First results from the deployment of Expert Centres supporting optical and laser observations in a European Space Surveillance and Tracking System

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ABSTRACT

The European Space Agency (ESA) continues its Space Situational Awareness (SSA) Programme with three segments; Space Weather (SWE), Near Earth Objects (NEO) and Space Surveillance and Tracking (SST). A total of 19 member states of ESA participate in the SSA programme, of which 11 subscribed to the SST segment. SST work focusses on the development of the technologies for detection, cataloguing and follow-up of space objects, alongside the derived applications and services for conjunction event prediction, re-entry predictions, and fragmentation event detection. During period 3 of the programme (2017 to 2020), the SST segment aims to successfully establish expert centres for optical and laser ranging observations. This objective addresses the need for networking and integration of heterogeneous sensors in a coherent SST segment. The expert centre serves as the focal point for the interfacing with system-external sensors and assets. This centre is designed to interface with system-external data sources to not only request and manage observations but also provide feedback on the received data. We report on the development and deployment of the Expert Centre with special focus being on the first deployment completed in Summer 2017. We present the demonstrated capabilities for coordination and monitoring of sensors and data providers, whilst reporting on the achievements for providing feedback to sensor operators, such as in particular for sensor qualification and calibration. We conclude with an outlook on the further work and overall strategy.

1 INTRODUCTION

ESA, recognizing the need to protect our critical infrastructure in space and on ground has been undertaking a Space Situational Awareness (SSA) Programme with three segments: Space Weather (SWE), Near Earth Objects (NEO) and Space Surveillance and Tracking (SST) since 2009.

ESA's SSA programme aims to support Europe's independent utilisation of, and access to, space through the provision of timely and accurate information and data regarding the space environment, and particularly regarding hazards to infrastructure in orbit and on the ground.

Ref [1] already introduced the programme in detail, and put focus on the activities in the SST segment. It reviewed the current status of the developments in the segment's technology areas addressing sensors, sensor networking and SST data processing, SST applications, and standardisation. It is important in ESA's SST approach to strive for the progressive evolution and integration of existing assets in Europe towards an interoperable European SST system [2]. ESA's expertise is available in multinational environments to support the research, development, and coordination of space-related technologies in the appropriate technology domains. For SSA and especially SST ESA can act as architect of a system of systems in Europe, maturing further all relevant technologies.

One prominent example for ESA enabling the development of new technologies and solutions in SST are the Expert Centres. During the second period of the SSA programme (2013-2016), ESA developed networking technologies and integrated these with ESA's SST data processing core and the related applications (objects catalogue, conjunction and re-entry prediction, fragmentation detection and analysis). In parallel to this ESA succeeded in establishing the first expert centre prototype.

Ref [3] introduced the conceptual design for expert centres supporting observations in an SST system. The motivation for expert centres in SST differs from the existing experts facilities in the SWE and NEO segments that are designed as central access points of networked sensors and services. In SST the assumed data centre and tasking centre architecture incorporates a large number of existing and heterogeneous sensors, widely under external control. As a consequence, an SST system using these valuable data sources faces a certain overhead in coordinating observations requests, data formats and general ways of interfacing. Further, sensor capabilities and related availability may differ considerably. The concept for ESA's SST Expert Centre foresees a proxy role between the backend SST system and the sensors to moderate requests and data provision and quality control, in addition to providing support services. These services address sensor calibration and qualification, support research on observations and SST technology development.

It is worth noting that in addition to classical SST sensor (radar systems and passive optical systems) the use of satellite laser ranging (SLR) has been developing rapidly during the last years. Already during programme periods 1 and 2 ESA has already worked with several SLR stations during test campaigns.

During the third programme period (2017-2020) ESA addresses SST with a focus on continuing the research and development, where for the expert centre development the efficient and effective data exchange with system-external optical and laser tracking sensors is further researched and developed. It is foreseen to demonstrate the capabilities with a deployed system in period 3. Testing the functionalities is also possible by using ESA's own optical test-bed telescopes in Cebreros, Spain, and a future one in Chile. Currently, ESA is also developing a test-bed station to test laser ranging technologies.

