OPTICAL OBSERVATIONS IN A PROPOSED EUROPEAN SPACE SURVEILLANCE NETWORK

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Abstract. *Space surveillance activities in Europe currently strongly depend on external sources. A limited number of European radar and optical facilities for space surveillance exist, but there is no operational European space surveillance system. Currently, ESA-funded feasibility studies awarded to ONERA are carried out to design a European Space Surveillance System. The system is proposed to consist of two subsystems, a phased-array radar system and a network of ground-based optical telescopes. The Astronomical Institute of the University of Bern (AIUB), Switzerland, contributes to the design of the optical observation part of the system, which is intended to cover the geostationary orbit (GEO) and the medium Earth orbit (MEO) regions.*

The developed observation strategy and the proposed preliminary sensor architecture will allow establishing and maintaining a catalogue of orbital parameters, and provide additional space surveillance functionalities such as fragmentation event identification, manoeuvre detection, new launch detection, and collision risk assessment.

The paper will present the most important system requirements, and the surveillance strategies for GEO and MEO, and will give an outline of the proposed optical sensor and network architecture. The expected performance of the proposed strategy, considering the preliminary sensor characteristics, will be discussed in terms of coverage of a reference population and in terms of minimum detectable object size. The performance assessment concludes with a validation of the algorithms to build up and maintain the catalogue, using observations acquired with ESA's Space Debris Telescope at Tenerife, Spain.

1 Introduction

Today, the number of satellites and the number of space debris objects is still growing. The end-to-end monitoring of space activities is essential for the success of present and future space missions. The task of space surveillance, combining the detection, tracking, identification, and cataloguing of artificial objects in space, is an integral part of space activity monitoring. Space surveillance was and is driven by military and governmental needs, but civil entities are becoming important drivers, too. Typical applications of a space surveillance system are in the field of space traffic management (as manoeuvre identification and assessment), fragmentation detection, re-entry prediction and monitoring, pre-launch assessment, and verification of compliance with space regulation treaties and recommendations.

Currently, a limited number of European radar and optical facilities perform space surveillance tasks, but there is no existing operational European space surveillance system. The various European commercial and scientific space activities are strongly dependent on external data in terms of space surveillance.

In the years 2002 – 2004 a study team led by ONERA (Office National d'Etudes et de Recherches Aérospatiales) conducted an ESA-funded feasibility study for a future independent European space surveillance capability. Alcatel Space, QinetiQ, and the Astronomical Institute of the University of Berne (AIUB) participated in this study. The study focussed on space surveillance in the Low-Earth Orbit (LEO) and in the GEO region. With considered minimum object diameters of catalogued objects of 10 cm in LEO and 1 m in GEO, the system is required to perform similar to the U.S. or Russian space surveillance networks. Contrary to the existing networks, the European system proposal focuses on space surveillance tasks and does not include additional early warning functions. The final report of this study is available [3]. An overview over the complete system is also given in two papers [4], [5].

A still ongoing follow-on study assesses in detail the system, taking also a closer look at objects in Medium Earth Orbit (MEO) and at objects in highly elliptical orbits (HEO). The study team is again led by ONERA. AIUB is responsible for the optical part of the detailed assessment. This study will be completed in autumn 2005.

Two sensor types were selected: ground-based telescopes equipped with CCD cameras shall cover the GEO and MEO region. Phased array radar sensors (like the French GRAVES system) will survey the LEO region. This paper will present the results from AIUB's work on the optical part of the proposal - the development of observation strategies, the selection of optical detectors and sensor architecture, and on the performance estimation of the proposed system.

In this paper we will address the space surveillance of the GEO and MEO region by optical sensors in individual sections (2 and 3). Both include the presentation of the selected observation strategy, the outline of the sensor architecture and network, and the estimated performance of sensor and population coverage. A section dealing with the validation of cataloguing algorithms that is applicable to both, GEO and MEO, is added (section 4). This paper ends with a conclusion and outlook to the next steps.

2 Concept for GEO space surveillance

It is assumed that GEO space surveillance needs to consider all objects larger than 1 m in diameter that orbit the Earth at 35768 km +/- 2000 km altitude in near circular orbits with inclinations below 17°. This is a common definition of the GEO population.

