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Laser ranging initiatives at ESA in support of operational needs and space surveillance and tracking

B. Jilete (1), A. Mancas (2), T. Flohrer (3), H. Krag (4),
(1) GMV@ESA/ESAC, Space Surveillance and Tracking Segment,
ESA Space Situational Awareness Programme. beatriz.jilete@esa.int
(2) GMV@ESA/ESOC, Space Surveillance and Tracking Segment,
ESA Space Situational Awareness Programme. alexandru.mancas@esa.int
(3) ESA/ESOC, Space Debris Office and co-lead Space Surveillance and Tracking Segment,
ESA Space Situational Awareness Programme.tim.flohrer@esa.int
(4) ESA/ESOC, Head of Space Debris Office and co-lead Space Surveillance and Tracking Segment,
ESA Space Situational Awareness Programme. holger.krag@esa.int

Abstract. *This paper describes the current and upcoming laser ranging initiatives at ESA's SSA Programme and at ESA's Space Debris Office. The concept of an Expert Centre facilitating the SSA space surveillance and tracking (SST) segment's use of laser ranging data from external sensors is detailed. Other on-going SLR projects include attitude and attitude motion determination, studying 'stare and chase' strategies, and tracking space debris. Finally, future activities are presented, such as testing and validating existing European SLR sensors for SST observations.*

Introduction

The objective of ESA's Space Situational Awareness (SSA) programme is "to support the European independent utilization of and access to space for research or services, through providing timely and quality data, information, services and knowledge regarding the environment, the threats, and the sustainable exploitation of the outer space" (ESA, 2008).

The high-level users' needs for the European SSA system, expressed by the SSA user group during its meetings in 2006-2008, can be summarised as (ESA, 2008):

- support safe and secure operation of space assets and related services
- support risk management (on orbit and during re-entry)
- assess the status and basic characteristics of space objects (both human-made and natural)
- support the assessment of compliance with applicable international treaties and recommendations
- enable the allocation of responsibility for space objects to organisations (ESA, Member States, etc.), and support confidence building measures (identification of owner and/or operator).

To meet these needs, ESA's SSA System comprises three segments: Space Surveillance and Tracking (SST) of man-made space objects, Space Weather (SWE) monitoring and forecast and Near-Earth Objects (NEO) search and tracking.

Space Surveillance and Tracking is required to maintain awareness of the population of man-made space objects. The SST segment today aims to provide research and development for high-level services to users: object cataloguing, conjunction risk analysis, re-entry prediction analysis, fragmentation analysis, special mission support, sub-catalogue characterization and mission characterisation (Krag, 2010). Today, ESA and European national space agencies are dependent on surveillance data from non-European (mainly US sources) for several applications, such as: conjunction prediction, fragmentation analysis, special mission support and mission characterization (Krag, 2010).

The exploitation of external space surveillance data is outside the scope of the SSA programme, and operational support to missions is provided through ESA's Space Debris Office.

The SST segment is foreseen to use both internal (sensors owned and operated by the segment) and external sensors. External sensors are owned and operated by other entities (universities, research centres, national agencies, commercial operators, etc.) and provide data to the SST segment based on a data-sharing agreement. The Expert Centre concept for SST was developed to facilitate this data exchange and to provide a common interface between the SST segment and external sensors. In addition, it can also provide external expertise to the SST segment, and provide feedback to the sensors. The ESA SSA programme has already set-up coordination or expert centres for the Space Weather and NEO segments.

The ESA Space Debris Office develops and maintains an infrastructure supporting ESA's commitment to space debris mitigation and risk reduction. Its activities include developing and maintaining debris environment and risk analysis tools (e.g. MASTER, DRAMA), acquisition and processing of measurement data, operational support to ESA and 3rd party missions, debris research, engineering support and promoting public awareness of space debris issues.

Satellite laser ranging in the SST context

Satellite Laser Ranging (SLR) of uncooperative objects is an emerging technology (Green, 2002), (Kirchner, 2013). The resulting data may be an external contributor to SST catalogue build-up and maintenance. There is interest in the SSA programme and the participating ESA member states to promote R&D, demonstration and evaluation activities for laser ranging sensors. SLR research and development is motivated by the new possibility of actually tracking debris objects, to resolve close approach situations to active satellites, to improve re-entry predictions and to provide support during contingency situations.

