ESA ACTIVITIES ON SATELLITE LASER RANGING TO NON-COOPERATIVE OBJECTS

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Satellite laser ranging (SLR) to non-cooperative objects is an emerging technology that can contribute significantly to operational, modelling and mitigation needs set by the space debris population. ESA is conducting various research and development activities in SLR to non-cooperative objects. ESA's Space Situational Awareness (SSA) program supports specific activities in the Space Surveillance and Tracking (SST) segment. Research and development activities with operational aspects are run by ESA's Space Debris Office.

We outline the motivation and objectives, as well as detail the current status of the various and parallel SLR-related SST and Space Debris Office activities at ESA. We provide an overview on plans for SLR activities in research and development, and for operational support. Current gaps in the standardisation of data exchange and sensor interfaces are addressed, reflecting the need of coordinating multiple stations in all tasks. This task is proposed to be provided through an expert centre, coordinating the contribution of SST system-external loosely connected SLR sensors, and providing back calibration and expert evaluation support to the sensors.

Operational support to ESA and third party missions is provided by the Space Debris Office. Currently, the office studies the potential benefits of laser ranging to resolve close approaches, to improve re-entry predictions, and during contingency situations, as well as the determination of attitude and attitude motion from a combination of radar imaging, optical and laser data.

Introduction

Today, Satellite Laser Ranging (SLR) of non-cooperative objects is an emerging technology. This situation is characterised by a push from new technologies becoming available for sensor and data processing. In addition there is a strong pull to support operational, modelling and mitigation needs set by the growing space object population.

We look in this paper in particular at the question how laser ranging data are expected to grow into an external contributor to a Space Surveillance and Tracking (SST) catalogue build-up and maintenance process, and also discuss some selected examples for addressing operational needs. We provide an update to a previous publication (Flohrer et al., 2015) that already introduced

ESA's Space Situational Awareness (SSA) programme, as well as reviewed satellite laser ranging in the SST context.

While this SST link addresses the need of coordinating multiple stations and providing back calibration and expert evaluation support to the sensors, ESA in parallel works on SCOOP as platform for collaborative (ad-hoc) multi-technique observations. SCOOP is essential as an ad-hoc mean to exploit the benefits of laser ranging in operations to resolve close approaches, improve re-entry predictions, to support contingency situations, and to determine attitude and attitude motion -combination of radar imaging, optical, and SLR. We briefly introduce SCOOP as a way to provide support to operational needs.

In a last section, we discuss the link with operational partners and SST systems calling for standardisation of data exchange and sensor interfaces.

Status of SST expert centre development

Flohrer et al. (2015) presented the outcome of an effort to analyse the benefits of a SST expert centre, the core set of requirements and draft system architecture. In 2016 the development activities have been started and the requirements have been re-visited to arrive at a matching system design.

The Space Debris Study Group (SDSG) has a task to define, establish and test calibration procedures for SLR stations for space debris measurements. As this task benefits from SST data, it seems natural that for this task the planning and data provision of the SLR stations is performed through an expert centre interacting with or inside the SDSG.

Another core benefit of the expert centre is the efficient coordination of external sensors, incremented by working with loosely connected SLR sensors (that may have proprietary formats and interfaces, different sensor capabilities and availabilities…etc). This leads into the need of a proxy between a backend SST system and the sensors to provide a single transparent interface for data acquisition, support services as calibration, research and technology development.

The previously identified benefits if an Expert Centre approach have been confirmed, and are the following:

- Data quality checks and applying consistent modelling, feedback to sensors
- Centralized scheduler meeting backend SST sensor status
- Standardisation of data exchanges (CCSDS Tracking Data Message and Navigation Data Message)
- Lower cost with better functionality and performance
- Expert support (calibration support) to the external sensors
- Provision of a test environment for advanced SST data processing techniques

