Concept for a new minimal SLR system

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Motivation

Despite the tremendous success and the excellent data products of the ILRS, a growing need for new SLR stations around the world is obvious. The main reasons are the uneven global coverage and the increasing numbers of satellite missions requesting laser ranging support. New applications such as laser communication, quantum cryptography, spacecraft attitude determination, time transfer and laser ranging to space debris objects have further increased the interest in laser ranging technology. While many SLR stations around the world are capable of participating in these interesting scientific fields, a large fraction of their observation time is spent on routine laser ranging to earth observation satellites in LEO and GNSS satellites. With today's technology it seems possible to design a new type of SLR station, which is capable of supplying high quality ranging data at a fraction of the costs (installation and operation) of current systems. Such fully automated "minimal" SLR stations could be deployed in many remote areas around the world to improve the geodetic data products, support a large range of new missions and relief current high-end stations from some of their daily tracking load.

Design goals

A minimal SLR system is defined by the fact that it only contains the bare minimum of components required for stable satellite laser ranging operation. As far as possible, these components should be available commercially to avoid reliance on individual, specialised suppliers and thus high costs and long lead times. The system should be made as small as possible to reduce infrastructure costs such as a large telescope dome. A simple design will not only help to bring the initial costs down but also facilitate on-site maintenance.

On the other hand, such a system can only contribute to the current data products if it reaches a sufficient performance. Since a large fraction of tracking time at current stations is used on GNSS targets, it is important that a minimal SLR station can reach all relevant orbits from LEO up to GNSS. Furthermore, a normal point accuracy of below 1 cm (preferably in the mm range) must be achieved with such a system. It should be noted that this *normal point accuracy* should not be confused with the *single shot accuracy,* which is often quoted for current systems but seems to be not relevant for most of the ILRS data products.

To achieve a high data output, a fully automated day and night operation is desirable.

Key technologies

The two main costs drivers for current SLR systems are a coudé path mount and a high energy picosecond laser source, so ideally both are avoided in a minimal SLR system. As alternatives to a coudé path, a small laser might be put on the telescope itself, or the laser light might be directed onto the telescope through an optical fibre. Both approaches have already been demonstrated

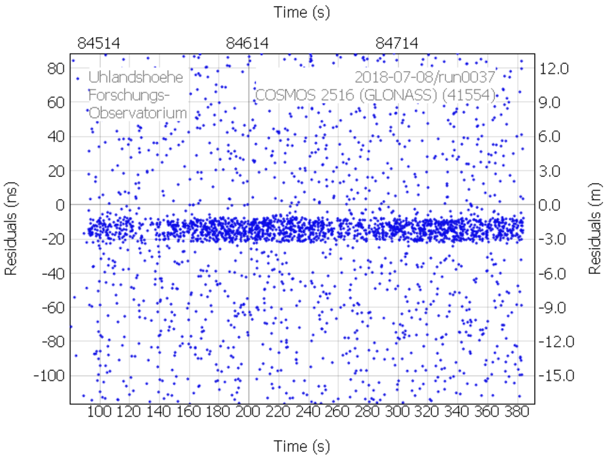

Fig 2: Ranging to Glonass 136, showing about 1500 returns during a 5 minute normal point measurement.

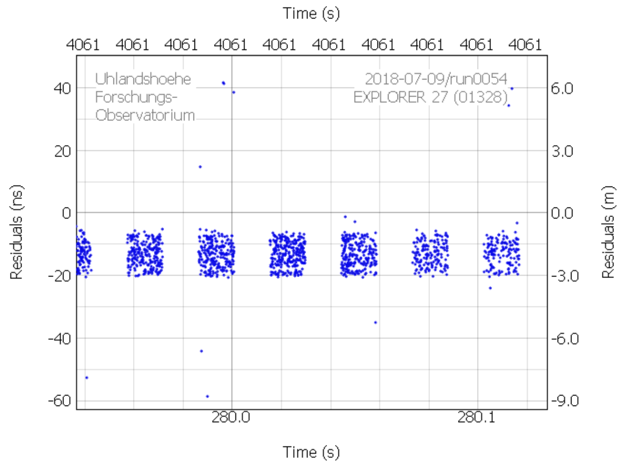

Fig 1: Ranging to Satellite Explorer 27 (Beacon-C), showing a 100 ms zoom into the return signals.

