MiniSLR: A fully automated miniature satellite laser ranging ground station

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Abstract

Satellite Laser Ranging (SLR) has evolved from a geodesy tool to a widely used mission support system. Currently, about 80 satellite missions depend on continuous laser ranging data to derive exact position information, among them several Earth observation and many navigation satellites. Even more satellites have used SLR measurements in their early orbit phase to calibrate or verify their on-board navigation. In the future, the demand for laser ranging measurements may rise further, as more and more operators of small satellites, or even the proposed mega-constellations, realize the potential of this technique for obtaining centimetre-precise orbit information during and even after the mission. On board, only a small and light-weight retroreflector is required. On the ground, a world-wide network of around forty stations is available for tracking (International Laser Ranging Service, ILRS).

However, many current ILRS stations are at their limit in terms of number of tracked satellites. Furthermore, the world-wide coverage is rather uneven, with many productive stations in Europe and Asia, only a few in Africa and the Americas and none at very high latitudes (north or south). A few new stations are under construction, more are being planned around the world.

The German Aerospace Center is currently developing a new, small and inexpensive SLR system that may be very well suited for the further expansion of the laser ranging network. The whole system is housed in a 2m x 2m x 1.5m box, which is fully sealed and weather proof. It contains not only the mount with transmitter and receiver telescope and the laser, but also all data acquisition and experiment control systems. Our own control software, which is already used in two other SLR systems, will be used to operate the system completely autonomously. Using an infrared laser at low pulse energies avoids problems with aircraft safety. Compared to current SLR stations, which often occupy a whole observatory building and are operated by on-site staff, this miniSLR system will cut both installation and operating costs significantly. This contribution will present the set-up and first tests with the miniSLR system.

1. Introduction

Satellite laser ranging (SLR) is an established technology to measure distances to satellites equipped with retroreflectors [2]. A world-wide network of about forty stations routinely tracks more than eighty targets, successfully supporting a wide range of applications from geodesy to scientific mission support. However, the uneven global distribution of stations and the growing number of targets make the expansion of the network desirable, as will be discussed in section 2.

On top of its currents objectives, the ILRS may provide valuable help to keep satellites safe from collisions in the future. As more and more payloads get equipped with retroreflectors, laser ranging may become a powerful tool for space surveillance and tracking (SST). We suggest that satellite manufacturers routinely include retroreflectors in their designs to enable easy and precise tracking. Satellite operators and payload users can greatly benefit from these precise position measurements to support their mission without the need for bulky or power-consuming on-board sensors. After the end of the mission, these reflectors can help to monitor the trajectories of decommissioned objects in order to avoid collisions and plan evasive manoeuvres. The idea to use laser ranging in future SST scenarios is discussed further in section 3.

The rising need to expand the current SLR network and especially the proposed use for SST re-

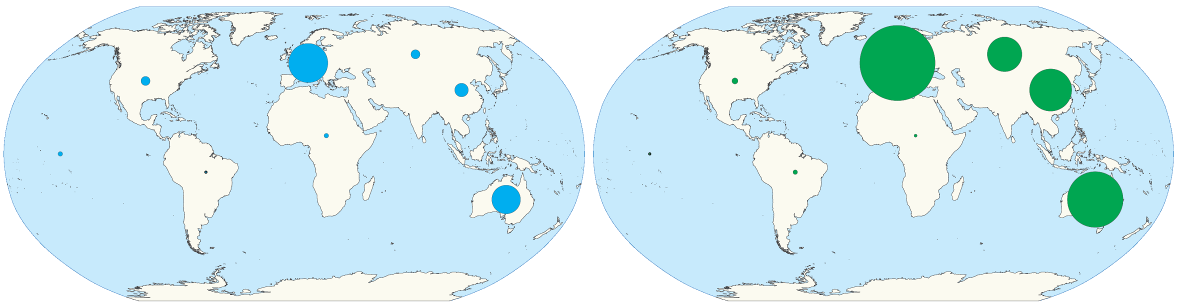

Figure 1: Laser Ranging data yield per region. Left: Data on reference frame satellites. Right: Data on GNSS satellites. [16]

quire the construction of new laser ranging stations. Currently, such stations are integrated in their own buildings, often occupying an observatory dome and adjacent laboratory rooms. Both installation and operation costs are substantial and are a serious impediment to the expansion of the network. In this contribution we will introduce the design of a small, standardised and inexpensive SLR system that can be deployed anywhere in the world and take data autonomously (section 4). If successful, this design may revolutionise the field of satellite laser ranging and make it a technique widely applied in many future missions.

2. The need for new SLR stations

Today, most of the SLR stations world-wide are part of the ILRS[1][17], which organises the use of common procedures and data formats and channels the communication between the data providers (SLR stations) and the data users (researchers or mission operators). Currently, the ILRS tracking list contains about thirty missions in LEO (low Earth orbit, up to 2,000 km altitude) and about fifty targets at higher orbits, mostly GNSS satellites (global navigation satellite system, 19,000 to 24,000 km altitude). Typically, a good SLR station today reaches a precision of about 1 cm in the distance measurement, and is able to work day and night.