2.1 GEO observation strategy

The proposed approach for GEO space surveillance is twofold, combining survey and tasking observations. Survey denotes the task of searching for so-far uncatalogued (new) objects. This also includes the search for lost, previously catalogued objects, the sometimes also called 'no-shows'. Tasking, on the other hand, stands for all scheduled observations carried out on-request. Tasking observations comprise the routine observations needed to 'secure' the catalogued objects (catalogue maintenance), and the special task observations. Special task observations are needed for orbit improvement of newly detected objects prior to catalogue correlation, for manoeuvre assessment, detection of fragmentation events and conjunction analysis, for searching for lost objects with specific patterns, among other tasks.

2.1.1 Survey strategy

The survey strategy is presented in detail in [6]. In brief, the survey strategy assumes that all objects in the GEO will appear under a given right ascension once in about 24 h, as the mean motion of GEO objects is about 1 rev/day. If survey sensor observations cover the declination range between -17° and +17° of a fixed right ascension continuously, within 24 hours the entire GEO is surveyed. A single site cannot observe this (so-called) stripe for 24 h, but a network of sites can. In such a network, the observed stripe is 'handed over' from one site to the next site westwards, requiring that there are no coverage gaps in the network.

The right ascension of the observed stripe is selected nearly opposite to the Sun, close to the Earth's shadow. This allows observation under optimal phase angle conditions. Of course, the right ascension of the stripe will undergo a change of about 1°/day during the year due to the revolution of the Earth around the Sun.

Further it is assumed, that it is sufficient to observe each GEO object at least once every 15 days, depending on the required orbit accuracy [8]. The stripe may therefore be divided into equally sized fields. This relaxes the sensor requirements in terms of covered survey area, as the size of an individual field corresponds to the field of view (FOV) of the telescopes. Each of the fields has to be observed for 24 uninterrupted hours once within 15 days so that nearly all objects in the GEO ring will be observed at least once within 15 days.

In order to be able to determine orbits from the survey we need to acquire a sequence of exposures. From experience, three to six observations of a particular object are sufficient to determine a first orbit and to prevent wrong correlations or even false detections caused by cosmic ray events. As the GEO objects cross the FOV in a (comparatively) uniform manner, ‘blind’ tracking during the exposure can be applied to improve the object signal at the detector. If the FOV of the sensor is wide enough so that the FOV dwell time of the GEO objects leaves some spare time, another (neighbouring) field may be observed in parallel. This in turn reduces the total ‘stripe scanning’ time and better allows compensating for sensor unavailability. If the FOV of the telescope is, however, not wide enough, it is mandatory to observe more fields in parallel to fulfil the 15 days stripe scanning time limit. To cover objects crossing the FOV close to the field border sufficiently, neighbouring fields should slightly overlap.

2.1.2 Tasking strategy

Most of the tasked observations will be scheduled to provide the observations of newly detected objects at defined epochs to determine ‘secured’ orbits. The request for a tasked observation consists of the position (right ascension and declination of an object) at a specific epoch. Therefore, the tasking strategy is simple and straightforward: the telescope tracks the ephemeris of the object and the exposures are acquired following the requested pattern.

The tasking strategy allows observing more than one object ‘in parallel’, if possible. It needs to be noted that the angular distance between objects observed ‘in-parallel’ may be limited by the tasking telescope slew rates and settling times.

2.2 GEO sensor architecture

The presented observation strategy requires dedicated survey and tasking telescopes. Both must be arranged in a network guaranteeing a permanent accessibility of the entire GEO. Both sensor types must allow the detection of objects with 1 m diameter. For the following considerations, the decision criteria for the detection of a so-called ‘crossing object’ (an object crossing the telescope FOV), is the signal to noise ratio (SNR). The sensor architecture must ensure that the SNR of crossing objects under normal observation conditions is always above a given threshold. In this case we consider the crossing objects as being detected by the sensor, all other objects are treated as undetected. For the SNR estimation we used an approach similar to the one described in [12].

2.2.1 Sensor parameters

The study [3] concluded that for both, survey and tasking, a 0.5 m diameter Schmidt-Cassegrain f/2 telescope equipped with a 2k*2k back-illuminated CCD performs best. The pixel scale (PS) of this system is 5.27 ”/pixel, leading to 3° FOV diameter. See Figure 1~~Figure 1~~ for an estimation of the SNR at the detector as a function of the background brightness. The assigned object diameter (in meters) is calculated for a geometric albedo of 0.1 and a phase angle of 0°. It is assumed that the objects move with a velocity of 5 ”/s with respect to the FOV, and that the exposure time is 2 s. For the detector a peak quantum efficiency of 0.9 was assumed, signal loss due to the atmosphere and the optical system is considered. Typical detector noise values of commercially available detectors were assumed.