successfully [1,2]. However, for both set-ups high energy picosecond laser sources are not ideal, as they are usually large and heavy, and their high peak power will easily damage the optical fibre. Therefore, a minimal SLR system, whether using a fibre or an on-mount laser, will be easier to construct with a low-energy, nanosecond laser source.
While very practical, two problems arise with the use of low-energy, nanosecond lasers: First, the maximum range might be limited due to the low pulse energy and GNSS targets might not be reached. Second, the nanosecond pulses add a considerable statistical error to the range measurement (6 ns correspond to about 1 metre).
However, it has been shown recently that both of these problems can be overcome by the new technology of *very high repetition rate laser ranging* [3]. At the SLR station in Stuttgart, a 100 kHz, 50 µJ, 12 ns fibre-coupled laser ranging system has been used to range satellites up to GNSS orbits, while achieving cm range precision at the normal points through averaging. While this system can currently not achieve competitive laser ranging accuracy due to stability issues, it has shown the potential of this technology. Figures 1 and 2 show two ranging plots obtained with the current Stuttgart SLR station.

The new miniSLR station

Building on the experience from the first SLR station in Stuttgart a new, minimal system has been designed. It uses a 200 µJ, 30 kHz nanosecond laser mounted directly onto the telescope. The whole set-up is enclosed in an aluminium box of about 1.8m x 1.2m x 1.6m size, and weighs about 200kg. It is planned to cover the enclosure with a fully sealed dome with azimuth rotation and a glass window for incoming and outgoing light. According to the specifications, the system will reach a similar performance as the current SLR station, albeit at a better long-term stability due to proper temperature management, shorter cables and a well-designed calibration target. Currently (end of 2018) first pointing and tracking tests are conducted. First laser-ranging tests are planned for 2019.
Figures 3 and 4 show the current state of the miniSLR and a CAD model of the finished system.

Open software, open hardware

To increase the impact of this novel approach, it is planned to publish and share all software as well as the designs for the hardware under an open source licence. Currently, the control software used at the current SLR station as well as the new miniSLR station ("OOOS") is already freely available [4]. The authors hope that this approach will attract collaborators from the ILRS and elsewhere to contribute to this idea.

Fig 4: MiniSLR set-up as of Nov. 2018. While most of the transmitter and receiver optics are already integrated, most of the electronics and the outer covers are still missing.

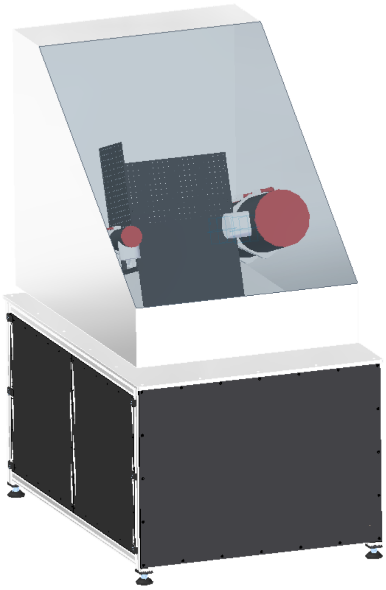

Fig 3: CAD model of the miniSLR system, showing the outer covers and the azimuth-rotating dome with its glass window.

Conclusion & Outlook

The work conducted in recent years at the Stuttgart SLR station has shown that low-cost SLR systems can reach a very competitive performance. Using very high repetition rates of 100 kHz has proven to be feasible and of critical importance for such systems. In the future, a further increase in repetition rate up to some 500 kHz seems useful to further decrease statistical uncertainties and increase the signal to noise ratio.
The new miniSLR system strives to make SLR a much easier and less expensive enterprise compared to today's standards. Current estimates show that a fully automated system can be built from hardware costing about 150 k€. If designs and control software are shared openly, this scheme will enable new parties to join the laser ranging community with their own systems, as well as new applications such as space traffic monitoring [5].

References

[1] Daniel Hampf, Fabian Sproll, Paul Wagner, et al. *First Successful Satellite Laser Ranging with a Fibre-Based Transmitter*. Advances in Space Research, 58, 05 2016

[2] Georg Kirchner et al. *Concept of a modular, multi-laser, multi-purpose SLR station*. In Proceedings of 20th ILRS Workshop, Potsdam, Germany, 2016.

[3] Daniel Hampf, Ewan Schafer, Fabian Sproll et al. *Satellite Laser Ranging at 100 kHz Pulse Repetition Rate.* Submitted to CEAS Space Journal (Nov 2018)

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[5] Daniel Hampf et al. *Mini-SLR: A fully automated miniature satellite laser ranging ground station*. In 69th International Astronautical Congress (IAC), Bremen, 2018