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ScienceDirect

Advances in Space Research 58 (2016) 498–504

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

First successful satellite laser ranging with a fibre-based transmitter

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Received 8 March 2016; received in revised form 10 May 2016; accepted 12 May 2016
Available online 20 May 2016

Abstract

Satellite laser ranging (SLR) is an established technology used for geodesy, fundamental science and precise orbit determination. This paper reports on the first successful SLR measurement from the German Aerospace Center research observatory in Stuttgart. While many SLR stations are in operation, the experiment described here is unique in several ways: The modular system has been assembled completely from commercial off-the-shelf components, which increases flexibility and significantly reduces hardware costs. To our knowledge it has been the first time that an SLR measurement has been conducted using an optical fibre rather than a coudé path to direct the light from the laser source onto the telescope. The transmitter operates at an output power of about 75 mW and a repetition rate of 3 kHz, and at a wavelength of 1064 nm. Due to its rather small diameter of only 80 μm, the receiver detector features a low noise rate of less than 2 kHz and can be operated without gating in many cases. With this set-up, clear return signals have been received from several orbital objects equipped with retroreflectors. In its current configuration, the system does not yet achieve the same performance as other SLR systems in terms of precision, maximum distance and the capability of daylight ranging; however, plans to overcome these limitations are outlined.

Keywords: Satellite laser ranging; Laser transmitter

1. Introduction

Laser ranging to objects in space is of great importance in many different fields. By measuring the distance to dedicated satellites various scientific phenomena such as tectonic plate drifts, crustal deformation, the Earth's gravity field or ocean tides can be investigated (Degnan, 1994b). Furthermore, precise orbit determination of cooperative as well as non-cooperative objects can support evasive manoeuvres to avoid collisions with space debris (Bennett et al., 2013). Besides, re-entry predictions and mission preparation can benefit from satellite laser ranging (SLR) (Jilete et al., 2015). Together with VLBI (Very Long Baseline Interferometry) it is one of the core technologies for the GGOS (Global Geodetic Observing System) (Rummel et al., 2005).

This variety of different SLR tasks requires a complete network of SLR stations. Whereas the coverage of stations on the northern hemisphere is sufficient at the moment, only a few stations are available on the southern hemisphere. Furthermore more stations will be required in the future due to the increasing number of satellites equipped with retroreflectors; also on the northern hemisphere. Especially for the rapidly increasing nano-satellite population, low cost and weight retroreflectors are attractive for orbit determination (Kirchner et al., 2013; Buchen, 2015; Young, 2015).

Since the first successful reported SLR experiment in 1964 (Combrinck, 2010) the technological progress is tremendous. Commercial InGaAs based single photon detectors with low dark noise in the kHz regime and diameters in the range of 100 μm are available (Hadfield, 2009;

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http://dx.doi.org/10.1016/j.asr.2016.05.020
0273-1177/

Rochas et al., 2009). This enables detection of infrared photons up to 1550 nm with efficiencies on the order of 30%. Thus the benefits of the fundamental Nd:YAG wavelength compared to its first harmonic for SLR can be exploited (Völker et al., 2013). Furthermore the detectors can be operated in a non-gated mode due to their low dark count rates, at least during night time.

Additionally laser systems with kHz repetition rate, picosecond pulse duration and several hundred micro joule pulse energy have been developed. Initially suggested by Degnan (1994b) first independent demonstrations of kHz SLR systems were conducted in 2004 by an SLR2000 prototype and the Graz SLR station (McGarry et al., 2004; Kirchner and Koidl, 2004). Higher repetition rates allow lower pulse energies while still obtaining the same number of returns per time interval as in conventional designs (Degnan, 1994b,a). Theoretical considerations and experimental verifications show that pulse energies in the range of several ten micro joules are sufficient for SLR (Humbert et al., 2015; Degnan, 1994b; McGarry et al., 2004; Kirchner et al., 2015); a big step towards new innovative SLR approaches.

