Space Debris Laser Ranging – Challenging and Rewarding – Update of the Izaña-1 Station

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Abstract

The Izaña-1 station (IZN-1) is located at the Observatorio de Teide on the Spanish island of Tenerife. It is a multi-purpose optical ground station for satellite observation, position measurements and communication. The telescope carries the Satellite Laser Ranging (SLR) laser package for ranging to cooperative targets equipped with retro reflectors. Currently on the two Nasmyth foci the laser ranging detector package and the laser communication terminal is installed. Additionally on one of the 2 optical ports a space debris observation camera is installed for passive optical space debris observations. As part of the upgrade of the IZN-1 (ESA project S2P S1-SC-06 - Laser Ranging - Evolution Towards Active Sensor Networking for Debris Observation and Remediation), it is planned to extend the functionality of the system with a space debris laser ranging transmitter for ranging during nighttime as well as daytime to uncooperative targets. The space debris laser system will be installed in a separate structure, on its own mount. Such a system can be installed adjacent to any SLR station, enabling it to perform Space Debris Laser Ranging (SDLR) without modifying the main SLR system. In order to improve the aircraft detection of the laser safety system, an additional thermal IR camera will be installed onto the telescope. The integration of a single-photon detector as light curve detector in the existing laser ranging detector package will enable high temporal resolution light curve recording simultaneously to the ranging measurements. The additional stare & chase functionality will allow the ranging to targets with worse predictions. Based on passive optical observations an orbit improvement will be carried out for increasing the accuracy of the orbit predictions and assists the SDLR system.

1. Introduction

The IZN-1 is located at the Observatorio de Teide on the Spanish island of Tenerife. It is a multi-purpose optical ground station for satellite observation, position measurements and communication. The telescope carries the SLR package for ranging to cooperative targets equipped with retro reflectors. Currently on the two Nasmyth foci the laser ranging detector package and the laser communication terminal is installed. Additionally on one of the 2 optical ports a space debris observation camera is installed for passive optical space debris observations.
As part of the upgrade of the IZN-1, we will extend the functionality of the system with a space debris laser ranging transmitter for ranging during night time as well as daytime to uncooperative targets up to 3000 km range orbits. The space debris laser system will be installed in a separate structure (IZN-2), on its own mount. Such a system can be installed adjacent to any SLR station, enabling it to perform Space Debris Laser Ranging (SDLR) without modifying the main SLR system.

The space debris laser tracking module will be added to the IZN-1 system using a so-called split configuration. In the split configuration, the new space debris laser package will be mounted onto its own new mount, which will be installed in a separate structure (separate transmitter section). The SDLR mount will be installed into a new dome, which will be set up adjacent to the existing IZN-station. This bistatic configuration uses two mounts for the laser ranging measurements synchronized such that both are tracking the same target. The laser pulses will be emitted from the transmitter system (Tx), and the returns will be received by the existing main telescope (Rx), with the existing laser ranging detector package.
An additional stare & chase functionality will allow the ranging to targets with worse predictions. Based on passive optical observations an orbit improvement will be carried out for increasing the accuracy of the orbit predictions and assists the space debris laser ranging system.

2. Space Debris Laser Tracking Module

The space debris laser ranging station concept is based on capable off-the-shelf hardware to the widest extent possible with the following key characteristics:

- The ELRS will fully maintain the original performance in tracking cooperative targets
- The IZN-1 station will fully maintain the original operational specifications.
- Range measurements to non-cooperative targets during night time up to 3000 km, during day time up to 1400 km.
- Range measurements using the primary wavelength of a pulsed Nd:YAG laser (1064nm)
- Automatic operation for space debris tracking, stare & chase, light curve measurements

The upgrade is based on state-of-the-art technology and uses proven designs wherever possible.

2.1. Dome subsystem

The dome is a slit type dome of about 2 m in diameter with a cylindrical base. It is extremely rigid against harsh environmental conditions.

2.2 Space Debris Laser Ranging Subsystem

The main components of the space debris laser ranging subsystem are the pulsed laser source for laser ranging to noncooperative targets, the transmitting refractor telescope and a camera used for guiding purposes. The space debris laser package, the telescope and the guiding camera are mounted on an alt-azimuth direct drive mount.

Space debris laser package

The space debris laser package mainly contains the laser head, the transmit telescope and the guiding camera. An additional telescope for the stare & chase mode will be installed on top of the SD laser package.

