PERFORMANCE OF A NETWORK OF STATIONS DEDICATED TO OPTICAL SURVEY AND ASSOCIATED SERVICES FOR SPACE SAFETYS

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ABSTRACT

The optical survey of the low Earth orbit is now a reality to provide a large amount of data for cataloguing purpose and to ensure space safety. A concept of multi-telescope observation station (MTOS) was developed and deployed by Aldoria with currently three operational stations. Each station is equipped of four telescopes, each one offering a large field of view and scanning a circular band of the sky to catch all objects travelling above the station and illmuminated by the Sun. Astrometric and photometric measurements are produced for catalogued and uncatalogued space objects ensuring to Aldoria an autonomy in catalogue building and maintenance.

In this paper, we introduce the concept of MTOS and the operational observation modes they provide. Moreover, we describe the complete production chain developed by Aldoria since the scheduling to the catalogue update. We provide the performances related to the data produced by this kind of individual station in term of volume and accuracy. Currently three stations are deployed but a larger network is scheduled. The deployment strategy, based on an optimization of the site location to observe objects on every orbit in LEO, will be discussed. Through its network of MTOS, Aldoria has a growing catalogue of space objects mainly covering the LEO region but also MEO and GEO. The current and future catalogue will be described.

Moreover, the SSA data platform of Aldoria is hosting the catalogue but also services for space safety. The space object characterisation service is based on patern-of-life analysis allowing to identify satellite during each phase of their life (orbit raising, station-keeping, decommissioning) or any change (longitude drift, change or orbital plane). The collision risk assessment service performs conjunction screening, computation of the risk and collision avoidance manoeuvre design if required. Both are event-driven services, triggered each time the catalogue is updated ensuring a very high reactivity.

The SSA data platform is natively multi-source. It is able to collect and process data coming from the Aldoria network but also any other third-party supplier able to push data through an Aldoria's API. Source like the 18 SDS catalogue are integrated. It allows to perform a systematic cross-checking of the data at all the data level (TDM, OPM, CDM) ensuring a greater confidence in the data but also to detect early an anomaly due for example to a manoeuvre.

Keywords: electro-optical sensor; survey; space safety.

1. INTRODUCTION

Optical observation systems differ from radar in that they allow observation of high orbits. Thus, at the end of the 1990s, the first optical surveillance campaigns were carried out by NASA and ESA, highlighting unknown populations of fragments [1][2].

In 2010s, concept of optical survey of the LEO region to build and maintain a catalogue of space objects was investigated [3]. The celestial mechanics tools needed for object correlation and orbit determination were introduced and simulations shown that such a catalogue is possible under the condition of large-field telescopes with a fast scanning capacity. A network of 7 stations, each equipped with 21 telescopes with a field of view of 6.66 degrees by 6.66 degrees, a 1.1 meter primary mirror, and taking an image every 3 seconds, was proposed and the performances were evaluated by taking into account the geometric constraints of visibility and the sensitivity of the detection by calculating a signal-to-noise ratio from an assumption on the magnitude of the observed object. This study also shows that the position of the Sun must be taken into account to optimize the monitoring. Indeed, the Earth's shadow on space objects changes during the night and differently depending on the seasons and latitudes. The shadow area makes any observation impossible and the correct phase angle optimizes detection.

The use of COTS telescopes for SSA emerged in the mid-2010s [4]. It is shown that the Celestron RASA-14 telescope offers the performance necessary for observing GEO satellites at a low cost (less than $20,000). Another paper ([5]) raises the question of using commercial telescopes for optical surveillance, inspired by devices such as Dragonfly, based on 10 Canon telephoto lenses and cameras on a single mount [6].

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For surveillance, several systems have been proposed, for example, with a combination of lenses equipped with CCD or CMOS cameras, however, detection performance remains poor in terms of sensibility and accuracy. The idea of a meta-telescope was proposed to cover a corona of the sky that would allow satellites to be detected in their ascending and descending phases [7]. However, such a corona requires more than ten telescopes. Following this set of proposals, the Multi Telescope Observation Station (MTOS) was invented to carry out monitoring with a significantly reduced number of telescopes offering a large field like the RASA 14, exploitable in particular thanks to the use of large sensors that appeared at the end of the 2010s.

2. MULTI TELESCOPE OBSERVATION STATION

2.1. Generality

Aldoria has developed an innovative concept of station based on electro-optical sensor in the visible for the survey of all orbital regions. This station concept is currently protected by two French patents (FR2010136 and FR2102684).

