SMARTnet: First Experience of Setting Up a Telescope System to Survey the Geostationary Ring

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Abstract: *Space debris in geostationary orbits may be detected with optical telescopes when the objects are illuminated by the Sun. The advantage compared to Radar can be found in the illumination: radar illuminates the objects and thus the detection sensitivity depletes proportional to the fourth power of the distance. The German Space Operation Center, GSOC, together with the Astronomical Institute of the University of Bern, AIUB, are setting up a telescope system called SMARTnet to demonstrate the capability of performing geostationary surveillance. Such a telescope system will consist of two telescopes on one mount: a smaller telescope with an aperture of 20cm will serve for fast survey while the larger one, a telescope with an aperture of 50cm, will be used for follow-up observations. The telescopes will be operated by GSOC from Oberpfaffenhofen by the internal monitoring and control system called SMARTnetMAC. The observation plan will be generated by SMARTnetPlanning seven days in advance by applying an optimized planning scheduler, taking into account fault time like cloudy nights, priority of objects etc. From each picture taken, stars will be identified and everything not being a star is treated as a possible object. If the same object can be identified on multiple pictures within a short time span, the trace is called a tracklet. In the next step, several tracklets will be correlated to identify individual objects, ephemeris data for these objects are generated and catalogued. This will allow for services like collision avoidance to ensure safe operations for GSOC's satellites. The complete data processing chain is handled by BACARDI, the backbone catalogue of relational debris information and is presented as a poster.*

Keywords: *Space Debris, Surveillance Telescope Network, BACARDI, Collision Avoidance*

1. Introduction

Increasing space debris is a challenge for spacecraft operators. To ensure safe operations of their own satellites, the operators must have knowledge about the orbits of the objects crossing or approaching to avoid any collision. To gain this knowledge, the United States Strategic Command (USSTRATCOM) is using several sensors and sensor systems to surveil Low Earth Orbits (LEO) as well as Geostationary Orbits (GEO). The sensor data is processed to catalogues by the Joint Space Operation Center, JSpOC, and partially published. As an extra service, JSpOC also informs spacecraft operators by sending warnings to the operators in form of Conjunction Data Messages (CDM) in case of a close approach of an object. If receiving such a warning, the operator can analyze the event and, in case of a collision with high probability, decide to perform an avoidance maneuver or not. Here, the term "high probability" is interpreted differently by each individual satellite and each satellite mission and is not discussed in this paper. In any case, each avoidance maneuver costs mission time, man power, and extra fuel which cannot be used for the mission. Hence, each operator tries to constrain the number of such avoidance maneuvers. One of the parameters which go directly into the collision avoidance analysis is the accuracy of the orbit of the primary and secondary object – in most cases the covariance matrix. To get as precise orbit information as possible for the secondary object, the German Space Operation Center (GSOC) is able to engage the TIRA Radar of the Fraunhofer Gesellschaft for tracking objects in LEO in case of a close approach. For small objects in GEO, this is not feasible as the distance to the objects is too large. Gain better warnings in this region require more sensors with certain accuracy and a distribution of such sensors worldwide. Therefore, the German Space Operation Center (GSOC) together with the Astronomical Institute of the University of Bern (AIUB) are planning and setting up multiple telescopes to survey the geostationary ring and labeling all objects within a data bank.

