SAN FERNANDO LASER STATION UPDATES AND NEW IMPROVEMENTS

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ABSTRACT

San Fernando laser station has been working on artificial satellite tracking since early 1980s. Since 2017 it has made severe changes. The most important has been the replacement of the old laser bench with two new ones.
One with a power of transmission of 500 mW and with transmission of pulses in picosecond range, and another laser bench with 25 W transmission power and 8 ns of pulses width.
The study for the installation of the last laser has been financed through European Union (EU) H2020 funds derived from the Decision 541/2014/EU establishing a Support Framework for Space Surveillance and Tracking Support, EUSST) and granted by the Spanish Centre for Industrial Technological Development (CDTI). Although it allows the tracking of collaborative objects, it is ideal for tracking non-collaborative objects.
Follow-up activities begin in November 2017. From then on, non-collaborative objects are monitored on a regular basis. This work shows the modifications already made, those currently undertaken and the results obtained throughout 2018.

1 INTRODUCTION

The Royal Observatory of the Spanish Navy (ROA) has worked on satellite geodesy since the early days of the space age, when the first artificial satellite tracking telescope was installed in 1958: the Baker-Nunn camera. In 1975 the French satellite laser ranging (SLR) station was installed at ROA. Since 1980, ROA has been operating this instrument, eventually upgraded to a third generation and continuously updated to attain the highest level of operability. Over the years ROA has participated in different space geodesy campaigns through the International Laser Ranging Service stations (ILRS) or its European regional organization (EUROLAS), tracking a number of artificial satellites types —ERS, ENVISAT, LAGEOS, and TOPEX-POSEIDON, to mention just a few. The old laser bench model available transmits at a 10 Hz repetition rate and 0.2 W as mean power at 532 nm wavelength. Since May 2015 and along several months we performed an experiment that consists of testing our ability to track decommissioned satellites equipped with retroreflectors. On May 2015 we started tracking this kind of space debris to the extent possible with our current technical limitations. Our power and beam divergence only allowed for tracking these objects at low earth orbit altitudes. This includes more than twenty objects that were tracked on regular basis till the end of 2015. Besides this new activity, our schedule included other tasks, such as active artificial satellite tracking (Low and High Earth Orbit-LEO and HEO), and on Lageos 1 & 2, crucial to help defining the international terrestrial reference frame.

With the aim of improving the performances of the Spanish contribution to EUSST activities, it was conducted a study on the impact of the installation of a more powerful laser bench than the one currently installed that was financed through EU funds, and granted by the CDTI. This new laser bench allows tracking on a more complete set of space objects, including non-collaborative. As deadline to have the new system fully operative it was set on November 22nd 2017 due to administrative reasons

2 PUT INTO OPERATION OF THE NEW LASER BENCH

2.1 Targets

On July 14th 2017 the new laser bench and the electronic unit block were received and moved to the top of ROA building. From then onward several actions were fulfilled which aim to integrate and have proper control on the new system. They were:

- Adaptation of the new preshot, shot, and synchronization signals to be recognized by our current old electronic system.
- To perform several actions in order the device could admit an external 10 Hz synchronization signal.
- Modification in the reception system to obtain precise distance measurements.
- To install a new external cooling unit.
- Changes and updates in the optical framework to increase the efficiency of the SLR telescope.

To fulfill the deadline, strategies were designed to allow the signals provided by the current system to be rapidly

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substituted for new ones adapted to the new laser bench protocols. It means to analyse the old software and isolate the instructions corresponding to the firing control. After that we substitute the previous modules with instructions compatible with the new laser bench. All these actions allow us to control the new laser bench and manage its signals as soon as it was received (July 2017) and installed in the ROA to integrate it as expeditiously as possible, using the current operating system with minimum modifications.