This paper will describe the adopted architecture of the expert centre based on earlier work [3]. The current status of the expert centre development, deployment, and testing, as well as the role of the expert centre in observations campaigns with a multitude of participating sensors is presented. We conclude with a brief outlook.

2 SST EXPERT CENTRE FUNCTIONALITIES AND ADOPTED SYSTEM ARCHITECTURE

The original system architecture is based on the results of different studies carried out in ESA that led to a first prototype deployment. The studies delivered a needs analysis, feasibility assessment, discussion of expected benefits, derived systems requirements and the matching system architecture with an operations model [3].

Benefits (in costs, functionality increases, performance gains) are expected by

- making available expert support to the system-external sensors,
- increasing the efficiency of SST orbit determination process using data quality checks and applying consistent modelling,
- implementing a centralized scheduler that best addresses the backend SST needs and the status of the external sensor network,
- contributing to standardisation of data exchanges, and
- establishing a test environment for advanced SST data processing techniques.

From the related use case scenarios two blocks of functionalities were identified: operations and support function and the high-level system requirements have been documented. These functionalities and system requirements have been published before [3]

During 2016-2017 the next activity was conducted with the aim to establish the first prototype of combined optical passive and laser ranging Expert Centre. Thorough requirement reviews were performed at functional, interface, and performance level. This applies in particular to the performance requirements, such as on response time, accuracy, availability, and coverage of survey scenarios.

It is important to highlight that the previously adopted sensor classification scheme has been revised, according to the level of sensor qualification by the Expert Centre, to comprise of:

- Candidate sensor: sensors that have not proved yet their capability to observe and provide reliable data of space debris,
- Validated sensor: candidate sensors, optical passive or laser ranging sensors, which passed the Expert Centre's validation procedures. For laser ranging sensors, this procedure is performed in cooperation with ILRS, and
- Qualified sensor: validated sensors, optical passive or laser ranging sensors, which passed the Expert Centre's qualification procedures.

The architecture of Expert Centre system has been refined as well. Ref [3, 4] present the high level interactions between the Expert Centre, the external sensors and other sensors (distinguishing candidate, validated and qualified sensors) and the internal sensors, i.e. those within the SST segment. The adopted design of the Expert Centre foresees a comprehensive set of interfaces that allow to perform all required functionalities, i.e.:

- Perform coordination of data acquisition by connected sensors and report consolidated status of system-external sensors to the connected SST system,
- Perform evaluation and calibration of data sources and provide evaluated data to the connected SST system,
- Validate and qualify sensors to meet requirements of the connected SST system,
- Provide a feedback to the connected sensors and the SST System,
- Monitor compliance with service level agreements (SLA) and other agreements for data acquisition,
- Provide a platform to conduct research and development with SST data and to provide SST expertise to sensors and networks (such as in particular the Space Debris Study Group (SDSG) of the International Laser Ranging Service (ILRS).

The interfaces reflect the large diversity of the connected entities and, in their implementation, range from web services to basic secured file transfer protocols.