2. Telescope Selection

For any collision between an operated satellite and another object, the impact energy is the main parameter to be considered. This impact energy depends on the mass of the object and the relative velocity between both components. Neither the mass nor the size of the object can be determined directly as the materials are not well-known and the objects appear point like. For telescopes, the observable is the brightness. To convert this brightness into size, models are applied with lot of estimations on the input parameters such like albedo, attitude, tumbling rate etc. To estimate the minimum size of an object which could result in a catastrophic collision, the well-defined impact energy is assumed and the catastrophic objects are estimated to be in the order of approx. 50cm. This is considered as a threshold object size which shall be discovered by the telescope system. Considering illumination conditions, exposure time of the camera, albedo etc., a 50cm object converts into a required aperture of the telescope of approx. 50cm. But, the larger the aperture of a telescope, the smaller is the field of view, and a small field of view requires more observations to cover the complete geostationary ring. Hence, a trade off must be made to get full coverage while still detecting and tracking small objects. To compensate this, we apply two different telescopes onto one mount: a small 20cm one for fast survey, and a 50cm one for follow-up observations and deep survey.
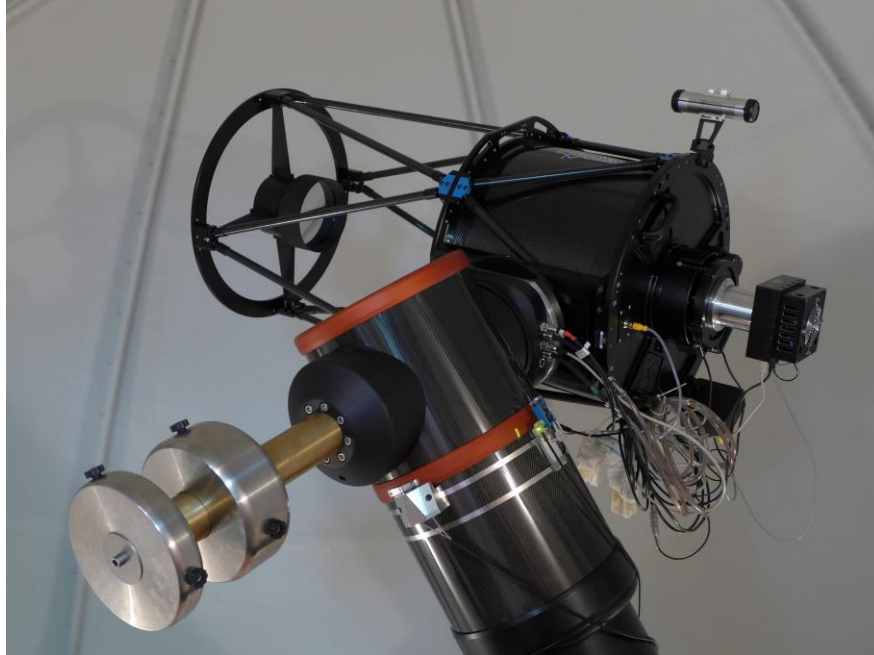
Figure 1: 50cm telescope mounted in Zimmerwald, Switzerland, during a test campaign.

With such a set-up, we will be well prepared to keep a maximum number of objects in the data bank with sufficient ephemeris precision.

3. Set-Up and Observing

At the observatory, the facilities consist of a container, a dome, and a lightning rod. Inside the container, the power supply from the provider is connected to a distribution box, and the internet is connected to the server. From this server, the SMARTnetMAC, the complete station will be operated autonomously. One part, which is not handled at the station, is the generation of the observation plan: in the near future, when more stations have free sight to the same part of the geostationary ring, it might be proficient to assign a certain part to a certain telescope. This can be e. g. in case of bad weather conditions or in using full capacity of all stations. Also other combinations of various survey fields from different locations might be possible, which will be subject to a later activity due to its complexity. In case of breakdown of the internet connection, there will be a back-up observation plan for a certain time period loaded onto the server, which will be used.

The control for the dome, the mount, and the cameras are connected via a cable tunnel with the container. For safety and security reasons, redundancy for control computers, webcams, cables and connections are implemented. Furthermore, several automatisms are foreseen and already implemented like

- to shut down the dome in case of bad weather conditions like strong wind, sand / dust storm, high humidity or rain
- to shut down the complete station in case of redundancy failure and / or link loss
- setting the station in safe mode during longer power blackout

To cover a blackout situation, all devices are run via an uninterruptible power supply inside the container. The whole set-up allows for tele-robotical operations to keep cost low. The server inside the container is linked via multiple firewalls and VPN connection to the main server located at GSOC (Oberpfaffenhofen), where the monitoring and control software for all telescopes inside SMARTnet is run.

