many artificial satellites, and the accidents of these satellites affect every area such as weather forecasts and communications. In the optical observation, the periodical change of the brightness which is caused by the type and the shape of the satellite is seen. For space debris, it is possible to estimate its approximate shape from its rotational condition. Recently, we are studying the estimation of the shape of the debris from the optical observation. In the case of LEO debris, since the movement is fast, it crosses the field of view in several seconds. We used an observation method to get the data of LEO debris. This method observes a field of view in the sky calculated from the TLE of targeted Iridium 33 debris so that a track of the target is obtained. The exposure is begun right before the targeted debris passes through the field of view. We tried this method at March 11, 2009, and observed several pieces of debris. It seems that comparatively large and bright debris was detected by this method. The positions and tilts of the streaks of light, and the observed times are in good agreement with forecasts from the orbital elements, convincing us that the observed streaks of light are the targets. In case of the GEO debris, the rate of motion is slow in comparison with LEO debris. Fixed stars are observed by the same position on the image when the telescope is operated in sidereal tracking mode. Then, an artificial satellite and debris are recorded on the image with streaks of light. When the telescope is observing an equatorial belt especially, satellites pass the field of view one after another. Rotation periods of some satellites and some pieces of space debris in the geosynchronous orbit which were detected in the observational images were calculated in this research. In this paper, the observation and the detection method of light curve of geosynchronous orbit debris are discussed. Observing the changes of the operative satellites with some time intervals may help to detect the abnormalities and accidents of them.

Automatic Reacquisition of Satellite Positions by Detecting Their Expected Streaks in Astronomical Images

Martin P. Levesque

DRDC

Artificial satellites, and particularly space junk, drift continuously from their known orbits. In the surveillance-of-space context, they must be observed frequently to ensure that the corresponding orbital parameter database entries are up-to-date. Autonomous ground-based optical systems are periodically tasked to observe these objects, calculate the difference between their predicted and real positions and update object orbital parameters. The real satellite positions are provided by the detection of the satellite streaks in the astronomical images specifically acquired for this purpose. This paper presents the image processing techniques used to detect and extract the satellite positions. The methodology includes several processing steps including: image background estimation and removal, star detection and removal, an iterative matched filter for streak detection, and finally false alarm rejection algorithms. This detection methodology is able to detect very faint objects. Simulated data were used to evaluate the methodology’s performance and determine the sensitivity limits where the algorithm can perform detection without false alarm, which is essential to avoid corruption of the orbital parameter database.

Leveraging the Space Plug-and-Play Avionics (SPA) standard to Enable Constellation-Level Collaborative Autonomy

Louis Marketos

Design_Net Engineering

On-orbit autonomy depends on the timely availability of situational awareness data. Data provided from ground stations, derived from telemetry from other spacecraft, need to be evaluated in conjunction with the real-time telemetry available from various subsystems on the spacecraft bus. Having direct access to telemetry from other spacecraft dramatically increases an autonomy engine's ability to make decisions based on near-real-time information and information from multiple sources with heterogeneous capabilities.

SPA is well suited to provide a platform to support spacecraft autonomy on several levels. It provides an abstraction layer between the autonomy engine and each spacecraft subsystem. This decoupling allows simplified reuse of the autonomy engine on future missions as well as reducing design-time efforts to develop the bus since interfaces between the bus and the autonomy system are standardized.

Introducing a Constellation Collaboration Manager (CCM) activity agent as a SPA-compliant application on the bus allows telemetry from other spacecraft, including telemetry from component types not available on the local spacecraft, to be available as inputs to an autonomy engine in the same abstracted manner that local telemetry is available. This allows an autonomy engine to base its decisions on a much broader range of data and increase the range of scenarios that it can handle. The telemetry available can be optionally pre-filtered or processed into aggregate information either by the CCM on the spacecraft broadcasting its telemetry or on the receiving spacecraft before it is sent to the autonomy engine. The CCM also opens additional options for autonomy engines by allowing them to generate tasking requests for other spacecraft in addition to its local spacecraft. Since the CCM is a SPA-based component, it can be added to an existing SPA-based system with minimal or no impact to other components on the bus.

