Application of satellite laser ranging techniques for space situational awareness efforts

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Abstract: With the numbers of conjunction avoidance maneuvers for the International Space Station and other Low Earth Orbit satellites rising and likely to continue to increase, the need to develop methods to produce accurate 72+ hour orbital predictions is becoming critical. One emerging solution is to utilize satellite laser ranging techniques to range to debris and refine the initial positions to improve the orbital predictions for objects predicted to experience a close approach. Some stations in Europe have already demonstrated that this technique is possible, but it has not been employed to refine the likelihood of collision. We will present a notional architecture for laser ranging to debris utilizing existing satellite laser ranging or visual tracking facilities. We will also discuss the capabilities of laser ranging for Space Situational Awareness and provide a direct comparison to current visual and radar tracking methods.

Introduction: Satellite Laser Ranging (SLR) was first used over 50 years ago to track objects in orbit. Since the original effort the techniques have been updated and refined to improve the precision of the range and directional data collected. Present day SLR efforts have achieved sub cm precision to specially designed spacecraft using corner cubes to reflect the incident laser light and several arcseconds lateral information as defined by the divergence of the laser pulse. This data is currently used to develop precise orbital tracks for these spacecraft needed for studies in Geodesy, laser altimetry, and various Global Positioning Networks. The techniques used for these efforts have also been used to track orbital debris and can be adapted further to improve the ranging precision and orbital predictions to aid in space situational awareness, maintaining object catalogues, debris remediation and conjunction assessment.

Discussion: SLR determines the range and position of a target by bouncing a laser pulse off an array of specially designed mirrors called corner cubes (also known as retro-reflectors). These mirrors are designed to reflect all incident light back to the source on a parallel path. By carefully measuring the time difference between the laser firing (start signal) and the return signal from the satellite (stop signal), the range to the satellite can be calculated. The absolute precision of the range measurement depends on a variety of factors including the precision of the timing system, speed of detector for both the start and stop signals and atmospheric effects. The current state of the art for such measurements has a precision of <1 cm to satellites like Laser Geodynamics Satellite (LAGEOS) and is working towards ~ 1mm precision. In addition, lateral information is gathered using the pointing information of the return telescope and its field of view (FOV) combined with the divergence of the laser beam. SLR systems being developed by NASA are designed to have a telescope FOV of ~50 arcseconds and a laser beam divergence which can vary from ~7 arcseconds to ~30 arcseconds to control the strength of returns from spacecraft in Low Earth Orbit (LEO) out to geo-synchronous orbits[1]. By limiting the FOV of the telescope, we can minimize the number of background counts from stray light in our detectors, allowing us to track objects 24 hours a day.

The main difference between ranging to spacecraft designed to be tracked by SLR and any other objects in orbit is the lack of corner cubes on the majority of the targets. The largest effect is on the return rate (generally measured in photons per pulse) coming back to the SLR station. Since instead of having a portion of the beam intentionally reflected back on a parallel path, the return rates depend on reflections from the skin of the object, thus the return rates will be orders of magnitude lower than that for craft with the corner cubes. This also means that the size and shape of the target will have an effect of the return rates, which with tumbling objects may be time variable as well. In addition, the corner cube arrays are in a known position relative to the spacecraft center of mass, which helps determine the spacecraft position to a higher precision. The above affects the design of a system wanting to range to any object in orbit by requiring optimization for high power of the laser pulses on the target and reducing the possible precision for the range measurements, in addition they will likely limit ranging to the nighttime. We expect that the likely precision obtainable for ranging to targets without corner cubes to be about 1 m rather than sub cm.

Some effort has already been made to use SLR stations to track orbital debris. In particular two European stations have successfully tracked debris, Grasse in France and Graz in Austria. The Graz station has shared their results with us and it is included below in fig. 1[2]. Of particular interest is the tracking of sub meter debris at ranges equal or slightly greater than 1000 km. In addition they have tracked larger objects out to greater than 3000 km. This data shows that SLR can be used to track debris, but we still would like to develop a better determination of the size of the objects tracked and develop methods to increase the return rate from the targets to reducing the size of the objects that we can track.

