EXPERT CENTRES: A KEY COMPONENT IN ESA'S TOPOLOGY FOR SPACE SURVEILLANCE

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ABSTRACT

We report on the current status of Expert Centres for optical and laser ranging observations in terms of deployment and demonstrated capabilities during specific observation campaigns.

The Expert Centre system acts a proxy between external heterogeneous and distributed sensors and a data processing backend. Therefore, it diminishes the overhead in case of coordinated observation campaigns by centralising observation requests, by assessing sensors status and KPIs (availability, latency, epoch bias, response time etc.), and by monitoring Service Level Agreement (SLA) compliance. Moreover, it can provide significant added-value expert support and calibration services to external sensors, data quality assessment and data exchange standards compliance verification.

We show how previous campaigns demonstrated the Expert Centre functionalities covering from coordination to qualification and calibration. The key role of the Expert Centre in a coordinated observation campaign with the objective to collect real observations to further test the data processing backend system is reported. The qualification of the Borowiec SLR station and ESA's TBT robotic telescope were two important milestones achieved by Expert Centre first prototype deployed at ESA and results are also presented.

A second ad-hoc qualification campaign has been performed with ESA's TBT robotic telescope as new improvements done in the sensor needed to be tested following Expert Centre qualification procedure. A comparison between first qualification results and the ones performed after the sensor upgrades is presented.

Networking of a large heterogeneous external sensors becomes a key challenge for space surveillance systems, and staying aware of the sensor availability in such dynamical network is a cumbersome functionality that needs to be automated. Homogenisation of the interfaces with all external actors, sensors and backend system, and automatic communication by means of web-services will increase as well the performance of the Expert Centre in the future. An ongoing activity is analysing the performance improvement through related enhancements of the Expert Centre. We report on recent results of these enhancement together with other initiatives for the boosting of the overall system performance.

1 EXPERT CENTRE CONTEXT, FUNCTIONALITIES AND ARCHITECTURE

The motivation for expert centres in the space surveillance domain differs from other existing experts facilities in the SWE and NEO segments. Those entities are designed as central access points of networked sensors and services.

In ESA's topology for space surveillance, the assumed data centre and tasking centre architecture incorporates large number of existing and heterogeneous sensors, widely under external control. This leads into a certain overhead in coordinating observations requests, data formats and general ways of interfacing. Further, sensor capabilities and related availability schemas may differ considerably.

The Expert Centre (ExpCen) system foresees to play a proxy role between external heterogeneous and distributed sensors and a data processing backend system. Hence, it increases the performance of the coordination through a centralised scheduler meeting tasking backend, by assessing sensor status and KPIs, and monitor SLA compliance, in addition to provide support services. These services address sensor calibration and qualification, support research on observations, technology development, perform data quality checks and verify compliance with data exchange standards (i.e. CCSDS [8]).

References [1] and [2] summarised the results of some studies carried out in ESA. The studies delivered a needs analysis, objectives and expected benefits analysis, feasibility assessment, derived system requirements and architecture, and operations model that establishes the

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basis of the definition of an Expert Centre for optical and laser ranging observations.

During 2016-2017 a new activity was conducted with the aim to establish the first prototype of a combined optical and laser ranging observations Expert Centre.

Thorough requirements revisit were performed at functional, interface and performance level (availability, data coverage and timeliness) [3], [4].

The architecture of the system was refined as well (Figure 1), leading into a subsequent new classification of type of sensors according to their data quality. (independently from their nature, optical passive and laser ranging).

The classification of type of sensors according to their level of qualification [4] comprises:

- Candidate sensor: sensors that have not proven yet their capability to observe and provide reliable data of space debris.
- Validated sensor: candidate sensors, optical passive or laser ranging sensors, which passed ExpCen validation procedures. For laser ranging sensors, this procedure is performed in cooperation with International Laser Ranging Service (ILRS).
- Qualified sensor: validated sensors, optical passive or laser ranging sensors, which passed ExpCen qualification procedures.

The ExpCen's validation procedure is a compilation of methods which cover observation planning and processing in order to test investigated sensor interfaces and asses minimum observation capabilities. The ExpCen's qualification procedure is an extended version of the validation procedure where the data quality is also investigated. To pass this procedure strict criteria covering the sensor performance (data latency, response time) and its data quality (e.g. astrometric and range accuracy) must be fulfilled.