Compressive Coherence Sensing

Daniel Marks, Ashwin Wagadarikar, David J. Brady

Duke University

The cross spectral density function provides a general model for optical field measurements. Wavefront characterization strategies, including phase diversity, Shack-Hartman sensors and wavefront coding, may be analyzed as projections of the cross spectral density. We have previously demonstrated exhaustive measurement of the cross spectral density using an "astigmatic coherence sensor" (ACS). We also demonstrated the use of an ACS to image through phase distortion. While conventional imaging methods exploit the aberrations of a distorted point spread function, a coherence measurement system applies coherence mode decomposition to distinguish and separate the fields of disparate incoherently emitting radiators. This decomposition is a powerful tool that can infer both the power of each source and the wavefront produced by each source.

The cross spectral density is four-dimensional and is greatly undersampled by most optical sensors. A new technique, compressive sensing, enables the inference of a sparse object even if the data is greatly undersampled. Sparsity, which requires the reconstruction to have only a few nonzero components in a specified basis, greatly constrains the number of possible objects and requires orders of magnitude fewer measurements to obtain an accurate reconstruction. By designing an instrument that samples a well-chosen small subset of projections of the partially coherent field, a sparse coherence function can be estimated with sufficient accuracy to enable coherence-mode analysis methods to be used. We introduce the idea of a sparse cross spectral density and present a new formalism to analyze the behavior and performance of compressive coherence sensors. This includes defining projections of the coherence function, how to enforce sparsity on coherence functions, what conditions are required of the measurements to enable sparse reconstruction of the coherence function, and the quality of the coherence mode decomposition that can be obtained from sparsely sampled projections. Simulations of this approach demonstrate the advantages and disadvantages when sensing phase distorted objects such as encountered when imaging through turbulence. A coherence sensing approach yields improvements over other well-established techniques such as inferring wavefronts using transport-of-intensity methods and blind deconvolution, and may offer a means of improving these established techniques.

The Race Toward Becoming Operationally Responsive in Space

Jeff Nagy[1], Veronica Hernandez[2], Robert Strunce[3]

[1]USAF, [2]USAF Research Lab-Mesa, [3]Star Technologies Inc

The US Air Force Research Laboratory (AFRL) is currently supporting the joint Operationally Responsive Space (ORS) program with two aggressive research space programs. The goal of the ORS program is to improve the responsiveness of space capabilities to meet national security requirements. ORS systems aim to provide operational space capabilities as well as flexibility and responsiveness to the theater that do not exist today. ORS communication, navigation, and Intelligence, Surveillance and Reconnaissance (ISR) satellites are being designed to rapidly meet near term space needs of in-theater tactical forces by supporting contingency operations, such as increased communication bandwidth, and ISR imagery over the theater for a limited period to support air, ground, and naval force missions. This paper will discuss how AFRL/RHA is supporting the ORS effort and describe the hardware and software being developed with a particular focus on the Satellite Design Tool for plug-n-play satellites (SDT).

AFRLs Space Vehicles Directorate together with the Scientific Simulation, Inc. was the first to create the Plug-and-play (PnP) satellite design for rapid construction through modular components that encompass the structural panels, as well as the guidance and health/status components. Expansion of the PnP technology is currently being led by AFRL’s Human Effectiveness Directorate and Star Technologies Corp. by pushing the boundaries of mobile hardware and software technology through the development of the teams “Training and Tactical ORS Operations (TATOO) Laboratory located in Great Falls, VA. The TATOO Laboratory provides a computer-based simulation environment directed at improving Warfighters space capability responsiveness by delivering the means to create and exercise methods of in-theater tactical satellite tasking for and by the Warfighter.