The performance of the proposed sensor is sky background signal limited due to the selected pixel scale and exposure time. The background signal is not constant, as the background magnitude is a function of the appearance and the phase of the Moon, the star background density, the general observation site quality, and the local atmospheric seeing conditions. We have to ensure that even under bad conditions, the sensor design allows for the observation of objects of 1 m diameter. Under optimal conditions, a ground-based sensor may be operated with background signals of less than 19.5 mag/arcs^2, while sites close to urban areas only rarely have a background fainter than 17 mag/arcs^2. If we assume a conservative SNR detection threshold of 4, we conclude from Figure 1 that with the proposed 0.5 m sensor, the detection of 1 m objects in the GEO region is always possible. Concerning the detection of smaller objects or considering the use of a narrower aperture, we have to bear in mind that the plot is for an optimistic case. For the tasking sensor the zero phase angle assumption is only rarely fulfilled, while for the survey sensors the velocity of FOV crossing objects is higher, with about 15”/s. As a result only a lowered SNR will be achievable and, thus, the detection of 80 cm objects cannot always be guaranteed, as the plot may suggest.

We will show an additional assessment of the minimal detectable diameter in the next section dealing with the GEO space surveillance performance.

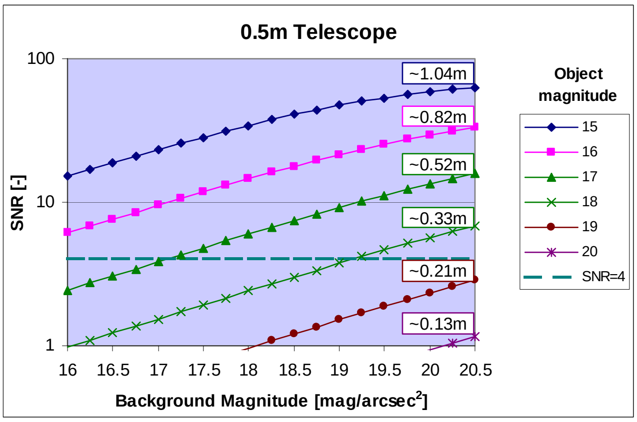

Figure 1 SNR for GEO objects of various magnitudes as function of background magnitude.

2.2.2 Network for survey and tasking

The analysis of the visibility of GEO objects from particular sites showed that for a minimum elevation angle of 20° and for typical GEO distances, an arc of about 125° in longitude is accessible from a near-equator site. Thus, to have some overlap and to use sites at low latitudes promising better weather conditions and accessibility, at least 3 low latitude sites are needed to cover the entire belt of GEO objects around the Earth continuously and almost completely. The study [3] selected four potential sites where the GEO sensors could be installed in order to guarantee some overlap and redundancy: Tenerife (Canary Islands, Spain), Cyprus (Mediterranean Sea), Perth (Western Australia) and the Marquesas Islands (French Polynesia).

Figure 2 shows the proposed GEO space surveillance network configuration and the coverage of the GEO. The network covers the GEO region sufficiently well. A prominent gap around 45° East is closed by the introduction of the Cyprus site. A smaller gap around 40° West remains.

The study proposes that each site of the network is equipped with at least two identical telescopes, one for the survey and one for the tasking. The use of identical sensor architectures promises a reduction of the network complexity and cost benefits. Additional telescopes may provide some redundancy and reduce the risk of observing site outage.

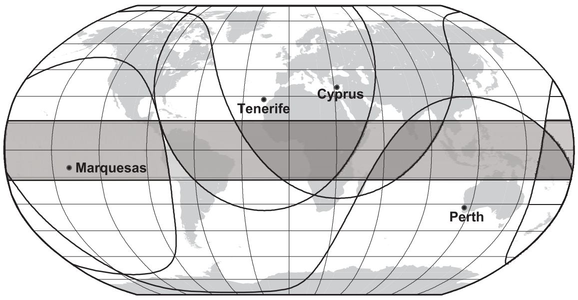

Figure 2 Coverage of the GEO region (grey band) by the proposed space surveillance network. The lines indicate regions where objects at GEO distances are observable from a particular site under 20° elevation.