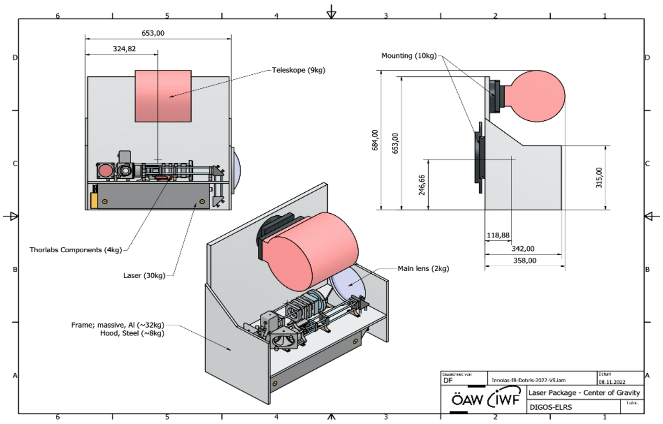

Figure 1. Space Debris Laser Package

For the space debris laser, a high-power laser with a wavelength of 1064nm, a repetition rate of 200Hz, a pulse energy >180mJ and a pulse width of 5-9ns is used for ranging. The simulated expected performance in Figure 2 shows the minimum optical cross section using detection limits of 3% and 10% for light-time and day-time ranging under good sky conditions. At night time, 10 cm objects may be observable at ranges below 600 km and 50 cm objects may be observable at ranges below 1400 km. Larger objects (e.g. rocket bodies) may be observable up to a distance of 3000 km. At day time, 50 cm objects may be observable at ranges below 1000 km. At day time, ranging will generally be restricted to shorter ranges and larger objects.

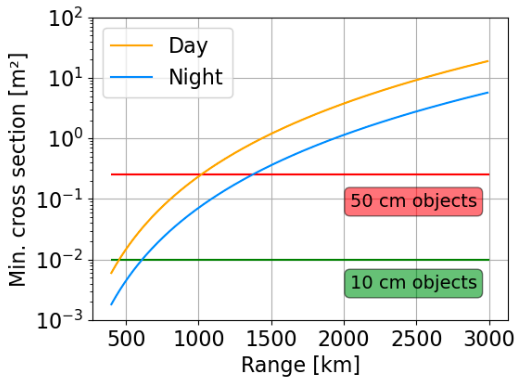

Figure 2. Minimum cross section vs range for day and night

An already integrated laser ranging detector package in the IZN-1 station contains the optical components in order to receive the returning laser light and to perform the ranging measurement. The detector package will be updated by a single-photon detector as a light curve detector (Figure 5) to enable high temporal resolution light curve recording simultaneously to the ranging measurements.

Guiding system

Since available space debris predictions are often rather inaccurate, a visual guiding system would offer a great benefit for successful ranging to targets with inaccurate predictions. Visual tracking will be possible as long as the target is not passing into the earth shadow. The most limiting factor for the visualisation is always the contrast to the sky background. It is obvious that the contrast is much weaker for the same object during day time than during twilight. The minimum target size which can be visualised should correspond to the minimum target size

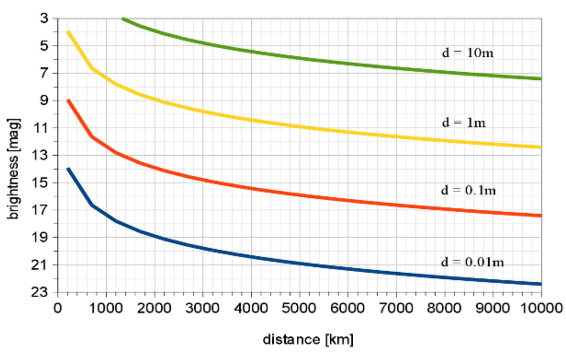

Figure 3. Estimated magnitudes of four spherical satellites from 1cm to 10m diameter with albedo of 0.2