In an effort to further support the evolution of ORS technologies with Warfighters involvement, Star recently started coordinating the integration of the TATOO Laboratory with a satellite robotics test bed. Accessible via the TATOO Lab, the robotics test bed will be used to demonstrate and evaluate leading edge satellite technologies, such as Guidance Navigation and Control, attitude control, formation flying, and plug-and-play electronics. The test bed will consist of a Mission Control Center with wireless control and telemetry, an exceptionally flat and smooth floor area, and two robotic satellite simulators equipped with next generation plug-and-play hardware.

When Satellites Collide: High-Performance Computer Modeling of the Cosmos-Iridium Collision

Scot Olivier

Lawrence Livermore National Laboratory

This paper describes the application of a new, integrated modeling and simulation framework, encompassing the space situational awareness (SSA) enterprise, to the recent Cosmos-Iridium collision. This framework is based on a flexible, scalable architecture to enable efficient simulation of the current SSA enterprise, and to accommodate future advancements in SSA systems. In particular, the code is designed to take advantage of massively parallel computer systems available, for example, at Lawrence Livermore National Laboratory. We will describe the application of this framework to the recent collision of the Cosmos and Iridium satellites, including (1) detailed hydrodynamic modeling of the satellite collision and resulting debris generation, (2) orbital propagation of the simulated debris and analysis of the increased risk to other satellites (3) calculation of the radar and optical signatures of the simulated debris and modeling of debris detection with space surveillance radar and optical systems (4) determination of simulated debris orbits from modeled space surveillance observations and analysis of the resulting orbital accuracy, (5) comparison of these modeling and simulation results with Space Surveillance Network observations. We will also discuss the use of this integrated modeling and simulation framework to analyze the risks and consequences of future satellite collisions and to assess strategies for mitigating or avoiding future incidents, including the addition of new sensor systems, used in conjunction with the Space Surveillance Network, for improving space situational awareness.

Astronomy as a Tool for Training the Next Generation Technical Workforce

Van Romero, Graham Walsh, William H. Ryan, Eileen V. Ryan

New Mexico Institute of Mining and Technology

A major challenge for today's institutes of higher learning is training the next generation of scientists, engineers, and optical specialists to be proficient in the latest technologies they will encounter when they enter the workforce. Although research facilities can offer excellent hands-on instructional opportunities, integrating such experiential learning into academic coursework without disrupting normal operations at such facilities can be difficult. Also, motivating entry level students to increase their skill levels by undertaking and successfully completing difficult coursework can require more creative instructional approaches, including fostering a fun, non-threatening environment for enhancing basic abilities. Astronomy is a universally appealing subject area, and can be very effective as a foundation for cultivating advanced competencies.

We report on a project underway at the New Mexico Institute of Mining and Technology (NM Tech), a science and engineering school in Socorro, NM, to incorporate a state-of-the-art optical telescope and laboratory experiments into an entry-level course in basic engineering. Students enrolled in an explosive engineering course were given a topical problem in Planetary Astronomy: they were asked to develop a method to energetically mitigate a potentially hazardous impact between our planet and a Near-Earth asteroid to occur sometime in the future. They were first exposed to basic engineering training in the areas of fracture and material response to failure under different environmental conditions through lectures and traditional laboratory exercises. The students were then given access to NM Tech's Magdalena Ridge Observatory's (MRO) 2.4-meter telescope to collect physical characterization data, (specifically shape information) on two potentially hazardous asteroids (one roughly spherical, the other an elongated ellipsoid). Finally, the students used NM Tech's Energetic Materials Research and Testing Center (EMRTC) to perform field experiments to discern how an object's shape affects disruptive outcomes, and what must be factored into mitigation schemes to attain the desired result of complete destruction of the object. The scientific findings (details will be presented) derived by the students were valuable, and the students benefited from this non-traditional teaching approach such that they acquired a superior appreciation for research and experimentation, and exited the course with an increased motivation to continue their engineering training.

