SSA Technology Development Status for LEO Observations at the German Aerospace Center (DLR)

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ABSTRACT

Todays established radar capabilities are the backbone of satellite monitoring and orbital debris detection for SSA around the world. However, passive and active optical systems using lasers can provide additional and unique object information in terms of orbit, attitude, shape, material composition, and activity status. Within the past 3 years, the Institute of Technical Physics of the German Aerospace Center (DLR) has built an optical observatory at a site located 60 km South of Stuttgart (Germany). The site provided necessary infrastructure and fulfilled security requirements. Furthermore, light pollution is at a much lower level compared to the previously operated station within Stuttgart city. The project started in May 2019 and site acceptance test was successfully completed in October 2021. Three main SSA topics will be addressed at the newly built observatory: passive (camera) observations, active laser ranging, and spectral analysis of satellites and space debris. The observatory building including slit dome is 15 m in height and has 2 levels. Level 1 serves as lab space with 2 optical tables and additional electronic racks and level 2 is the telescope level. The 1.75 m telescope (f/6 Ritchey-Chrétien design) with Coudé path option serves as main component for satellite laser ranging, space debris detection, and SSA technology development in the near-infrared spectral region at the observatory. Four Nasmyth ports at the telescope can be selected by rotation of the tertiary mirror of the telescope and enable object analysis using various detectors during a single object flyover. A piggy-back installed astrograph with an aperture of 40 cm and a field of view of 2.4° provides additional guidance of the main telescope and supports initial orbit determination of unknown objects. Efficient eye-safe lasers based on solid-state and fiber technology in the near-infrared spectral region (1400-1700 nm) are being deployed for ranging and backscatter measurements. The light of the 1.75 m telescope can be fiber-coupled and guided to a grating spectrograph for object composition measurements and cataloguing. Prior implementation to the observatory, all optical and electronic components including lasers and detectors are tested and specified at the institute labs. Additionally, a transportable laser ranging station is co-located at the observatory site to enable bi-static laser ranging measurements to satellite and space debris. It can be deployed and operated within a few hours to a new location and is fully remotely controllable. The transportable station has the size of a standard ISO-container and features an on-board laser system, a 43 cm aperture receiver telescope, and an electronics system for satellite and space debris laser ranging. Furthermore, synergies of radar and laser ranging SSA technologies are investigated within the course of this project. We believe that radar could provide initial object orbit information followed by a more precise laser ranging measurement (radar to laser handover). This contribution presents the development and current operational status of the observatory and transportable laser ranging station and demonstrates selected object tracking, passive observations, and active laser ranging capabilities of satellite and space debris in low Earth orbit (LEO). Furthermore, radar and laser station handover strategies for initial orbit determination are discussed.

1. INTRODUCTION

Due to increased space traffic by commercial, military, and research activities [1], space situational awareness (SSA) programs gained significant importance over the past decade. Especially the space debris situation in low Earth orbit (LEO) is dynamically changing. Therefore, knowledge and monitoring of orbits, origin, and material properties of LEO objects are of high importance. Although radar serves as the backbone of the available SSA infrastructure, optical technologies show significant advantages in terms of achievable accuracy and detection limit. However, both radar and optical sensor networks can jointly provide the required information needed for critical mission planning and also to stay operational with own space assets.

This contribution describes the latest SSA developments at DLR TP with its recently built ground-based station (Johannes Kepler observatory, JKO) and transportable station (Surveillance, Tracking and Ranging Container, STAR-C).

2. JOHANNES KEPLER OBSERVATORY

As DLR's local satellite laser ranging station UFO (Uhlandshöhe-Forschungs-Observatorium, Stuttgart, Germany) reached its capacity limit, DLR TP started the development of a future ground-based station for SSA technology development in late 2018. The basic project concept called MS-LART (MS-LART: Multi-Spectral Large Area Receiver Telescope) featured a telescope (>1.0 m primary mirror) with building including dome.
Project kick-off was in May 2019 and the original concept was upgraded to a telescope with a primary mirror of 1.75 m. Final design review of the project was in November 2019. Selected telescope site is located 60 km South of Stuttgart (Empfingen) within commuting distance to DLR TP institute, and observatory building construction started in July 2020. The 1.75 m telescope (Astro Systeme Austria (ASA) AZ1750) was delivered in December 2020 and installed in the observatory dome in March 2021. Site acceptance test was successfully completed in October 2021. Fig. 1 shows the AZ1750, and Tab. 1 lists JKO telescope specifications. In July 2022, the observatory (Fig. 2) was inaugurated and named after Johannes Kepler (1571-1630) who was born in the close-by city of Weil der Stadt.

Fig. 1. 1.75 m telescope of DLR's Johannes Kepler observatory (JKO).

Tab. 1: JKO telescope configuration.

Parameter	Specification	Comment
ASA AZ1750		JKO main telescope
Optical design	Ritchey-Chrétien	
Aperture	1.75 m	
Focal ratio	f/6	
Image field[a]	150 mm	0.82 deg.
Field of view[b]	~0.1 deg.	
ASA H400		mounted piggy-back
Optical design	Hyperbolic	
Aperture	40 cm	
Focal ratio	f/2.4	
Image field[a]	70 mm	4.2 deg.
Field of view[b]	~2.4 deg.	

Image field[a]: max. image field provided. Field of view[b]: dependent on camera sensor size and optional optics, e.g., focal reducer.