The adopted design of the Expert Centre foresees a comprehensive set of interfaces that allow to perform all identified functionalities [2], [4]:

- Perform coordination of data acquisition by connected sensors and report consolidated status of system-external sensors to the connected data centre backend.
- Perform evaluation and calibration of data sources and provide evaluated data to the connected data centre backend.
- Validate and qualify sensors to meet requirements of the connected data centre backend.
- Provide a feedback to the connected sensors and the backend system.
- Monitor compliance with SLAs and other agreements for data acquisition.
- Provide a platform to conduct research and development with space debris data and to provide expertise to sensors and networks (such as in particular the Space Debris Study Group (SDSG) of the ILRS).

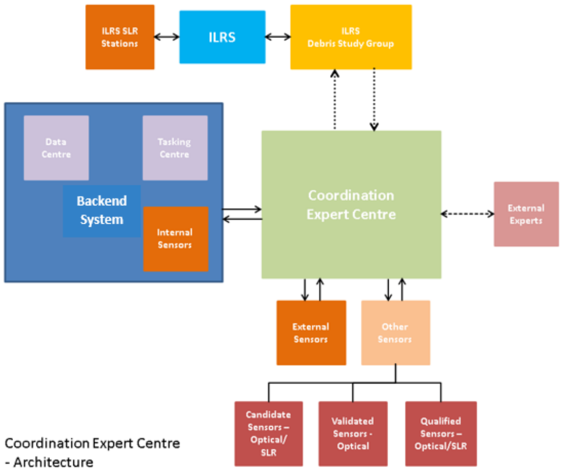

Figure 1 High-Level Architecture of Coordination Expert Centre

The interfaces reflect the large diversity of the connected entities which varies from web-services type (backend system – Expert Centre) to basic secured file transfer protocols (Expert Centre – Sensors, Expert Centre – Experts, Expert Centre – SDSG).

The first Expert Centre deployment was accomplished at ESOC in July 2017.

To properly validate the system, several observation campaigns were conducted. 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/range accuracy and epoch registration biases, as well as miss-correlation probability.

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

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

During the activity two sensors were validated and qualified (section 2.2):

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

2 EXPERT CENTRE USE CASES DEMONSTRATION VIA OBSERVATION CAMPAIGNS

Expert Centre functionalities have been already thoroughly demonstrated by participating in real observation campaigns with different objectives and where several sensors with different maturity level participated.

2.1 Coordination, calibration and data quality control

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 data processing and tasking systems developments in ESA. 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 Expert Centre was tasked to coordinate the contributions from the optical passive sensors that participated in the observation campaign. This proved to be an excellent opportunity to demonstrate all Expert Centre capabilities, and the first use to coordinate a backend system and external sensors. This observation campaign helped in identifying as well, the need of additional functionalities in future Expert Centre evolutions. During these tests, studying the networking of the external sensors in detail became a key topic; 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

As reported in [6] the emphasis during the campaign remained at gathering enough calibration observation to duly characterise the performance of participating sensors and at identifying possible biases.

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

- Tracking Sensors:
  - ESA OGS telescope (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

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 tool
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 backend system standard (in CCSDS TDM xml format) [8]

Expert Centre acting as the coordinator and expert entity supported during the identification of the list of objects to be observed by the tracking sensors, and provided expertise in the survey strategies definition aiming at acquiring more than one observation per object and night.

