WENESSA, Wide Eye-Narrow Eye Space Simulation for Situational Awareness – Update on Recent Progress

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Abstract

Timelier indications of anomalous object behaviors in geosynchronous earth orbit are considered under a Planning Capability Concept (PCC) for a "Wide Eye-Narrow Eye" (WE-NE) telescope network. The PCC addresses the problem of providing continuous and operationally robust, layered and cost-effective, Space Situational Awareness (SSA) that is focused on monitoring deep space for anomalous behaviors. It does this by first detecting the anomalies with wide field of regard systems, and then providing reliable handovers for detailed observational follow-up by larger aperture assets. WENESSA explores the benefit of such a system to the existing space surveillance network. The study will assess and quantify the degree to which the PCC completely fulfills, or improves or augments, these deep space knowledge deficiencies relative to current operational systems.

In order to improve organic simulation capabilities, we have explored options for the federation of diverse community simulation approaches to evaluate the efficiencies offered by a network of small and larger aperture, ground-based telescopes. Existing Space Modeling and Simulation (M&S) tools designed for evaluating WENESSA-like problems have been taken into consideration as a means for defining and developing the tools needed to perform this study. The creation of a unified Space M&S environment for the rapid assessment of new capabilities is a key near-term goal. The primary goal of this effort is to perform a Military Utility Assessment (MUA) of the WE-NE concept. The assessment will explore the mission utility of various WE-NE concepts in discovering deep space anomalies in concert with the Space Surveillance Network (SSN). The secondary goal is to generate an enduring M&S environment to explore the military utility of future proposed concepts. Ultimately, our validated simulation framework would support the inclusion of other ground- and space-based SSA assets through integrated analysis. Options will be explored using at least two competing simulation capabilities, but emphasis will be placed on reasoned analyses *as supported by* the simulations.

1. Introduction

AFRL/RDS has been pursuing a Wide-Eye, Narrow-Eye (WENE) SSA study in an effort to clarify the advantages of a cluster of collocated telescopes working together to both surveil very large regions of the sky and perform detailed follow-ups on objects whose behavior has been flagged anomalous. The astronomical community has several examples of related, but often non-collocated capabilities, including Gamma Ray Burster detection by space-based telescopes that provide only coarse positional information, followed up with high-resolution ground-based detection and characterization. The collocation of WENE telescopes is not a strict necessity for SSA but does ensure a simplified handover of objects without parallax corrections, and allows command and control over a local, secure network.

Surveillance (and the related notion of reconnaissance) of space has always been challenging – pixel fields of view on the sky are small (seeing-limited optical blurs of about two arcsecs), and angular extents of the surveilled regions are vast. Object number density (per solid angle) is a strongly increasing function of detection magnitude – with active and dead satellite, rocket body, and debris numbers per square degree growing as a power law of the limiting detectable brightness.

For a full description of challenges relating to the difficult physical and technological obstacles, the reader is referred to the 2017 AMOS Technical Conference Proceedings (Albairat et al., "Paper I" hereafter). These include a combination of surveillance area coverage and its angular resolution, and limiting magnitude for detections. A key figure of merit found in Paper I for any WENE embodiment is the maximum latency time corresponding to the worst-case delay between the onset of an anomaly and the time of its detection.

The WENESSA effort therefore seeks to develop and validate a Modelling & Simulation capability that allows the performance of proposed WENE systems to be evaluated on the basis of selectable limiting magnitude and maximum allowable warning times. The task would be nearly overwhelming, except for the experience gained with the Dynamical Optical Telescope System (DOTS; see Fig. 1) at the AFRL/RDSM AMOS site, and its modeling and simulation software system (TASMAN), to be described below.

Fig. 1. The Dynamic Optical Telescope System of the MSSS.