SLR activities are, in general, coordinated under the International Laser Ranging Service (ILRS) (Pearlman, 2002). The ILRS is responsible for providing the global satellite and Lunar laser ranging data and several data products to support research activities. The ILRS Networks and Engineering Working Group (NEWG) seeks to improve and optimize the input-output functions and products of the ILRS network by working closely with the data analysis community and the individual laser ranging stations. Its primary responsibility is to facilitate the generation, collection and distribution of data in a timely and efficient manner to the user community while meeting the data quality and quantity requirements. In October 2014 the ILRS, on request of Georg Kirchner (IWF), established the Space Debris Study Group (SDSG). The ILRS defined several primary tasks for the SDSG, including sensor calibration. It will be the task of the SDSG to define, establish and test calibration procedures for SLR stations for space debris measurements. In this case the planning and data provision of the SLR stations to a SST system will best be performed trough an expert centre interacting with or inside the SDSG.

Working with external SLR sensors creates additional overhead for the SST segment, as proprietary formats and interfaces, different sensor capabilities and availabilities are involved. For example the ILRS uses its own formats for data exchange, while the SSA system will use the formats developed by the Consultative Committee for Space Data Systems (CCSDS). Therefore the main task of the Expert Centre is to be a proxy between the SST segment and the sensors and to provide a single transparent interface for data acquisition, support services, research and technology development. In any case the architecture foresees that the Expert Centre is always external to the SST system and will not replace any core SST functionality.

Benefits of a SST expert centre, requirements and draft system architecture

A benefits and requirements analysis under ESA contract found that there are several benefits from the outlined Expert Centre approach:

- Lower cost with better functionality and performance: the SST segment does not have to deal with each sensor individually, but can simply send the same consistent type of requests to the Expert Centre.
- Expert support to external sensors: most SLR sensors in Europe are experienced in tracking cooperative targets, but are not yet as familiar with tracking non-cooperative targets or with SST needs. The Expert Centre can act as a 'repository of knowledge' for laser tracking on non-cooperative targets (mainly space debris) and for how to optimise their operations for SST.
- Data quality checks with consistent modelling: the Expert Centre will qualify all the data provided to the SST segment, and use the same tools and models to do so. Feedback to the sensors is considered important.
- Centralised scheduler meeting backend SST sensor status: observation scheduling can be centralised, either in the Expert Centre or, alternatively, in the SST segment's Tasking Centre. The Expert Centre can provide the Tasking Centre with the availability periods of the external sensors and the Tasking Centre can schedule the observations as if they were internal sensors. The observation request are then sent to the Expert Centre, which converts them to the appropriate format and sends them to the sensors.
- Standardisation of data exchanges: the Expert Centre can promote the use of standard data exchange formats (e.g. CCSDS Tracking Data Message or the Navigation Data Messages).
- Provision of a test environment for advanced SST data processing techniques: the Expert Centre can use external experts to test new data processing techniques/algorithms/etc.

The identified benefits stipulate that the Expert Centre will have operational and support functions. The operational functions are to coordinate external sensors for tracking and, potentially, survey tasks, qualify external data sources and monitor service-level agreements. Support functions are sensor calibration, 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), and research and development.

The first Expert Centre implementation phase will deploy a combined centre for (passive) optical and laser ranging observations as a hybrid. Future implementation phases could split the centre in separate optical and SLR centres. Figure 1 presents the high level interactions between the expert centre, the external sensors and the internal sensors (Flohrer, 2016).