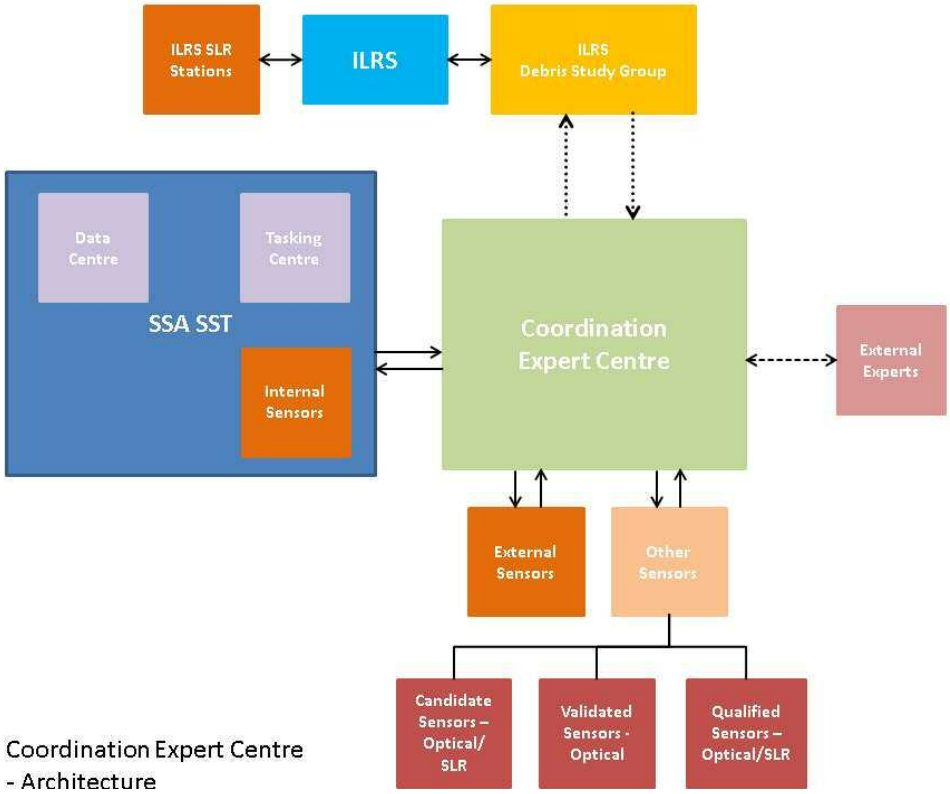

Fig. 1. High-Level Architecture of Coordination Expert Centre.

3 CURRENT STATUS OF THE SST EXPERT CENTRE FIRST DEPLOYMENT AND TEST CAMPAIGNS

In this section we address the conclusions from the first deployment, and outline the role the Expert Centre in a coordinated observation campaign conducted for SST backend integration activity aiming at collecting real data for further validation of the system.

3.1 Expert Centre first deployment

The first Expert Centre deployment was accomplished at ESOC in July 2017. To properly validate the system, several observation campaigns were conducted with different maturity levels of sensors, both optical passive and laser ranging sensors. It was intended to perform coordinated observation campaigns per type of sensor (passive and laser ranging), i.e. included:

- test of the validation and qualification procedures
- test of data format homogenisation tools
- test of expert support on astrometry accuracy and epoch bias assessment
- test of interfaces and communication protocols
- interface with qualified candidate sensors for the first time in space debris observation capabilities
- test the SLA monitoring and key performance indicator (KPI) collection.

The sensors involved during the first observations campaigns comprised previously qualified sensors:

- Optical passive: AIUB’s ZimSMART as survey sensor, and ZIMLAT as tracking sensor, and
- Laser ranging: ILRS Graz SLR station.

As demonstration cases two further sensors have been selected to test validation and qualification procedures:

- Optical passive: ESA’s Test-bed telescope (TBT) a Cebreros, and
- Laser ranging: Borowiec SLR station.

During the observation campaigns, the Expert Centre demonstrated that for a validated sensor through repetitive observation of selected objects key sensor metrics can be derived, such as acquisition success ratio, data provision latency, consistency of the astrometric accuracy and epoch registration biases, as well as miss-correlation probability.

AIUB’s ZIMLAT sensor [5] was selected to conduct typical operations of the SST Expert Centre. The ZIMLAT sensor was used for one night to simulate support for a hypothetical contingency scenario in the MEO regime for a Galileo satellite, and for a conjunction between two objects in MEO, and to support re-entry predictions for an object in Molniya orbit.

Through these first campaigns testing and verifying the data exchange, schedule transmission and reception, processing of data, validation and final data delivery could all be demonstrated. An important milestone was the validation of ESA’s TBT system at Cebreros [6]. This has been achieved through execution of the SST Expert Centre’s sensor qualification procedures. TBT has been found to be capable of providing data with an astrometric accuracy of 1.4 arcsec and a time bias in the order of 60ms. While this result is already within the specifications, further improvements are assumed by the sensor operators as still possible. Another important achievement was the validation and qualification of a newly established SLR sensor capability, i.e. the upgraded Borowiec SLR sensor ranging to non-cooperative objects.

A demonstration of the coordination function of the expert centre had to be delayed to a later test campaign with more participating sensors.