which can be ranged with the new space debris ranging system.
The visualisation during night time requires a telescope with an aperture of 20 to 30cm. As the exit aperture of the space debris laser package with a diameter of 20cm fulfils the specification related to the aperture, guiding during the night can be performed with the satellite camera mounted in the space debris laser package. For the visualisation of targets with larger angular offsets than the FOV of the satellite camera, the Stare & Chase telescope can be used. Even the smallest objects which can be ranged during night time with the space debris laser system can be visualised in both cameras. A spherical object with 10cm diameter in a distance of 600km will have a brightness of 11mag assuming 20% reflectivity. A similar brightness will have a spherical object with a diameter of 50cm in a distance of 1400km. For the faintest objects the integration time has to be increased to a few tenths of a second.
Completely different is the situation during daylight. As the contrast to the sky background is the limiting factor for the visualisation, it has to be maximised by selecting the hardware components carefully, especially the telescope aperture in conjunction with the sensor of the camera. Link budget calculation (Figure 2) for the SD laser ranging system show that the limiting object size for ranging during the day will be approximately 50cm in a distance of 1000km. This corresponds to a brightness of 10mag. As shown in Figure 3, only objects brighter than 8mag can be visualised by a properly designed guiding system with the given telescope aperture. Objects brighter than 8 mag can be visualised in day light under perfect atmospheric conditions using the cameras installed on the main telescope. Additional band pass filters will be used for reducing the sky background. The SD laser ranging system allows successful ranging during the day to objects fainter than 8 mag. As a consequence, ranging to the smallest objects during the day has to be carried out without any guiding system (blind tracking). Successful ranging observations will only be possible if the predictions have only little uncertainty and proper search strategies are available. The transmit telescope and the Stare & Chase telescope are for various mostly programmatical reasons not too well suited for day light visualisation of objects. Due to the small aperture of 20cm only objects brighter than 6 mag might be visualised (see Figure 3). The use of the already integrated space debris observation camera on the main telescope as a guiding camera suffers from the situation that it cannot be used in parallel to the laser ranging measurements. Summarising, different guiding systems are available (Figure 4). For night time observations the transmit telescope as well as the Stare & Chase camera system are most suited (Tx Guiding System). The only difference between both systems is the larger FOV of the Stare & Chase telescope. But it should be noted that the optical axis of the Stare & Chase telescope deviates by a small amount from the optical axis of the transmit telescope. In both cases tracking corrections calculated by the Tx Guiding System will be sent to the main telescope (Rx) to ensure that the object is within the FOV of the Rx Satellite Camera. During day light operation the cameras of the IZN-1 main telescope (with an aperture of 80cm) will be mainly used as guiding system. First the object will be visualised with the Rx SD Observation Camera located on an additional Nasmyth port and the angular offsets will be calculated on a sequence of images. After correcting the predictions with help of these angular offsets, the tertiary mirror will be switched back from the additional Nasmyth port to initial Nasmyth port. This will take roughly 5 seconds including the time for the required refocusing. Subsequently the closed loop tracking will be started using the Rx Satellite Camera of the detector package. The calculated angular offsets will be permanently sent to the Tx telescope.

