SSA RADAR AND OPTICAL SENSOR DATA FUSION FOR ORBIT DETERMINATION OF GTO AND GEO OBJECTS

EXECUTIVE SUMMARY

Prepared by:	Laura Aivar (Project Engineer)	28/02/2012 X Laura Aivar Signed by: Laura Aivar García
Approved by:	Isabel Bachiller (Quality Manager)	28/02/2012 X Alberto Águeda on behalf of Isabel Bachiller
Authorized by:	Alberto Águeda (Project Manager)	28/02/2012 X Alberto Águeda

Code:	GMV-SSAOD-EXE
Version:	1.0
Date:	27/02/2012
Internal code:	GMVAD 22222/11 V1/12

GMV AEROSPACE AND DEFENCE S.A.U.
Isaac Newton, 11; PTM Tres Cantos; Madrid 28760
Tel. +34 918072100; Fax. +34 918072199
www.gmv.com

DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	27/02/2012	13	First draft version

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

No table of figures entries found.

1. INTRODUCTION

1.1. PURPOSE

The purpose of this document is to briefly present the work done in the frame of the "SSA Radar and Optical sensor data fusion for orbit determination of GTO and GEO objects" (SSAOD) activity.

1.2. SCOPE

This document is a GMV's delivery in the frame of the contract with ESA for the "SSA Radar and Optical sensor data fusion for orbit determination of GTO and GEO objects" (SSAOD) activity.

1.3. 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
ESA	European Space Agency
GEO	Geostationary Earth Orbit
GTO	Geostationary Transfer Orbit
HEO	Highly Elliptical Orbit
OGS	Optical Ground Station
MEO	Medium Earth Orbit
NAPEOS	Navigation Package for Earth Orbiting Satellites
ODIN	Orbit Determination via Improved Normal Equations
OGS	ESA Optical Ground Station
OLS	Observatorio Astronómico de La Sagra
PREOD	Angles-only Initial Orbit Determination
RD	Reference Document
SoW	Statement of Work
SSA	Space Situational Awareness
TIRA	Tracking & Imaging Radar (Fraunhofer FHR)
TLE	Two-Line Elements

1.4. TERMS, DEFINITIONS AND ABBREVIATED TERMS

None identified.

2. APPLICABLE AND REFERENCE DOCUMENTS

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]	SSA Radar and Optical sensor data fusion for orbit determination of GTO and GEO objects: Statement of Work	Appendix I to ITT AO/1-6409/10/D/SR GSTP-OBS-SOW-000057-OPS-GR	1.2	17/06/2010
[AD.2]	GMV's Proposal to ESA for Space Situational Awareness SSA Radar and Optical sensor data fusion for orbit determination of GTO and GEO objects	GMVAD 10466/10 V1/10	1.0	09/09/2010
[AD.3]	SSA Radar and Optical Sensor Data Fusion for Orbit Determination of GTO and GEO objects: KOM´s minutes	GMV-SSAOD-MOM-KOM	-	11th January 2011
[AD.4]	ODINcl Interface Description	ODIN-IF-ICD-00062-OPS-GR	1.1	May 2010

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]	Flohrer, T., H. Krag, H. Klinkrad, J. Kuusela, L. Leushacke, T. Schildknecht, M. Ploner, "Orbit Determination from Combined Radar and Optical Tracks during XMM Contingency Operations", In: Proceedings of the Fifth European Conference on Space Debris, Darmstadt, Germany, March 30 – April 2, 2009, ESA-SP 672	ESA-SP 672	---	2009
[RD.2]	SSA Surveillance and Tracking Segment – Customer Requirements Document	SSA-SST-RS-CRD-1001	4.0	06/11/2009
[RD.3]	Space Situational Awareness – Space Surveillance and Tracking System Requirements Document	SSA-SST-RS-SRD-0001	2	01/08/2011
[RD.4]	N. Sánchez-Ortiz, E. Olmedo, N.Guijarro, F. Jiménez and P.Keinänen "PDAOSSS Optical Segment of SSN Requirements Document"	PDAOSSS-DMS-SRD-001	1.1	29th October 2010
[RD.5]	NAPEOS Architectural Design Document	GMV-NAPEOSEV-ADD	1.4	22/11/2007
[RD.6]	J. R. Alarcón Rodríguez —ODIN Final Report	--	--	2005

3. OBJECTIVES OF THE PROJECT

The project “SSA Radar and Optical Sensor Data Fusion for Orbit Determination of GTO and GEO Objects” had the following objectives (extracted from the SoW [AD.1]):

- Analyse optical and radar observations from a few sample objects in GTO, Molniya, MEO and GEO
- Define and apply orbit determination approaches for combined radar and optical data to the observations of the sample objects.
- Discuss, verify and validate, if possible, the obtained results. Analyse the impact on the definition of SSA observation concepts for catalogue build-up and maintenance.
- Characterize radar and optical data acquired, and derive sensor characteristics. Analyse potential trade-off with SSA system architecture.

4. OVERVIEW OF ACTIVITIES

This section provides a brief overview of each activity performed during this project. It has been organized taking into account the evolution of the activities performed through the project.