A key point was to time the output the pulse of light. To do it properly we had to choose which photodetector should be suitable for this kind of laser bench according with the laser pulse characteristics. We considered the DET025AFC/M model as suitable as it has a rise and fall time of 150 ps, which fits quite well our needs. This allows the conversion of the laser optical pulse into an electrical short time duration pulse able to start the time-of-flight counter.

Besides we need a 4.1-µm diameter core optical fibre. The small core diameter of the optical fiber and the reduced laser output used for calibration (≈ 1mW), call for converging lens to increase the light flux into the fibre input. The last, after some tests, shows to be non-necessary. To precisely align the focused light spot onto the fibre, this group of lens is held onto a tilting platform equipped with two fine 'Pitch & Yaw' screws. In front of the lens a computer-controlled, motorised filter wheel allows to select one of six neutral-density filters to prevent damage of the photodiode when the laser is used at higher operating powers. The main drawback has to do with the fact that the amplitude of the photodetector output was near the constant-fraction discriminator lowest limit (approx. 50 mV), so you have to tune it properly.

The laser works with different amplification modes expressed in %. As during normal conditions we manage different modes of operation: calibration (1 mW), and operational at different power levels (1 W on collaborative active satellites tracking, 5 W on collaborative inactive satellites and 25 W shooting on non-collaborative objects), it was absolutely necessary to link all those % levels with real power. To do that we performed direct power measurements.

2.2 Syncronization signal

Although the laser bench is able to shoot pulses of light at 10 Hz using its own reference of time, to work integrated inside a tracking system means to synchronize assort of different modules. It means that we need to time the exit of every pulse of light using an external triggering.

To accomplish that we need to generate two signals separated by 1000 µsg. This delay was rather severe; as it must keep a stable delay at tenth of µsg otherwise the output power fluctuates. We finally fulfilled this by using a specific module to delay the signal. We got our best results with a 995.2 µsg delay.

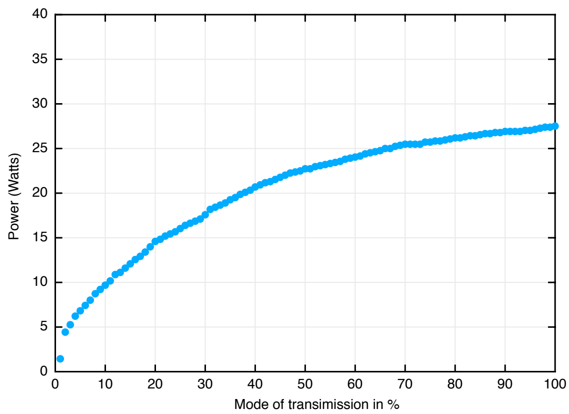


Figure 1: This plot displays the link between the different modes of transmission and Power in Watts.

2.3 Cooling unit

The laser bench and other auxiliary units must be kept working in an optimal temperature-stabilized environment. Taken into account the high transmission power they need a water supply, which should be kept working into a temperature range (15^{o}C ± 2^{o}C). These requirements were far more demanding than those needed by the old laser bench installation. It was got using a compressor and a pump which work in tune from another installation of the Spanish navy. Besides we had to perform some minor modifications in order to fit exactly our needs (new pipes, connectors,...).

2.4 Optics

Our goals were to redesign the optical train to guide the laser beam toward the sky using three dichroic plane mirrors and an afocal optical system (an inverted Galilean telescope used as a beam expander). The latter was originally configured for an input laser beam diameter of only a few millimetres and would not accept the new larger beam. We conceived a new design which allows the input of a ≅ 21-mm diameter beam. It outputs a ≅ 113 mm diameter beam with a minimum ray-trace calculated divergence of 10 arcsecs that, when convolved with the laser beam divergence (claimed by the manufacturer as ≤ 0.5mrad), gives a theoretical minimum divergence of ≈ 15 arcsecs.

Compared with the original design, the beam expander inverted telescope is now 10-cm shorter. We machined some metal components at ROA's mechanical workshop to hold the new lens and bushings for coupling the unit to the mount. All optical elements were thereafter properly aligned.