While the ILRS is hugely successful, it faces a few challenges to further improve its output. First of all, the global coverage of SLR stations has always been quite uneven and remains so despite the recent addition of the Hartebeesthoek station in South Africa. As can be seen in Figure 1, a lot of data is recorded in Europe, Asia (mainly China and Japan) and Australia, while there is only very little data from Africa and the whole of America. At very high latitudes, especially in the South, there are no stations at all (the southernmost station currently is Mt Stromlo, Australia, at 35° south). This uneven coverage limits the accuracy of some of the main geodetic data products, such as the geocenter position [15].

On the other hand, many stations are already at or beyond their limit in terms of tracking requests. This is especially true for stations that cannot work continuously, but have to shut down on weekends or at night due to organisational constraints. However, even very efficient stations increasingly encounter conflicting tracking possibilities and have to miss out on some potential targets more and more often.

Furthermore, the demand is likely to increase in future years. Current and future GNSS satellites rely on SLR for cross-calibrating their position, which will become even more important as the precision of these systems improves [7]. More and more Earth observation satellites (such as Grace-FO, Swarm, TerraSAR-X / Tandem-X) use SLR data to derive highly accurate orbital information. Finally, laser ranging measurements may become a great tool for space surveillance, if more and more satellite operators equip their vehicles with retroreflectors.

3. Using SLR as a space surveillance tool

Space debris has become a major concern for satellite operators in recent years. Evasive maneuvers need to be conducted on a regular basis to avoid collisions. The maneuver planning relies on a comprehensive knowledge of the space situation, i.e. the exact positions and predicted trajectories of all objects in orbit. Today, this information is gathered mainly by radar systems for the LEO and passive-optical telescopes for GEO (geostationary orbit, 35,786 km altitude). However, laser ranging may become a competitive alternative for LEO ob-

[1] International Laser Ranging Service, `https://ilrs.cddis.eosdis.nasa.gov/`

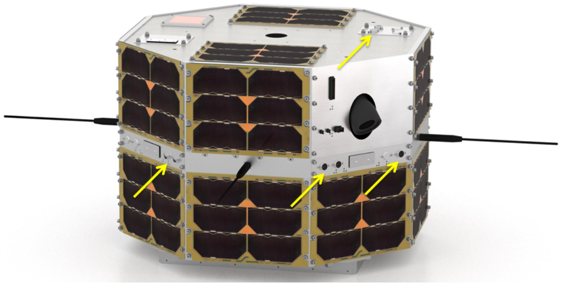

Figure 2: The Technosat microsatellite (NORAD ID 42829). The yellow arrows indicate seven of the total fourteen 10 mm retroreflectors [1].

servations in the future. So far, space debris laser ranging requires strong laser powers, since the laser pulses are scattered on the object's surface and only a small fraction arrives back at the ranging station. While such laser ranging systems exist and produce excellent results [18, 10, 12], they are bulky and expensive.

To improve the situation, we propose to equip all satellites and rocket bodies with small retroreflectors by default. Such reflectors usually measure less than 20 x 20 mm, weigh only a few grams and require no power. If considered early in the design, they can be integrated onto the satellite bus with very little effort and no impact on the rest of the payload. The approach has been demonstrated successfully in several microsatellites, e.g. S-NET and Technosat (Figure 2).

Ranging to these objects can be a routine task for any existing or future SLR station. The position of the satellite can be determined with a precision in the centimetre range, and its trajectory usually be predicted with uncertainties of a few metres. Additionally, if multiple reflectors are installed (as on Technosat), the attitude of the satellite can be determined with a resolution of down to 1° [9]. During the lifetime of the mission, this can support many position sensitive tasks which might otherwise require heavy, bulky and power-consuming on-board position sensors.

As fully passive technology, retroreflectors are inherently fail-safe and remain available after the end of the payload's mission. Thus, the object can be tracked for its complete on-orbit time, and possible conjunctions with active spacecraft can be predicted with high reliability. The high precision of the trajectory predictions helps to avoid unnecessary evasive manoeuvres, thus saving propellant on affected spacecraft. While strong laser systems and radar facilities are still needed to monitor fragments (which currently make up the majority of orbital objects), this scheme will facilitate monitoring of a growing number of structurally intact but inoperational objects.

The practicality and usefulness of this technology for collision avoidance has been demonstrated in June / July 2017, when general predictions showed a considerable danger of a collision between the active Jason-2 mission and the defunct TOPEX / Poseidon satellite. While the trajectory of Jason-2 was very well known due to regular measurements by the ILRS, the predictions for TOPEX were much more uncertain. However, TOPEX had made use of SLR support during its mission as well and is equipped with several reflectors that remain well visible despite the object's fast tumbling. The Jason-2 team therefore requested ranging measurements to TOPEX, which were promptly delivered by several ILRS stations. Using the precise measurements, the danger of a collision could be ruled out with high confidence, and no evasive manoeuvre was scheduled [13].