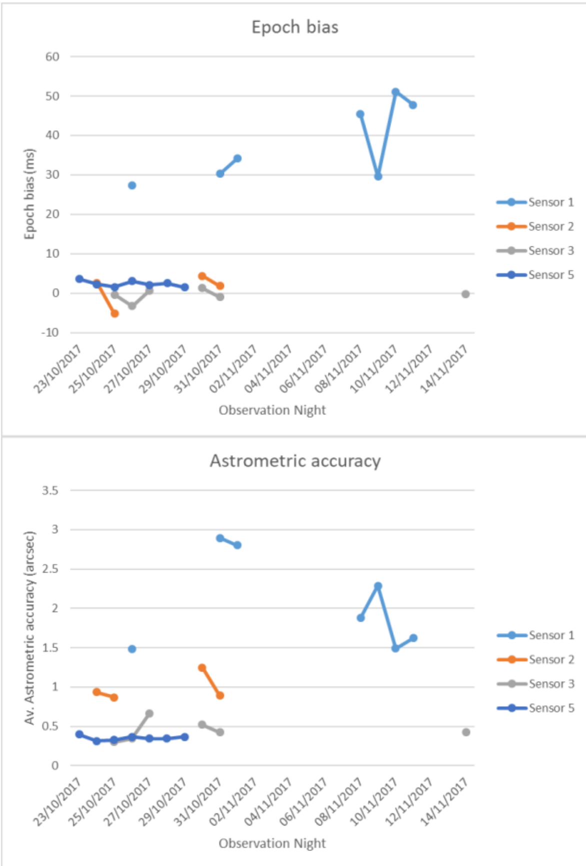

Figure 2 Daily quick-look assessment of epoch biases and astrometric accuracy

A total of 6628 tracks were observed during the test, and routine epoch bias and astrometric accuracy were assessed by the Expert Centre on a daily basis, providing feedback to sensor operators (Figure 2). 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 Expert Centre met all requirements to collect data and monitor SLAs, by assessing elements of agreed key performance indicators.

2.2 Validation and qualification of external sensors and provision of expertise

In this section we present the results of the qualification of two external sensors, Borowiec SLR station and ESA's TBT robotic telescope, following Expert Centre procedures. With those observation campaigns, the Expert Centre functionalities of provision of expertise, sensor calibration and qualification were demonstrated.

The Borowiec SLR station was proposed to be used to demonstrate the Expert Centre system capabilities to validate and qualify SLR sensor stations to track non-cooperative targets. The station went through the Expert Centre validation and qualification process, to demonstrate its upgraded SLR sensor ranging to non-cooperative targets capability [4].

The validation observation campaign consists in the estimation of its range bias based on known satellites. The candidate SLR station is requested to perform at least 3 full passes of either Lageos-1 or Lageos-2 satellites, and results are compared to Lageos IRLS provided reference orbits. The validation criteria establishes that the normal point accuracy evaluated from the passes match the specs of the station. Borowiec SLR station completed the full validation routine [7] for both Lageos-1 and 2 satellites, and the evaluation of the full rate data resulted in values in the order of 0.2 m for the mean, and 0.3m for the standard deviation (details of Lageos-1 first pass in Figure 3).

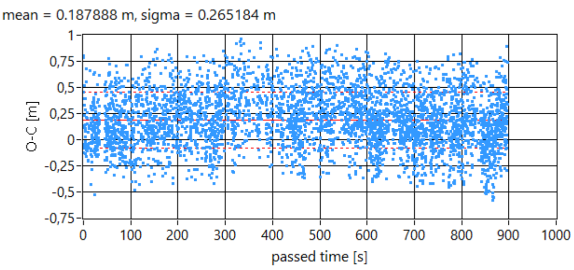

Figure 3 Observed-Calculated residuals for Lageos-1 observed by Borowiec SLR station

The qualification campaign consists in a more extensive campaign, requesting to the validated station to perform 5 observation sessions. The sensor is regarded as qualified if different criteria indicators, such as, minimum number of successful sessions, data quality in terms of normal points, success rate, response time and latency are fulfilled. Borowiec SLR station measured a total of 17 passes of debris targets within 5 successful observation terminators, and the evaluation of the full rate data resulted in the order of meters for the range bias and an RMS range data accuracy in the order of mm.

ESA's TBT robotic telescope was proposed to be used to demonstrate the Expert Centre system capabilities to validate and qualify optical passive sensors to track space debris. The station went through the Expert Centre validation and qualification process [4], [6], [7].

ESA's TBT telescope was requested to perform observations to GNSS satellites following the observation plan provided by the Expert Centre. Epoch bias and astrometric accuracy were then assessed with the data provided after annual aberration correction. The validation criteria is that at least 50% of tasked observations are accomplished with low percentage of miss-correlations.

The qualification campaign demonstrates that a validated sensor is capable repeatedly to observe objects in a selected orbital region. The qualification criteria is more restrictive that the validation one, requesting to perform a minimum of 3 observation nights and fulfilling certain performance numbers (reliable and stable figures) in data latency, efficiency, epoch bias and astrometric accuracy.