Other WENE complexities noted in Paper I relate to the complex backgrounds found for fainter levels of GEO object detection, and include star densities that grow as the brightness limits for GEO object detection are lowered but also increase in general with decreasing latitude relative to the *galactic plane* (tipped with respect to the GEO plane). Zodiacal radiation (strongest at smaller sun angles in the ecliptic plane) has a truly diffuse character that can add to pixel photocurrents, diluting the object signal levels. Fainter limiting magnitudes serve to both increase the star densities and raise the contributions of extended (structured) zodiacal and galactic backgrounds. Intricacies and interactions with these foreground and background sources are such that the difficulty of the problem of faint anomaly detection in support of a given number of GEO objects (N_{geo}) grows faster than linearly with N_{geo}, as a greater number of fainter objects are monitored against more complex backgrounds.

In addition, Control System Modeling, including *real-world* issues of failed reacquisition (lost object), interruption of the handover tasking by the control system (handover "recalls"), cloud obscurations, and other forms of delayed reporting back to the to the WENE client, do increase the complexity of the control system. Diverse issues of this type with real-world hardware and observing conditions make modeling of the control system non-trivial. For this reason, a WENE Modeling and Simulation capability with the fidelity to model accurately such control systems is viewed as essential for high confidence performance estimates.

2. TASMAN, a simulation framework for WENE

TASMAN, or Tasking of Autonomous Sensors in a Multiple Application Network, supports AFRL/RDS efforts to develop a simulation environment (software and processors) that can test SSA tools (including real-time WENE) in a closed-loop environment. The level of validation of TASMAN by the DOTS allows scripted and Monte-Carlo testing of WENE tools and capabilities for rigorous testing of new tools and/or capabilities under various operating conditions and scenarios. This allows detailed concept evaluations to be performed prior to and without having to invest in hardware.

The TASMAN team has developed a suite of integrated algorithms and software to provide configurable simulations of optical space surveillance networks with sensors on the ground and in space. TASMAN is used to simulate the entire closed-loop cycle for space situational awareness (SSA), which includes tasking sensors and scheduling observations, detecting targets and producing observations, correlating observations to a catalog, producing orbit estimates, and re-tasking the sensors based on dynamic events. TASMAN comprises a physics-based SSA network simulation environment that includes models of the Space Surveillance Telescope (SST), the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system, the Space Based Space Surveillance system (SBSS) and the MSSS telescopes, including DOTS. The sensor models are capable of producing accurate simulated observations of desired satellites including both astrometric and photometric measurements. The simulation environment must also be capable of injecting variable anomaly scenarios into the environment and changing parameters such as revisit rates and the number of objects of interest in the simulations.

TASMAN was developed by using a multi-threaded, parallel architecture which simulates the primary components of a sensor network in closed loop operation, including mission planning with network tasking and sensor scheduling, sensor observations from either a low fidelity statistical sensor model or high fidelity scene generation and image generation, processing, orbit determination and updates to allow high fidelity sensor simulations, and feedback to mission planning for revised scheduling and response to events.

As shown in Fig. 2, TASMAN includes the high level computer software components (CSCs) shown in blue rectangles including a Tasker, a Scheduler, a low and high fidelity Scene Simulator, and an Orbit Determination component. Key data, organized within four databases, found needed in support of these CSCs, are shown in the grey “drums” which include a Star Catalog, Truth Ephemeris, Estimated Ephemeris, and Sensor Properties. The objectives of these CSCs and databases are described in greater detail in Paper I.

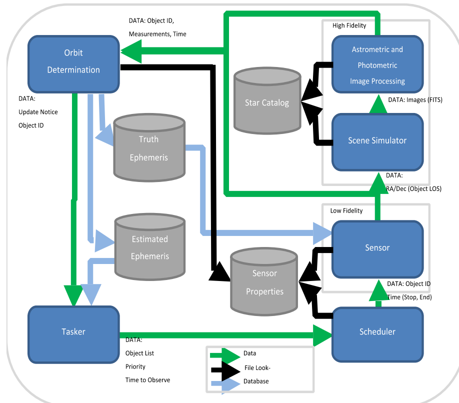

Fig. 2. TASMAN Top Level Architecture

TASMAN was found capable of generating requirements for the DOTS hardware, including revisit rates, number of objects, timeliness and system capacity. TASMAN was initially tested against scenarios including simple maneuvers and rendezvous between satellites.

