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Ranked Tasking of Electro-Optical Sensors Observing Geostationary Orbit

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Extended Abstract: This project supports the Joint Commercial Operations (JCO), an organization within the United States Space Com- mand (USSPACECOM). The Operationally Responsive Space 5 (ORS-5) is a satellite in Low Earth Orbit (LEO) currently observing Geostationary orbit (GEO) satellites with a revisit rate under two hours. The JCO is considering leveraging commer- cial ground-based sensors in place of ORS-5. The JCO purchases unclassified satellite surveillance data collected by commercial ground-based electro-optical (EO) sensors to support Space Domain Awareness (SDA). Currently, the JCO manually requests sensors to observe specific satellites in GEO. The JCO's High Rate Revisit (HRR) list provides satellite priority level, which de- termines how frequently they should be observed. Our framework provides a proof of concept for identifying commercial-based sensors capable of observing a specific satellite and for providing a weight-ranked list of sensors to observe the satellites.

The United States Space Command (USSPACECOM) "plans, executes, and integrates military space power into multi-domain global operations to deter aggression, defend national interests, and when necessary, defeat threats" (United States Space Force, 2020). Within USSPACECOM, the Joint Commercial Operations division (JCO) purchases data effectively increasing awareness of space to enable necessary operations (Bonnette, 2023). The Unified Data Library (UDL), a data repository, stores purchased commercial sensor data. Meanwhile, the High Rate Revisit (HRR) list produced by the JCO prioritizes a satellite's revisit rate by considering the satellite's origin and pattern of life, as well as other data to support space domain awareness (SDA). The Operationally Responsive Space 5 (ORS-5), is the primary system used by the government responsible for tracking satellites in Geostationary orbit (GEO) from Low Earth Orbit, which is coming to the end of its life. The main interest of USSPACECOM in this respect is determining whether or not they can leverage existing commercial electro-optical (EO) sensors as a cost-effective alternative to the ORS-5. This project aims to develop an algorithm that ensures satellite observations meet their respective revisit rates from the HRR.

Commercial companies sell their sensor data to the JCO and other interested entities. Dealing strictly with GEO, this project focuses on EO Sensors since they provide a large volume, velocity, and variety of data. EO Sensors require fewer resources than active radar systems, allowing for larger networks across the globe (Shaddix, 2023). Meanwhile, weather condi- tions, such as severe storms, affect these EO ground-based sensors, impeding their detection capabilities. Moreover, a universal limitation to EO sensors and the ORS-5 is solar exclusion. This occurs when the sun is positioned behind a satellite relative to a sensor, thereby blinding the sensor or ORS-5 and limiting the time when observations of a specific area can be taken (Gerber et al., 2022). Currently, JCO has access to data collected by three EO Sensor data providers: ExoAnalytic Solutions, Lockheed Martin, and Slingshot Aerospace.

Commercial providers submit observation data through the UDL, facilitating the team's ability to pull bulk data. This analysis utilized two primary data sets: JCO's HRR and EO Observations (OBS). The EO OBS data set provides detailed information about each satellite observation, to include observation ID, observation time, satellite number, sensor ID, GEO latitude/longitude/altitude, and sensor latitude/longitude. The April and May time frame of 2023 had the greatest number of observations, sensors, and satellites detected, and therefore we chose this period for further analysis. The team can evaluate the sensor's observable range by identifying the minimum and maximum longitude recorded by each sensor primarily through the use of historical data gathered in the specified time.

This project developed a model that optimizes the frequency of observations of commercial ground-based sensors on the satellites in GEO according to their priority on the HRR. Task automation incorporates technology to carry out tasks typically performed by humans, increasing efficiency and limiting errors. The purpose of this project is to automate the tasking of the sensors to watch specific satellites. The JCO's Mission Management Board receives the recommendations, and the commercial providers can task the sensor's orientation based on our recommendations.

Based on empirical and historical data, the team utilized a swing-weight matrix. The team determined the coverage range by calculating each sensor's historical longitudinal minimums and maximums. The team employed a framework that recommends and prioritizes surveillance sensors based on the number of unique satellites detected within a specific time frame, the frequency of observations by a given sensor, and the ranking of the satellites in the HRR that the sensor observed. A sensor's rank correlates with the number of satellite observations and unique satellites observed. Conversely, a sensor's rank is inversely correlated with the number of high-ranking satellites observed from the HRR. If a sensor observes a high number of rank 'one' satellites, it receives a lower rank to ensure higher-priority satellites maintain frequent observation. Each factor is then normalized on a scale from 0-100. These normalized values are combined with a weight percentage dependent upon the user. This allows greater flexibility, allowing the end user to tailor the tasking approach based on their preference and values.

Few sensors fail to surpass the desired threshold set by the revisit rate standards of the HRR. This finding exemplifies the concept of the flaw of averages when displaying the observations chronologically. Due to limited visibility during daytime hours, there are two distinct 12-hour windows regarding the frequency of observations. The first window contains numerous observations, whereas the second window does not contain any observations. This concept leads to the other initial finding - the relationship between satellites and sensor observations. Specifically, the number of sensors observing each satellite. At the moment, approximately a 1:1 ratio exists. If multiple sensors can observe the same satellite, dependent on the disparate locations of the sensors, then cutting down the time between large gaps in observations due to solar exclusion may be possible. Utilizing a swing-weight matrix, our team produced a ranked list of sensors recommended for tasks for a specific satellite.

The team utilized the empirical data for the sensor's field of view. By requesting sensor range capabilities, we can more accurately account for the field of view. We recommend working with the sensor provider to validate the feasibility of a tasking. This study is limited to ExoAnalytic Solutions (EXO) sensors due to their data completeness in providing the satellites' GEO latitude and GEO longitude locations. Therefore, requesting this data from other sensor providers will provide a more complete dataset. We recommend conducting a cost-benefit analysis of the data quality received for each data provider to ensure that USSPACECOM receives high-quality data enabling them to meet the HRR criteria using the EO sensors.

Keywords: Weight-Rank, Satellite Data, Automated Tasking

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