Plans for a Fully Automated SGSLR System

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Abstract

The Space Geodesy Satellite Laser Ranging system (SGSLR) is being designed with the goal of full automation. Lessons learned on NASA's Next Generation Satellite Laser Ranging System (NGSLR) and other systems are being implemented in SGSLR. Automation will be achieved in stages with the first stage being remote operational capability at the McDonald and Ny-Ålesund SGSLR systems when many of the operational tasks will already be automated. Ultimately, SGSLR will send science and engineering data to, and receive commands from, the Space Geodesy Network Operations Center (SGNOC), similar to the way spacecraft now operate. The hardware and software needed to achieve full automation, and the implementation stages are also discussed.

Background

NASA's Satellite Laser Ranging (SLR) operations and development are part of the Space Geodesy Project (SGP). [Merkowitz 2014] SGP is currently developing and deploying next generation stations as part of a new global Space Geodesy network, which will replace most of the currently operating legacy systems as well as expand the network with other important sites. SGP techniques include Very Long Baseline Interferometry (VLBI), Global Navigational Satellite Systems (GNSS), and Satellite Laser Ranging. Most SGP sites will include all of these techniques.

NASA is developing these new stations to improve performance to meet increasing science requirements and to reduce operational costs. The new system development includes automating the stations and using a central operational facility that will coordinate and optimize the operation of all of the stations. This paper looks at the automation aspects of the SGSLR system in support of the requirements.

SGP stations will communicate with a central facility called the Space Geodesy Network Operations Center (SGNOC) which will collect housekeeping, engineering and science data from the SGSLR stations, provide the capability to remotely monitor the health, safety and performance of the stations, and coordinate of network activities. The first SGSLR systems will be developed, integrated, tested and verified at the site at the Goddard Geophysical and Astronomical Observatory (GGAO) in Maryland. These systems will then be deployed to the McDonald Geophysical Observatory (MGO) in Texas, and the Ny-Ålesund Geodetic Observatory (NGO) in Norway.

A prototype SGSLR system, NGSLR, was developed and tested to prove the new SLR performance and automation concepts. [McGarry 2013] The performance of NGSLR met many of the new SGSLR requirements and the system achieved partial automation. NGSLR is the foundation of the SGSLR system's design.