A key point to get return pulses of light after shooting non-collaborative targets consist in being able to assure that we concentrate the energy as much as possible. On the other hand the poor quality of the debris prediction ephemerids suggests to spread as much as possible the energy to the target. To fulfill both requirements it is essential to control the beam divergence finding a balance between both needs. On November 9th we perform an experiment using a 200-mm aperture, f/10 telescope focused to infinity placed in front of the output lens of the beam expander in order to cover the entire beam (at low energy mode) and look for the minimum spot size. By using this simple method we were able to set the beam expander to minimum divergence. After that we shot a far away target at a building. Shifting laterally the spot until it came out of the wall we were able, using encoder's readings, to get the divergence value, about 13 arcseconds, quite close to the calculated amount. Thereafter, a useful range of divergence values can be set by a ray-tracing calibration of focal position of the beam expander.

2.5 Calibration

On November 10th 2017 we finished our calibration module. From then onward after every tracking during the tests we performed a calibration. It means to generate a swarm of 1000 shots which travels through a well-known path. Results provide stable and coherent values.

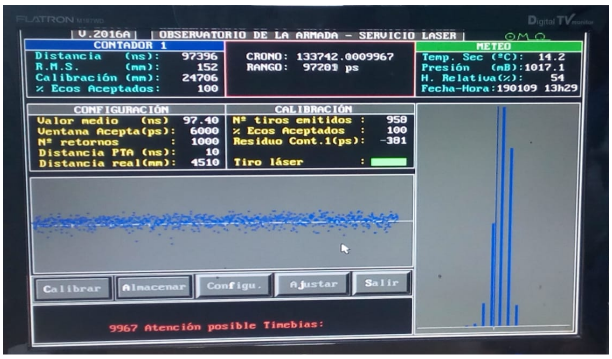


Figure 2: Screen presentation after an internal calibration using the 25 W laser bench. The dispersion is 15.2 cm

2.6 Development of an air safety alert system

One of the main issues in the context of the study consists in avoiding the laser beam to shot a flying object. The project has been carried out. Our aim has been to provide a system, which acts as an interface between the observer and the laser station software system, which analyses the commercial air traffic that surrounds the area and provides alerts. The system merges different pieces of software (developed in C ++, QML and JavaScript), controlled under the cross-platform application framework **Qt**. It obtains information in ADS-B format (Automatic Dependent Surveillance - Broadcast) sharing information from an acquisition system entirely developed by ROA and public information available from Internet. The first consist on a network of antennas connected to a set of reduced- size computers. Besides it integrates azimuth and elevation data from the telescope.

All these information helps to display in real-time the position of the aircraft in the area. Besides it provides detailed information regarding the flight as: altitude, course, speed, the direction of the laser shot in real time, and a series of safety zones as request.

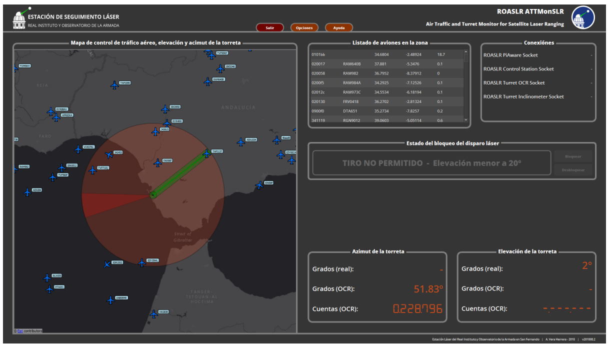


Figure 3. Air safety warning system.

