Mobile Station for Orbit Determination of Satellites and Space Debris

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ABSTRACT

Initial orbit determination of satellites and space debris is of major interest for satellite operators and agencies with critical infrastructure in low Earth orbit (LEO). At DLR, a mobile platform is under development for the surveillance, tracking and ranging of LEO objects (STAR-C). The mobile platform has the size of a 20 ft ISO container with a mass of 10 tons. The container is divided into an air-conditioned operator and laboratory section and a transceiver section containing laser, transmitter, and receiver telescopes. For station operation, the sliding roof of the transceiver section is retracted, and the platform with an Alt-Azimuth mount is elevated to the height level of the container. The laser ranging system consists of a fully diode-pumped Nd:YAG laser at 1064 nm with a single-pulse energy of 50 mJ at a pulse-repetition frequency (PRF) of 1 kHz. The beam is guided through a Coudé path to the 2 in. transmitter telescope. The receiver consists of a 17 in. telescope. The backscattered signals are detected using an InGaAs SPAD and processed with a GPS-synchronized event timer. A camera is used to detect LEO objects during twilight and to guide the Alt-Azimuth mount for laser ranging. For laser safety, the airspace is monitored during station operation using a thermal imaging camera and compared with data from air traffic control. It's planned to operate the mobile STAR-C station fully remotely in populated areas with busy airspace. For this purpose, a high-average power eye-safe laser system will be integrated in the near future.

1 INTRODUCTION

ESA's annual space environment report 2019 [1] shows more than 12,000 objects in low Earth orbit with perigee and apogee height < 2,000 km. Due to NewSpace activities and planned mega constellations, it's expected that the number of active satellites in LEO will increase by another 12,000 by 2027. To ensure mission safety and secure space assets, suitable technologies have to be developed to determine and verify the orbit of satellites and space debris. Satellite laser ranging (SLR) [2] can provide the required precision and accuracy for orbit determination. While the International Laser Ranging Service (ILRS) [3] tracks a limited number of satellites for geodetic applications, a cost-effective and autonomously operated station for satellite and space debris laser ranging (SLR/SDLR) can deliver the required orbit data. Furthermore, a global SLR/SDLR station network could improve data quality and would be independent of cloud cover. In order to fulfill the internal requests at the German Aerospace Center (DLR) and of other agencies, a mobile SLR/SDLR station development was initiated in 2016. This contribution lists requirements (Section 2), describes the mobile station setup (Section 3), and reports the current status with a summary and outlook in Sections 4 and 5, respectively.

2 REQUIREMENTS

The SLR/SDLR measurement principle is based on the flight time measurement of laser pulses [2]. Short laser pulses are emitted and the photons are scattered at the satellite or space debris. The backscattered photons are collected using a receiver telescope and guided to a detector connected to a fast data acquisition system, e.g., event timer. The requirements for a SLR/SDLR system are listed in Tab. 1 and the specifications have been determined using SLR/SDLR link budget calculations [2].

Table 1: SLR/SDLR system requirements.

Parameter	Specification	Comment
Laser		
Laser type	Nd:YAG, Nd:YVO_4	diode-pumped solid-state laser
Wavelength	1064 nm	-
Average power	10 W	50 W for space debris
Pulse length	ns	ps
PRF[a]	1 kHz	50 kHz burst mode [4]
Mode operation	single mode	preferred
Emission width	-	not critical
Spectral Tuning	-	not critical
Beam quality	M^2: 1.5	-
Beam profile	Gaussian	-
Transmitter		
Telescope dia.	2 in.	10 in. in preparation
Receiver		
Telescope dia.	17 in.	Ritchey-Chrétien
Detector type	InGaAs SPAD	-
Detector QE[b]	> 20%	at 1064 nm
DAQ		
Event timer	<5 ps resolution	-
GPS synchron.	-	not critical

[a]PRF: pulse repetition frequency, [b]QE: quantum efficiency.

3 MOBILE SLR/SDLR STATION SETUP

The setup of the mobile container platform and key units are presented in the following subsections.

3.1 Mobile Container Platform

Figure 1 shows the mobile container platform for the SLR/SDLR station for surveillance, tracking and ranging (STAR-C). The 20 ft standard container with an overall weight of 10 tons is divided into an air-conditioned operator and laboratory section (Fig. 1, left), and a transceiver section containing laser, transmitter telescope, and receiver telescope mounted on an Alt-Azimuth mount (Fig. 1, right).