2.3 GEO performance estimation

Using the preliminary sensor architecture from the previous section, we discuss the performance of the GEO system proposal in terms of coverage of a reference population and in terms of minimum diameter of detectable objects. For both steps we use the ESA PROOF tool (Program for Radar and Optical Observation Forecasting), in the version 2001. PROOF is a tool for debris model validation and observation forecasting [7]. With this tool, observations from radar and optical sensor can be simulated for both, ground-based and space-based applications. PROOF makes use of ESA's MASTER reference population of uncatalogued objects [1].

We will only consider the performance of the survey strategy here. The tasking strategy performance was addressed in detail in [6]. There we concluded that for a catalogue of 1500 objects, the necessary tasking observations could be carried out with the proposed system. If the tasking sensors provide a high telescope slew rate above 5 °/s, it is proposed to observe up to three objects "in parallel". In this case the remaining telescope time of up to 70% of the total observation time can be used to support the survey system, or for other purposes such as tasking of MEO objects.

2.3.1 Coverage of reference population

We implicitly assume that the coverage of an existing and known population of objects by the survey strategy is valid for the discussion of the general survey performance. The PROOF tool was used to simulate observations scheduled according to the proposed survey strategy. The ESA DISCOS TLE catalogue provided a reference population of 793 objects. The simulation covers one complete survey cycle in December 2003 and considers two cases: 8 h observation time per site and day and 12 h observation time per site and day. However, 12 h of survey are not always possible throughout the year. The observation of two fields observed in parallel was simulated - it would take 8 days to cover the entire declination stripe in this case. These 8 days are, therefore, the repetition rate of the survey observations for particular objects.

The analysis was carried out for each survey sensor site individually and later all results were combined. The combined results for the proposed system architecture are contained in Table 1~~Table 1~~. The term 'Uniques' denotes objects that cross the FOV only once within the simulation period or once detected. 'Doubles' refers to objects that cross the FOV at least twice or were detected multiple times. 95% to 99% of the reference population crossed the FOV of the sensor network, proving that the survey strategy is sufficient.

When excluding the fast drifting objects (drifting faster than 5 °/day), an analysis of the longitude distribution of the missed objects shows the mentioned small coverage gaps at 40°W [6]. The tabulated results also show that some objects (about 5% of the crossing objects) cross the FOV undetected. Mostly, the bright background conditions during twilight, while the object crossed the FOV, could be identified as the reason. For very few objects that were found still bright enough, but remained undetected, the PROOF detection algorithm failed for unknown reasons. With this strategy, a (peak) crossing rate of 50 objects/hour is expected. The analysis also confirmed the assumption that objects with diameters larger than 1 m are always observed with magnitudes brighter than 17 mag.

We conclude that the proposed survey strategy is sufficient to be used in the GEO part of the proposed space surveillance system. It is, however, important to stress that the survey strategy requires the entire observation time of a single survey sensor. In consequence, there is no time left to perform tasked observations and there is no redundancy for the survey using a single dedicated survey telescope per site.

Table 1 Number of unique and double crossings (white columns) and detections (grey columns) and the coverage of the reference population. Detection algorithm simulated with PROOF.

Solution	Uniques		Doubles		Coverage [%]	
4 sites, 8 h observation	295	409	463	299	95.6	89.3
4 sites, 12 h observation	177	343	611	392	99.4	92.7

2.3.2 Minimum detectable objects size

The minimum detectable object diameter can also be assessed with the PROOF tool. The minimum detectable object diameter is an important parameter for the planning of surveys. Further, in order to evaluate systems capability to maintain a catalogue of objects above a required diameter, the minimum detectable object diameter during tasking must be known. The simulation was limited to objects crossing between 30,000 and 60,000 km altitude and covered the entire survey cycle starting at two different epochs: a full Moon run, starting 2003-Sep-23, and a new Moon run, starting 2003-Dec-03. For each night during the simulation period an observation sequence of 8 h was simulated. The simulations were performed for the Tenerife site. Again, a ‘conservative’ SNR detection threshold of 4 was used. As no ‘blind’ tracking during the exposures was applied, we expect that improvements in terms of the minimum detectable object diameter are possible.