High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA)

Chris Sabol[1], Paul Schumacher[1], Bruce Duncan[2]

[1]AFRL, [2]MHPCC

This poster paper firstly provides a status of the Institute project team's work to date over the past year, starting with brief HSAI background from the Department of Defense (DOD) High Performance Computing Modernization Program (DOD HPCMP). HSAI-SSA is one of only nine DOD institute projects that have been selected by the Deputy Under Secretary of Defense (Science and Technology) to focus and use advanced computational science and high performance computing to accelerate solving the DOD's highest priority challenges and make important advances in research, development, test, and evaluation. HSAI-SSA is the only DOD institute project focused on Space. We next describe Space Situational Awareness (SSA), how its many challenges necessitate supercomputing, and identify the type of disciplines required to solve many SSA problems; and the role of the Institute, which is led by the Air Force Research Laboratory AFRL/RD Directorate and an Onsite Director located on Maui. We then follow with a short discussion of the vision, mission, and overview of the Institute's strategic goals and core competencies. HSAI-SSA core competencies include Image Enhancement, Astrodynamics, Non-Resolvable Satellite Characterization, Data Integration, and High Performance Computing. We then follow up with and most of the poster shows and discusses the technical status for several of our current software applications projects and show the high performance computing metrics we have been able to achieve to date. In closing, we quickly summarize HSAI-SSA challenges, members and partners, and technology transition payoffs for selected applications and users.

Small Aperture Telescope Observations of Co-located Geostationary Satellites

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DRDC Ottawa

As geostationary orbit (GEO) continues to be populated, satellite operators are increasing usage of co-location techniques to maximize usage of fewer GEO longitude slots. Co-location is an orbital formation strategy where two or more geostationary satellites reside within one GEO stationkeeping box. The separation strategy used to prevent collision between the co-located satellites generally uses eccentricity (radial separation) and inclination (latitude separation) vector offsets. This causes the satellites to move in relative motion ellipses about each other as the relative longitude drift between the satellites is near zero. Typical separations between the satellites varies from 1 to 100 kilometers.

When co-located satellites are observed by optical ground based space surveillance sensors the participants appear to be separated by a few minutes of arc or less in angular extent. Under certain viewing geometries, these satellites appear to visually conjunct even though the satellites are, in fact, well separated spatially. In situations where one of the co-located satellites is more optically reflective than the other, the reflected sunglint from the more reflective satellite can overwhelm the other. This less frequently encountered issue causes the less reflective satellite to be glint masked in the glare of the other. This paper focuses on space surveillance observations on co-located Canadian satellites using a small optical telescope operated by Defence R&D Canada - Ottawa. The two above mentioned problems (cross tagging and glint masking) are investigated and we quantify the results for Canadian operated geostationary satellites. The performance of two line element sets when making in-frame CCD image correlation between the co-located satellites is also examined. Relative visual magnitudes between the co-located members are also inspected and quantified to determine the susceptibility of automated telescopes to glint masking of co-located satellite members.

Expanding Lookout Capabilities for Architectural Analysis

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SMC/SYSW/ENY's Lookout tool provides a M&S capability for architectural analysis. It models the contributions of ground and space-based assets in several mission threads and scenarios to quantify overall Space Situational Awareness (SSA) capability. Plotting performance results versus costs enables decision makers to identify and evaluate Best Value families of systems and combinations of architectures. Currently, SMC intends to use Lookout to impact the Fiscal Year 2012 budget programming cycle, the National SSA Initial Capabilities Document (ICD) and Architecture definition effort, planning for programs of record, and AFSPC & SMC leadership. Ultimately, Lookout will enable additional space superiority analysis.

Previous Lookout work focused on modeling the metric tracking capabilities of the Space Surveillance Network (detecting and tracking) and proposed concepts to close identified collection shortfalls. SMC/SYSW/ENY leveraged some of the lessons learned in developing and implementing the metric tracking models to expand Lookout to develop an initial characterization capability, including non-resolved space object identification (SOI), imaging, and Foreign Instrumentation and Signals (FIS) Intelligence. Characterization collection phenomenologies added in FY08 and FY09 include mechanical tracking and phased array radars, visible telescopes, and signals collection. Lookout enables evaluating the characterization collections for quantity, quality, and timeliness.