For surveying the complete geostationary ring, one telescope is of course not sufficient. Three telescopes evenly distributed between 20°-40° North or South would allow for observing theoretically all objects. But, due to seasonal variations of the length of the night, it is more proficient to set up three telescopes on the northern hemisphere and three on the southern hemisphere. With such a set-up, the averaged observation time will be enhanced to more than 11 hours per night while the Sun is below 12° under the horizon. With these considerations, the minimum number of stations would be six. The set-up is designed such that also other sensor data can be processed by BACARDI. Hence, it is not prerequisite for GSOC to operate all sensors for a global coverage. An exchange of data is envisaged with other entities like e. g. space agencies from other nations on a no-exchange-of-funds basis. A schematic view of the network can be seen in Fig. 2.
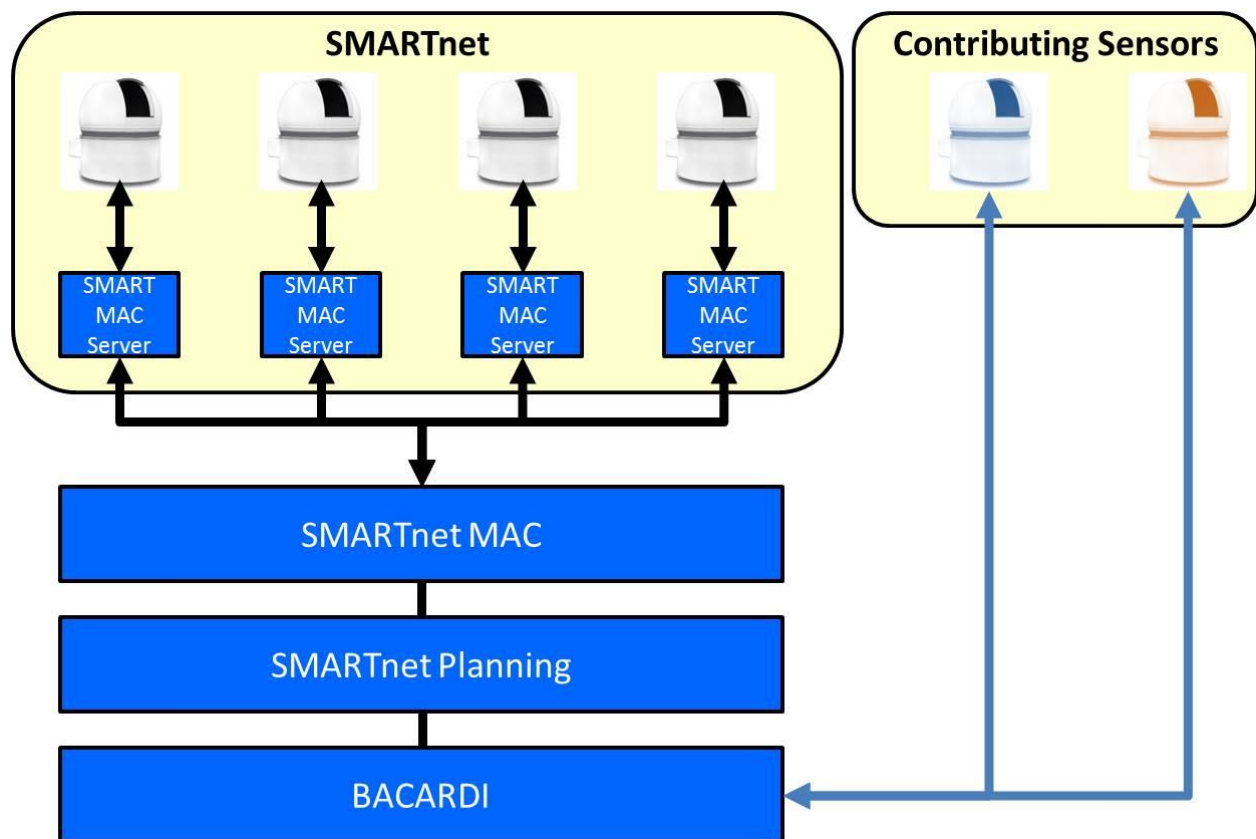

Figure 2 Schematic view of the telescope network to monitor the geostationary region.