The results in Figure 3 for the 0.5 m telescope show that the detection of 1 m GEO objects is always possible. As a result of the Moon phase, a clear bifurcation is visible in the plot. The minimum diameter of detectable objects is at 1 m under bad conditions, while under better conditions objects as small as 50 cm (on some occasions even 30 cm) are detected.

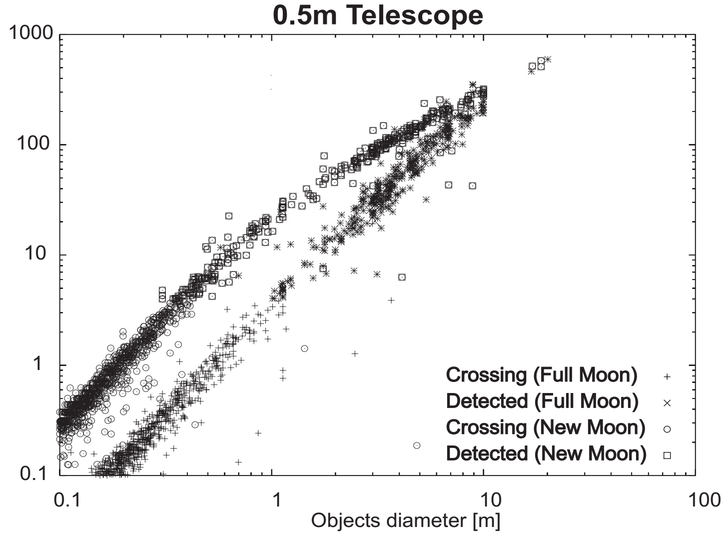

Figure 3 SNR of crossing and detected objects vs. object diameter as resulting from simulations using the PROOF tool.

3 Concept for MEO space surveillance

Not very much information is published on MEO space surveillance so far, which may indicate a lower interest in this region. Nevertheless, the availability of orbital elements for the active and inactive GPS and GLONASS satellites in the USSTRATCOM catalogue shows that MEO space surveillance is successfully performed for the MEO region. Brief examples of possible MEO space surveillance strategies were only found in [10].

As no common MEO definition is available, we had to come up with our own definition for the purpose of this study: MEO combines all objects orbiting the Earth in low eccentric orbits ($e<0.16$) with a mean motion between 1.5 and 2.5 revolutions/day and an inclination below 67°.

As for the GEO, the future European system is required to consider all objects larger than 1 m in diameter in the MEO region. Contrary to the GEO population, objects in the MEO may cross the FOV of a sensor with a wider range of possible directions and velocities, as well as topocentric ranges and phase angles.

A detailed analysis of the existing and future MEO population revealed that the worst possible phase angle is approximately 120° during nighttime, but phase angles of 0° are possible, too. Further analysis showed that for the most cases at least one observation of an particular object per night could be carried out under a phase angle of less than 90°. As topocentric ranges are typically smaller than 25,000 km (or 29,000 km for Galileo), we may estimate typical magnitudes (for conservative assumptions for albedo and shape) for the 1 m objects. We expect 1 m objects in the MEO to appear as bright as 15.5 mag (best illumination conditions) and brighter than 18 mag (worst illumination conditions at 120° phase angle).

The angular velocities are between 20 and 45 “/s in the azimuth/elevation system, and between 15 and 40 “/s in the right ascension/declination system when the objects are at low declination. Therefore, the typical dwell times for a 1° FOV fixed in the inertial space is 5 minutes for low declination (6 min for Galileo) and about 15 minutes at high declinations (>50-60°).

3.1 MEO observation strategy

Considering the population characteristics, it becomes evident that the GEO strategy is not applicable for MEO observations, as the allowed sensor gap time in GEO and the high angular velocities of MEO objects prevent any leak-proof coverage of the MEO region.

The analysis of typical space surveillance cases shows that the MEO space surveillance strategy needs to provide survey capabilities as well as some tasking capabilities (scheduled observations of individual objects). Thus, depending on the needed tasking frequencies and the number of objects, two strategies can be formulated: a pure survey strategy and a combined survey and tasking strategy. A pure survey strategy is sufficient, if the acquisition of the necessary tasking observations is guaranteed within the survey observations.

It became clear during the study that it is beneficial to limit the considered survey space, since for a permanent and complete accessibility of the entire MEO space at least 6 observation sites would be needed.