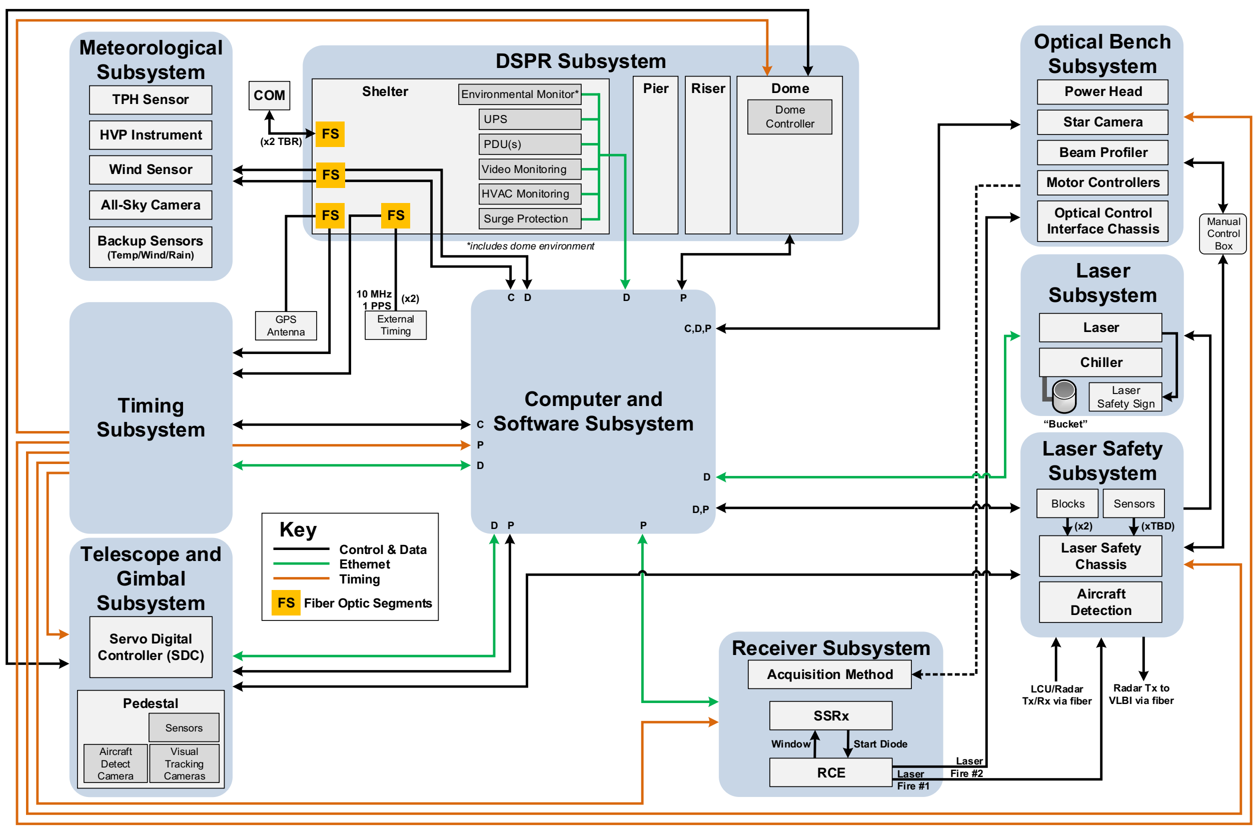

Figure 1: SGSLR Simplified Block Diagram showing the nine subsystems

System Design

SGSLR has nine subsystems. All are being designed to support automation. Status information and data from each of the subsystems is collected and sent to the SGNOC for monitoring, performance analysis and archiving. A simplified block diagram of the subsystems and their interconnections is shown in Figure 1.

Timing

The Timing subsystem generates, regulates, and provides the various timing signals distributed to and used by other subsystems. It acquires GPS time and ensures that the timing signal remains stable, and outputs a 10 MHz signal from an oscillator disciplined by GPS, a 1 PPS that is synchronized to that 10 MHz, and a time code (IRIG-B) that provides time of day. The system also includes a monitoring subsystem that uses a secondary GPS timing source to compare the GPS 1 PPS outputs and provides the data to the computer subsystem to assess the accuracy of the timing.

Meteorological

The Meteorological subsystem is designed to measure outside environmental conditions to provide information for precise ranging and for health and safety of the system. This subsystem consists of a variety of measurement devices including an all sky cloud camera, wind and precipitation sensors. The most important of the measurements are the barometric pressure, temperature, and humidity which are necessary to correct range errors introduced by an altitude dependence of the atmospheric index of refraction. [Degnan 1993]

Telescope and Gimbal

The gimbal and telescope assembly (GTA) is designed as a monostatic system to both transmit laser energy and receive light from targeted objects through common optics. The gimbal drives the telescope to track satellites, stars and point at fixed ground targets. This subsystem includes the telescope and Coudé path through the tracking subsystem, two cameras mounted on the telescope (one low light camera for viewing dim targets and one wide field of view camera for visual tracking), and all associated environmental monitoring and control devices such as temperature sensors, accelerometers, etc. It also includes the gimbal, encoders, servo electronics, and additional hardware/software to monitor/maintain environmental limits. Information sent to the SGNOC from the GTA includes gimbal pointing, pictures from the cameras, and video (when requested).

