

EXECUTIVE SUMMARY

IDENTIFICATION AND ANALYSIS OF MEO OBSERVATION STRATEGIES FOR A FUTURE EUROPEAN SPACE SURVEILLANCE SYSTEM **MEOSTRATESSS**

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1. INTRODUCTION

1.1. PURPOSE AND SCOPE

MEOSTRATESSS is the internal project code used by GMV to refer to the activities associated to the “Identification and Analysis of MEO observation strategies for a future European Space Surveillance System” project.

The purpose of this document is to briefly present the work done in the frame of this project.

1.2. DEFINITIONS AND ACRONYMS

1.2.1. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 1-1: Acronyms

Acronym	Definition
AD	Applicable Document
AIUB	Astronomical Institute University of Bern
BAHN	Napeos Batch Orbit Determination
ESA	European Space Agency
FOV	Field of View
GEO	Geostationary Earth Orbit
GLONASS	GLObal'naya NAVigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
KOM	Kick-Off Meeting
MEO	Medium Earth Orbit
NAPEOS	Navigation Package for Earth Observation Satellites
NORAD	North American Aerospace Defense Command
ODIN	Orbit Determination via Improved Normal Equations
OGS	Optical Ground Station
PREOD	Preliminary Orbit Determination
RD	Reference Document
SoW	Statement of Work
SSA	Space Surveillance System
TLE	Two-Line Elements
US	United States

2. REFERENCES

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

Table 2-1: Applicable documents

Ref.	Title	Code	Version	Date
[AD.1]	Identification and Analysis of MEO Observation Strategies for a Future European Space Surveillance System: Statement of Work	GSP-SD-SOW-00017-OPS-GR	5.0	5 th Sep 2008
[AD.2]	Identification and Analysis of MEO Observation Strategies for a Future European Space Surveillance System: GMV 's proposal	GMVSA 1086/08 V2/08	2.0	12/11/2008
[AD.3]	Identification and Analysis of MEO Observation Strategies for a Future European Space Surveillance System: KOM 's minutes	GMV-MEOSTRATESSS-MIN-KOM	1.0	09/12/2008

2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

Table 2-2: Reference documents

Ref.	Title	Code	Version	Date
[RD.1]	T. Schildknecht, R. Musci, M. Ploner, U. Hugentobler, M. Serra Ricart, J. de Leon Cruz, L. Dominguez Palmero "Geostationary Orbit Objects Survey", Final Report and Executive Summary to ESA study 11914/96/D/IM, Switzerland 2004	N/A	N/A	2004
[RD.2]	T. Schildknecht, R. Musci, M. Serra Ricart, J. de Leon Cruz, L. Dominguez Palmero, P. Beltrami, K.D. Bunte "Geostationary Transfer Orbit Survey", Final Report and Executive Summary to ESA study 12568/97/D/IM, Switzerland 2006	N/A	N/A	2006
[RD.3]	Identification and Analysis of MEO Observation Strategies for a Future European Space Surveillance: Final Report	GMV-MEOSTRATESSS-FR	1.0	01/03/2011

3. OBJECTIVES OF THE PROJECT

The project "Identification and Analysis of MEO observation strategies for a future European Space Surveillance System" had the following objectives (extracted from the SoW [AD.1]):

- Demonstrate the feasibility and performance of survey and follow-up strategies, identify optimisation strategies.
- Demonstrate the possibility to synchronise MEO and GEO surveys.
- Analyse the orbit determination performance and maximum follow-up gap-times to guarantee successful correlation.
- Extrapolate the gathered experience to identify requirements on an optical MEO surveillance system (FOV, pixel scale, tracking movement, camera performance).
- Finally, a campaign for a first characterisation of the MEO environment shall be conducted. Search patterns shall be carefully selected to achieve a reasonable and statistically relevant sampling of the region if possible below the current detection limit (1m by the US space surveillance network) and to demonstrate the build-up and maintenance of a temporal MEO catalogue.

These ambitious objectives have been subject to several changes along the project due to the challenge they represented. The first challenge was to use the OGS telescope to perform surveys of the MEO region. OGS has been doing routinely GEO's survey where the high sensible, accurate and small field of view matches perfectly for the work, but that small field of view is not very suitable for the huge MEO's region. It was decided to use Starbrook's system for surveying while OGS was devoted to follow-up and catalogue maintenance.

