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Application of the Optimal Maintenance and Survey Tasking (OMST) strategy at the Telescope Network SMARTnet

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Abstract

As of February 2022, the catalogue of space objects in the geostationary regime consists of about 5000 objects. Although not all of them are visible from a single telescope station, it is not possible to observe all of them in a single night. Together with the search for new objects, the task of catalogue maintenance becomes challenging.
With the telescope network SMARTnet, we test different strategies to optimise planning of observation times of the individual stations. One strategy is called Optimal Catalog Maintenance and Survey Tasking (OMST) and tries to achieve the maximum number of detections with the minimum amount of viewing directions in sum of all involved telescopes. The strategy may be applied to a single telescope as well as to a sensor network. In the latter case, an optimisation trade-off is made in terms of sensor availability, probability of detection including the local viewing conditions and sensor capabilities.
SMARTnet's telescope stations are located on the Southern hemisphere utilising winter nights during the observation period. The observation plan is calculated for each station at the German Aerospace Centre (DLR) and distributed to the telescope stations. Conditions permitting, each plan is executed as complete as possible. Afterwards, the observation tracklets are analysed. Using subsequent nights, the performance of single object trasking – also called classical tasking – and OMST tasking is evaluated. Evaluation criteria are the comparison between the predicted and actually successfully observed objects, the total number of successfully observed objects and the rate between already catalogued objects, for which the tasking was run and previously uncatalogued objects .

1. Introduction

The number of objects related to the geostationary ring, and the geosynchronous orbit region in general, exceeds the number of objects which may be tracked by a single telescope station. Even in a globally distributed sensor network, this task is challenging. Therefore, methods were proposed and presented to apply selection criteria for objects to be observed in a single night (e. g. [10]).

Another possibility is to minimise telescope movements to optimise the covered ara of the sky as described in the following section. We compare this strategy with one that uses declination stripe at fixed right ascension positions.

We analyse both strategies in terms of observation length, acquired images, and extracted tracklets. An object identification process is then performed with these tracklets to identify observed objects of a base catalogue (in this case: TLE catalogue [27]). We will show how many objects were observed during the test campaign and how many of them were identical.

2. Optimal Maintenance and Survey Tasking (OMST) Method

Sensor tasking is a well-investigated topic [26, 1, 14, 15, 12, 13, 6, 7, 21, 11, 16, 17, 25]. The sensor tasking algorithm, Optimal Catalog Maintenance and Survey Tasking (OMST), which is used in this paper has been initially proposed in [5, 3] and has been further developed in recent years [4, 18, 19, 20, 23, 24, 22]. The tasker can be used for a ground-based telescope network in both modes, the follow-up of already catalogued objects and the detection of new objects, where no a priori information is available and a combination of the two.

The optimization principle in both cases is the maximal number of detection of objects in the minimal amount of viewing directions in sum of all involved telescopes. This then corresponds to the minimal cummultative observation time spent within a telescope network. For the follow-up observation of already catalogued objects, their propagated states including uncertainty information, as available, is used [5, 4, 18, 19, 20, 23, 24]. For the survey of new objects, observation surfaces are created based on hypothesized or suspected object populations [5, 22]. The algorithm can be used for just a single telescope, which then optimizes to the minimal observation time for that one sensor. For the use within a telescope network, an optimization trade-off is made in terms of sensor availability, probability of detection including the local viewing conditions and sensor capabilities. Within the optimization framework the lag-time between taking the observations and being able to process them and give feedback to the optimizer is explicitly taken into account, a mode of only day processing with no interaction is available [20, 23, 24].

For the optimizer, a greedy method is used. A trade study with machine learning algorithms have been made. While machine learning methods did outperform the greedy method, the gain was marginal for a ground-based optical sensor observing high altitude targets, such that in those scenarios the greedy algorithm is preferred for computational speed eliminating learning and training periods [19]. Heuristic principles learned from decades of human-made object observations have been incorporated and mathematically quantified. As an example: local horizon conditions can be taken into account either fixed or using the probability of detection [23, 24]. For fixed conditions, in the absence of other local obstructions, an elevation constraint of 25 to 34 degrees is optimal for the investigated use cases. OMST has been used to evaluate proposed networks for complete coverage of an orbital region, such as the geosynchronous region [24].

