CHANGE DETECTION FROM PERSISTENT PHOTOMETRY

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Abstract. *Unresolved ground-based optical imagery of space objects is a critical component of space domain awareness (SDA), particularly for space objects in geosynchronous orbit. When collected persistently, changes in this photometric signature can allow inference about space object structure and behavior.*

Introduction. ExoAnalytic Solutions owns and operates a telescope network which collects persistent SDA data on all objects above 10,000 km. Unresolved and persistent space object data can help characterize objects at GEO which generally are not imaged directly.

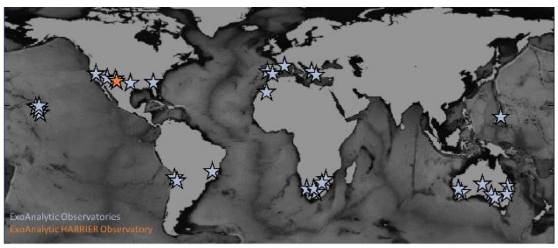

Figure 1: ExoAnalytic Global Telescope Network (EGTN) Footprint

Background. The ExoAnalytic Global Telescope Network consists of over 30 automated observatories on multiple continents as well as Hawai'i and Guam as shown in Figure 1, with each observatory consisting of between 2 and 20 telescopes. This telescope network allows us to cover all 360 degrees of the GEO belt, and to track objects persistently down to MEO altitudes. On bright GEO objects, our daily persistence reaches ~19 hours per day, depending on site conditions, with the remaining approximately 5 hours in solar exclusion. Measurement cadence ranges from 2-5 observations per minute, which allows the observation of transient or short-lived phenomena. The observation data collected by the EGTN is astrometrically accurate to within 0.1-0.2 arcseconds, and target sensitivities achieved are typically on the order of 18th visual magnitude, depending on conditions.

The advantage of persistent, accurate measurements in the space domain awareness arena cannot be emphasized enough. Historically, the challenges of space object characterization for GEO objects have been 1) the relative paucity of optical data, and 2) the presence of significant miscorrelation, particularly for active objects of interest.

Persistent observations allow us to largely overcome these problems. Our highly reliable correlation results in very few instances of cross-tagged observations, which in turn decreases the number of corrupted data points in any analysis of signatures to find patterns and anomalies.

If a near-GEO space object is stable and relatively static, trends and repeating patterns in signature as a function of solar latitude (seasonal) and solar longitude (daily) can inform us about long-term and short-term operational changes. Figure 2 shows an example of observations of a GEO communications satellite (SES-4) over a one-week period. Plotting the visual magnitude data against solar phase angle would expose any variation from day to day, and none is observed except that consistent with sensor noise.

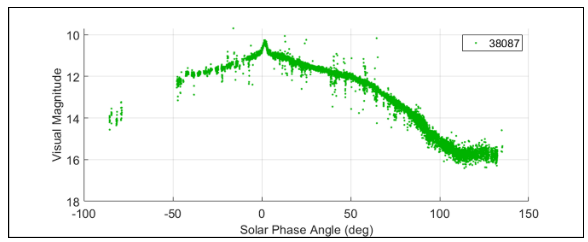

Figure 2: Accumulated signature data over a 1-week period for SES-4, showing very little day-to-day signature variation.

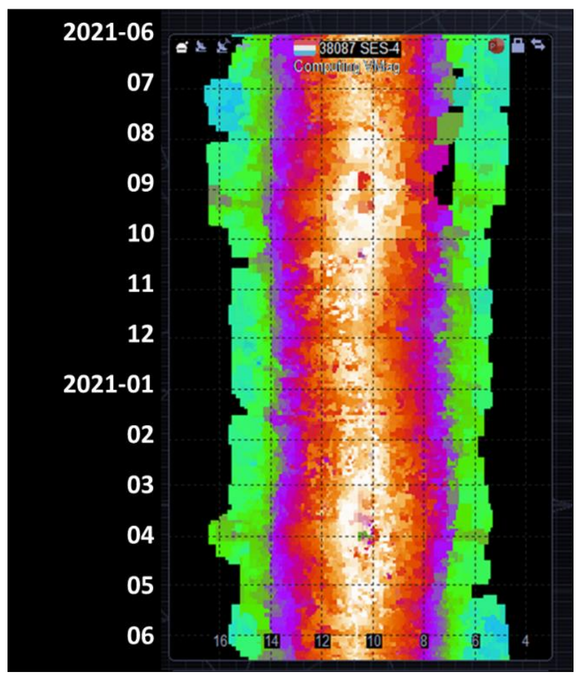

Figure 3: Heat map of visual magnitude data for SES-4 over a 12-month period, showing mild seasonal variation between solstices and equinoxes.