While such situations may still only happen occasionally today, they may become a regular problem when the planned mega-constellations by OneWeb, Boing or SpaceX are launched [3]. With several hundred satellites on very similar orbits, the inevitable failure of individual spacecraft will threaten a whole range of other objects from the same constellation. As any collision might trigger a chain reaction, whole orbits may be rendered unusable if the situation gets out of hand. If all of these objects are equipped with retroreflectors from the start, a later surveillance will be much easier and informed decisions on evasive manoeuvres for the rest of the constellation can be taken. This rationale is especially valid for small satellites such as cube-sats, which are hard to track by radar systems but can easily carry one or several retroreflectors.

4. MiniSLR design and set-up

Due to the discussed rising demand, several new SLR stations are currently under construction, e.g. in Ny Alesund (Norway), La Plata (Argentina) or Haleakala (USA). Both new and existing stations usually require an expensive infrastructure with a coudé-path satellite tracking mount, a high-energy laser and sensitive electronics. Usually, the equipment is scattered over a dedicated observation dome and an adjacent laboratory room. Most systems (with the notable exceptions of Mt Stromlo and Zimmerwald [14, 11]) can only be operated by onsite staff. Both installation and operation pose a

Figure 3: Current set-up of the miniSLR system on the institute's roof, still without the outer covers.

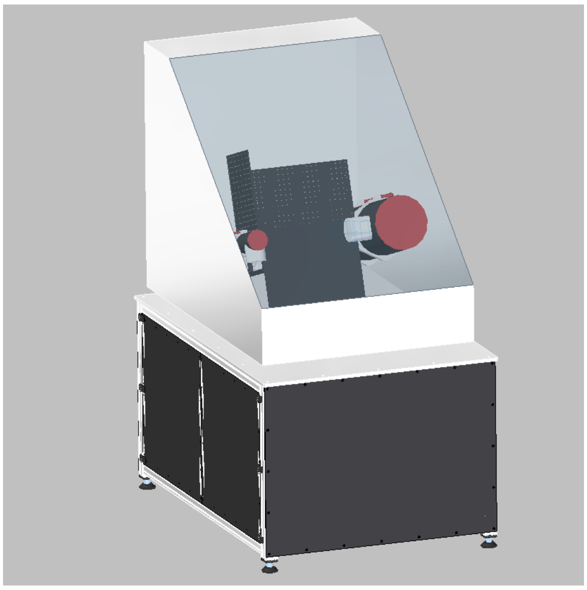

Figure 4: CAD model of the miniSLR system, including the covers.

significant financial burden on the agency running the system.

In view of this situation, possibilities to design a simpler and less expensive SLR system have been explored in recent years. Some technological advances have been instrumental on this path: Small, powerful and robust lasers make it possible to place the laser onto the telescope mount, thus avoiding the need for an expensive coudé-path mount [8]. Direct drive mounts have become widely available, and even amateur-class mounts now offer sufficient tracking accuracy up to high angular velocities. Finally, a new generation of event timers enables laser ranging at very high repetition rates, which in turn eases the requirements on the laser.

Exploiting these capabilities, the first SLR station in Stuttgart (Stuttgart Uhlandshöhe) has been pioneering the development towards a minimal laser ranging system. In 2016, it became the first station to successfully range to satellites feeding the laser light through an optical fibre rather than a coudé-path [6]. Recently, it has demonstrated the possibility and the benefit of using repetition rates of up to 100 kHz [4]. With this technology it becomes possible to use lasers with low pulse energies and high repetition rates, which – at the same average power – are usually smaller and less expensive than high energy lasers.

The new miniSLR system under construction in Stuttgart is built on this experience. It uses a small direct drive mount (ASA DDM 60) and a 20 cm Newton telescope as receiver. The small diode pumped Nd:YAG laser (200 µJ pulse energy, 30 kHz repetition rate) is installed directly onto the mount. Like the station on the Uhlandshöhe, the operational wavelength is in the infrared at 1064 nm, thus avoiding problems with aircraft safety. The whole set-up, including all control and data acquisition electronics, is contained in a small aluminium container (1.80 m x 1.20 m x 1.60 m). The container is sealed and air-conditioned, thus avoiding problems with moisture or strong temperature variations. The complete system contains only a minimal set of easily replaceable components to facilitate on-site maintenance.

The miniSLR system will run using the same software employed in the current Stuttgart SLR station [5]. It allows fully automated operation, remote control and diagnostics. Data will be processed automatically and uploaded to a web server.

Figure 3 shows the current set-up of the miniSLR. First tests confirmed that the mount is capable of tracking even fast LEO targets with sufficient accuracy. The laser ranging system will be completed and tested in late 2018 and 2019. Figure 4 shows a CAD model of the complete system including the covers.

5. Summary & Outlook

This contribution has presented a novel design for a minimal SLR station. If the system reaches the envisaged performance goals, it may become a blueprint for future SLR stations around the world. Due to its sealed design, robust set-up and automated operation it should be particularly suited for use in harsh environments and remote locations. It may thus serve to fill gaps in the SLR network and help to achieve a more uniform global coverage.

If more and more satellites, especially in mega-constellations, are equipped with retroreflectors, laser ranging may become a valuable technique for space surveillance and tracking. A minimal SLR system as introduced here might then become an important tool to obtain sufficient measurements from different parts of the world.

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