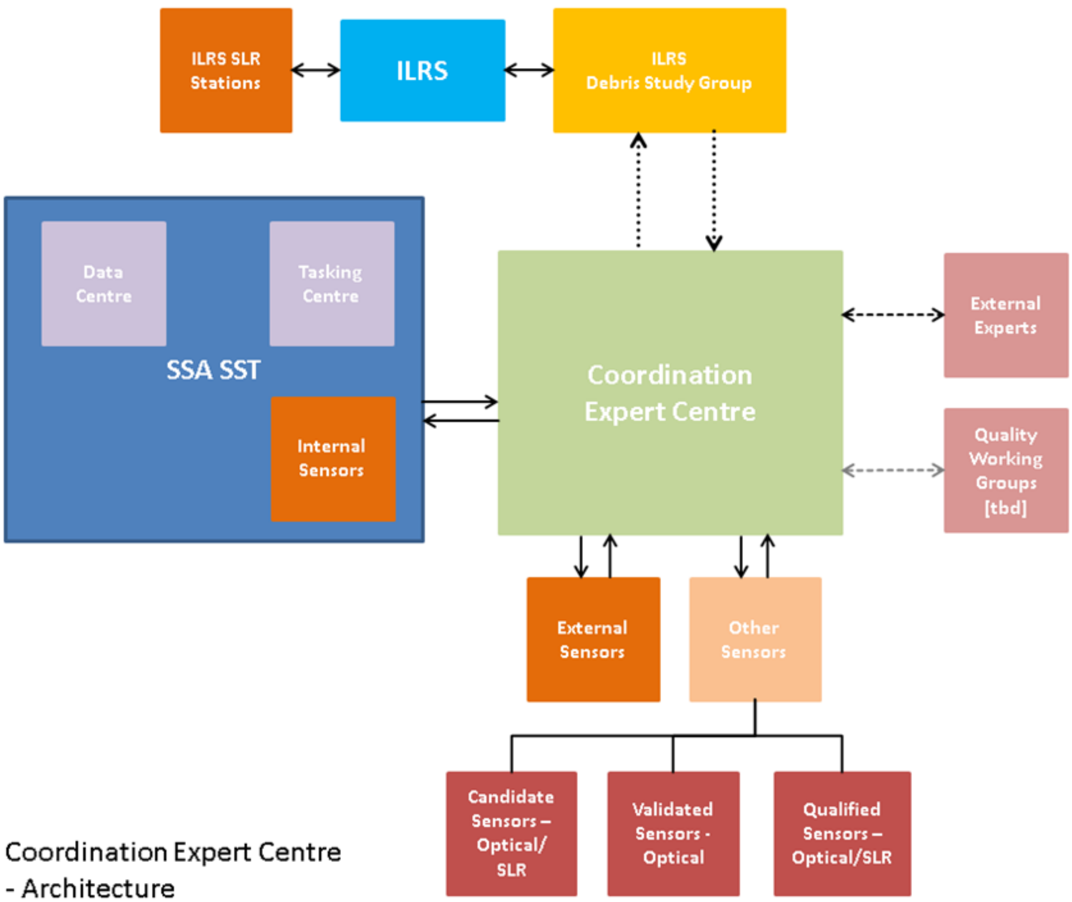

Figure 1 Expert Centre system architecture

The outlined benefits show that the Expert Centre will have two fold top level functions: operational and support functions. The operational functions are:

- Coordinate the sensors for tracking and surveillance tasks
- Qualify external data sources
- SLAs monitoring

The support function are:

- Calibration of sensors
- Evaluation of observation and data processing techniques
- Data quality control
- Expert support (considering both types of experts, internal and external to the Expert Centre, e.g. ILRS Debris Study Group)
- Research and development

Figure 1 depicts the high level interfaces between the Expert Centre, the backend SST system, and the internal and external (federated) optical and SLR sensors. It is important to bear in mind that this Expert Centre concept will be an external component to a SST system, and none of the central SST functionalities will be replaced, which of course calls for the difficult task of an efficient mitigation of duplication of observation requests.

The started first Expert Centre implementation phase aims at deploying in 2017 a combined centre for optical and laser ranging observations. A next implementation phase will follow and an extensive testing. This could, potentially, then split the centre in separate optical and SLR centres.

As of the time of the workshop the revisited benefits analysis, requirements consolidation, architecture and interfaces design consolidation and SW design are nearing completion and the software and procedure developments are progressing. A test campaign with passive robotic telescopes demonstrated already partially the approach.

