Optical Detection for Space Situational Awareness (ODESSA)

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ABSTRACT

In the next two years Georgia Institute of Technology's (Georgia Tech) School of Aerospace Engineering will launch three cubesats into LEO. These satellites will perform ranging and guidance, space-based space surveillance, and laser ranging experiments. Recognizing that these launches presented a unique opportunity to have both observational and on-orbit telemetry data, the Georgia Tech Research Institute (GTRI), along with the Georgia Tech School of Aerospace Engineering (GTAE), are conducting a Strategic Initiative independent research and development effort entitled Optical Detection for Space Situational Awareness (ODESSA).

ODESSA will expand upon existing programs and develop new research opportunities within GT and GTRI. It will (1) demonstrate verified modeling and simulation capabilities for satellites through lab-based measurements, advanced radiometric modeling, and ground-based observations; (2) improve satellite signature detection, tracking, and analysis techniques through the advancement of existing low-light detection and tracking algorithms; and (3) construct an SSA data archive and database architecture that will enable future big-data research efforts, including SSA-focused machine learning techniques.

In this inaugural report, we provide an overview of the ODESSA program and indicate progress on optical characterization and modeling of GT's cube satellites.

1. Introduction

Classically, Space Situational Awareness (SSA) was synonymous with catalog maintenance using a handful of data sources; however, as the number of objects in space grew, SSA broadened into a multi-disciplinary field in which data from multiple modalities are fused to provide a more comprehensive picture of space. As this trend continues, it appears inevitable that SSA will enter a big data era defined by the volume, variety, velocity, and veracity of data provided by a myriad of sensors that span the electromagnetic spectrum.

In order to realize the full potential of these data, the SSA industry must invest in a variety of big-data focused infrastructure, systems engineering, software, and human capital efforts. Relevant areas include cloud computing with scalable database and data store technologies that permit rapid ingestion, analysis, storage, and search capabilities; relevant models and model-based systems engineering tools that enable rapid verification and validation of new algorithmic approaches, and evaluation of system performance bottlenecks; and training material to educate analysts in statistics, software development, and data science.

The Optical Detection for Space Situational Awareness (ODESSA) program will leverage data collection and modeling opportunities surrounding the launch of GTAE's cube satellites to explore a subset of these issues. Between 2018 and 2020 the Georgia Tech School of Aerospace Engineering (GTAE) will launch three cube satellites into LEO. Each satellite is designed, built, and operated by students working within the GTAE Space Systems Design Laboratory. The satellites are as follows:

- Ranging and Nanosatellite Guidance Experiment (RANGE [1]). RANGE consists of two 1.5 U cube satellites (CubeSat) that will fly in a leader-follower formation. The goal of this experiment is to improve the relative and absolute positioning of nano-satellites. RANGE is schedule to launch in 2018. The precise position of each satellite will be tracked by on-board dual-frequency GPS receivers, as well as with ground-based laser ranging measurements.
- RECONnaissance of Space Objects (RECONSO). RECONSO is a 6U cubesat with a passive electro-optical payload. It will use onboard real-time multi-target detection and tracking methods to autonomously detect and track space debris in LEO, and potentially MEO and GEO . RECONSO was initiated as an AFRL/AFOSR University Nanosatellite project (UNP-8), and will launch in 2019.

- Tethering and Ranging Mission of the Georgia Institute of Technology (TARGIT). TARGIT is a 3U cubesat that will test a miniaturized LiDAR imaging camera on a deployable, inflatable tethered target. TARGIT is planned to launch in late 2019.

The ODESSA team will use ground-based observations and on-orbit telemetry data from these satellites to perform verification and validation of our modeling and simulation software, low-light detection and tracking algorithms, and big-data systems engineering efforts. These objectives of each of these tasks are detailed in the following sections.

2. MODELING AND SIMULATION CAPABILITIES

At present there are two dominant software packages for modeling the spatial bi-directional reflectance distribution function (sBRDF) in public literature. These include the AFRL's Time-Domain Analysis Simulation for Advanced Tracking (TASAT) [2] and the Digital Imaging and Remote Sensing Image Generation (DIRSIG) software developed by Rochester Institute of technology's Digital Imaging and Remote Sensing Laboratory. Both software packages use models of the satellite (structure, materials, pose), illumination source, and observing sensor to generate a hyper-spectral image (or unresolved point source) of the satellite as if it were observed by the real system. TASAT's capabilities are well developed for this purpose, whereas DIRSIG still regards its applicability to SSA as experimental[1].

GTRI has an engagement-level simulation tool, the Georgia Tech Simulations Integrated Modeling System (GTSIMS, [3]), which provides accurate radiometric modeling of objects, intra-atmospheric effects, and sensors. The ODESSA project will adapt GTSIMS to model satellites, space background, and other relevant physical processes.