3. Comparison with a different Survey Strategy

To compare results, we use a different survey strategy, which is already in use at SMARTnet telescope stations: pairs of declination stripes at fixed right ascension positions are set east and west of the Earth's shadow. Observations at low phase angles can be acquired with this approach. Objects, which are close to the limiting magnitude, may be detected that might have been unobserved otherwise.

This strategy only relies on the geocentric position of the geostationary ring and its extend. No knowledge of object distribution or other apriori information is needed. Right ascension positions to the east and west of the Earth's shadow are selected, and declination positions chosen such that the extend of the geostationary ring is covered. In this study, we used two pairs of stripes, one east of the shadow, the other west thereof. The stripes of each pair are separated by 15°.

A more detailed description of this strategy and its different possible set-ups may be found in [8]. Results of a study using this survey strategy were presented at last year's IAC (cf. [9]).

4. Test Campaign

The observation schedules provided by the OMST algorithm are used by SMARTnet's observation planning tool to distribute each plan to the telescope stations. We used SMARTnet's telescope stations at Sutherland, South Africa (called SMART-01-SUTH) and at Mt. Kent, Australia (SMART-02-KENT).

The test campaign started on 2022-07-08 with observations from SMART-02-KENT. Due to pending maintenance at SMART-01-SUTH, this telescope station started observations later.

Figure 1 shows an example of an observation schedule. Each point marks the center of the scheduled field. They are separated by the field of view of the designated telescope (here: 2.9°) in right ascension and declination, hence the regular pattern. The colour code represents the time of start for each field.

Other nights – depending on weather conditions – were used to perform observation with the survey strategy with declination stripes at fixed right ascension positions as described above.

Although the OMST strategy relies on well-defined observation intervals, the current observation software used by DLR's telescope stations is not able to guarantee the fulfilment of this requirement. With the definition of observation intervals as true as possible to the schedule, we tried to accomplish the requirements.

5. Results

In total, the test campaign comprised of 10 nights with observations, with one having observations of both telescope stations. Table 1 lists the nights with observations together with the observation interval. Nights in which observations were carried out accoring to the OMST schedule are denoted with a star ($\star$). The listed observation time represents the sum of exposure times. The non-observational time includes weather-related interruptions, telescope motion, read-out times as well as problems related to the used software and hardware.

Shortened nights were due to declining weather conditions or software/hardware issues. During this test campaign, we are able to consider only one night to be observed from dusk to dawn with the optimised schedule and two nights with the declination stripes strategy.

Whether the strategy is successful is determined by comparing the detected objects to the expected objects. The latter stem from a catalogue of objects, e. g. a catalogue with Two Line Element sets.

Due to the fact that we were not able to observe each pointing direction exactly at the calculated epochs, we were not able to detect all of the scheduled objects.

We set up three different categories of observed objects:

- objects that were observed in the designated interval
- objects that were observed at other epochs during the night
- objects that were not scheduled

The latter category consists one the one hand of objects not in the base catalogue but in the complete public catalogue and on the other hand of new detections. The discrimination between both sub-catagories was not part of this study.

Table 2 shows the observational results. We could observe only a limited number of objects in their scheduled time interval, although we were able to observe some of them in surrounding time intervals.

Only three objects could be detected in their scheduled time interval, while we were able to observe 224 objects of the initially scheduled objects outside their targeted time interval.

Additionally while unscheduled, we observed 462 objects outside the base catalogue. This is not surprising, as the base catalogue consists of objects related to the geostationary orbit. Objects on highly eccentric or lower objects were not scheduled but were crossing the field of view at the time of observation.

The observed objects have to be compared to those which where detected with the survey strategy consisting of declination stripes. We could identify 99 objects which were observed with both observation strategies. Figure 2 shows the number of objects together with their orbital region. The categories are based on ESA's Annual Space Environment Report ([2]). Five objects are related to eccentric orbits (geostationary transfer [GTO], MEO-GEO-crossing [MGO] orbits), the others are related to the geostationary ring (geostationary [GEO], extended geostationary [EGO] orbits).