The second challenge was the processing software of OGS, that generates the observables (right ascension and declination) to be used in the orbit determination step. This processing software has been developed mainly for the GEO scenario, where objects are constrained in inclination and drift rate. MEO objects can drift much faster (mainly in declination when compared to a GEO) and its inclination is usually quite high. These constraints implied that the original processing tool was not perfectly fitted for the MEO processing. In order to overcome these difficulties, and taken into account that the source code was not available, different configuration "tricks" were set-up to *disconnect* the correlation algorithms that the software implemented and to rely on a post-processing step (the orbit determination) to identify the correct objects in the images.

The consortium that carried out this project included a wide field of view telescope (Starbrook) more suitable for surveying MEOs, even if its sensitivity is not as good as OGS's, so it loses small (and faint) objects. One of the objectives proposed was to synchronise both telescopes (OGS and Starbrook) so an object detected by Starbrook is later followed by OGS. This was done with a delay of one day, as it was necessary to estimate the state vector of the object with the observations gathered with Starbrook.

Finally a huge effort was devoted to analyze the accuracy obtained in the orbit determination of the object's tracked. This has been done using observations from OGS and Starbrook.

4. OVERVIEW OF ACTIVITIES

This section provides a brief overview of each activity performed during this project.

Firstly the survey and tracking strategies for MEOs were analyzed. At the same time the OGS system was analyzed and configured to carry out the subsequent campaigns.

During the second part of the project the observational campaigns were done together with a detail orbit determination analysis using the observations gathered with OGS and Starbrook.

4.1. Development of survey and tracking strategies

This section addressed the early activities in the project.

MEO population characterization

The first approach was to characterize the current known population of MEO objects. This analysis was done using the current NORAD catalogue which showed that the current knowledge of the MEO region shows an almost empty region with some specific areas used by the GNSS systems.

Analysis of given system

The OGS and Starbrook sensor systems were analysed to establish their capabilities and limitations, in the context of observing MEOs. The characteristics of the current MEO population and ESA's wider MEO specification were determined and used to analyse the on-sky viewing location and motion requirements, to which both sensors were compliant. The detection capabilities of both sensors were checked using a signal-to-noise model and this showed that while the OGS could detect MEOs while tracking sidereally, Starbrook would need to use open-loop (blind) tracking. The ability of both sensors to collect data on any one object was examined and this is driven critically by the size of the field of view.

Identification of MEO strategies

Driven principally by the size of the sensor's field of view, the strategy adopted for the study was to use the wide field of view Starbrook sensor to carry out surveys and to use the narrow field of view OGS to track objects for which orbits had been determined from the surveys. Although an orbit of sufficient accuracy could not be determined from just the fence-crossing observations, a first phase of orbit improvement was carried out using Starbrook's companion sensor to provide follow-up observations, and a second phase of orbit improvement was carried out using Starbrook observations from multiple nights.

Analysis of long-term evolution of MEOs and TLE accuracy

A couple of analyses were done to support the definition of the MEO area subject to this study and to investigate the usability of TLEs to schedule observations.

The first analysis propagated some MEO objects 90 years in the future to see if their eccentricity and inclination changed sufficiently to go outside the current GNSS orbits.

The second analysis assessed the accuracy of the long term propagation of TLEs to find out if they can be used to schedule follow-up from one campaign to the next one (usually one month later).

4.2. Early experimentation with OGS

This section summarizes the effort devoted to prepare OGS for the observational campaign. This task was intended to prepare the software needed for the observation campaign. This activity was of major difficulty due to the lack of the source code that was used. The software used to schedule the observations at the OGS and to process the images belongs to AIUB. GMV received a license to use the software but it has not access to the source code. Originally the work was devoted to set-up a running version of the code at GMV premises. This task was complex on both sides (ESA, who prepared the version for GMV, and how GMV uses it because the AIUB software was never exported to another "environment" out of AIUB or OGS sites.

Once the software was ready, the second task was to find out if there were any necessary modifications to be carried out to the observations, as the software was initially developed to track objects in the GEO belt. It was found out that with minimal configuration changes the software could be used to carry out follow-ups, but with surveys some software changes would be needed. This was one of the reasons (although not the only one) why it was decided to carry out follow-ups with OGS while the survey part was done with Starbrook.

Finally only configuration changes were done by GMV while some adaptations were requested by GMV and carried out by ESA.

4.3. Experimental MEO test campaigns

Observational campaigns carried out during this project have been done using two telescopes: OGS and Starbrook.