In summary, the TASMAN mission-planning framework supports a centralized network tasker, centralized or distributed sensor schedulers, sensors operating as independent remote agents, and an integrated network scheduler with coordinated sensor observations. This framework allows analysis of the current AF Space Command SSN. Other supported sensors include the SBSS, MSSS sensors and Ravens.

3. An ultimate WENESSA Simulation Framework

The prospects for accurate WENE assessments by a non-expert government entity are believed promising based on recent, AFRL-wide developments in Modeling & Simulation. By contrast, controlled simulations (e.g., TASMAN) will continue to provide high fidelity performance predictions conducted by subject matter experts, in response to well-defined customer scenarios.

Recently, the WENESSA team worked to establish a TASMAN baseline for a preliminary WENESSA study analysis. The baseline included a catalog of 3325 deep space objects, the simulation of four putative and identical DOTS systems at four different longitudes along with two maneuvering space objects. Fourteen simulations were conducted with the four globally situated space surveillance sites conducting nightly DOTS-like operations[1]. The team thus achieved its 2017-stated goal to define a TASMAN baseline that captures salient features of its simulation of DOTS performance in the form of an output parameter set. The breadth and depth of this baseline simulation "capture" should now allow for its faithful reproduction by any future TASMAN run. It should also make possible an instantiation of an alternative, open source simulation that would thereby encompass a measure of verification from the DOTS embodiment to anchor suggested excursions from DOTS.

A further objective of the DOTS Block I simulations performed in TASMAN was to assess the performance of the DOTS Block I hardware configuration against 14 deep space anomaly scenarios. The simulation runs were set up utilizing 4 identical global SSA sites located around the world: MSSS, Maui; Socorro, NM; Moron, Spain and Diego

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[1] Further details regarding the TASMAN baseline and study results are available for U.S. Government agencies and their contractors via request to AFRL/RDS.

Garcia, and each site possessed 3 sensors: a Custody Raven, a Tactical Raven, and an Advanced Acquisition Tracking Sensor (AATS). The 4 sites were selected due to their ability to cover most of the GEO belt continuously with the combined Fields of Regard (FORs), as in Fig. 3 below.