When we look at the observed objects for each strategy individually, then it turns out that the fraction of objects for each orbital region related

Table 1: Test campaign, observations summary

Date	Telescope	Observation interval (UTC)	Observation time (h)	Non-observational time (h)	Images	Tracklets
2022-07-08*	SMART-02-B-KENT	09:03:34 – 12:05:14	0.76	2.28	362	58
2022-07-12*	SMART-02-B-KENT	13:29:42 – 19:41:44	1.40	4.89	672	70
2022-07-26*	SMART-02-B-KENT	07:59:06 – 19:42:55	2.85	8.92	1324	226
2022-08-14	SMART-02-B-KENT	08:07:33 – 13:14:54	1.59	3.55	696	86
2022-08-15	SMART-02-B-KENT	08:09:38 – 19:39:08	3.00	8.53	1262	279
2022-08-16	SMART-02-B-KENT	08:33:55 – 14:09:34	0.52	5.08	346	26
2022-08-18	SMART-02-B-KENT	08:09:39 – 19:33:18	2.37	9.05	1118	148
2022-08-19*	SMART-02-B-KENT	08:12:12 – 15:15:03	1.32	5.74	704	105
2022-08-20*	SMART-02-B-KENT	08:10:12 – 16:11:41	1.77	6.27	848	184
2022-08-20*	SMART-01-B-SUTH	16:51:00 – 21:19:40	0.65	3.88	324	184

Table 2: Results of the test campaign, detected objects compared to scheduled objects

Date	Scheduled	Correct Interval	Other Interval	Unscheduled observed
2022-07-08*	558	1	19	37
2022-07-12*	555	0	25	33
2022-07-26*	573	1	58	116
2022-08-14	—	—	—	67
2022-08-15	—	—	—	87
2022-08-16	—	—	—	22
2022-08-18	—	—	—	125
2022-08-19*	554	1	40	45
2022-08-20*	917	1	82	231

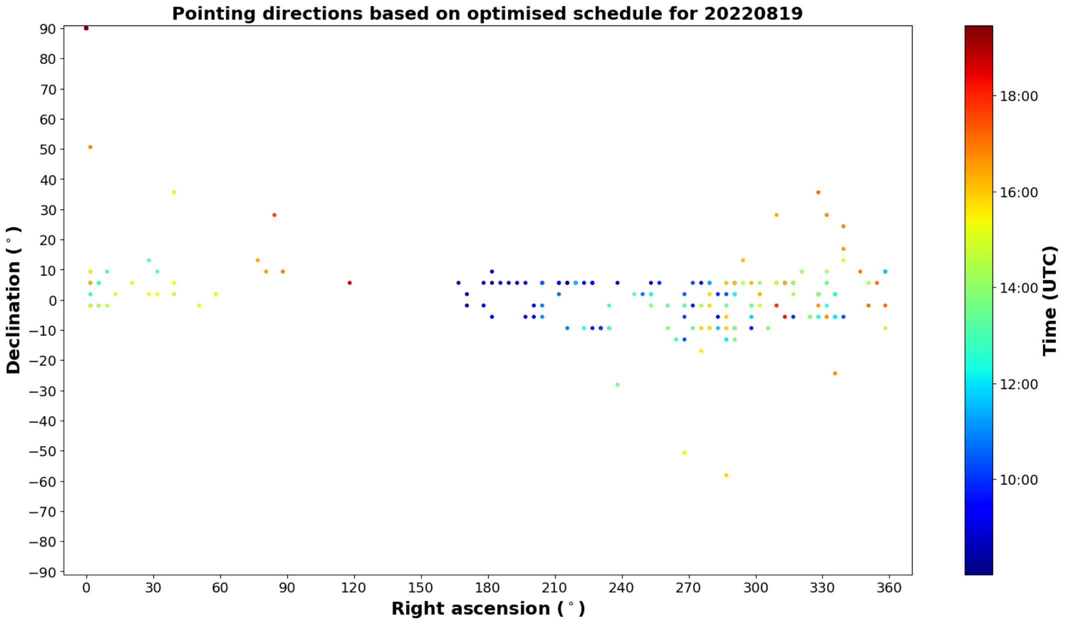

Figure 1: Graphical representation of an observation plan as sent to a telescope station, here fore SMART-02-KENT. The colour scheme represents the targeted start of the observation.