3.2 Demonstration observation campaigns

During a subsequent test in 2017, the Expert Centre was requested to participate in a larger observation campaign for the test and validation of the SST backend developments. The expert centre was tasked to coordinate the contributions from the optical passive sensors of the GEO part of that larger observation campaign. This proved to be an excellent opportunity to demonstrate all of the Expert Centre capabilities, and the first use to coordinate the backend SST system and external sensors:

- Test the interfaces between sensors – Expert Centre – SST backend
- Further test of the Expert Centre software tools: format converters, KPI compilation and visualisation, calibration expert support, support of experts on observation strategies definition…etc.
- Identification of needed additional functionalities implemented into future versions of Expert Centres

The emphasis during the coordinated observation campaign was on gathering enough calibration observations so as to characterise the participating sensors and to identify possible biases and astrometric reference system issues. Also, efficient collaborative tracking of a drifting object in GEO was studied. For all observations a throughout verification of the acquired data to meet the CCSDS (Consultative Committee for Space Data Systems) data formats, was performed.

The passive optical sensors selected for this observation campaign were divided in tracking and surveillance sensors:

- Tracking Sensors:
  - ESA OGS telescope, located at Tenerife, Spain
  - Deimos DeSS Tracker 2 telescope, located in Spain
  - Zimmerwald ZIMLAT telescope, located in Switzerland
- Surveillance Sensors:
  - Zimmerwald ZimSMART telescope, located in Switzerland
  - Starbrook telescope located in Cyprus and operated by UK
  - ESA's TBT-Cebreros, located in Spain

For planning purposes, a list of objects to be tracked were agreed, including some of interest objects such as MEO and HEO, and GEO clusters. On a daily basis the Expert Centre proposed a list of GNSS satellites for calibration. These could be freely chosen by each sensor every night (2-3 objects with 2 tracklets each are found sufficient to monitor data quality). The calibration observations of GPS satellites differ for tracking and survey sensors. The Expert Centre expected the operators to observe 4-5 objects every night in 15-minute slots. For the surveillance sensors, calibration observations were acquired once at the beginning of each night.

Survey strategies were defined based on the experience of the selected sensors and some inputs from the Expert Centre. A survey volume of 9 degrees in declination over the GEO band was required to be covered by each sensor with the constraint to schedule several re-observations of the same longitude, aiming at more than one observation per object and night.

The tracking activities for each sensor were (re-)planned per night to observe a specific object several times, comprising individual observation slots of about 3-5 minutes. Once a round of all objects had been completed, the schedule requested the sensor to repeat the plan, ensuring re-observations. This again was derived from the needs of the validation of the correlation and orbit determination processes.

The observation campaign started on mid October 2017, with the aim of acquiring 5 nights of observations (as consecutive as possible). Due to poor weather conditions across the sites the schedule was extended beyond 2017, in order to guarantee a minimum overlap between observation and an underlying SLA agreement.

The nominal operation scenario conducted by the Expert Centre during the observation campaign consisted of:

1) Set up of a server by Expert Centre, where the TLEs of the targets to be tracked and the TLEs of visible GPS satellites (used as calibration targets) were placed
2) Daily coordination of the sensors:
   a. Daily weather monitoring of each sensor and informing about forecast
   b. Daily compilation of the tracklets provided by each sensor in the FTP server after each night of observation
   c. Daily compilation of sensor status regarding weather or other unavailability issues
   d. Daily compilation of other KPIs and stored in the Expert Centre database, as input to the SLA compliance monitoring
3) Daily support in evaluation and calibration of provided data by means of astrometric accuracy assessment and time bias estimation, providing findings back to the sensor operators daily
4) Daily generation of tracklets according to SST backend standard (in CCSDS TDM xml format)

3.3 Observation campaigns reporting

During these tests studying the networking of the external sensors in detail became a key topic. Fig. 2. gives as an example a resulting sensor availability chart. Obviously, staying aware of the sensor availability in that dynamical network is a crucial and cumbersome task that needs to be automated as far as possible.