Optical Bench

The optical bench subsystem is designed to allow the laser subsystem, receiver subsystem, and star camera to reside in an environmentally controlled environment, while supporting automatic laser divergence changes for different satellites, point-ahead (off-axis pointing) of the laser beam for satellites, beam blocking and beam attenuation for laser safety, system configuration changes for the various modes (star calibration, ground target ranging and satellite tracking), and reduction in the background light that the detector is exposed to (ND wheel, spatial and spectral filters). Laser light is directed along a path on the optical bench that is aligned to the telescope optical axis. The transmitted light goes from the laser to the pit mirror along the Coudé path, and eventually out through the telescope. Receive light captured by the telescope is directed to the receive path on the optical bench which is aligned to the telescope optical axis. A variable field of view is used in the receive path to support acquisition of targets with poor predictions. Finally, this subsystem includes diagnostic components to monitor the laser characteristics and to support alignment. The configuration of the optical bench between satellite, star and ground target ranging is completely controlled by the software. All devices controlled by the software on the optical bench will be regularly monitored for status.

Laser

The laser subsystem consists of: (1) the SESAM-modelocked Nd:YAG laser oscillator/ amplifier, which generates a 2 kHz train of 50 ps FWHM pulses; (2) a nonlinear crystal which converts the fundamental NIR wavelength at 1064 nm to the visible green wavelength at 532 nm; (3) the laser diode pumps and their power source; (4) switches and associated control electronics for selecting pulses from the train; and (5) a chiller to maintain the laser's internal temperature. The software monitors the chiller status and controls the laser, including turn on and off. The repetition rate of the laser is also controlled by the software to prevent collisions between outgoing laser pulses and incoming light from the target.

Laser Safety

The laser safety subsystem is designed to meet all NASA, ANSI, FAA, and local safety standards for outdoor laser use as well as to protect SGSLR and other ground personnel. It includes an instrument for aircraft detection which is co-aligned with the laser beam, support electronics, beam blocks and ND filters for eye-safety external to the system, and sensors to inhibit the laser should a subsystem fault occur or should someone access an area in the system where the laser light can cause damage, such as the roof of the shelter or the dome. The system is failsafe and redundant, reporting information to the software, but independent of the software.

Receiver

The range receiver subsystem consists of the detector and associated electronics to detect and measure the start and stop event times, support the software's determination of the signal from the background noise and the range to the target, and provide angular offset information to allow for closed loop tracking. The angular offsets are determined from the image location in the 7 x 7 pixelated detector which is being developed for SGSLR. The software uses this angular information to correct the GTA pointing and optimize the return signal strength. [Degnan 2016]

The range receiver subsystem also includes the RCE (Range Control Electronics) which provides the Computer and Software subsystem with control of both the laser fire frequency and the detector range window, and generates the fixed ground target range window.

Dome, Shelter, Pier, Riser

The Dome, Shelter, Pier, and Riser (DSPR) subsystem includes the components which enclose, protect and support the SLR operation. During normal operations the dome will be slaved to the GTA azimuth position. The software has complete control of the dome shutter. In addition the software can shut down all of the subsystems through the use of the DSPR Uninterruptable Power Supplies (UPS).

Computer and Software

The computer and software subsystem monitors, controls, calibrates, and maintains the system as a whole, and communicates with the central facility. The software is designed to support local, remote, and fully automated operations. This subsystem links all other subsystems together, transfers and stores data, processes the ranging data, monitors and protects the system, and communicates with the SGNOC. [Horvath 2014]

Security is of crucial importance in the design and development of automated systems. It is very important that SGSLR be secure both physically and through the internet. Information Technology (IT) Security must protect against intrusion from unauthorized users, corruption of the computers from malware, disabling of internet access, and corruption or disruption of the data delivered to the SGNOC. The SGSLR team is working with NASA experts to develop an approach that will allow SGSLR to perform and communicate as needed while protecting it from unauthorized access, system and data corruption, and internet and/or data disruption.

Initial System Operation

SGSLR will have seven modes of operation:

- Satellite Ranging (science data collection mode)
- System Calibration (ranging to ground targets and internal cal)
- Star Calibration (using stars to generate mount pointing corrections)
- Vector Tie System Support (automated survey monitoring)
- Standby / Maintenance
- Diagnostics / Simulation
- Power-up / Shutdown

Regardless of the mode, operations will be the same whether a human operator is physically present, remotely controlling, or not participating (automated operation). The only difference will be who makes the decisions - not what functions are performed.