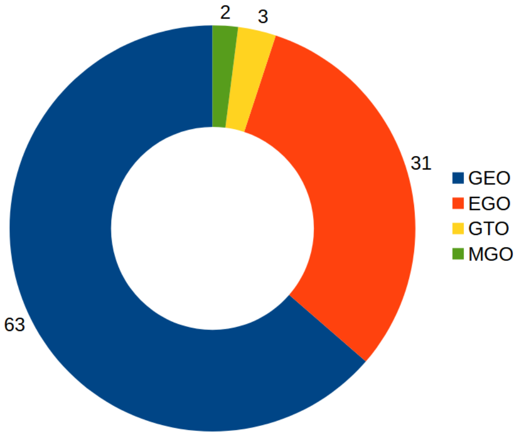

Figure 2: Number of objects that were observed with both observation strategies during the test campaign, together with their corresponding orbital regions

to the geostationary ring (i. e. GEO, EGO) is approximately equal. While the others differ more. This is based on the fact that those objects were unscheduled and crossed the field of view at the observation epochs by chance. They are, too, very useful in terms of database maintenance. For details on all orbital regions mentioned, we want to refer again to [2].

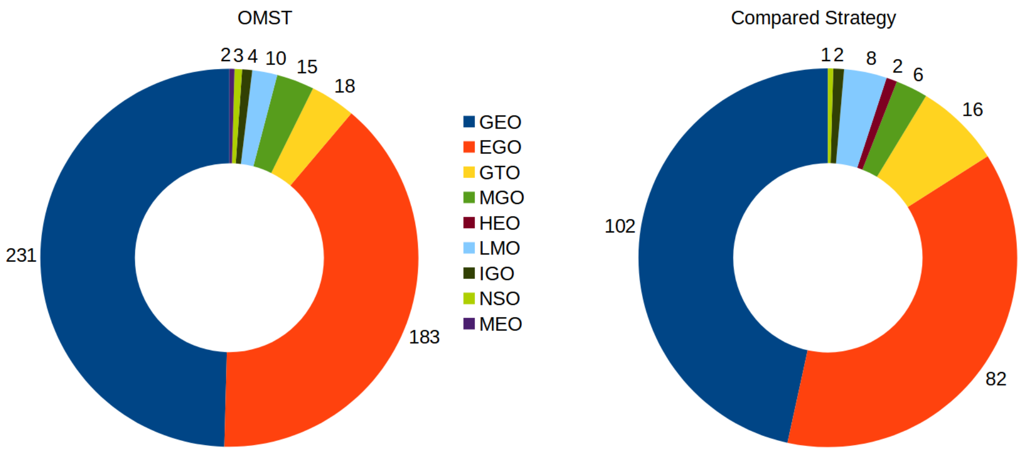

Figure 3: Number of objects that were observed with the observation strategies individually during the test campaign, together with their corresponding orbital regions.

6. Analysis

The results point to different issues in our observation execution and object identifications processes. More objects might have been observed, yet the object identification did not result in a successful observation.

Observation execution at specific epochs is not possible with our current software; a newly developed observation software is in its integration phase. A deployment to the present telescope stations is planned when the integration and testing phase has been successfully completed.

Another major issue in terms of database maintenance is the missing feedback of observations into the upcoming schedules. The processing chain momentarily lacks information of a successful performed orbit determination for each associated object looped back into the observation schedule. In this case, we had to rely on the automatically updated catalogues provided by space-track.org (see [27]).

7. Conclusions

In this paper, we presented the application of an optimised planning schedule to an sensor network. Our sensor network consisted of two telescope stations: one in South Africam the other in Australia. We could obtain observations in 5 nights and analysed the extracted tracklets regarding the detected objects.

We recognised that we could not observe many objects within their designated time intervals, but at other times during the night. We could attribute these deviations to the observation software. Existing bugs in the object association process cannot be ruled out.

In another stage of the test phase, we will test a different observation software and put a deeprer focus on the association process. Including other telescope stations and providing omptimised nightly schedules is also planned.

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