Novel laser transmitter designs can be realized without using a coudé path. Such a coudé path is the common solution in the SLR community for guiding the laser pulses from the source to the transmitter telescope on an astronomical mount. While enabling high laser pulse energies, the coudé path has several disadvantages. An expensive design as well as a crucial alignment of the mirrors are two main drawbacks. Smaller laser systems in the micro joule regime can be mounted directly onto the astronomical mount as proposed by Degnan (1994b) and realized for example by Kirchner et al. (2015). However, in this configuration the laser is exposed to the environment and various weather conditions. Furthermore the orientation of a laser attached directly to the mount changes continuously. To avoid these issues we prefer a fibre based laser transmitter. Laser pulses from a source in a controlled environment are guided via an optical fibre onto the mount. This enables an easy upgrade of existing small telescopes to SLR stations without any weight or size limitations of the laser system. Even light from several different laser sources for different tasks (e.g. LIDAR, optical communication) can be coupled into the fibre. Therefore a very modular and versatile system using only one telescope is possible with the fibre based approach.

In this paper we present the combination of an innovative multi mode fibre (MMF) based laser transmitter design with a low noise, non-gated infrared detection technology. We describe the system set-up (Section 2), first experimental results (Section 3) and discuss the potential of this technology for high-precision SLR (Section 4).

2. Hardware

This section describes in detail the innovative set-up of the system, with the goal of making the replication of our system feasible for other parties. All components are readily available for purchase from various suppliers, with two exceptions: The beam splitter unit in the receiver channel has been designed and built by our institute, and the single photon detector has been discontinued by the manufacturer.[1]

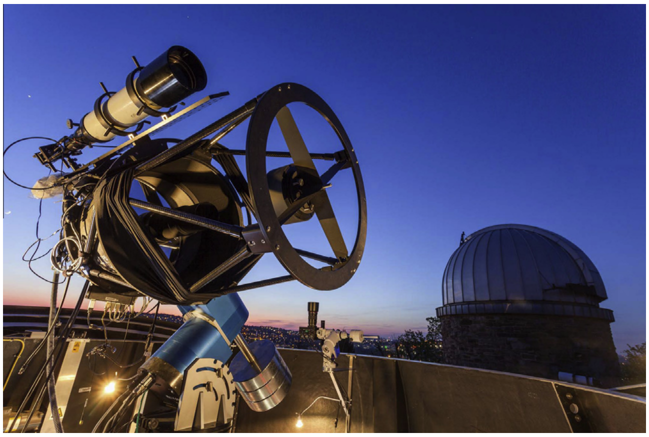

Fig. 1. Telescope assembly used for laser ranging: The 43 cm mirror telescope is used for tracking and as receiver for the laser photons, while the 10 cm refractor telescope transmits laser pulses.

With its small footprint, the complete system including laser and IT infrastructure, fits into a 3.6 m clamshell dome. Total hardware costs are estimated to about 175 k€ in 2016 prices. The modular approach used here is believed to be especially useful for the extension of existing, passive-optical systems.

2.1. Tracking

Fig. 1 shows the tracking system consisting of a 43 cm corrected Dall-Kirkham telescope,[2] an sCMOS camera[3] and a direct drive equatorial mount.[4] Due to the large camera sensor, a field of view of $0.32^\circ \times 0.27^\circ$ is achieved while maintaining a resolution of about 0.5 arcseconds per pixel.

Publicly available TLE data[5] or the more accurate CPF predictions[6] are used to track the target object. Even when using less accurate TLE data, the object can be captured reliably due to the large field of view. The object is identified in the camera image as the only point-like structure (stars appear as streaks). Its offset from the target point in the image is used to correct the pre-programmed trajectory of the mount. Using a PID control loop with appropriate settings, the object can usually be moved to

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[1] However, commercial alternatives exist also for these two components, see Section 2.4.

[2] Planewave CDK 17, http://planewave.com.

[3] Andor Zyla 5.5 USB 3.0, www.andor.com.

[4] Astelco NTM-500, www.astelco.com.

[5] Two Line Elements, see e.g. http://www.celestrak.com/NORAD/elements/.

[6] Consolidated prediction format, as used by the International Laser Ranging Service, see http://ilrs.gsfc.nasa.gov/data_and_products/predictions/.