In the beginning, we do not have any knowledge of the distribution of the detectable objects. Hence, the complete geostationary region shall be observed at least once to retrieve this information. Then, for keeping all objects in the data bank, it would suffice to observe objects

only which have been tracked before. But, this would not allow for discovering new objects which might be generated or launched in the meantime. Hence, a combination of surveying and tracking will be applied. For a complete set of objects, the telescope will be pointed to a range of declinations while keeping the right ascension fixed. Here, the declination range shall cover the desired maximum inclinations of the objects. With a field of view of 0.7° x 0.7° a total of about 22 survey fields is required to cover all orbits with inclinations $i \leq 15°$. Assuming an observation period of 10 days, 11 hours of observation per night, and the scanning of two declination stripes simultaneously (with two telescope), we can assign a time period of approx. ten hours to each search field. At the same time, an object should be observed multiple times at different orbital positions to allow for retrieving precise orbit information. Taking this information, combined with downtime (e. g. due to bad weather conditions or maintenance), high priority objects (e. g. in case of a close approach), a more sophisticated observing strategy is essential. This will be derived in the near future.

4. BACARDI

At GSOC, the Backbone Catalogue of Relational Debris Information (BACARDI) will handle processing tasks, such like
- correlating objects and object candidates
- determining orbits
- predicting orbits
- detecting of manoeuvres within ephemeris data
- tracking all meta- and log data (provenance data)
- prediction close approaches between objects and satellites
- predicting long-term evolution and re-entry of objects.

Additionally, is also possible to incorporate data from other sources into BACARDI. BACARDI is designed to allow for a huge variety of data policies: in principle, each individual data record may be assigned to a certain data policy. Furthermore, each user has a definable role with definable rights. This will allow for a various number of users the simultaneous use of BACARDI with different roles and right. At the ISSFD, BACARDI is presented at the poster session and details about its functionality can be seen there [1].
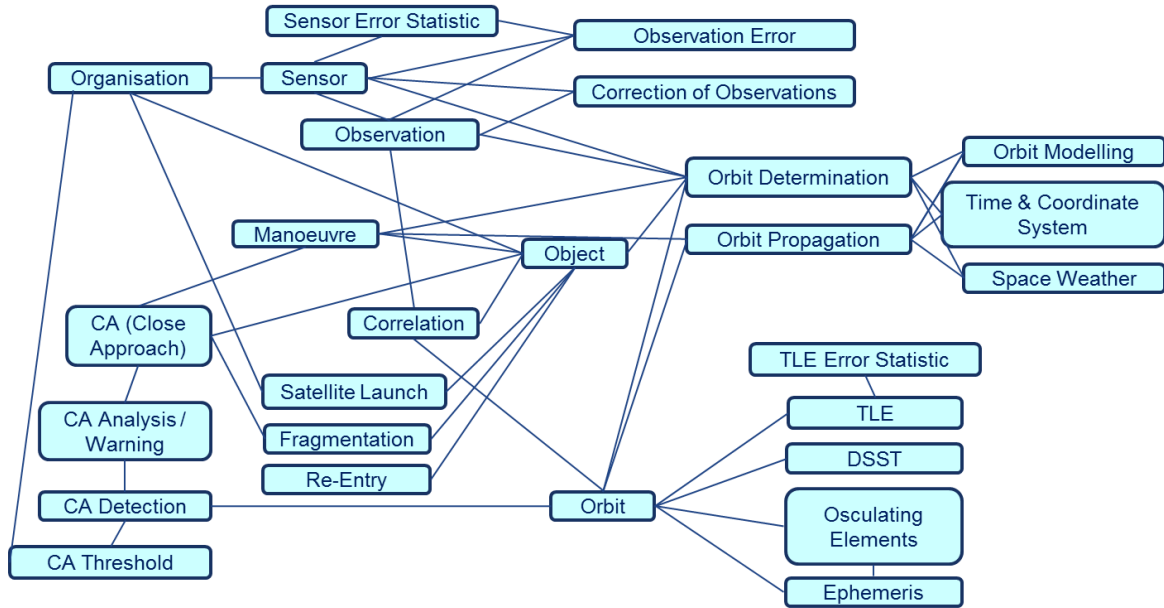
Figure 3 Internal data nodes within BACARDI.