Rather than seeking to cover a large part of the sky (which would require a large number of detection instruments), a Multi Telescope Observation Station (MTOS) approach seeks to establish observation rings, making it possible to detect all objects that cross it, as long as they produce a sufficient signal-to-noise ratio (SNR). This is made possible using four synchronized telescopes whose fields of view maintain a 90 degrees azimuth gap and that continuously scan a ring of the sky. For any area of the observation ring, the minimum time required to a Resident Space Object (RSO) to cross the ring is higher than the delay between two telescopes field of view. This allows to detect every objects passing over the station without needing a preliminary knowledge of the object's state.

The main skills of the MTOS stations are:

- Autonomous detection for capturing RSO tracklets, the MTOS does not require any pre-existing catalogue or ephemeris.
- Small object detection: Aldorias has already demonstrated the ability to detect objects of 10 cm with COTS telescopes and is now pursing in house optics development to reduce this detection size.
- Scalability: When performing survey, a MTOS replaces up to 70 telescopes. MTOS deployment and operating costs are between one and two orders of magnitude below the radar systems.
- Flexibility: each telescope of an MTOS can be individually tasked to perform on-demand tracking on top of LEO orbit survey.

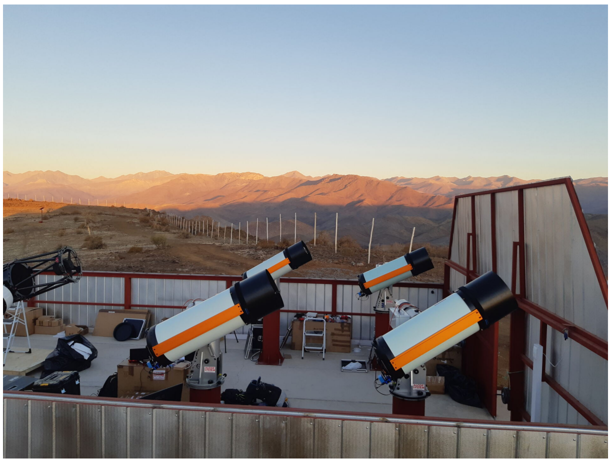

Figure 1. MTOS deployed in Chile and operated by Aldoria.

2.2. Survey strategies for each region

The strategy survey of the LEO and MEO regions consists in a swept of the field of view at a constant elevation. The steering directions of the four fields of view stay orthogonal in azimuth, and a sequence of image acquisition and shift in azimuth is performed in a synchronised way. In each image, a space object crossing the field of view appears like a streak and stars like dots. The exposure time is long enough to have a streak of dozens of pixels. Then, the exposure time is longer for the survey of the MEO region due to the slower apparent velocity of these objects.

The survey of the LEO region is performed at the beginning and the end of the night when illumination conditions are favorable (when the solar elevation is between -8 degrees et -36 degrees). The survey of the GEO region is performed in the middle of the night during one hour. The rest of the night, the survey of the MEO region is performed.

The strategy of the GEO survey is different. A band centered on the geosynchronous orbit is swept by the four fields of view of the MTOS. At each step, a serie of three images are taken, before to be shifted on the adjacent position. The GEO region can scanned a few times each night.

2.3. Acquisition and maintenance

In a survey mode, a few measurements are acquired during the passage of an object in the field of view. Offering a large object coverage, it is an efficient way to produce data for catalogue maintenance. A significative part of 10 per cent of the detections are uncorrelated tracklets. Then, an acquisition strategy is applied, supported by a secondary network of Single Telescope Observation Station (STOS). These systems, equipped with only one telescope as in Figure 2, can received an observation plan to

Figure 2. Single Telescope Observation Station (STOS) deployed in South of France.

Table 1. Station of the Aldoria's network at the end of 2024.

Type	Location
STOS	France
STOS	Chile
STOS	Australia
MTOS	Spain
MTOS	Chile
MTOS	Canada

reacquire observations of the space object of interest from a preliminary estimation of the orbit.

3. NETWORK OF ALDORIA

A network of STOS and MTOS has been deployed across the world (Table 1). The location of each station has been selected to provide the best observation conditions in terms of cloud coverage, magnitude of the sky during a clear night, and illumination by the Sun.

The network is split in two parts with MTOS for survey and STOS for dedicated tracking of space object. Dedicated observation of space objects are crucial for acquisition of new objects but also to increase the revisit and at the end, the accuracy of the orbit determination with additional measurements.