Figure 3 shows a year of signature data for the same object as in Figure 2 (SES-4) in which small variations in signature can be seen between the summer and winter solstices and the spring and autumnal equinoxes. This heat map is also a very useful technique for observing significant configuration changes. Heat maps of this sort have been used for satellite characterization and identification (for example, in [1] and others).

Some GEO objects behave more dynamically, for example alternating between drifting around the GEO belt and staying at a fixed longitude, or frequently exhibiting signature changes inconsistent with sun-tracking. For these cases, persistent observations can still help to identify changes in activity, although identifying anomalies is more challenging.

Alerts. ExoALERT is an automated system, designed to combine trained human analysts with automated algorithms [2]. This system operates autonomously in a continuous loop involving image processing, correlation, and orbit determination to identify recurring and anomalous events.

Both astrometric and photometric changes are detected and presented as alerts to a human analyst. Examples of alerts associated with photometric changes include detection of apparent attitude change such as a change from stable to tumbling and whether an object is sun-tracking (also called "sidereal slewing") or changing its pose ("slewing") in some other controlled manner.

There are challenges associated with the assessment of overall performance of an alert generation system in a case where ground truth is not inherently known (except in cases where satellite owners share their maneuver plans and other operational data). Fortunately, the broad range of persistent data collected by the EGTN has allowed an understanding of typical GEO object behavior to be developed.

Anomalous Behaviors. Unexpected behaviors are sometimes revealed in the large volumes of space object data collected. For example: an ostensibly inactive object in the GEO graveyard (GEO + 300 km) may change from an apparently uncontrolled tumbling state to appearing to be sun-tracking. This behavior is unusual, and not necessarily cause for concern, but still very interesting.

Of much more significant concern with respect to flight safety and the future of operations in space are debris generating events, several of which have occurred in the past few years (for example [3]). Some of these events unfolded quickly, while others took place over several days. While failures of spacecraft and near-misses between objects in LEO garner significant press and policy attention, an understanding of spacecraft risk in GEO is no less important for economic and other reasons.

Transient Features. The debris generating events mentioned above are one example of transient photometric features that are only able to be observed due to a high cadence, persistent system of space object data collection performed by the EGTN. In general, transient events such as glints or other short-lived photometric features are unlikely to be observed unless observation techniques that support persistence are used.

Transient features can be short-lived, as in the case of a brief configuration change (the opening and closing of an aperture or panel), or they can be repeatable, such as a seasonal glint observed when a particular space object feature aligns favorably with a sensor. Many transient features alternatively represent a pose change, where a space object is altering its orientation in inertial space and the subsequent phase angle change results in a signature change from the sensor perspective.

In other cases, transient features represent a long-lived or even permanent configuration change in the space object itself. Recent examples include events such as the MEV-1 and MEV-2 spacecraft docking with their respective service customers [4]. Figure 4 shows one recent such example from April 2022.

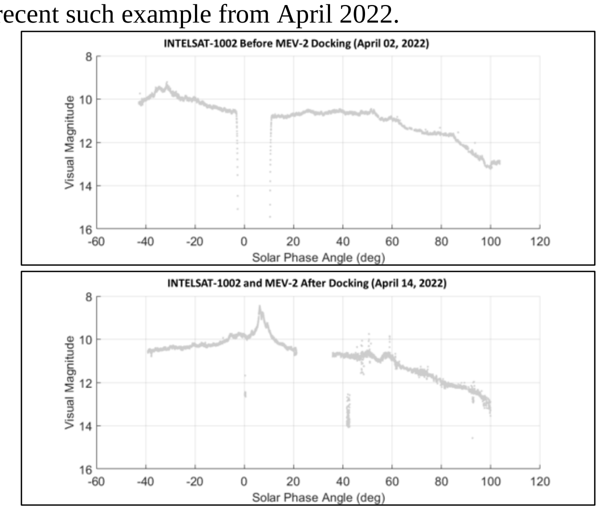

Figure 4: Signature of Intelsat-1002 before (upper plot) and after docking with MEV-2

References

[1] C. Ingram, "Fingerprint Exploitation and Network Update," MIT LL Space Control Conference, May 2018.

[2] J. Bishop, C. Ingram, D. Hendrix, M. Jeffries, "Persistence Enabled Space Traffic Alert Services for GEO," IAA STM Conference, March 2022.

[3] C. Henry, "Intelsat-29E satellite suffers fuel leak, spotted drifting along GEO arc," April 2019. Accessed June 2022. https://spacenews.com/intelsat-29e-satellite-suffers-fuel-leak-spotted-drifting-along-geo-arc/

[4] ExoAnalytic Solutions Inc., "ExoAnalytic Demonstrates Value-Added Service to Provide Direct Support to First Successful On-Orbit Servicing in Geosynchronous Orbit," April 2022. Accessed June 2022. https://exoanalytic.com/exoanalytic-demonstrates-value-added-service-to-provide-direct-support-to-first-successful-on-orbit-servicing-in-geosynchronous-orbit/