3.1.1 Survey strategy

The proposed approaches of the U.S. network (an eccentric semi-synchronous orbit apogee search and a circular semi-synchronous orbit search, see [10]) were found to be only partly suited. For both, an initial catalogue is needed and the MEO region cannot be covered entirely. As the European Space Surveillance System is required to have a cold-start capability, and uncatalogued objects shall be searched for, another survey strategy was developed.

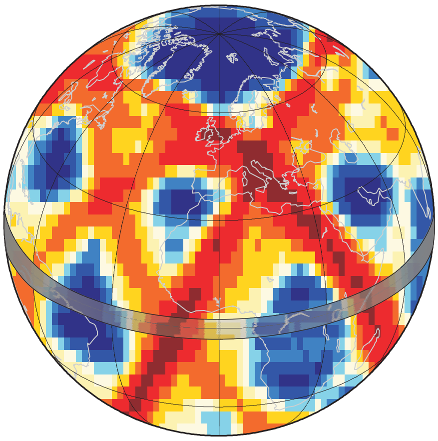

Figure 4 Apparent density of (catalogued) MEO objects together with the “fixed declination stripe” for DE=0.

A promising survey strategy is based on the fact that MEO objects orbit the Earth with a mean motion around 2 rev/day. Thus, the continuous and uninterrupted observation of a so-called ‘fixed declination stripe’ allows a complete survey of the MEO population. Such a declination stripe denotes a region in the sky defined by the entire right ascension range (considered as stripe “width”) and the sensor FOV (considered as stripe “height”). In order to access even objects in low-inclined orbits, a stripe covering the declination of DE=0 deg is proposed for the survey strategy (see Figure 4~~Figure 4~~). This stripe will be crossed 4 times per day, at least 2 times under valid phase angle conditions.

Some improvements of this strategy are still possible. In particular, the accessibility of the whole MEO population under valid illumination conditions is guaranteed from a single site within a few (about 3) months, as the orientation of the orbital plane with respect to the direction to the Sun changes only slowly. The change is caused by the revolution of the Earth around the Sun (about 1 °/day) and the significantly smaller motion of the right ascension of the ascending node of the MEO objects (about 2 ’/day). This would theoretically allow using one survey sensor only for the entire MEO space surveillance survey task. It is, however, proposed to use two dedicated MEO survey telescopes that are spaced by about 90° in longitude to cope with objects appearing under very poor illumination conditions or having longer revolution periods (like the Galileo satellites).

This (desirable) limitation of the number of MEO survey sensors requires a combined survey and tasking strategy. The dedicated survey telescopes are used to fill the catalogue with newly detected or re-detected lost objects. Tasking telescopes are required to cover the whole longitude range in order to allow uninterrupted accessibility of the MEO region for tasked observations. Those tasking telescopes are used to improve the orbits of the newly detected objects through follow-up observations, and for catalogue maintenance. The tasking sensors also perform observations required to fulfil the collision avoidance, fragmentation detection and launch assessment tasks.

The disadvantages of this combined survey and tasking strategy in the MEO are the longer catalogue built-up time and the inability to guarantee a short time to detect fragmentation events.

In principle, any fixed declination stripe could be scanned that is crossed by the target objects. The study proposes, however, to observe the stripe at 0° declination, as this allows to cope with objects in low inclined orbits. Also, this stripe appears from the existing low latitude sites under very good elevation angles.

3.1.2 Tasking strategy

The MEO tasking strategy is identical to the proposed tasking strategy in the GEO case. As the GEO tasking sensors provide unused observation time, and it is not expected that the

MEO catalogue grows larger than the GEO catalogue in the near future. The MEO space surveillance may use the proposed GEO tasking sensors. Using ephemeris tracking, these 0.5 m sensors are sufficient to observe 1 m objects in the MEO region, too.

3.2 MEO sensor architecture

The presented MEO observation strategy requires dedicated survey telescopes. We will discuss the suitability of the sensor architecture as a function of the achievable SNR.

The survey strategy requires that target objects dwell as long as possible within the ‘stripe’, so that the time span until re-observing a particular field can be extended. As the sensor FOV sets the stripe ‘height’, the FOV should be ‘as wide as possible’. This is not without trade-offs in terms of the pixel scale (the size of the detector is limited), the FOV diameter must be balanced against the background signal, and the required astrometric accuracy of the object detection. We will have to search for the FOV diameter “as wide as affordable”.