Capturing the Tasking, Collection, Processing, Exploitation, and Dissemination processes represent one of the biggest challenges in including characterization capabilities in mission thread and scenario-based analysis. The SMC/SYSW/ENY team met with several representatives of the community and held community-wide Technical Interchange Meetings. Based on feedback from these meetings, SMC created an infrastructure for modeling the tasking processes and scales to relate collection quality to intelligence utility through the processing and exploiting processes.

This paper summarizes the expansion of Lookout capabilities from metric tracking to include characterization, additional scenarios and technical performance measures for evaluation, and additional sensor concept models. It presents analysis based on those capabilities and highlights future stages of growth.

High Speed Optical Imaging Photon Counting Microchannel Plate Detectors for Astronomical and Space Sensing Applications

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In recent years we have implemented a variety of high-resolution, photon-counting MCP detectors in space instrumentation for satellite FUSE, GALEX, IMAGE, SOHO, SSULI, HST-COS, rocket, and shuttle payloads as well as sensors for ground based Astronomy, reconnaissance and biology. These detectors can meet many of the challenging imaging and timing demands of applications including astronomy of transient and time-variable sources, Earth atmospheric imaging and spectroscopy for real time space weather monitoring, biological single-molecule fluorescence lifetime microscopy, airborne and space situational awareness, and optical night-time/reconnaissance. Our recent work on high performance photon counting imaging readouts enables significant advancements over previous detector systems used for these applications. We have developed novel Cross-Strip and Cross-Delay-Line anode structures that can, in combination with small pore MCP's in sealed tube detectors, can achieve high spatial resolution (better than 10 um FWHM) with self triggered ~1 ns timing accuracy at up to 10 MHz event rates. Sealed tubes with formats, of 18mm, and 25mm with efficient S25 photocathodes have been

built and are being used in several applications. The detectors and their properties will be discussed in this paper. Our installation and astronomical commissioning of one of these detectors at the South African Astronomical Observatory, South African Large Telescope (SALT) 10m telescope will be described. Our photometer is positioned in an auxiliary instrument port of the SALT. This is a stand-alone instrument that includes our detector system with two filter wheels (neutral density and U, B, V), an iris, and all the control modules necessary to operate the system. This instrument gives us access to the southern sky with significant sensitivity and unprecidented time resolution (microsec). High time resolution astronomy is still in its infancy, such that high cadence observations of the variable visible wavelength emission from cataclysmic variables, short period pulsars, M-dwarf flares, low mass X-ray binaries, flickering from black-holes in AGN, stellar occultations of solar system planets and high precision timing of transiting extra-solar planets are all topics of potential interest to the astronomical community. During two weeks of initial observations a large range of these objects were observed, including high time resolution observations of cataclysmic variables, pulsars, and flare stars. Results from these observations will be discussed, along with implications for future observations that will result from continuing development of the instrumentation.

Simulation of Satellite Light Curves for a Combination of Simple Shapes for Ground and Space-Based Sensors

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In order to improve Space Situational Awareness, it is helpful to be able to track earth-bound satellites in order to know and predict their position, movement, size, and physical features. However, there are many satellites in orbit that are simply too small or too far away to resolve by conventional optical imaging. We can use photometric techniques to gather information about the body in question, but the problem comes in how we interpret the light curve data. Light curves are created by measuring the intensity of reflected sunlight off of the object as it passes overhead. The intensity is dependent on a variety of factors to include the size, shape, orientation, and material composition of the satellite. When we attempt to solve the inverse problem for light curves, we are attempting to extract information about these different factors.

Forward modeling of photometric light curves provides a way to generate a large amount of data with the exact conditions we desire for working the inverse problem and is an effective way to test Non-Resolved Space Object Identification (NRSOI) techniques. Currently, there are few implementations of such modeling programs, one of which only allows simple geometric shapes with the option of antennas. We present our modification to that existing code to create complex models plus our new code to calculate shadowing on the complex object. Then we show the results from the new model and a comparison to the original tool.