5. Results

During several test campaigns in Zimmerwald, Switzerland, the following results were derived:

- The limiting magnitude (18.5^{mag}) is better than expected. It is assumed that this result will be topped in Sutherland due to the darker sky background. A typical picture of an object can be seen in Fig. 4.
- NORAD objects have been identified.
- AIUB objects have been identified.
- Unknown objects were already found.
- Object correlation was performed successfully.
- Orbit determination was performed with better accuracy than expected (see Fig. 5).
- Object identification including orbit determination within a cluster was performed successfully (see Fig. 6).

Figure 4. Typical picture of an observation night. An object can be identified as a spot (e. g. in the middle of the picture), stripes are identified as stars.

Orbit detemination

For orbit determination, the standard batch-least-square method is applied to the tracklets. The example shown in Fig. X is Meteosat 8 with the COSPAR ID 200-040-B. It is based on six tracklets captured during 22-08-2014/23-08-2014 and 24-08-2014/25-08-2014. The angular coverage of the orbits is roughly 45° which is not enough for very precise orbit determination. The orbital data of Meteosat 8 is published at the EUMETSAT webpage and publicly available. By estimation the spacecraft's cross section and including force models for parameter estimation, the calculated state vector was propagated and a reference orbit obtained. The deviations to TLE and the operator's ephemeris data is shown in Fix. 5. It can be seen that the result is much better than TLE data and fulfils the requirement of 1km residuals in all directions. For a more precise evaluation of the orbit determination error, also GPS satellites had been tracked, for which the orbit data is well-known. The results are much better and can be seen in [1].
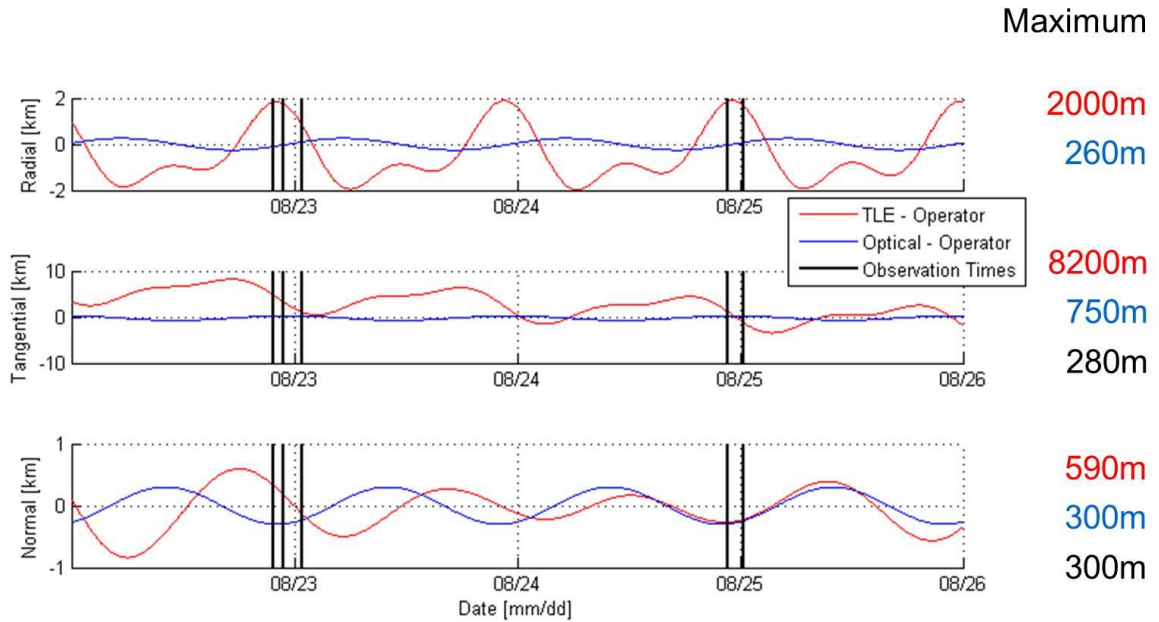
Figure 5: Orbit determination of Meteosat 8. Residuals to published ephemeris data shown in blue, the ones to the orbit derived by TLE are shown in red. Numbers show the maximum deviations (at observation time in black). The black bars in graph indicate an observation.