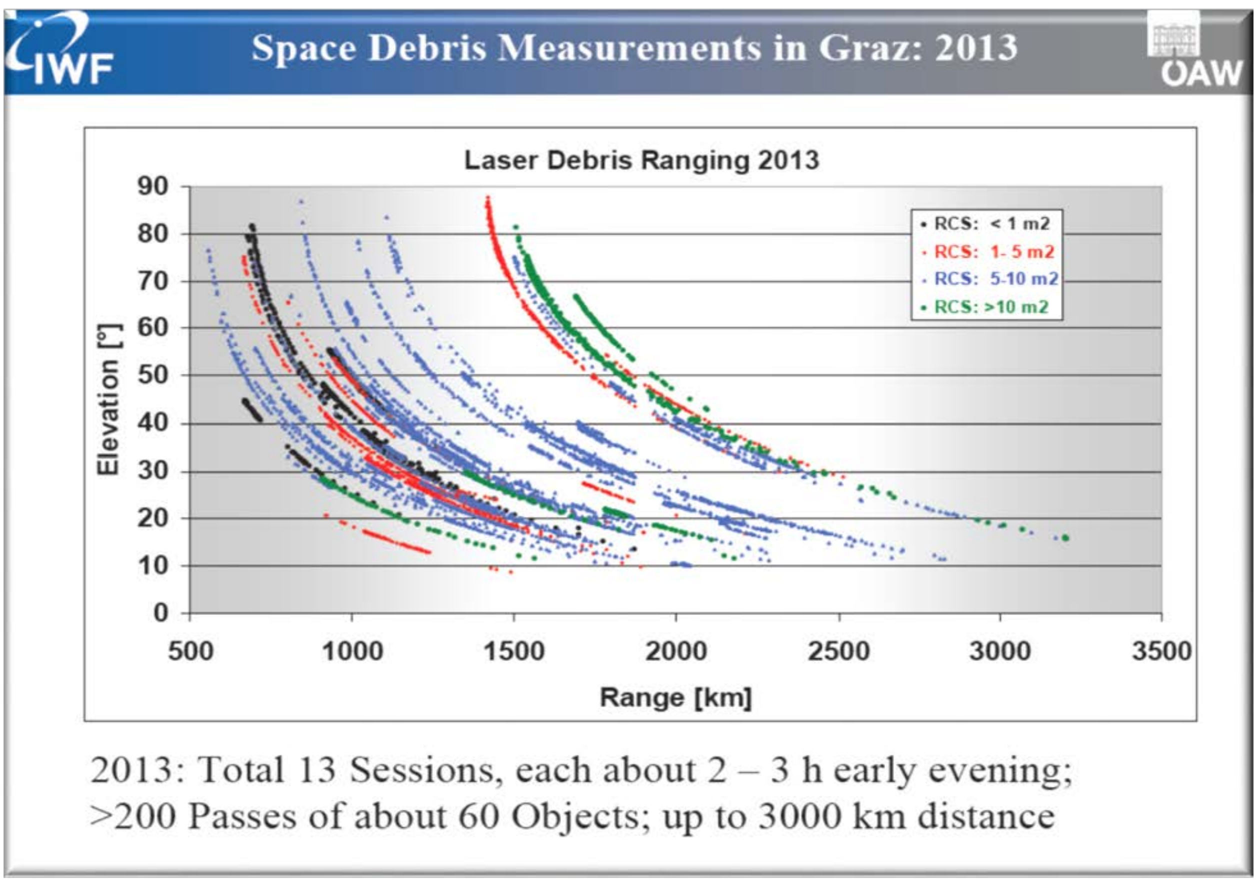

Fig. 1: Orbital Debris tracking results from the Graz SLR station in Austria

We considered methods for improving the returns from the targets and are working on developing methods of using IR wavelength lasers. Our first effort at estimating the returns from targets using 1557 nm lasers is shown in table 1 below. For comparison, we also included the 532nm laser setup used by Graz to track debris. For this effort we limited the power of the 1557 nm laser to "eye safe" levels, which was not the case for the 532nm Graz effort. In addition we selected a commercially available detector for the return signals and improvements to either would affect the end results. Finally we used a telescope at Goddard Space Flight Center that is used for developing experiments such as this. The results of the comparison indicate that we could expect a factor of 12 increase in returns rates at the Goddard facility compared to the Graz station. However it must be noted that a large part of the increase is due to the larger active area of the telescope. If instead we normalize the return rates by the active area of the telescope we still see an estimated increase in return rates of a factor of 2 per unit area by switching from 532m, to 1557nm. Using a more powerful 1557 nm laser and increasing the detector efficiency would lead to larger gains.