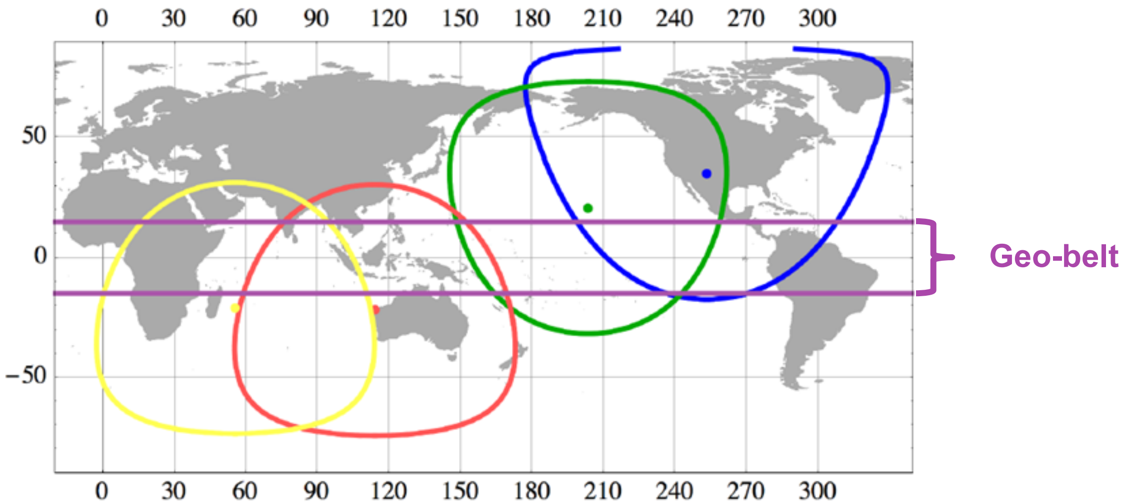

Fig. 3. "Four-site DOTS" Wide Area Search

Every sensor at each of the SSA site locations was assigned to its own unique mission. The Custody Raven is assigned with collecting imagery for High Interest Object (HIO) custody. The Tactical Raven is assigned with collecting Tactical Persistent Monitoring (TPM) Follow-Up imagery, and the AATS is assigned with collecting object stability, Deep Space (DS) Characterization, and Missing HIO search data. Each of the 14 simulation scenarios runs contained 15 HIOs, 13 High Value Assets (HVAs) and 15 Resident Space Objects (RSOs), all needing characterization and all evenly distributed throughout the GEO belt. Each simulation was tested against a space environment containing a catalogue of 3352 deep space objects and 2 HIOs maneuvering and conjuncting with a HVA per scenario. Every scenario had similar starting constraints, 10 HIOs in custody and 5 HIOs not in custody, and nightly DOTS operational missions. Nightly DOTS-like operational missions consisted of maintaining custody of the 10 HIOs distributed semi-uniformly throughout the GEO belt, characterizing the 5 HIOs not in custody at the beginning of nightly operations, and performing TPM Follow-ups for any Uncorrelated Tracks (UCT) discovered throughout the operational period. In every scenario, the same HIO was maneuvered at the same time every night to assess the simulation performance across a common baseline. It is important to note that the TASMAN simulation results were not able to completely emulate the deployed DOTS Block I functionality and lacked the Wide Area Search (WAS) functionality within the simulation due to funding constraints.

Analysis of the TASMAN simulations was conducted for simulation output data observed by the putative DOTS sites compared to the truth data files containing the information that was performed during the simulation. The key performance metrics assessed were: first indication of a HIO maneuver, delta-t from maneuver time to first indication time, the number of HVAs the maneuvered HIO could potentially intersect at the time of each TPM follow-up, and the predicted HIO to HVA conjunction time associated with TPM follow-up. A summary of the performance of the simulations is shown in Fig. 4, and Scenario 5 for "HIO 28884" (a surrogate for an actual HIO) is shown in Fig. 5.

HIO	Custody	Day /Night	Scenario # 1	2	3	4	5	6	7	8	9	10	11	12	13	14
36516		Night														
28884	✓	Night	❌	❌	❌	❌	🟢✓	❌	❌	❌	🟢✓	🟡✓	🟡✓	🟢✓	❌	🟡✓
37737	✓	Night		🟢✓												
38049	✓	Day														
37210		Night														
37843	✓	Night					🟢✓									
33154	✓	Day														
26388		Day														
39504	✓	Day														
25639	✓	Day														
24901	✓	Day														
29349	✓	Day														
24665	✓	Night											❌			
23846		Night														
29398		Day														

🟢 – Successful conjunction prediction < ±20 min from truth conjunction time
🟡 – Successful conjunction prediction < 2 hours from truth conjunction time
❌ – Failure to predict correct HVA conjunction

Fig. 4. Summary of First Indication After Maneuver and Successful Conjunction Prediction Performance for fictitious HIOs.