Object identification

If multiple objects are within the same picture of an observation or very close to each other, it is sometimes hard to assign the correct tracklet to the right object. This can happen in fragmentations, orbital explosions or even in the case of co-located satellites. This latter is quite often the case in geostationary orbits, where the usable space is getting crowded. Hence, satellite operators tend to allocate more satellites within the same box. To make the correct assignment, Two Line Elements (TLE) are used as a first guess if there is no other information available. Now, every tracklet is associated to the TLE with the lowest error. Then, all tracklest associated to a single object are transferred to batch-least-square orbit determination. If a tracklet does exceed a certain threshold, here we assumed 1" for all angles, this tracklet is rejected for the orbit determination process. This process is repeated until all tracklet associations stay unchanged. The result can be seen in Fig. 6.
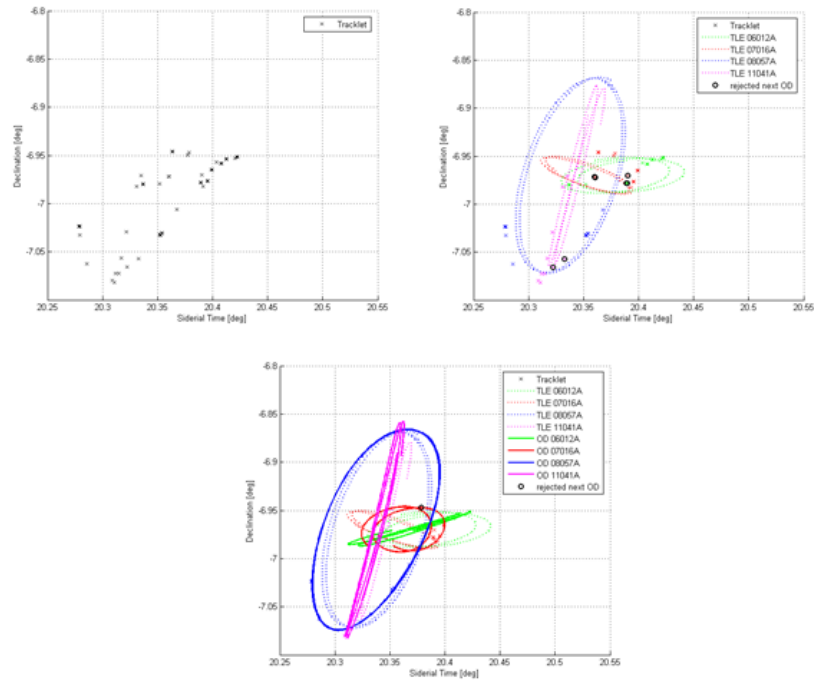
Figure 6: Object correlation and orbit determination of the Astra cluster. Tracklets (upper left) are associated to publicly available TLE (upper right, dotted lines) until all tracklets can be assigned to the correct object (lower picture). All tracklets (colored crosses) but one (black circle) could be assigned to the correct satellites within the cluster. Final residuals are less than one arcsecond one sigma.

6. Outlook

The first telescope will be set up in Sutherland in the beginning of 2016. This will allow for observing the two geostationary satellites SATCOMBw-1 and SATCOMBw-2 which are operated by GSOC. This telescope together with the Zimmerwald telescope will result in the first version of the network, where additional functionalities and tasks can be tested and implemented. This includes e. g. an optimized scheduler as well as bi-static observations of the same object. The latter might result in better ephemeris data of the objects which can be applied to any collision avoidance analysis – saving fuel and mission time.
Other locations for more SMARTnet telescopes are in discussion and not settled yet.

6. Literature

[1] Weigel, M., Meinel, M., Fiedler, H., „Processing of Optical Telescope Observations With The Space Object Catalogue BACARDI", 2015, Poster at ISSFD