Table 1: Details of a comparison of a proposed tracking station (NASA/GSFC) using 1557 nm lasers to the Station at Graz Austria using 532nm.[3]

Lidar sensing assumptions & parameters	**Proposed NASA/GSFC**	**Austria/GRAZ 2013**
Lidar Transmitter Parameters:		
Transmitter Wavelength (nm)	1557	532
Photon Energy (J)	1.28E-19	3.74E-19
Laser ouput pulse energy (J)	0.400	0.200
Transmitter optics transmission	0.90	0.90
Launched Pulse Energy (J)	0.36	0.18
Laser pulse-rate (Hz)	50	100
Launched Pulse Power (W)	18.00	18.00
Launched beam divergence effective diam. (microradian)	50	50
Target Link Assumptions		
Range to target (km)	1,000	
1-way Atmospheric transmission	0.6	
Target cross-section diameter (m)	0.5	
Area of target surface (sq. m)	1.96E-01	
Area of transmitted beam at the target range (m)	1.96E+03	
Fraction of beam reflected	1.00E-04	
Diffuse Surface Target reflectivity	0.1	
Target backscatter coeff. ((fraction*reflectivity)/ster)	3.18E-06	
Receiver Parameters:		
Telescope Diameter (m)	1.2	0.5
Telescope Central Obscur. (m)	0.3	0.1
Telescope Area (sq. m)	1.060	0.188
Receiver System optics transmission	0.5	0.5
Receiver time gate duration (microsec)	10	10
Detector Parameters:		
Detector material and type	InGaAs APD geiger mode	SiAPD geiger mode
Detector Photon Detection Efficiency	0.18	0.5
Detector Dark count rate (/sec)	30,000	10,000
# of Detector Dark Counts in Integ. Time	0.30	0.10
Received mean signal (photo-electrons) per transmitted pulse	**0.308**	**0.026**

There are stations across the globe using SLR for Geodesy and other studies. Some of these stations are already attempting to apply SLR to tracking other orbital objects like Grasse and Graz. We are developing our system so that it can either be installed into a new station built specifically for that purpose or installed with minimum modifications in existing stations. In addition, data handling facilities exist both for the production of orbital predictions and the transfer and storage of the generated data. Fig. 2 shows a notional network for the gather, processing and distribution of the data and orbital predictions.