Fig. 1. DLR’s mobile SLR/SDLR station (STAR-C).

For station operation, the sliding roof of the transceiver section is retracted, and the platform with the Alt-Azimuth mount is elevated to the height level of the container. The container is equipped with a weather station including cloud sensor, and a GPS receiver (Fig. 1, top left). If required, the container can be powered using an external power generator with 14 kW.

3.2 Laser System and Transmitter Unit

The fully diode-pumped laser has an average output power of 50 W at a PRF of 1 kHz (pulse energy: 50 mJ) with a pulse length of 10 ns. The water-cooled laser is based on a Nd:YAG master-oscillator power-amplifier (MOPA) design [5], where a low-energy pulsed laser is amplified using 2 isolated amplifier stages. The output energy of the laser is controlled using a motorized half-wave plate and a Glan-laser polarizer.

The laser output is guided to the Coudé path of the mount and the beam size is increased to 2 in. using a Galilean beam expander. The output beam direction is controlled using a mount with motorized actuators. It's planned to increase the output beam size to 10 in. using a Ritchey-Chrétien (RC) telescope. The loss associated with the central obscuration due to the secondary mirror of the RC telescope can be avoided using an axicon pair to create an annular-shaped beam [6].

3.3 Receiver Setup and Data Acquisition

The photons scattered at the orbital object are collected using a receiver telescope with a diameter of 17 in. [7], and a bandpass filter in front of the fiber-coupled InGaAs-SPAD detector [8] rejects background radiation. The signal output of the detector is processed using a PCIe time interval analyzer card [9].

3.4 Laser Safety Concept

As the laser radiation is not eye-safe at standard operation and transmitter settings [10,11], several technical safety measures are installed to meet the requirements of federal aviation administration and local government. The telescope mount is equipped with an infrared (IR) camera to detect aircrafts using image processing. Furthermore, data of an automatic dependent surveillance broadcast (ADS-B) receiver and data of air traffic control is evaluated. If the airspace cannot be closed during station operation, an additional aircraft spotter is mandatory.

The wavelength region >1400 nm alleviates the requirements for laser safety as radiation is not focused on the retina and lasers with higher average output power can therefore be used for SLR/SDLR. Promising lasers in the spectral region of 1600 nm are lasers based on Erbium-YAG crystals pumped with Erbium-fiber lasers. A laser system is currently under preparation at DLR to test SLR/SDLR at 1600 nm.

3.5 Software Control

The SLR/SDLR station STAR-C is operated using a modular software package (OOOS: orbital objects observation software) written in Python 3. Software modules for object scheduling, tracking and ranging, laser control, laser safety, and housekeeping are available and the system can be remotely accessed using a 4G network connection.

3.6 SLR/SDLR Station Operation

Station operation is currently limited to twilight. The orbital object is acquired using a sCMOS camera [12] and the mount tracking position is controlled and adjusted (passive optical tracking) as orbit data, e.g., TLE (two line element) data, is usually not accurate enough. Although blind tracking capability is not a primary goal of this project, a refined pointing model could compensate mount instabilities and will be performed using CPF (consolidated prediction format) data.

3.7 SLR/SDLR Network

A worldwide distributed network of multiple STAR-C can take advantage of limitations due to weather conditions and improve data quality. The stations can be autonomously operated and scheduled from a remote facility.

A network could also take advantage of bistatic ranging configurations, where multiple (receiver) stations collect the backscattered photons originating from a single transmitter station [13].

4 PROJECT STATUS

STAR-C is currently stationed at a closed facility and system development and specification is ongoing. Since the project started in 2016, a large number of improvements have been initiated to improve, e.g., mechanical system stability.

5 SUMMARY AND OUTLOOK

The mobile platform STAR-C for SLR/SDLR was presented. STAR-C is currently under development and operated for further specification. Main focus is on tracking stability, improving the pointing model, integration of a 10 in. transmitter telescope, testing of an eye-safe laser system, and improvement of optical system efficiency. A first deployment of STAR-C is planned for summer 2020.

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure or proposed design setup adequately. Such identification is not intended to imply recommendation or endorsement by the German Aerospace Center (DLR), nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

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