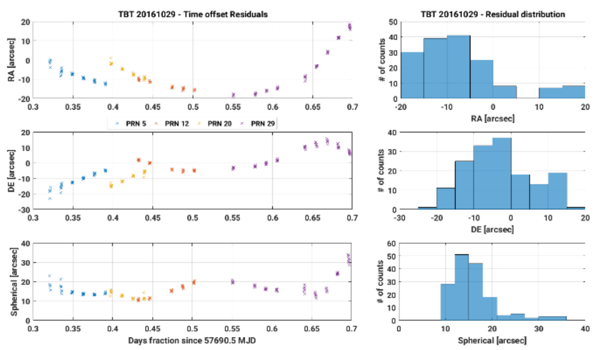

Figure 4 Residuals distribution for TBT validation night 2016-10-29

TBT has been found to be capable of providing data with an astrometric accuracy of 1 to 1.6 arcsec and a time bias in the order of 60ms [5]. While this result is already within the specifications, further improvements are assumed by the sensor operators as still possible and further investigation was proposed by the experts as the residuals showed trend (Figure 4).

3 ESA's TBT NEW IMPROVEMENTS AND EXPERT CENTRE SUPPORT

ESA's TBT Cebreros telescope was developed and deployed under ESA's General Studies and Technology Programme (GSTP) with the objective of implementing a test-bed for the validation of an autonomous optical observing system [9].

In previous sections we reported the support provided by the ExpCen during the validation and qualification campaigns, estimating an astrometric accuracy of 1 to 1.6 arcsecs and an epoch bias of 60ms.

An on-going ESA activity focused on networking capabilities of robotic telescopes foresees software and hardware improvements in TBT. The activity started beginning of June 2018 and after a successful PDR mid-September 2018 the works in TBT started. Software improvements and corrections agreed to be implemented comprise:

- scheduling automation including survey observation strategies,
- control software fine tuning,
- success ratio of the image processing software (ASAP)
- development of a Graphical User Interface (GUI) that will allow to monitor and control main telescope functions

Hardware enhancements will cover the installation of an Autonomous Emergency System.

Agile methodology is being followed. Sprint meetings are held every two weeks where the issues to be covered in that period are agreed. Every two sprints a formal delivery is done following a Continuous Integration - Continuous Delivery (CI/CD) process. After the delivery, one week is allocated to test that the deployment is correct. Following week, coinciding with the new moon, observation campaign is conducted to test the delivery. In order to track and check the consistency of the quality of data respect to the accuracy demonstrated by the Expert Centre in the past, GNSS observations are requested every night at the beginning of the observations.

Three observation campaigns attempts were tried since October. However new problems discovered (e.g. camera drivers) and weather conditions prevented to collect enough data for Expert Centre to re-calculate TBT's astrometric accuracy and epoch biases and no results can be presented in this paper.

Though no results and lessons learnt are available yet, this section describes a clear example where a system like the Expert Centre is of paramount and valuable importance, assessing the quality of the data in real-time after any change in the sensor and providing expertise in the identification of the source of any potential problem well in advance.

4 EXPERT CENTRE CURRENT STATUS AND FUTURE EVOLUTION

An on-going activity at ESA is leading further the first prototype deployed in 2017, pursuing to increase the performance of the system. At the end of the activity the system shall be ready to deal with a large number of heterogeneous and different maturity level sensors in parallel. For the remaining top-level performances needs, where the existing data centre backend system requirements can be directly converted into Expert Centre requirements, only the specification of the notification delays is needed for planned and unplanned unavailability periods and the availability of sensors and processing capabilities. Hence, performance requirements in terms of availability, data coverage and timeliness are in the process to be determined and, derived scalability requirements of the system will be identified to allow the system be ready to deal with a larger number of heterogeneous sensors in the future.

The activity is focusing as well on improving the interfaces, as part of the performance enhancement, and web-services interfaces with the backend system are being developed. Such kind of interfaces based on web-services 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.

Refinement and improvement in the validation and qualification procedures is expected as a natural consequence of the experience gathered during the observation campaigns and new sensors that will be requested to go through them.

A key functionality in Expert Centre is research and development. Several emerging needs are being analysed in both SLR and passive optics domain to be included, as light-curves data exploitation among others.

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 Expert Centre to a second and ESA-external site is foreseen at the end of the activity.

At the time of writing this paper, the activity is in CDR phase.

5 SUMMARY AND CONCLUSIONS

Expert Centres are an important part of an ESA's topology for space surveillance. Expert Centres act as a proxy between external sensors and the data processing backend. Hence, the Expert Centre can increase the performance of the coordination through a centralised scheduler meeting backend system, 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 in ESA's technology developments supporting the topology for European space surveillance systems.

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