To verify and validate the modifications to GTSIMS, ODESSA will (a) collect hyper-spectral images and sBRDF measurements of each CubeSat prior to launch, (b) construct accurate radiometric models of each satellite within GTSIMS (c) collect ground-based observations of the satellites in orbit using the Georgia Tech Space Object Research Telescope (GT-SORT [4]) and the OMNI-directional Space Situational Awareness system (OMNISSA [5]), and (d) Compare the GTSIMS model against lab and ground-based observations.

To date, the ODESSA team collected a series of hyper-spectral images of RANGE (see **Error! Reference source not found.**), obtained sBRDF measurements of select spacecraft materials, and began modifications to GTSIMS to support space object modeling.

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[1] DIRSIG SSA Handbook (http://dirsig.org/docs/new/ssa.html)

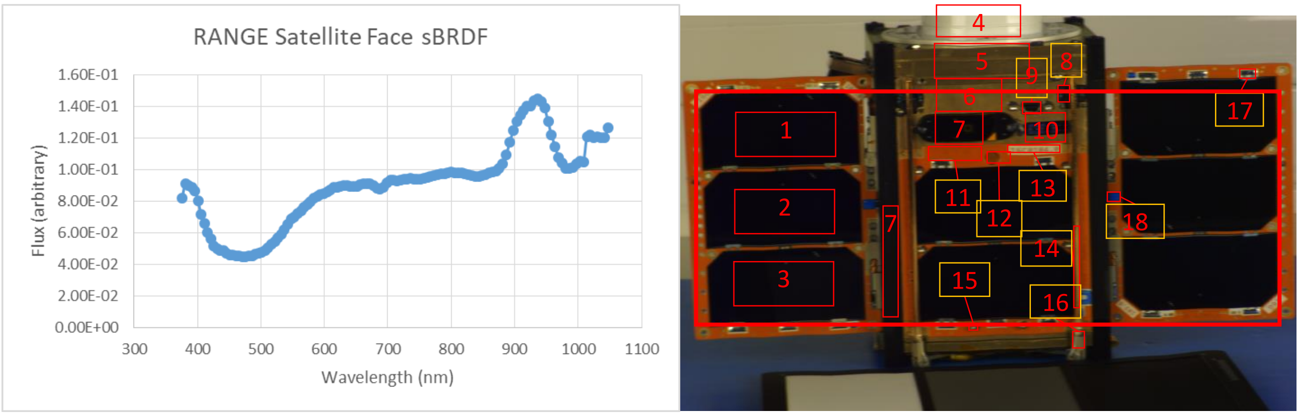

Figure 1 (left) Total reflectance spectrum of RANGE showing high reflectivity from the solar panels around 920 nm and absorption from the spacecraft body near 490 nm. (right) RANGE satellite with key areas of interest labeled.

3. IMPROVED SATELLITE DETECTION AND TRACKING CAPABILITIES

The ODESSA program will improve satellite signature detection, tracking, and analysis techniques through the advancement of existing low-light detection and tracking algorithms testing using GT-SORT observations of our cube satellites. Prior work has shown that 1.5 U cube satellites, like RANGE, appear as bright as 12-14 M_V [6] when observed using a Raven-class telescope. Despite their intrinsic brightness, observing cube satellites using GT-SORT may be challenging due to the heavy light pollution in downtown Atlanta which average some 14-16 M_V/arcsec^2 [4].

These difficult observing conditions provide an ideal testing ground for the ODESSA team's low-light detection and tracking algorithms. The team's previous work includes using Multi Bernoulli Filtering [7] and particle filtering techniques [8]. Our application of Bernoulli Filters has been demonstrated at photometric SNRs as low as 1.5 on Hitomi Astro-H (see **Error! Reference source not found.**).

4. A SSA DATA ARCHIVE AND DATABASE FOR MACHINE LEARNING RESEARCH

As state above, the rapid growth of objects in space seen in the last few decades lead to an increased demand for multiple-modality data to be acquired and fused to form a more comprehensive picture of space. This need encouraged the creation of a plethora of additional data sources from governmental, commercial, and private entities. The commercial sector, in particular, has seen a rapid expansion of capabilities including ExoAnalytic's worldwide network of optical telescopes, LeoLab's pair of phased array radars[2], AGI's deep-space radar tracking facility[3], and a variety of laser ranging and passive RF facilities.

Recent advancements in computational capabilities provide an opportunity to not only fuse track and ancillary data to form a more coherent operational picture of the space environment, but also to apply big data, machine learning (ML), and artificial intelligence (AI) technologies to automate rote operator/analysis tasks. For example, machine learning has been applied to orbital maneuver detection [9], fault detection [10], and dynamic sensor tasking [11] with great success. As with any ML/AI task, it is important to note that these accomplishments rely heavily on large quantities of labeled training and test data that demonstrate the desired learning objective adequately.