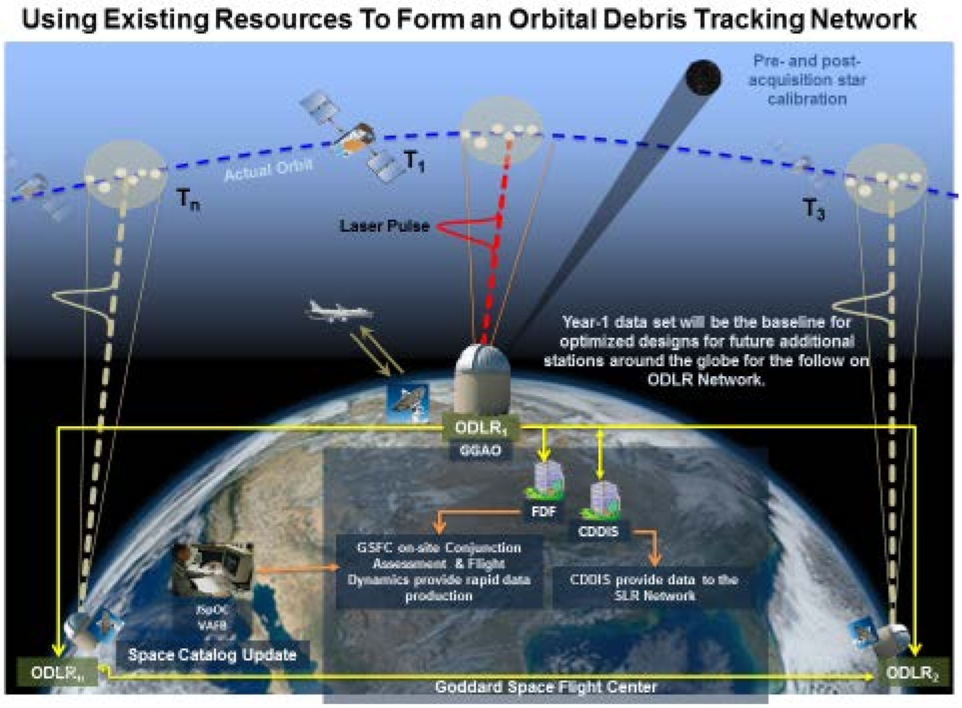

Fig. 2: Notional network for tracking Orbital Debris and other space objects

Since optical and radar system in operation for debris identification and tracking tend to be designed to address a subset of the tracking issues, direct comparison of their capabilities to SLR is difficult without knowing the details of the individual systems. In general, optical systems like the MCAT, are designed with wide FOV telescopes (on the order of 100 of mdegs) combined with arrays of detectors with pixel sizes on the order of arcseconds[4]. This combination allows the telescope to have a relatively fine angular resolution. These systems rely on observing sunlit debris and so are limited in observation times to dawn and dusk periods where the sky is both dark enough to see the reflection of sunlight off the object but the object is not in the Earths shadow. When compared to the amount of light flux that SLR system lasers provide, the relatively bright sunlight allows for the detector of smaller objects than is likely obtainable with SLR while SLR by providing its own light source can track objects through Earths shadow, extending the observation time. Optical system do not return any range data.

Radars are designed to track objects of varying size by using radio frequencies. They therefore illuminate objects with their own source and in addition are not subject to issues stemming from background noise from the sun like both SLR and optical systems. Radar can track object down ~0.2 cm[5]. Since radar is measuring reflected pulse from the objects, they generate range data though we have not uncovered information on what the precision the radars are capable of measuring now, the figure that tends to be used is 100m, while SLR is predicted to obtain 1 m precision range data. Radars angular resolution has also not been found in the literature, but is generally coarser then that of both SLR and optical systems.

Using a combination of optical and radar to track objects would allow the combination of the fine angular resolution of the optical system with the ranging data of the radar. This would improve the positional information on the object, and thus the orbital predictions. Currently the predicted performance of SLR does not match either radar or optical systems for object size, nor does it match optical system for angular resolution. SLR is predicted to improve on the range precision compared to radar and in one system combines both fine angular resolution with range information, in essence combining both optical and radar measurements in one station with longer observation duration since it does not rely on the target to be sunlit. Finally, it needs to be noted that while SLR is very capable of tracking individual objects and improving the orbital predictions compared to either optical and radar stations alone or together, it works best when provided with an initial orbital estimate for the object and does not work well for the initial object identification.

Conclusion: SLR has been ranging to objects in orbit for over 50 years and while most of the objects ranged to have been designed to efficiently reflect the incident light using corner cubes, SLR is being adapted to range to objects like debris which generally do not have corner cubes. While SLR in not likely to be able to detect objects in the size range that optical and radar system can in the near future, it can improve upon the positioning of larger objects (~10cm and larger) over both optical and radar systems by combining aspects of both systems into one station. SLR systems have been successfully used to track sub meter debris in LEO, but both the size of the object tracked and the altitude at which it is tracked can be improved upon by optimizing the SLR stations to use 1557 nm lasers and refining the measurement techniques. The result is another tool to be used for space situational awareness which can generate more precise orbital predictions and to aid in space situational awareness, maintaining object catalogues, debris remediation and conjunction assessment.

References:

[1] J. McGarry, et. al., “Developing and Deploying NASA’s Space Geodesy Satellite Laser Ranging (SGSLR) Systems” ILRS workshop proceedings, 2014

[2] Graz Observatories, private communication.

[3] Jack Bufton and Graz Observatories, private communication

[4] S.M. Lederer, et. al., “Deploying the NASA Meter Class Autonomous Telescope on Ascension Island” AMOS conference proceedings 2015

[5] NASA Tech. Briefs, “NASA Orbital Debris Program” Orbital Debris Program Office, NASA Johnson Space Center