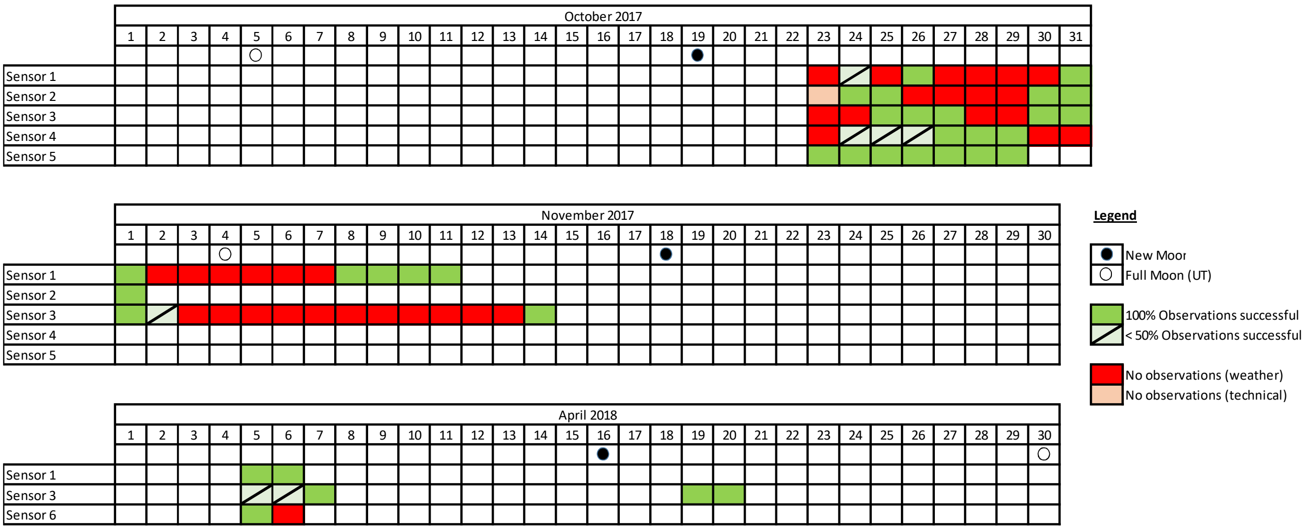

Fig. 2. Example availability chart for selected participating sensors in a collaborative optical test campaign executed in 2017 and 2018.

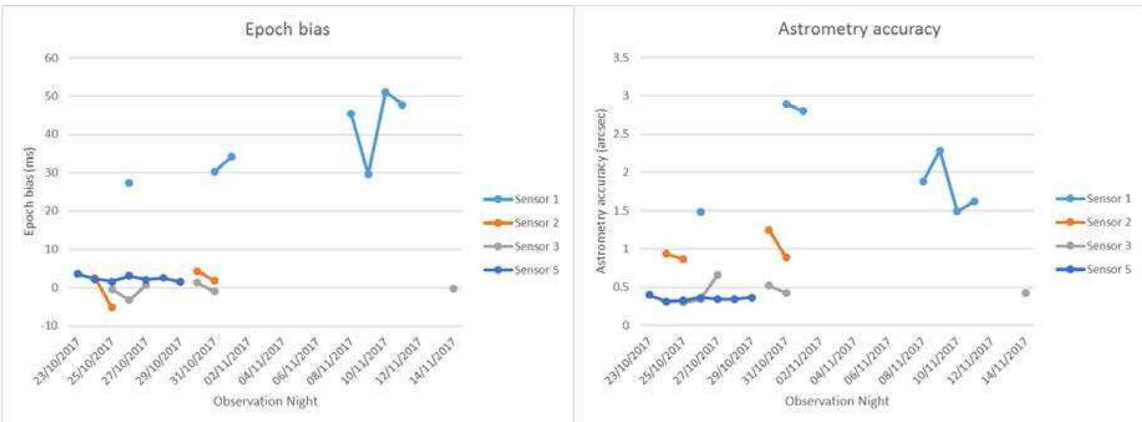

Fig. 3. Daily quick-look assessment of epoch biases and astrometry accuracy for selected participating sensors in a collaborative optical test campaign executed in 2017 and 2018.