The next generation of space surveillance sensors will be on satellites. Space based sensors avoid many of the problems of ground based sensors, such as, waiting for lighting conditions to match satellite passes and a night sky. These sensors are restricted only by sun exclusion angle and line of sight around the Earth. This allows for more effective techniques and a much longer time on target. We present an addition to the existing code to consider a sensor in orbit. The code is generalized to provide flexibility in testing different orbital parameters and provides pass prediction with predictive forward modeling for any TLE set.

Conjunction Risk Assessment with Spherical Quadrature

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The assessment of conjunction risk serves an integral role in space situational awareness. Decision makers must have the tools to assess the conjunction risk based on normal maintenance of the space object catalog and mechanisms to resolve that risk through timely tasked observations of susceptible object pairs. Overly conservative risk assessment either wastes limited resources on unneeded maneuvers or numbs satellite operators to the intrinsic risk of conjunction. Underestimation of conjunction risk has its own, obvious shortcomings. A computationally efficient conjunction evaluation approach is offered which estimates the cumulative density function of conjunction miss-distance based upon the 3-D position and velocity state covariances of both objects. The approach leverages a spherical quadrature approach developed by Lebedev which easily vectorizes and limits the required number of trigonometric evaluations to achieve a given level of numerical precision.

Design of InAs/GaSb Superlattices for Infrared Focal-Plane Arrays

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The InAs/GaSb superlattice system, with its broken gap type-II band alignment, has been used extensively in high-brightness coherent laser sources and more recently for the fabrication of focal-plane arrays in the 2-10 micron region. The design of laser devices and detectors based on the type-II band alignment between these two materials has allowed for a number of advantages, including facile tuning of the transition wavelength and improved higher-temperature performance.(1) When compared to typical camera systems based on quantum well infrared photodetectors, InAs/GaSb superlattice detectors offer the possibility of much higher quantum efficiencies, making this material very promising for camera systems where short integration times and high frame rates are required.(2)

Accurate predictions of the superlattice band structures for mid- to long- wavelength IR detection, as well as optimization of the superlattice design for optimum detector performance are essential. The most widely used theoretical tools for calculating the electronic and optical properties of these materials have been based on k.P perturbation theories in combination with envelope function approximations.(3) Although these effective mass methods have provided reasonably accurate results for type-I superlattices containing relatively thick constituent layers, their accuracy for type-I and type-II short period superlattices, remains in question.(4,5) Pseudopotential techniques have often been implemented as more accurate alternatives to the effective mass approaches when determining the subband structures of these superlattices.

In this presentation, we will predict cut-off wavelengths, as well as the photo response intensity for a number of InAs/GaSb superlattice focal-plane array structures. In addition, we will make detailed calculations of the electronic mini-bands in the conduction band states of these superlattice structures; these mini-band properties are critical in determining carrier transport properties in the detectors.

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Polarization Pulse Ranging for Space Situational Awareness

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The proliferation of satellite technology and small ("nano-") satellite technology implies the need for a space situational awareness technique that doesn't depend on direct imaging with large telescopes. We present a technique to discriminate among different satellites or among different orientations ("poses") of a particular satellite by measuring laser pulses reflected by the satellite. Both the shape and the polarization state of the reflected pulses altered in a way characteristic of satellite orientation and material composition. In this overview, we present the major components of our concept study, including an innovative algorithm to map measured return pulse characteristics back to object parameters.