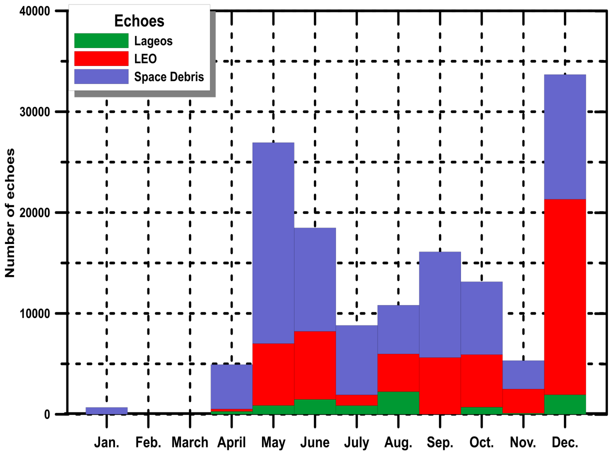
Some of those features offered by this system include real-time analysis for interception prediction between the flying object and the laser beam. It offers alerts using flashing LEDs and sounds. We will continue working on this issue and we plan the network to send these alerts so that they can be picked up by other subsystems of the station (for example, to stop the laser shooting automatically if necessary).

3 RESULTS

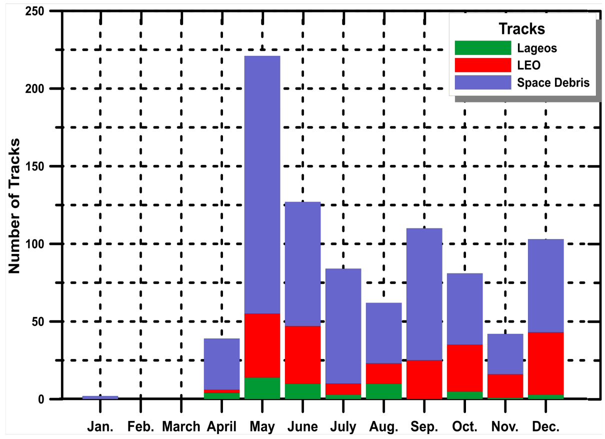
3.1 Tracking on opaque objects

On October 20th 2017 we got the first laser echoes from collaborative satellites. We got return pulses from Ajisai (1600 km), LAGEOS (6000 km), and inactive collaborative objects as: Topex/Poseidon (1350 km), ERS-1 (800 km) and ERS-2 (500 km), and ADEOS (800 km), transmitting at 2 W, and at 20 W.

From then onward we have set a daily schedule every night. About 1.5 h during early evening, was devoted to non-collaborative objects (rockets, tanks). These orbiting objects were still in sunlight, but with San Fernando in darkness. This allowed us to visualize the objects with cameras in the main receiver telescope, to correct the telescope pointing taking into account the relatively large time and range biases, and to adapt range gate positions and offsets accordingly. All these objects were tracked at full power and minimum divergence.



(a)



(b)

Figure 4: Figures obtained through 2018.

Along our first tests, we checked different divergences and range gates always taking into account the peculiarities of such targets. We checked divergences of 20, 30 and even 50 arcseconds in order to maximize our chances (of getting echoes) in azimuth, and different range gates (500 ns, and microseconds ranges: 5, 10, 15, 30 and even 50) to take into account the range bias. On November 10th we decide to use a minimum divergence and a range gate equal to 10 microseconds. This night we got two tracking on rockets: THOR-R and SL-3. The first with a radar cross section (RCS) equal to 9.4 m^2, and the second equal to 5.6 m^2.

3.2 Statistics

Along 2018 we have participated as an active asset in the Spanish SST Sensor Network (S3TSN).. We have been called for special observational campaigns (e.g.: Tiangong-1) and continuously active since September 1st till December 12nd 2018. During this whole year we have been able to track non-collaborative and collaborative objects on regular basis.

4 CONCLUSIONS

San Fernando SLR station has conducted a severe transformation, which involves its laser bench, optics and complementary units. All these modifications allow to tracked non-collaborative and already inactive collaborative objects on regular basis. Nowadays we act as an active asset of S3TSN. Next aims are to modify the software to work under Unix umbrella, and to improve the angular resolution.

5 ACKNOWLEDGEMENTS

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