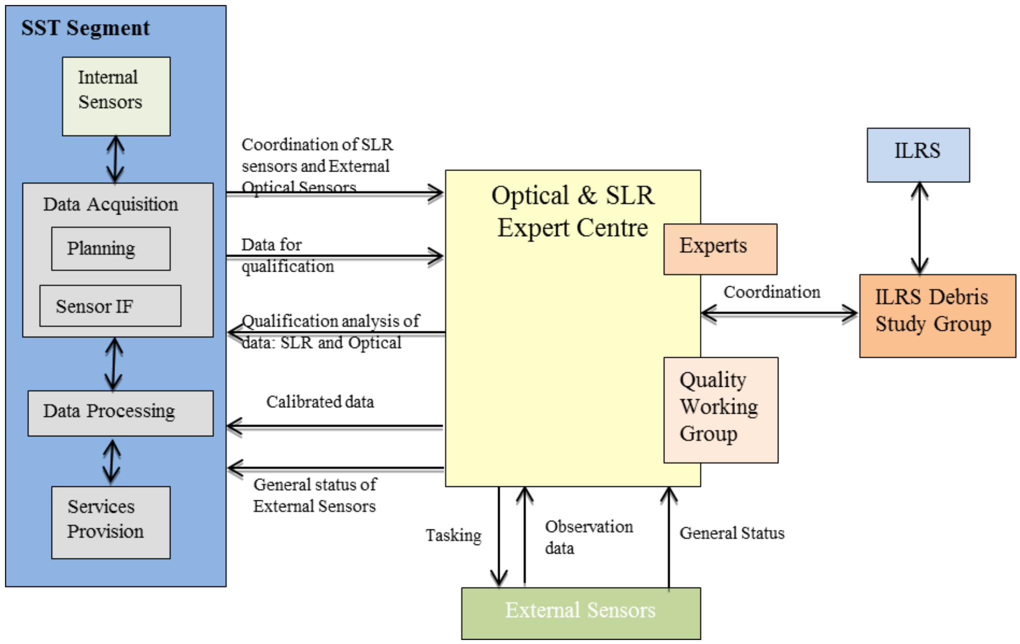

Figure 1. Expert Centre system architecture.

ESA has already studied working with external sensor data to a larger extend in the SST segment. Test campaigns using radars, optical telescopes and laser ranging (in particular with the SLR station in Graz) have been conducted successfully (Kirchner, 2013). During 2013, the Austrian Academy of Sciences in Graz performed a laser ranging and tracking experiment together with three other stations: Zimmerwald, Wettzell and Herstmonceaux, which covered around 60 objects and aimed at understanding the general capabilities of that observation technique and to learn about data formats and interfaces.

During the campaign, Graz ranged to space debris in single, bi- and multi-static mode. In all 3 modes, Graz tried to record echoes from the targets. The other 3 stations participated when weather allowed. About 140 passes of 60 objects in distances from about 500 km up to more than 3000 km was tracked, during early evening sessions of each 2 to 3 hours. A sample of these passes is shown, to indicate the variety in Radar Cross Section, elevation and distances:

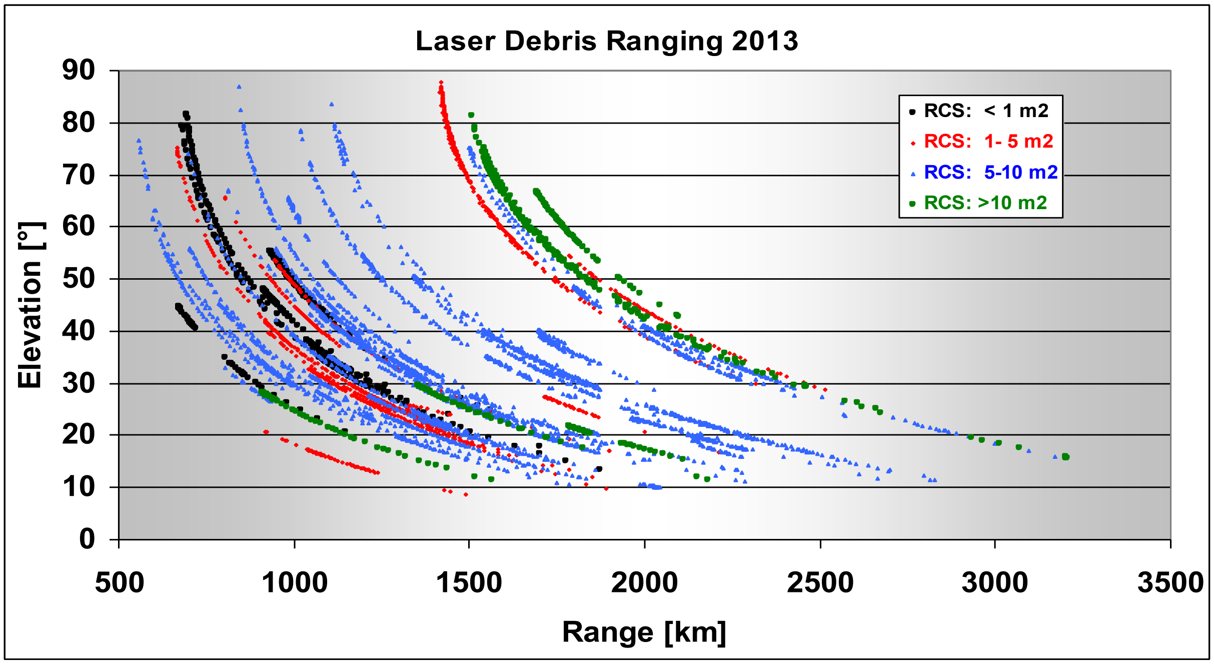

Figure 2. Graz laser debris ranging during 2013 campaign

Satellite laser ranging in the Operational support context

Operational support activities are within the responsibility of ESA's Space Debris Office. Current activities using SLR observations are contributing to the determination of the attitude and attitude motion of debris (uncooperative objects) in combination with light-curve and radar imaging data, tracking space debris to address operational challenges, and 'stare and chase' observation strategies definition to prepare the ground for future research and development activities. These activities may also contribute to improve space debris environment models, but are mainly focussing at a better understanding of larger space debris objects in the operational context.

The Space Debris Office, together with 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, are investigating using SLR, passive optical and radar imaging to determine the attitude state and motion of targets in LEO and GTO. The project aims to provide representative data sets to help select removal technologies and to develop mechanisms for determining the attitude state for spacecraft contingencies. A 6 DoF simulator is being developed and collaborative attitude measurements are being performed, which will enable the development and calibration of attitude prediction tools. Calibration can be achieved by performing long-term predictions for selected objects and comparing them with observation data.

The accurate orbit determination of space debris using laser tracking, studied together with the German Aerospace Centre (DLR), the Astronomical Institute at the University of Bern (AIUB) and the Technische Universität München (TUM), covers the developing hardware components and software algorithms and test campaigns (both single- and multistatic). The goals are to show that: space debris in

LEO can be observed and tracked and to demonstrate that the data acquired can support operational needs, such as collision avoidance and re-entry predictions.

Considering SLR data is also useful for defining ‘stare and chase’ observation strategies. These kind of strategies are based on a scenario where an unknown object (uncooperative targets for example) is detected in an optical or radar surveillance campaign and a co-located or near-by tracking device is commanded immediately to track the object before the pointing information is inaccurate. On-going activities at ESA aim at understanding the feasibility of SLR follow-up of optical fence detections and at the technical and operational requirements for hand-over between (co-located) SLR and optical sensors.

Experience gained in previous activities, also including ad-hoc scenarios, includes support for the collection of laser ranging measurements quickly after spacecraft failures, especially for contingency support. Possible SLR support for a future active debris removal missions, either through tracking or contribution to attitude determination, is also considered today.

Future key SLR areas in SST and in support of operations at ESA

Future laser ranging activities in SST will address testing and validation of current sensors for SST observations, hardware and software research and development and further developing the SLR Expert Centre (stand-alone or as part of an hybrid expert centre with optical sensors). There is a growing interest in qualifying existing sensors for SST observations and closing any existing performance gaps.

Operations-related research projects for SLR will focus on several topics, such as:

- Tracking and discriminating multiple and smaller satellites using laser ranging.
- Studying orbit determination methods and conduction tests specific for laser ranging under stare and chase scenarios, and investigating whether SLR can support data correlation tests in SST.
- Studying aspects and feasibility of laser-induced collision avoidance.

Summary and conclusions

ESA has a demonstrated interest in laser ranging to uncooperative targets in the frame of the SSA programme and for operational mission support and for space debris research. On-going research and development projects include developing an SLR Expert Centre under SSA/SST, possibilities and limits in providing operational support, support in determining the attitude and attitude motion of spacecraft, and ‘stare and chase’ observation strategies. Upcoming SST activities will focus on testing and validating existing sensors, too.

Using data from external sensors in the SST segment needs efficient interfaces, coordination and monitoring, sensor evaluation and calibration. These are to be best covered by the SLR Expert Centre. In addition, the Expert Centre will support SST research and development, standardisation and provide access to external expertise.

Spacecraft operations may benefit from SLR data for supporting collision avoidance, re-entry support and contingency resolution, but more demonstration activities are needed here. SLR support could also be useful in planning and operating future active debris removal missions.

Standardisation is one area where further work is needed, both in improving laser ranging support in the widely used CCSDS messages (especially the tracking data message that is central for SST) and in promoting CCSDS standards knowledge among the SLR community.

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