Advanced SPeckle Imaging Reconstruction Environment (ASPIRE)

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The Advanced SPeckle Imaging Reconstruction Environment (ASPIRE) is a Web-based front end that has been recently developed for use with the Physically Constrained Iterative Deconvolution (PCID) and other image processing software applications by Air Force Maui Optical and Supercomputing Site (AMOS) image analysts, and other DOD users. ASPIRE development work has been performed under the DOD's High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA), which is managed and operated by the Air Force Research Laboratory Directed Energy Directorate (AFRL/RD). The image processing software applications cited above remove atmospheric and system blurring from observed and measured data to produce high-resolution images. ASPIRE provides an intuitive, Web-based user-friendly Graphical User Interface (GUI), using default algorithm parameters, and capability to submit/re-submit and manage multiple processing job submissions asynchronously to select supercomputers. ASPIRE allows users to easily visualize the image processing results and related information, and provides many other functions for use by AMOS researchers/developers and image analysts. ASPIRE is also closely integrated with AMOSphere, which is the data repository for the AMOS organization and the location from which the vast majority of data that is generated and processed by the AMOS site is disseminated to customers. One example of this integration is that users that log into ASPIRE will automatically be provided login privileges to AMOSphere, and vice versa. Another example is that when a user logged into ASPIRE needs data from AMOSphere, there will be links on the ASPIRE pages to AMOSphere. Additionally, when a user logged into AMOSphere desires to process the data they are viewing, there is a link to the ASPIRE image processing page. This poster paper introduces ASPIRE, we then summarize the data flow and ASPIRE-AMOSphere integration, and we mostly focus on stepping reviewers through the primary ASPIRE sequence of operations and functions, while highlighting new capabilities that have been realized through ASPIRE.

Activities of JAXA's Innovative Technology Center on Space Debris Observation

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The innovative technology research center of JAXA is developing observational technologies for GEO objects in order to cope with the space debris problem. The center had constructed the optical observational facility for space debris at Mt. Nyukasa, Nagano in 2006. As observational equipments such as CCD cameras and telescopes were set up, the normal observation started. In this paper, the detail of the facilities and its activities are introduced.

The observational facility contains two telescopes and two CCD cameras. The apertures of the telescopes are 35cm and 25 cm, respectively. One CCD camera in which 2K2K chip is installed can observe a sky region of 1.3 times 1.3-degree using the 35cm telescope. The other CCD camera that contains two 4K2K chips has an ability to observe 2.6 times 2.6-degree's region with the 25cm telescope.

One of our main objectives is to detect faint GEO objects that are not catalogued. Generally, the detection limit of GEO object is determined by the aperture of the telescope. However, by improving image processing techniques, the limit may become low. We are developing some image processing methods that use many CCD frames to detect faint objects. We are trying to use FPGA (Field Programmable Gate Array) system to reduce analyzing time. By applying these methods to the data taken by a large telescope, the detection limit will be significantly lowered.

The orbital determination of detected GEO debris is one of the important things to do. Especially, the narrow field view of an optical telescope hinders us from re-detection of the GEO debris for the orbital determination. Long observation time is required for one GEO object for the orbital determination that is inefficient. An effective observation strategy should be considered. We are testing one observation method invented by Umehara that observes one inertia position in the space. By observing one inertia position for two nights, a GEO object that passed through the position in the first night must pass through the position in the second night. The rough orbit is determined from two nights' data. The test observation showed that this method was able to detect many GEO objects and determined their orbits by three nights' observations.

We also joined the campaign observations of IADC(Inter-Agency Space Debris Coordination Committee). By analyzing the observed data with the method that we developed, 88 catalogued and 38 un-catalogued objects were detected. The magnitude of the faintest object detected in this campaign observation was 18.5. The object is un-detectable by human inspection.

Comparison of Optical Sparse Aperture Image Restoration with Experimental PSF and Designed PSF

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The digital post-processing is needed to restore the image of high quality from the blurring image output directly from optical sparse aperture imaging systems. The common method for post-processing is the Wiener filter, where the important parameter is the point spread function (PSF). The Wiener filter will deconvolve the convolution effect if the PSF is the precise impulse response of the optical sparse aperture system. Usually it is hard to measure the PSF experimentally; on the contrary, it is easy to calculate the PSF based on telescope array configuration, which is given by design. In order to evaluate whether the calculated PSF is adaptable to the image restoration, a comparison of the image restoration has been done by using these two kinds of PSFs. The results show that the calculated PSF works well in the case that the co-phasing error is small, while the measured PSF is ineffective.

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