Firstly the here concerned populations, and mainly HEO, were analysed and some objects of these populations were selected to be tracked taking into account not only the characteristics of the objects to be tracked, but also the characteristics of the sensors to be used. Once the objects were selected, the observation campaign took place where 2 sensors were used: one telescope (OGS) and one radar (TIRA). In order to be able to determine orbits from the acquired measurements, the whole procedure of orbit determination has been analysed and the software was adapted to the later processing of measurements and orbit determination. Finally, based on the obtained results from the observation campaign and from simulations, an overview of the needed SSA architecture to cover the HEO population was presented.

4.1. OBJECTS SELECTION AND OBSERVATION PLANNING

This section addressed the early activities in the project where the whole observation campaign was defined.

Objects selection

Candidate and back-up objects from all the population groups: eccentric objects (scientific ESA missions, Molniya and other HEOs) and verification objects (GEO and MEO) were selected in order to be tracked during the observation campaign. Good potential observation opportunities, precise orbits availability, big radar cross section were the criterion used to select these candidates.

Sensor selection

The instruments requirements for satellite observations are very specific, which makes many existing optical observatories inadequate for the task. However, 3 already existing telescopes (OGS, OLS and Zimmerwald) and one existing radar (TIRA) have been detected as suitable for tracking HEO objects

Observation planning

Objects and sensors candidate were taken into account for the elaboration of the preliminary observation planning whose main objective was to analyse the potential visibilities of the candidate objects in order to select the objects to be observed.

Finally, taking into account the objects selected and the availability and budgetary restrictions, the final observation planning was elaborated.

Radar tracking was intended to be done as close as possible to the perigee whereas optical observations were intended to be done far from the perigee.

4.2. ANALYSIS OF OBTAINED MEASUREMENTS

The observation campaign included some innovative and challenging concepts for this type of campaigns: firstly TIRA acquired interleaved observations whereas continuous tracking has always been performed from this sensor and secondly, OGS and TIRA were scheduled together for observing multiple objects whereas up to now, when they have been scheduled together, the plan was only focused on one single object.

Observation campaign was performed during 3 consecutive days from OGS and during 1 night from TIRA. Reference orbital information used in both sensors was TLEs, which have been updated daily in order to avoid minimise pointing errors coming from this source.

After that, an analysis of the obtained measurements was done in order to study the quality of the acquired data. Regarding the optical data, angular biases have been found in the observations, around 4 millidegress in right ascension and 1 millidegree in declination with respect to the precise orbit, whereas range biases were found in the radar tracking measurements, up to 200km in the XMM tracking with respect to the precise orbit. Moreover, some of the radar tracking presented a drift which were caused by potential tracking errors. This study, previous to introduce the obtained data to the orbit determination software, is very important to understand the results that will be obtained in the orbit determination.

4.3. ORBIT DETERMINATION

First of all, an analysis of orbit determination approaches focusing on eccentric orbits and data fusion was done. A preliminary study of the processing strategies and used algorithms has been presented, mainly depending on the final purpose to be achieved and the data available. The different approaches presented correspond to initial orbit determination, batch orbit determination and sequential orbit determination.

Once that different orbit determination approaches were presented, the orbit determination software was adapted (NAPEOS and ODIN) or developed (PREOD) to include all these mentioned approaches. The before mentioned software including all these performed adaptations has been delivered to ESA: PREOD, NAPEOS and ODIN.

After OD software was adapted, orbit determination processes following the different proposed approaches have been done for the obtained data during the observation campaign. Interesting conclusions have been extracted from here that were used in the analysis of the proposal of a SSA system architecture to cover this group of population (HEO)

4.4. SSA SYSTEMS ARCHITECTURE

This activity was intended to derive the main characteristics and trade-offs of the SSA system architecture, considering both optical and radar sensors, to detect objects from the eccentric population and maintain its catalogue under the SRD criterion (updated version of CRD).

Analysis of observations concepts for catalogue build-up and maintenance for HEO population were the starting point of this activity, which concluded with the observation and tracking conditions needed in order to first detect the object and, after that, maintain the catalogue.

Once these conditions were know, required characteristics for telescopes and radars needed to fulfil the presented requirements have been driven discussed.

Moreover, trade-offs of the whole SSA architecture considering all the previous mentioned aspects have been presented.

Finally, considering all the outputs of the previous steps, configuration of SSA architecture, sensors properties and observation strategies, HEO cataloguing performances have been addressed.

4.5. MAIN ACHIEVEMENTS

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

- Coordinated observation campaign using both types of sensors, telescopes and radars, to observe multiple satellites, including those in eccentric orbits.
- Orbit determination processing of the measurements acquired during the observation campaign.
- Analysis of expected performances for the catalogue coverage of the eccentric population as a by product of the proposed current surveillance strategy for GEO.
- Derivation of the main drivers and steps forward of the SSA systems architecture to cover the population of eccentric objects.