3.2.1 Survey sensors

The study proposes to use very fast f/1 optics, most likely a modified Schmidt design. Further, it was found that an aperture of 0.8 m is needed to guarantee the detection of 1 m diameter objects in the MEO. It is proposed to use a 16 μm pixel size 4k*4k detector with a focal plane area of 66*66 mm^2 and a pixel scale of 4.2 ”/pixel. The resulting FOV diameter is 4.8°. The exposure time is proposed to be 1 s.

The expected performance of such an optical system (Figure 5) should allow detecting objects of 17 mag, if the background signal is 18 mag/arcs^2 (good sites as Tenerife provide background signals of less than 19.5 mag/arcs^2). 17 mag objects correspond to a 90° phase angle observation of a 1 m diameter object orbiting in the MEO.

Further analysis of this system with modified exposure times showed that an extension of the exposure time to 2 s or 5 s does not change the performance significantly. On the other hand, the exposure time should not be shorter than 0.5 s, as this would result in a readout-noise dominated system.

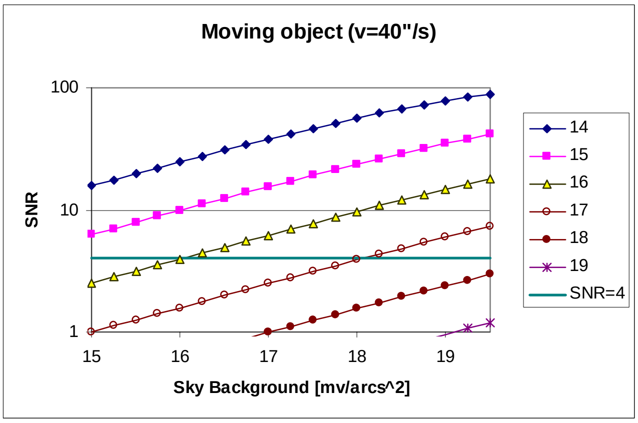

Figure 5 SNR for objects of various magnitudes crossing the FOV with 40”/s as function of the background signal.

If we assume a typical object velocity of 40 “/s, the minimal reacquisition time of a given field is 211 s for the 4.7° FOV to have the survey leak-proof. As this is a very short reacquisition time, some ways must be found to deal with this requirement. There are several options: first, we may limit the length of the surveyed stripe in right ascension. Second, the detector readout may be accelerated by using frame-transfer CCDs and read out to multiple channels at high frequencies. Third, the slew rate of the telescope must be high, while the settling time should be kept short. Finally, the number of exposures forming a series may be minimized.

The analysis of the achievable reacquisition time made clear that for the aimed coverage of 120° in right ascension with 4 consecutive exposures per field a comparatively high readout frequency of 5 MHz through 4 channels is needed. With a relaxed readout frequency of 2 MHz, only 100° in longitude can be covered and only if 3 exposures per series are sufficient. With 1 MHz readout frequency only 80° in longitude are covered if a series consists of only 2 exposures, which is not acceptable. On the other hand, if the survey is limited to 80° in longitude, a wide range of combinations of readout frequencies and number of exposures per series is possible. From 1 MHz with 2 exposures up to 5 MHz with 4 exposures, everything is possible. There is even some margin left.

3.2.2 Tasking sensors

The performance analysis of the 0.5 m GEO tasking sensor showed that the detection of 17 mag objects is possible even under non-optimal observation conditions [6]. The apparent object brightness of 17 mag corresponds to an object diameter of 1 m observed under a phase angle of 90°. Using ephemeris tracking, 1 m objects may be observed under less favourable phase angles.

3.3 Coverage of reference population

The estimation of the coverage of a MEO reference population by the proposed space surveillance strategy is ongoing work and therefore not presented here. The minimal detectable object diameter and the coverage of a reference population are to come.

4 Cataloguing algorithm validation

AIUB validated the performance of the algorithms developed to build up and maintain a catalogue of orbital elements using observations from GEO surveys conducted with ESA’s Space Debris Telescope at Tenerife, Spain. This validation involved the prototype implementation of modules for the correlation of observations with a catalogue and the scheduling of observations to maintain this catalogue using the On-Line Data Processing System (ODPS). The ODPS is used by AIUB on a routine basis for the ESA surveys; its core functionalities are presented in [11].