3. TRANSPORTABLE SATELLITE AND SPACE DEBRIS LASER RANGING STATION

STAR-C (Surveillance Tracking and Ranging Container) is a transportable development system for S(D)LR SSA technology in LEO [2]. STAR-C (Fig. 2, left) can be fully remote-controlled, and main specifications are summarized in Tab. 2. STAR-C can be deployed and operated within a few hours at a new location.

Fig. 2. Transportable station STAR-C (container with elevated telescope mount platform, left) and ground-station JKO (building with dome, right).

Tab. 2: Specifications of STAR-C[a].

Parameter	Specification	Comment
System platform		
Dimensions	20 ft ISO container	
Mass	10 tons	
Power	<4 kW	
Laser systems		
Wavelength	1064 nm, 1645 nm	Independent laser systems
Average power	50 W, 18 W	
Pulse length	10 ns, 65 ns	
PRF[b]	1 kHz, 1 kHz	
Beam profile	Gaussian	
Transmitter		
Telescope dia.	5 cm	
Receiver		
Telescope dia.	43 cm	
Detector type	InGaAs SPAD	
Detector QE[c]	>20%	1064 nm, 1645 nm
DAQ		
Event timer	<5 ps resolution	Time interval analyzer card
GPS	Time synchron.	

STAR-C[a]: [2] for detailed system description and specifications, PRF[b]: pulse repetition frequency, QE[c]: quantum efficiency.

Currently, STAR-C is co-located at the observatory site to enable bi-static laser ranging measurements to satellites and space debris in LEO. In bi-static configuration, STAR-C serves as transmitter and JKO is used as large receiver telescope.

4. SSA TECHNOLOGY DEVELOPMENT FOR LEO

SSA technology development for satellites and space debris in LEO at DLR TP involves mainly three topics: passive observation technology, active satellite and space debris laser ranging technology, and spectral analysis of satellites and space debris. LEO SSA technology development strategy is depicted in Fig. 3.

Passive optical observation technology uses optical telescopes to detect and monitor satellites and space debris and their environment. Measurements of light curves can contribute to rotational state and attitude information.

Active optical observation uses lasers to determine range information of satellites and space debris. In contrast to common laser technology used, e.g., at the ILRS (International Laser Ranging Service), DLR TP focuses on the deployment of lasers in the spectral region of 1100-2000 nm, and implementation of eye-safe lasers and latest detector technology including data acquisition. Obtained ranging data can be used for orbit verification of known objects and orbit determination of uncatalogued LEO objects.

Spectral analysis covers reflection spectroscopy of satellites and space debris. The reflected sunlight of the satellite and space debris is received and guided to a grating spectrometer using an optical fiber. Obtained spectral information can be used to classify satellites and space debris. Additional laboratory measurements at DLR TP are conducted to investigate space aging effects on common materials, e.g., aluminum, solar panels, and MLI foil.

Prior implementation at JKO and STAR-C, electro-optical parts, lasers, and detectors are specified and tested at the laboratories of DLR TP institute in Stuttgart (Germany).

Deployment of STAR-C to perform bi-static measurements at a field campaign is planned for late 2023.

Besides the technology development at JKO and STAR-C, simulations are performed to investigate synergies of radar and optical sensor (especially S(D)LR) technology. As a use case, radar can provide initial object orbit information followed by a more precise laser ranging measurement (radar to laser handover). Hybrid network simulations and definition of interfaces is ongoing and we find that combined radar and S(D)LR networks should be extended and further optimized to serve increased demands in LEO operations.

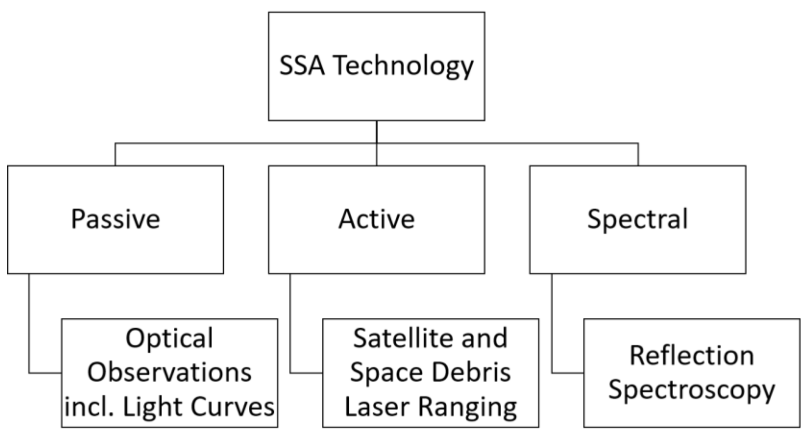

Fig. 3. SSA technology development strategy.

5. SUMMARY, STATUS, AND OUTLOOK

Within the past 3 years, the Institute of Technical Physics of the German Aerospace Center (DLR) has built an optical observatory (JKO) at a site located 60 km South of Stuttgart (Germany) for SSA LEO technology development. Additionally, a transportable station (STAR-C) is available for bi-static S(D)LR measurements. System implementation at JKO has begun in 2022 and passive observation capability is available at the time of writing. S(D)LR measurements will be available early 2023 and first spectral measurements will be conducted late 2023.

6. ACKNOWLEDGMENT

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7. REFERENCES

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