Initial operation of SGSLR at each deployment location will be local, i.e. the operator must be present in the SGSLR shelter and is fully responsible for the performance and safety of the system. Local operation will allow the operator to better assess the system performance and to determine any issues that need resolution.

At MGO, even at the local operation stage, much in the system will be automated, including almost all of the laser safety, signal processing, angular bias calculation, downloading of the predictions and schedule, and automated processing and transmission of the normal point data to the SGNOC. Some status information from the subsystems will flow to the SGNOC. By the time NGO is deployed much more of the system will be automated and most of the status information from the systems will flow to the SGNOC.

The transition to near remote operation will occur within several months of operation for the MGO system. Near remote implies having a remote operator on the site but not in the SGSLR shelter. The operator will control the SGSLR system through the use of the Remote Access Terminal (RAT) which will have the same software that is used for local operational control but where the connection is routed through the NASA secured SGNOC. The operator is still responsible for the performance and safety of the system. Near remote operation is necessary at MGO to allow the remote operator to have a laser enable/disable line hardwired from the station as required by the current U.S. Federal Aviation Administration (FAA) laws. The FAA regulation that governs the use of outdoor lasers is currently being rewritten to address automated laser operations and it is anticipated that the new laws will allow the SGSLR systems to autonomously re-enable the laser after an aircraft avoidance event has disabled the laser.

Initial tests of full system automation will include two daylight shifts operated by humans, and a nighttime shift where the system attempts automated operations under the supervision of a skilled caretaker at the shelter. The caretaker will take notes in support of the system developers who will use this information to fix problems and optimize performance.

Challenges in the path to full automation include changing FAA regulations in the U.S. to remove the need for a human operator to re-enable the laser; ensuring that the system IT Security is capable of protecting the system and its data from intrusion and corruption; developing a sophisticated cloud recognition algorithm for use by the software to determine where in the sky to select targets; and working through all of the decision paths and hazard analysis needed for an automated system to ensure we have all of safety and all of security planned for and covered.

Future System Operation

The future of operations for SGSLR is for both remote operation and full automation. In both of these cases the SGSLR hardware and software are responsible for the system performance and safety but with monitoring at the SGNOC. The SGSLR system will operate independently most of the time, collecting data and sending in normal point data along with status, housekeeping and engineering data to the SGNOC regularly. SGSLR will monitor status information from all subsystems and will protect itself, including taking actions such as closing the dome shutter, cutting off power to subsystems as needed, and alerting the SGNOC as well as local technicians through text messages and emails when there are problems.

Remote operations will allow operators to take control of SGSLR from across the globe. This is expected to occur for newly launched satellites, for special experiments, and to debug issues that have been seen with the system or data. The operator will control SGSLR through the SGNOC.

There will always be technicians at the sites during one or two shifts per week to perform routine maintenance, to support repairs, and to attend to the system should a problem arise. The technicians at each site will support all of the SGP techniques. There will always be a local technician on call who will respond to SGSLR alerts.

Summary

The Space Geodesy SLR Network of the future will consist of globally distributed, fully automated, high performance SGSLR systems that can operate in daylight as well as night and can track satellites from Low Earth Orbiting to Geosynchronous. Each SGSLR system will have the capability to protect itself from weather, to protect humans from the laser, to monitor its own performance, and to alert local technicians and the SGNOC of issues or emergencies as needed. The SGSLR system will make its own decisions but will continuously transmit a stream of information and science data to the SGNOC for monitoring, trending and archiving. Science data (normal points) will be quality checked and sent to the ILRS Data Centers hourly. The SGNOC will have the capability to remotely take control of the SGSLR systems whenever needed. This is expected to occur when tracking a newly launched satellite, for a special experiment, or to diagnose and debug issues occurring at the station.

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