The proposed combined survey and tasking approach, for both GEO and MEO space surveillance systems, will allow the use of identical algorithms. As such the results of the algorithm validation are applicable to GEO and MEO with the exception that the frequencies for tasking observations needed to secure the orbits of newly detected objects differ. A previous paper [8] presented a method to determine those ‘follow-up’ observation frequencies for objects in the GEO using the CelMech software [2] for the orbit determination implemented in the correlation procedures. The estimated MEO tasking frequencies will be presented in a later paper.

4.1 Catalogue Correlation

Comparing the determined orbital elements and positions with propagated elements and positions from each object in the catalogue is a typical approach to correlate objects with a catalogue. These correlation algorithms using orbital elements may fail sometimes, if several candidate catalogue objects have very similar orbits (e.g. in clusters of co-located satellites), due to unavoidable inaccuracies of the elements in the available catalogue. To circumvent this, we introduced in our algorithms as a second selection criterion the quality of the orbit determination using the new observations.

This second step will be carried out for a list of so-called candidate objects that is obtained from the orbital elements comparison step. For all candidates, all past observations of the candidate are merged with the new observations. Using the merged observations, the best fitting orbit is determined. For an orbit determination resulting in a root mean square (RMS) error smaller than about twice the pointing accuracy, the correlation is considered successful.

The catalogue correlation algorithm was successfully tested with observations from the ESASDT on Tenerife. Even objects of clusters could be distinguished (see [6] or [9] for examples).

4.2 Catalogue Maintenance

The catalogue maintenance is based on two different catalogues, a main catalogue for the objects with “secured” orbits (accuracy and covered observation duration meet the requirements), and a temporary catalogue for the other objects.

While the public main catalogue contains only the secured orbits, the temporary catalogue is only used internally during the acquisition of a secured orbit.

The proposed system infrastructure allows storing both catalogues at a processing centre, where also the correlation will be performed. This processing centre is responsible for the planning of the survey and tasking observations, and for the data distribution.

5 Conclusion and Outlook

This paper outlines the key points of a proposal for the optical part of a future European space surveillance system. The entire space surveillance system proposal was developed in the context of ESA funded studies lead by ONERA. AIUB was and is involved in the development of the optical part of this system that is intended to observe the GEO and MEO region. We showed that the optical system proposal is technically feasible and that a sufficient performance is expected for the GEO part. The performance analysis of the MEO part is not yet completed.

The space surveillance strategy is combining survey and tasking observations for both, MEO and GEO. For the GEO, a so-called ‘stripe’ with a ‘height’ of 34° in declination and a ‘width’ of a few degrees shall be scanned within 8 days. This strategy allows for a leak-proof survey of the GEO region.

Tasking observations are required to secure the orbits of newly detected objects and to allow the space surveillance system to provide additional services like dedicated observations for conjunction analysis.

The proposal for the GEO space surveillance system architecture requires four sensor sites, each equipped with one 0.5 m telescope dedicated to survey and one 0.5 m telescope for tasking. Redundancy may require additional telescopes. Tenerife, Cyprus, Perth and the Marquesas Islands were selected as potential sites. Possibly, already existing sensors such as the 1 m ESA Space Debris Telescope at Tenerife or AIUB’s 1 m multi-purpose system ZIMLAT near Bern may contribute as tasking sensors, even though these telescopes are not optimally suited for survey tasks. The minimal detectable object diameter is 1 m in the worst case. The presented survey strategy covers over 95% of a reference population (USSTRATCOM catalogue).

For the MEO survey the system shall continuously scan a right ascension ‘stripe’ at 0° declination. It is possible to limit the system to 2 sites, spaced by about 90° in longitude. Two dedicated survey sensors (0.8 m f/1 telescopes with 4.7° FOV equipped with a 4k*4k CCD that allow fast readout through multiple channels) are required, preferably co-located at proposed GEO sites. The MEO space surveillance system may re-use the GEO tasking network.

Algorithms for correlating new observations with a catalogue and for the catalogue maintenance have been presented. These algorithms were successfully validated using observations of GEO objects from the ESA Space Debris telescope in Tenerife.

The next steps in the development of an independent European space surveillance system have been recommended in the final report of the study [3]. In this report, solutions for near-term and far-term systems were presented. Also the use of existing systems for limited space surveillance activities has been discussed.

The further development of the optical part of a future space surveillance system requires the set-up of experimental hardware, software and infrastructure in order to gain first experiences in the field of operational space surveillance.

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