[2] LeoLab's Midlands Space Radar (https://platform.leolabs.space/instruments/msr) and Phased Array Radar in Poker Flat, AK (https://platform.leolabs.space/instruments/pfisr)
[3] AGI's Algonquinn Radio Observatory for GEO observing https://spacenews.com/agi-establishes-commercial-deep-space-radar-tracking-system/

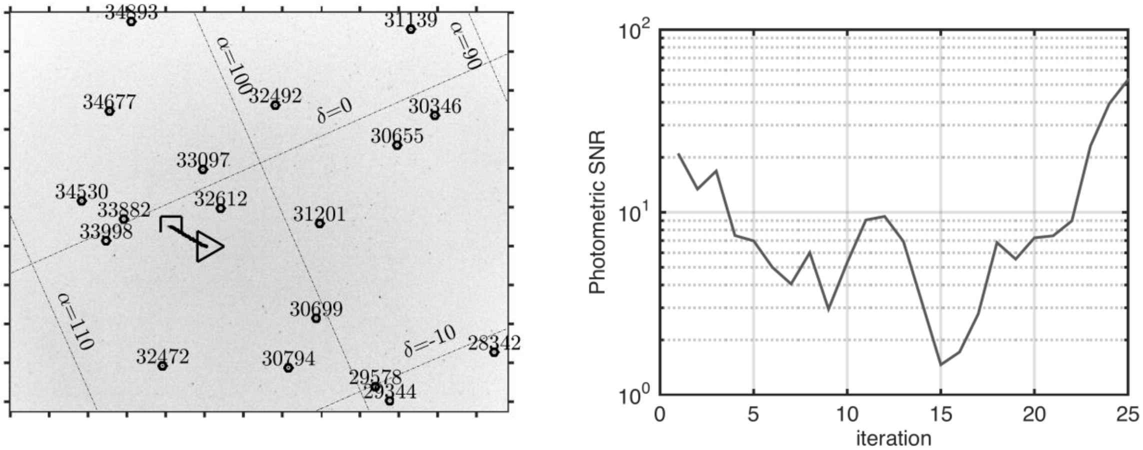

Figure 2 Demonstration of low-light detection and tracking capabilities. (left) Track of Hitomi Astro-H. (right) photometric SNR as a function of time. See text for reference.

The final objective of the ODESSA program is to enable the next generation of SSA-focused ML/AI technologies through the construction of an SSA-focused data archive and suitable big-data framework. Our team will execute these two tasks in parallel. The data archive team will collect and repose all relevant data from our observing facilities, satellite downlink stations, and various public data sources (e.g. SpaceTrack.org, NOAA SpaceWeather, etc.). Given typical observing conditions in Atlanta, we expect GT-SORT and OMNISSA to contribute approximately 5 TB of raw data each month. In addition to data collection, the data archive team will perform traditional object detection, extraction, and correlation tasks. Meanwhile, the framework development team will take a more global perspective. They will address issues related to SSA data representation and search within a big data framework. The team will (a) investigate sources, formats, biases, and known issues related to SSA data; (b) create a list of hypothetical questions that could be explored using big-data technologies that are not possible using single- or few-modality data archives; (c) generate relevant scenarios, simulation tools, and data labeling tools for subsequent ML/AI efforts; and (d) train and evaluate the efficacy of ML/AI models applied to these data sets.

5. CONCLUSIONS

The Optical Detection for Space Situational Awareness (ODESSA) program will explore several issues related to the application of big-data technologies to SSA problems. It will leverage data collection opportunities provided by the launch of three cube satellites by the Georgia Tech School of Aerospace Engineering (GTAE) to perform verification and validation of modeling and simulation software, and improve upon existing low-light detection and tracking algorithms. Lastly, the ODESSA program will construct a SSA-focused data archive and related big-data framework that will permit the evaluation of ML/AI technologies.

6. ACKNOWLEDGEMENTS

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7. ABBREVIATION AND ACRONYMS

- AI – Artificial Intelligence
- DIRSIG - Digital Imaging and Remote Sensing Image Generation
- GT – Georgia Tech
- GTAE - Georgia Tech School of Aerospace Engineering
- GT-SORT – Georgia Tech Space Object Research Telescope
- GTSIMS - Georgia Tech Simulations Integrated Modeling System
- GTRI – Georgia Tech Research Institute
- ML – Machine Learning

- NOAA – National Oceanic and Atmospheric Administration
- ODESSA – Optical Detection for Space Situational Awareness
- OMNISSA – OMNIdirectional Space Situational Awareness
- RANGE - Ranging and Nanosatellite Guidance Experiment (GTAE cube satellite)
- RECONSO - RECONnaissance of Space Objects (GTAE cube satellite)
- RF – Radio Frequency
- RSO – Resident Space Object. Typically a man-made object like a satellite or space debris.
- sBRDF - spatial bi-directional reflectance distribution function
- SSA – Space Situational Awareness
- TARGIT - Tethering and Ranging Mission of the Georgia Institute of Technology (GTAE cube satellite)
- TASAT - Time-Domain Analysis Simulation for Advanced Tracking

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