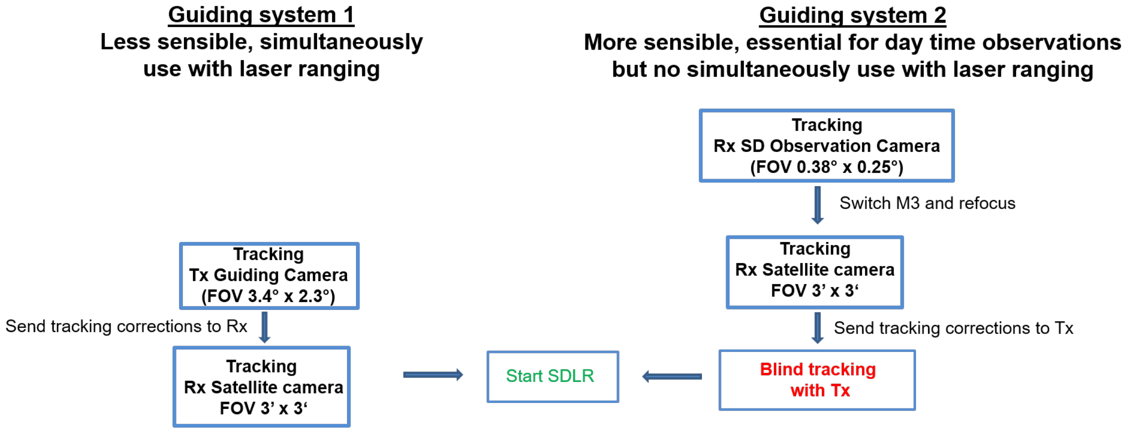

Figure 4. Procedure overview for two different guiding

2.3 Stare & chase subsystem

The new stare & chase operation mode will allow tracking and laser ranging of orbital objects whose orbital parameters are only known with large uncertainty. As this mode requires good image quality and low background noise, it can only be conducted at night time. The objects must be illuminated by the sun. The Stare & Chase telescope will start tracking on the basis of the rather inaccurate orbital parameters. The wide FoV camera continuously records and analyses images of the sky. In case the object is not within the FoV, a sky survey will be started around the predicted position. As soon as the object is within the FoV, its astrometric coordinates will be determined on a few subsequent images by comparison with background stars. Subsequently, an automated processing chain is started to generate improved orbital parameters of the object. Due to the short observation period and the relatively large uncertainties in the measured coordinates, these orbital parameters will be still rather inaccurate, but usually accurate enough to immediately initiate object tracking, starting the search loop and ranging with the space debris laser system ("chase"). The results of these tracking and ranging measurements can be used to obtain accurate orbital parameters.
For the staring mode a telescope of 20cm aperture and a focal ratio f/2.4 is used. As a space debris observation camera, a CMOS camera with sensor size of 36 x 24mm (resp. a FOV of 4.3° x 2.9°), and a pixel size of 3.76µm (corresponds to a pixel scale of 1.6"/pixel).

2.4 Light curve subsystem

In astronomy Light Curves (LC) is a common method to extract physical and dynamical characters of space objects. The application of LC on satellites or space debris is to collect the solar radiation reflected by the surface of the object, and LC shows the brightness variation of an object over a period of time. The signal density is firmly connected to the geometry relations between observer, object and sun, cross-section and the reflectivity of object. The light curve package installed at IZN-2 focuses on dynamic properties of space objects, such attitude, attitude motion, using a single photon avalanche diode (SPAD) and a field programmable gate array (FPGA). In Figure 5, the incoming light gathered by a receiving telescope is guided by the mirror M1 to the detection package. The two ranging wavelengths (532nm and 1064nm) are directed to their individual detectors. The remaining light is divided further into 2 portions: < 800 nm is used to visualize space object, and all above 800 nm light is collected by LC SPAD detector.

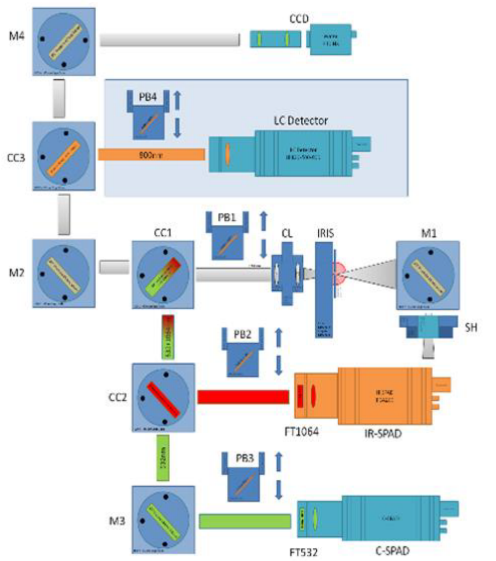

Figure 5. Optical layout of the detector package

2.5 Computer and software subsystem

The computer hardware and software, which controls the space debris laser station in addition to its previous functionality, are mainly already integrated into the IZN-1 station. The existing network subsystem of the IZN-1 station provides communication links between the different station components for time synchronisation, data exchange, command & control, backup as well as an uplink to the internet. The new infrastructure of IZN-2 also has two additional computers installed. The station, as already done in IZN-1, will be operated by the off-the-shelf SCOPE command and control SW. All laser functionality can be accessed by the operating software of the used laser. The data filtering is an off the shelf software whose interfaces will be modified in order to directly interface with SCOPE.

2.6 Station protection and laser safety

A station protection function is already available by the existing IZN-1 station and this function is used to protect the space debris station as well.

The Laser Safety functionality that is already integrated in IZN-station ensures that persons inside and outside the station as well as airplanes and other "flying objects" in the local airspace are not exposed to hazardous laser light emitted by the system and will also take care of the space debris system laser safety. Any risks to humans in case of motor control errors will be avoided. The system is also responsible to minimise interference with other observation systems on ground and in space. In addition to existing laser safety unit, a thermal infrared camera is integrated to ensure detection of objects without ADS-B (Automatic Dependent Surveillance - Broadcast).

In order to survey the station at day and night time consistently, two surveillance cameras are installed.

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