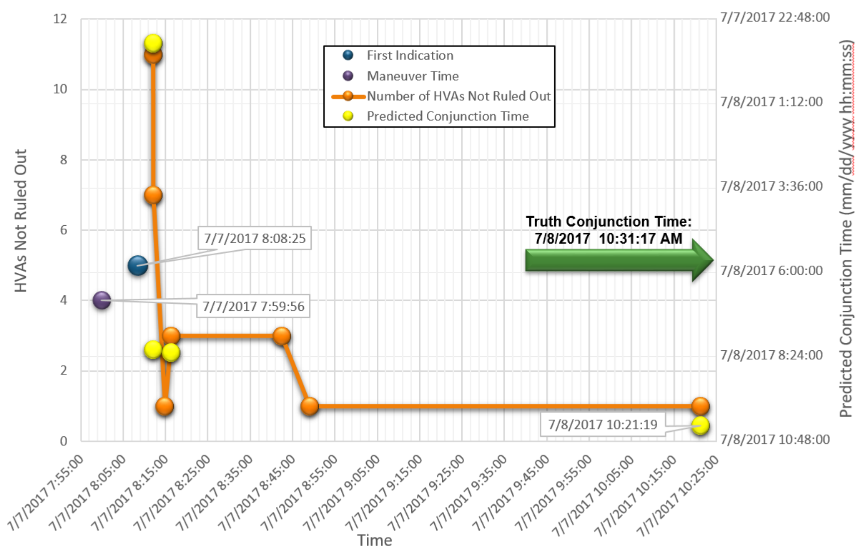

Fig. 5. Performance Analysis for HIO 28884 from Scenario 5

The DOTS Block I simulations performed in TASMAN show interesting results, two of which we discuss here. The first is that the inability to observe a HIO maneuver occurring during the daytime is due to site operational times being constrained to strictly dusk to dawn. The second is that when a HIO maneuver was observed by a SSA site, the DOTS Block I simulation was able to accurately predict the conjunction time to within 2 hours of the truth conjunction time in 8 of 17 cases when the first indication of a HIO maneuver was observed, and within 20 minutes of truth in 5 of 17 cases. The correct HIO and HVA conjunction pairing was predicted in 8 of 17 cases when the first indication of a HIO maneuver was observed. It's important to note that the first indication of a HIO maneuver was observed in all 14 of the common baseline cases, but the correct HVA conjunction was only predicted in 6 of the 14 cases.

Overall, the conclusions drawn from analysis of the TASMAN simulation results point towards a few major areas of improvement for future WENESSA simulations. The first is that a wide area search capability needs to be included in the simulation space to more reliably detect a HIO that maneuvered after the last TPM follow-up occurred. The second is that daytime operations are necessary to detect a maneuvering HIO over a site that is in view of the sun, although there are cases where a second DOTS-like site at an adjacent location on the Earth that is in the dark could perform the detection at larger zenith angles. The simulation identified issues in finding at night a HIO that maneuvered in the daytime, due to the lack of a simulated wide area search capability to detect objects far outside the neighborhood of the TPM follow-ups that were simulated here.

4. Comments on code federation and a role for AFSIM

The latest release of the Application Framework for Simulation, Integration, and Modeling (AFSIM 2.2.1) exhibits a marked increase in space-related capabilities for this AFRL framework. This, coupled with newly available training materials, provides a capability set that appears promising to support WENESSA. However, the level of sophistication of the sensor representations in AFSIM appears to fall short of those available in TASMAN, resulting in the generation of pseudo-images that are processed efficiently for a simulation, but due to their limited fidelity, make difficult the use of standard point source extractions needed for basic WENESSA position and maneuver quantification., as well as correlation of separated observations based on object brightnesses. In addition, the use of pseudo-images circumvents other standard image processing techniques needed by WENESSA. Another limitation imposed on a full WENESSA simulation by AFSIM is the use of simple Lambertian-sphere reflection models for object brightnesses. Ultimately, a high-fidelity simulation would have to support the use of materials-mapped CAD models to generate a realistic brightness dependence on solar phase angle. Despite these limitations, AFSIM is currently able to run low-fidelity WENESSA simulations. In addition, the gaps identified above are being addressed through various AFRL development efforts. AFSIM, with the potential for inclusion of relevant third-party plugins, can therefore serve as the future simulation framework for WENESSA.

Conclusions

The core WENESSA activities to date have made heavy use of TASMAN and have begun investigation of the extension of its modeling of the single-site DOTS to multiple sites. "WENESSA Evolved" will simulate an objective system for WENE, with lower fidelity simulations explored first for quick turn studies on newly proposed WENE concepts. The ultimate desire is for the WENESSA simulation to embody a modular, open source code environment, allowing quicker-look WENE concept assessments without specialized knowledge of code intricacies. This approach would allow use by non-expert government entities, most likely in conjunction with AFSIM. TASMAN will continue to be employed for high fidelity evaluation of refined WENE concepts, perhaps after a cursory exploration with a lower fidelity simulation.

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