5. CONCLUSIONS

The main conclusions of the project are:

- The successful observation campaign performed during this project proves that it is possible to track HEO objects using optical (OGS) and radar (TIRA) means. Furthermore the observation campaign included some innovative and challenging concepts for this type of campaigns: firstly TIRA acquired interleaved observations whereas continuous tracking has always been performed from this sensor and secondly, OGS and TIRA were scheduled together for observing multiple objects whereas up to now, when they have been scheduled together, the plan was only focused on one single object.

  However, some tracking errors during TIRA campaign occurred and were reported. Moreover, angular biases per pass in optical observations and range biases per pass in the radar tracking have been detected.
- It was possible to perform orbit determination based on the fusion of the optical and radar data.
- Orbits could have been determined for all the scenarios, except for those involving XMM radar data using NAPEOS-BAHN. The bad results in the mentioned OD are mainly caused by the used tracking mode (open-loop) and the error that occurred during its tracking (loss of track).
- Orbits determined from data fusion (optical and radar data) are significantly more accurate than the ones determined only considering optical or radar data.
- Using just optical measurements give an orbit whose cross-track component is the best fitted, whereas using only radar tracking results an orbit whose in-plane component is the best fitted one.
- It is not possible to determine the orbits sequentially (NAPEOS-SRIF) with the obtained measurements (radar measurements from just one night and scarce optical data from different nights) due to different batch lengths.
- Initial determined orbits were not accurate enough (minimum errors of around 100 km) to start the precise orbit determination procedure.
- Optical detection requires an immediate tracking in order to assure the object's reacquisition at least during the next apogee.
- The most important issues to be considered for the orbit determination has been identified: revisit time (should be minimised), length of the passes (should be maximised), orbit frequency and orbit region where tracking is performed (observations should be obtained in diverse regions).
- The considered architecture for this study included 4 telescopes in each of the 4 sites, Marquises Islands, Tenerife, Cyprus and New Norcia, and one surveillance radar located in Europe.
- In order to have enough information to determine an orbit, the minimum duration of an optical detection must be 15 minutes and 3 minutes for radar acquisition.
- Tacking optical observation during apogees make possible to fulfil the accuracy requirements for catalogue maintenance provided by the SRD, but only in the apogee region.
- Adding one radar tracking in the perigee contributes significantly to the accuracy of the determined orbit, making the catalogue maintenance during the whole orbit possible in some of the simulated scenarios.
- Tracking by radar or optical means as follow-up after optical detection seems to be one of the most suitable approaches to enhance the detection of HEO objects.
- Using Doppler information from a radar in the OD procedure (assuming that noise sigma for Doppler in m/s ~ 1/100 noise sigma for range in m) does not improve the orbit determination accuracy obtained using only range data.
- Accuracy improvements in perigee (region where the collision are more probable due to objects congestion in this area) can be challenging because most of the HEO perigees are located in southern hemisphere or near the Equator (low inclination) as European radars are most likely to be located in the northern hemisphere due to geopolitical and economic issues. Space-based tracking via scheduled tasking could be one possible workaround.
- Detecting HEO as by-products of other population surveys (e.g. GEO) not only cause surveillance gaps in HEO population, but also could entail data processing problems. Consequently, comprehensive surveillance strategies for eccentric orbits are needed. Space-based surveillance strategies could be one possible approach.

- In order to characterize HEO properly, the propagation model must include (at least) solar and lunar gravity perturbations, aerodynamic acceleration, solar radiation pressure and the geopotential model must be at least 15x15 expansion (full 30x30 is recommended).
- The provided software, PREOD, NAPEOS (mainly BAHN, SRIF and CONSIGO) and ODIN, has been used for all the analysis of this study.
- Most important limitation in the planned optical sensor system is the tracking accuracy, limited up to 75”/s.
- A telescope mount capable to keep the tracking accurate above a relative velocity of 315”/s in the maximum exposure time is needed.
- For sufficiently bright objects, the exposure time would be reduced and tracking accuracy restrictions could be relaxed.
- To concentrate as much radar energy on the target, the L or S-band should be used.
- Multi-pulse processing in combination with the appliance of “track before detect” techniques will enhance both sensitivity and accuracy.
- More detailed analysis are required regarding the SSA architecture requirements, i.e. what are the requirements for collision avoidance in terms of accuracy, timeliness, object size…
- It is not possible to catalogue all the detected objects by using only one single tracking telescope per site. Moreover, high telescope loads result from the simulation. Therefore, additional tracking telescopes are needed in each site.

In short, it is considered that the study brought a lot of inputs which are relevant for the SSA programme and, thanks to the performed observation campaign and the later simulations analyses, it is noted once again the strong difference between simulations and actual observations in the real world, which is a very important issue to take into consideration in all the studies.

DISTRIBUTION LIST

Quantity	Names	Company
1	T. Flohrer	ESA
6	Alberto Águeda, Jaime Fernandez, Laura Aivar, Adrian de Andrés, Javier Cuesta, Isabel Bachiller	GMV
2	Dr. Guido Bartsch, Dr. Ludger Leushacke	Fraunhofer FHR
2	David Abreu, Jyri Kuusela	ATAMAN
1	Dr. Jens Utzmann	ASTRIUM

END OF DOCUMENT