4. CATALOGUE AND SERVICES

Aldoria has developed a centralised SSA data platform to collect, store, process and distribute measurements produced by the network. Services of catalogue building and maintenance have been deployed including:

- The correction service consists in removing from raw measurements the physical and temporal bias including the rolling shutter (temporal bias induced by the sensor acquisition mode), the clock bias (temporal bias that is the difference between the acquisition time of the image given by the computer and the effective time of the acquisition), and the aberration of light (physical bias induced by the motion of the Earth).
- The pairing is made on corrected measurements. It consists in creating tracklets from measurements belonging to the same image set. A tracklet is a set of measurements, temporally and spatially close enouth to assume that they belong to the same object.
- Tracklet association with catalogues of reference (public catalogue of the 18 SDS, Aldoria's catalogue). The correlation process occurs after the pairing process and involves associating a tracklet with a known object. The principle behind this process is to compare our measurements against reference orbits and select the closest matching object, under a predefined threshold. If no match meets this criterion, the measurements remain uncorrelated.
- Orbit determination to update the orbit state of known RSOs
- Initial orbit determination to track an uncatalogued RSO

In addition, interfaces have been deployed to provide the following services:

- Delivery of Survey Orbital Data (measurements, orbits, ephemeris).
- On demand tracking of RSO objects and LEOP monitoring.
- Objects Attitude Analysis to characterise the attitude state from light curve.
- Objects characterization including manoeuvre detection and behaviour classification (orbit raising, decommissioning, orbital change, etc.).
- Event identification and alerts such as conjunction, anomaly and threats.

5. PERFORMANCES

The network of Aldoria procudes measurements each night with a clear sky. The distribution in longitude of

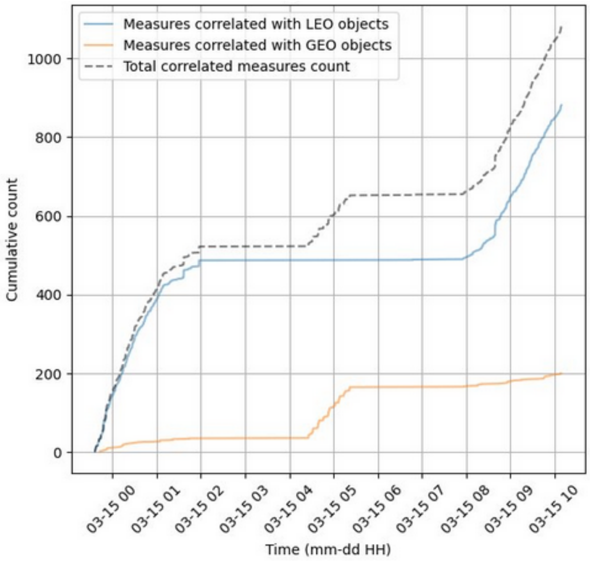

Figure 3. Production rate during the night for a MTOS. The majority of the detections occurs at the begin and the end of the night when LEO objects are illmuminated by the Sun.

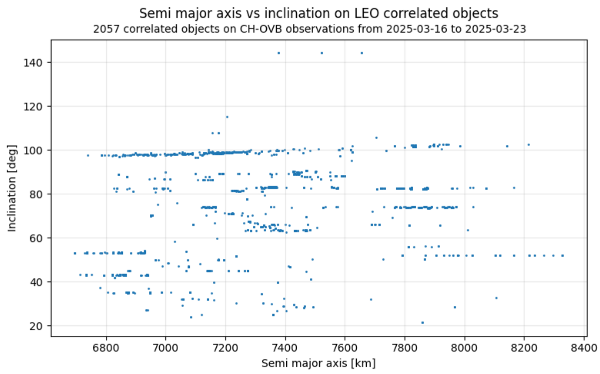

Figure 4. Distribution of space object population observed by the Aldoria's network.

the station allows to maintain a continuous flow of production. As explain in the previous section, the nigh production is split in different parts. In Figure 3, the cumulative number of measurement is ploted as a function of the time. At the begin and the end of the night the production rate is high due to survey of the LEO region. In the middle of the night the GEO survey is the main contributor of observation.

For all the network, the mean daily production is about 1 4000 tracklets per day with a mean rate of 10 per cent of uncorrelated tracklet. Over a period of 7 days, a total of 2 057 distinct space objects are observed in LEO. This population is ploted in Figure 3.

6. CONCLUSIONS

The optical survey for all orbital regions was demonstrated with the concept of MTOS developed and deployed by Aldoria. It is a credible alternative to the radar sensor providing a full coverage of all orbits but also available for a very investment in terms of development and operation. At the time, the Aldoria network produces observation data every day in a continuous way. The network deployment will continue with at least two new stations deployed each year. Major evolutions are scheduled: (i) the optimisation of the scanning strategy to avoid to observe region in Earth's umbra, (ii) the use of telescope with larger aperture to improve the sensibility. These two developments must increase performance in terms of number of observations and minimal size of the detected objects.

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