OGS was used during 15 observing campaigns (from July 2009 to February 2011). The first four were used to test procedures and software as explained in the section 4.2. The rest of the campaigns were used to schedule follow-ups in order to test the maintainability of a catalogue. It included the planning of the observations, the post-processing of the images to obtain the observations (Right Ascension and Declination) and the orbit determination processing to assess the accuracy attainable with each campaign.

Starbrook was used during nine observing campaigns (from June 2010 to February 2011). These campaigns were centred on the process of demonstrating

- basic detection
- survey capability, using a leak-proof fence technique
- survey-and-hand-off, for the acquisition of longer-arc observation sequences.

This activity also contained an attempt to coordinate the two observatories (OGS and Starbrook) to model a network in which each observatory is specialized in a task and both work together. In particular Starbrook will be surveying some MEO regions and will generate observations that, after post-processing to obtain an accurate enough state vector, it will be used to schedule a follow-up the following night using the OGS telescope.

4.4. Orbit Determination results

The last step in a space surveillance system is the estimation of the orbital characteristics of new and catalogued objects. For initial orbit determination Starbrook used in-house software to estimate a circular orbit used for hand-off between its observatories. PREOD (part of ODIN suite) was also used with the OGS and Starbrook observations to assess its capabilities.

For the final and accurate orbit determination NAPEOS (and ODIN also but just as a cross-checking tool) was used. Different scenarios were analyzed ranging from using different numbers of observations and nights, to analyzing how many parameters can be estimated with the low amount of measurements available.

4.5. Main achievements

Although this project addressed different topics, the following deserve a special mention:

1. Analysis of the observation strategies for the MEO region.
2. The coordination between OGS and Starbrook to split survey and follow-up tasks.
3. Orbit determination processing, including some initial orbit determination results.

5. CONCLUSIONS

The main conclusions of the projects are:

- it is possible to detect MEOs using the large aperture small field of view OGS telescope and also with the small aperture but wide field of view Starbrook sensor
- although OGS was intended for surveys and follow-ups, the field of view and the processing tool of the OGS were not suitable for surveys, so the primary OGS task was follow-ups for catalogue maintenance while Starbrook was devoted to surveying
- the configuration of the OGS processing tool was successfully changed to allow MEO processing although it needed a post-processing step, the orbit determination, to correlate objects between different images and days
- the hand-off concept between Starbrook and OGS – to survey objects with Starbrook and prepare a follow-up on the OGS using the observations from Starbrook – has been proved
- NAPEOS has been used successfully to do orbit determination of the Right Ascension – Declination measurements from both OGS and Starbrook systems
- it has been shown that it is possible to maintain a catalogue of MEO objects by observing them and determining orbits during a limited period of time and then re-observing again in the next campaign. A minimum of three observational nights are needed to assure the process can work
- initial orbit determination has been done routinely at Starbrook and as test cases with PREOD (ODIN suite)
- although the original 10cm aperture Starbrook had to use open-loop tracking to detect MEOs the new version of the sensor (with 15cm aperture) can detect MEOs without open-loop tracking
- the ability of Starbrook to detect MEOs is due to the large pixels (~12 arcsec) which means that a MEO spends a longer time in a pixel than it does in the small (~1.4 arcsec) pixels of the OGS; the longer time-in-pixel compensates to some degree for the smaller signal collected by Starbrook's much smaller aperture
- a single transit of a MEO through the Starbrook field of view is sufficient for an initial orbit to be determined but this has up to ~100km scatter in the semi-major axis and is not accurate enough for OGS scheduling but it is accurate enough to allow hand-off to Starbrook's companion sensor
- although the large pixels used by Starbrook result in a higher scatter of observed positions, the poor single-observation accuracy is offset by the ability to collect more observations (because of the large field of view) and the ability to obtain immediate follow-up observations from the companion sensor which gives a longer track (which is better for orbit determination)
- using the detection transit and follow-up observations taken over a period of ~1 hour with both Starbrook sensors enables an orbit to be calculated which is still not accurate enough to schedule OGS observing but which is accurate enough to enable next-night identification of the object during the next night's survey
- where multiple-night observations are available from Starbrook, an orbit can be computed which is accurate enough to schedule the OGS
- where multiple-night observations are available from Starbrook and the OGS, an orbit can be computed which is accurate (to within 30 km, as judged against a precision IGS orbit) over a period of 1 month

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