The development activities are expected to continue in the period 3 of the SSA Programme (2017-2019) with the finalisation of the implementation, deployment, and extensive test campaigns with both optical and SLR sensors. In this testing all Expert Centre functionalities and performance will be validated.

On-going ESA Studies on SLR to debris

Flohrer et al. (2015) also addressed the core needs of satellite laser ranging in support to the satellite operations. The three key areas of current work, attitude and attitude motion characterisation, accurate orbit determination from tracking, and stare and chase, have all made great progress and all are subject to dedicated presentations at this workshop (Kucharski et al., 2015), (Steindorfer et al. 2015), (Sproll et al., 2015), and (Bamann et al., 2015). Therefore these recent achievements are not covered in detail in this paper, but briefly introduced.

Since 2015 the determination of attitude and attitude motion is subject of a study with a consortium led by the Astronomical Institute at the University of Bern (AIUB), the Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR), Hyperschall Technologie Göttingen (HTG) and the Austrian Space Research Institute (IWF) of the Academy of Science.

Together with SLR, passive optical and radar imaging observation techniques are exploited and a set of targets in LEO and GTO (spacecraft and upper-stages) have been observed. This collaborative approach is expected to provide the required input data for studying debris removal technologies and to develop mechanisms for a full investigation of the determination of the attitude motion vector and its evolution after spacecraft contingencies in order to support recovery actions and root cause analyses. The study develops a 6 DoF simulator for various force models, allowing to predict the attitude motion vector (Kanzler et al., 2015), called iOTA (In-Orbit Tumbling Analysis). The study looks into the long-term prediction of the attitude motion vectors of selected, repeatedly observed targets to calibrate predictions (see, e.g., Kucharski et al., 2016). It is very interesting to learn from these regular observations that, e.g., the spin period of Envisat: increases by 72 ms/day, doubles every 4 years, and will become equal to the orbital period (6000 s) in the year 2036.

Tracking space debris for operational needs is studied with the German Aerospace Centre (DLR), the IWF, and the Technische Universität München (TUM) that started in 2014 and will close early 2017 (Sproll et al., 2016). User and system requirements for the support of operations have been developed, hardware components have been designed, implemented and tested, and software algorithms supporting the execution of (single/multistatic) test campaigns have been implemented. The study demonstrates that space debris objects in LEO can be observed, with the goal to meet the needs of collision avoidance and re-entry predictions at ESOC. The on-going analysis (Bamann et al., 2016) focusses now at assessing and validating the underlying orbit determination accuracy. That will then allow to answer to core questions on the quantification of the benefits from active optical observations in supporting spacecraft operations.

A feasibility study for optimal observation strategies for "stare and chase" with GMV Spain and AIUB that looked into the principles to hand over detected unknown objects from (any) surveillance campaign to (any) tracking asset. While the original study needs have been set for radar systems, the goals have been extended to cooperate with IWF to look into a demo with SLR systems in 2015/16. As tracking cooperative targets is well established, it has been important to learn about the achievable data volume and metrics to assess the needed data quality vs. a-priori information needs. From the successful demo (Steindorfer et al., 2016) the study provided technical and operational requirements for hand-over between SLR and passive (co-located) sensors.

SCOOP as a way to provide support to data exchange

SCOOP is a platform for facilitating collaborative coordinated observations of spacecraft. The project aims at supporting multiple observation technologies, among them SLR. The need for the development is based on requirements from scientific space debris observer and modelling communities (e.g. in the Inter-Agency Space Debris Coordination Committee (IADC)) for coordinated, collaborative, observations of selected objects, as well as from previous experiences from contingency situations. In these situations a rapid coordination with many very different contributors is needed.

SCOOP provides the design and a first implementation of a prototype web-based platform, hosted by ESA. SCOOP has access to services in backend, allowing also to try out new methods in orbit determination, pass prediction, and data correlation easily.

The SCOOP development includes dedicated user workshops to obtain feedback on the developed prototype and use this for optimizing the design.