A total of 6628 tracks were observed during the test and routine epoch bias and astrometry accuracy were assessed by the Expert Centre on a daily basis, providing feedback to sensor operators (for a summary see Fig. 3). The needed data conversion into CCSDS TDM XML format was also performed by the Expert Centre. All participating sensors of the campaign have received feedback on the data calibration immediately during the day following the observations. The evaluation of the test showed that the deployed SST Expert Centre met all requirements to collect data and monitor SLAs, by assessing elements of agreed key performance indicators.

In addition to these findings on the operations, two cases are worth to be mentioned as excellent examples for the provision of expert support through the Expert Centre.

During the first part of the observation campaign, the SST Expert Centre identified an apparent data quality problem for one sensor, which was limited to cases where the sensor tracked MEO objects. During investigation of the issue with the Expert Centre, the sensor operators identified an image processing issue and re-processed the data with an immediate improvement in epoch bias and astrometry accuracy, which was revalidated by the Expert Centre.

ESA's TBT-1 Cebreros, was used for the first time, still in commissioning, in the survey mode. A qualification of the survey strategy definition was performed by the Expert Centre. Unfortunately, TBT-1 Cebreros was only available for the second part of the campaign, and only a fraction of the survey area overlaps with Starbrook. The observation region and strategy for TBT-1 Cebreros were also limited by the Moon phase. A time offset between both sensor was estimated at -0.0425msec and TBT-1's the astrometry accuracy was estimated at 1.0 arcsec. For the TBT-1 sensor design this exceeds the specifications and is slightly better than the value obtained during a first sensor qualification in 2017. Supporting the sensor commissioning, the Expert Centre ran an exhaustive analysis correcting the observation data from annual aberration and some trends in the biases due to mainly lack of shutter characterisation.

4 OUTLOOK TO SST EXPERT CENTRE FURTHER EVOLUTION

SST expert centres are an important part of an ESA's SST System topology. SST expert centres act as a proxy between external sensors and the SST data processing back-end. Hence, the SST Expert Centre can increase the performance of the coordination through a centralised scheduler meeting SST backend, by assessing sensor status and KPIs, and monitor SLA compliance. It can provide expert support and calibration to external sensors, perform data quality checks and verify compliance with data exchange standards.

The observation campaigns described in previous sections of this paper have been the perfect real use cases to demonstrate the very promising possible contributions of the Expert Centre to observation campaigns, diminishing the overhead in case of a coordinated observation campaign. Expert support can be of significant added-value to ensure the quality of the obtained data, can support sensors during their qualification processes, and can provide data quality assessment and problems identification, also including sensor data formats.

ESA is currently demonstrating the capabilities of a first prototype deployment of a hybrid Expert Centre. An ongoing activity aims at increasing the performance of the deployed system. The Expert Centre shall be ready to deal with a large number of heterogeneous and different maturity level sensors in parallel.

The activity will then focus on homogenisation of the interfaces with the SST backend, and lean webservice interfaces will be developed for an automated communication with that system. Such kind of interfaces based on webservices will be analysed further also with external sensors, using ESA's TBT-Cebreros telescope as precursor testbed.

Continuous evolution in the format software tools are foreseen as well, depending on the agreements established by means of SLAs with the external sensors. Improvement in the visualisation of KPI parameters to cross check the validity of the SLAs was identified during the observations campaigns to be of crucial importance, as it helps the expert centre operator to identify quickly any misalignment from the conditions defined in each SLA.

Finally, ESA plans for extensive demonstration of the capabilities through an extensive coordinated observation campaign with a large number of sensors. A deployment of the SST Expert Centre to a second and ESA-external site is foreseen.

5 SUMMARY

ESA's development of an Expert Centre system supporting coordinated laser and optical tracking technologies and providing SST expertise is continuing. Test campaigns using the deployed first version of the sensor have been conducted. The results are very promising and showed the capability of the centre to support coordinated data acquisition with minimised overhead at the SST system, and efficient support to sensor calibration and evaluation. Sensors have been supported for improving their data quality and optimising observation strategies. The second (and final) development activities have just started, and a deployment to an external side is planned.

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