The project started in Nov. 2015 and a first user workshop has been held in January 2016. The followed agile development approach allowed having a first alpha version of the frontend ready in April 2016, which is now under full development and saw the Critical Design Review in November 2016. A larger test campaign is now planned, followed by a second workshop with the user community. It is planned to involve more the SLR community in the test and workshop, as concrete needs for better coordination, e.g., of ad-hoc campaigns, have been identified in discussions with system operators.

Figure 2 gives the interfaces and general architecture of SCOOP, composed of a front-end and back-end. The supported data formats are those of the ILRS, but also, as set by the spacecraft operators, these from the CCSDS.

PP	Pass prediction
OEM	Orbit ephemeris message
CRD	Consolidated laser ranging data format
CPF	Consolidated prediction format
TDM	Tracking data message
TLE	Two-line elements
DB	Database

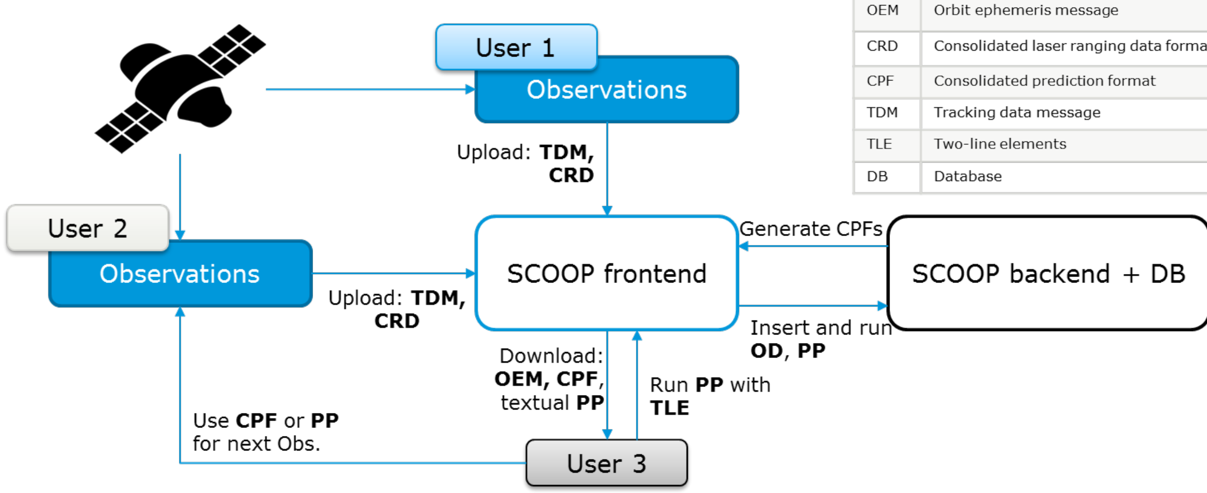

Figure 2 SCOOP Interfaces for collaborative observations with three different user scenarios.

Figure 3 gives a preview of the web-based interface to the user. A Gantt-type window for observation opportunities, “booked passes” that the user intends to cover, and a log of previous data contributions are displayed in the centre. The right column shows user information and a activity indicator that can be controlled by the organiser of the observation campaign. The left column gives access to all projects or campaigns in which the user participates.

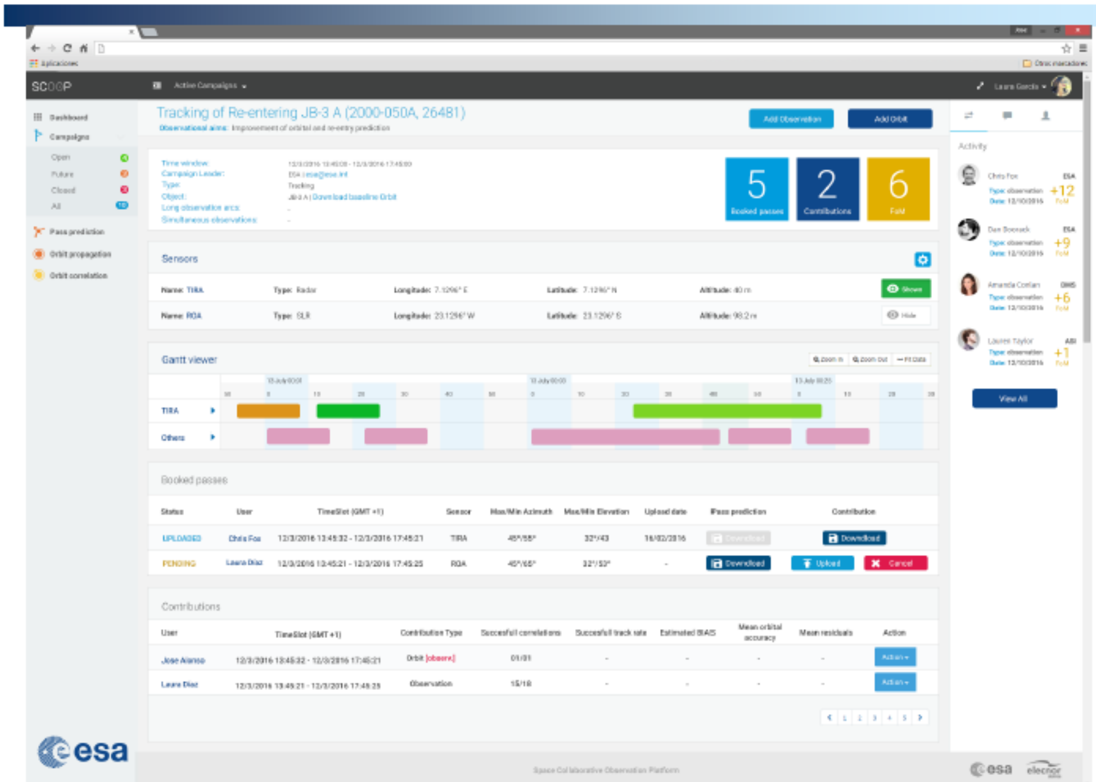

Figure 3 SCOOP screenshot for an example tracking collaboration (simulated data).

Standardisation

The Consultative Committee for Space Data Systems (CCSDS) provides “the language” for the data exchange among satellite operators. In general, CCSDS data formats are also adopted as ISO standards.

Adopting CCSDS data formats is emerging also for Space Surveillance and Tracking needs, with a prominent example the Conjunction Data Message. Further, the CCSDS data formats for orbit and measurement data exchange have been selected for ESA’s SSA program development in the area. New ideas for describing sensor systems and sensor scheduling are being discussed today.

It is therefore recommended that the SLR community interested in tracking space debris contributes with their views to the further development of CCSDS data formats. Hot items calling for support are currently covering the specifics of laser ranging in CCSDS messages (e.g. Tracking Data Messages, and ECEF Ephemeris), and the awareness of stations to track objects from Orbit Data Messages, either states and ephemeris. Of course it is not intended to interfere with the decades of experience and successes in the ILRS on interfaces and converters, but rather, to approach to the SST and satellite user community. The proposed SST Expert Centre could be a potential catalyst for related tasks.

Summary and Outlook

ESA continues to support technology developments and demonstration of laser ranging to uncooperative targets in the frame of the SSA programme and for operational mission support and for space debris research.

Key areas are the further development of SLR Expert Centre under SSA/SST, the development of SCOOP as a possible way to exchange data ad hoc for operational support and research. There is a very promising outlook in further exploiting the SLR support to determining the attitude and attitude motion of spacecraft, in tracking of non-cooperative targets, and success in applying 'stare and chase' observation strategies. SLR support could also be useful in planning and operating future active debris removal missions, either through tracking or contribution to attitude determination.

Standardisation efforts need to promote and provide feedback for laser ranging applying the CCSDS messages (especially for SLR data provided as Tracking Data Message).

Further research ideas on research and challenges could be set by answering the following questions:

- How can SLR help to track and discriminate and identify multiple releases of small satellites?
- Is there a way for laser-induced collision avoidance?
- Which new sensor technology developments are upcoming that are relevant for addressing space debris observation needs?
- How can SLR (ranging) data support correlation tests in SST data processing?

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