EARLY SATELLITE TRACKING RESULTS FROM SLR2000

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Abstract

NASA's SLR2000 was conceived as a totally autonomous, eye-safe, photon-counting, two-kilohertz satellite laser ranging (SLR) system. Prototype development of SLR2000 has been underway for the past several years at the Goddard Space Flight Center. These efforts recently culminated in successful satellite tracking. The authors now have an integrated semi-automated prototype system that can range to satellites and can perform many of its functions without operator intervention. Results from recent satellite and ground ranging experiments will be presented along with the current system status and plans for further development.

Introduction

SLR2000 was conceived in the mid-1990s to be NASA's next generation Satellite Laser Ranging System, capable of operating completely autonomously and continuously for months without any manned intervention [Degnan 1994]. The system was envisioned to be completely free of optical, electrical and chemical hazards and would use the internet for two-way communications with a central facility. The system performance was expected to be similar to current NASA MOBLAS capabilities: ~1 cm RMS single shot (or better) with 1 mm precision Normal Points for LAGEOS.

Today the prototype SLR2000 system (Figure 1) is a reality, currently going through system testing and debug. The system still has a few technical challenges to resolve, and it is not yet completely automated, but the system is getting returns from satellites. Star calibrations are now performed routinely, appear to be very stable, and generate mount models with RMS values around 2 arcseconds. Ground calibrations have been performed on many occasions and system delays are being calculated for all four detector quadrants. Satellite returns have been obtained for segments of STARLETTE, BEC, AJISAI and TOPEX passes.

The SLR2000 system characteristics are given in Table 1 below. Details of the various subsystems can be found in previous Laser Workshop papers [Degnan 1996], [Titterton 1996], [Degnan 2002], [McGarry 2002], [Patterson 2002].

The purpose of this paper is to describe the current performance of the prototype system, and to show the plans for its completion.

Table 1: Current SLR2000 prototype system characteristics

Laser:	**Nd:YAG Diode pumped Osc/Amp**
Fire rate:	**2 kHz**
Pulse Energy:	**~60 microJoules/pulse at exit aperture**
Beamwidth:	**10 to 40 arcseconds (FWHM)**
Point ahead:	**Risley prism pair (0-30 arcseconds)**
Detector:	**Photek quadrant MCP PMT**
Gain:	**3.E+6**
QE:	**13% at 532 nm**
Image area:	**6mm diameter quadrant centered**
Receiver:	**4 independent channels**
Field of View:	**10 to 40 arcseconds**
Discriminator:	**Phillips Scientific 708**
TIU:	**Honeywell Technology Solutions, Inc. 1.5 psec resolution Event Timer**
T/R switch:	**Passive (Polarization insensitive)**
Tracking mount:	**Xybion Corp Az/El gimbal**
Tracking error:	**~1 arcsecond RMS**
Telescope:	**Orbital Sciences Corporation 40 cm off-axis**

Figure 1: **SLR2000 Prototype at NASA's Geophysical and Astronomical Observatory**

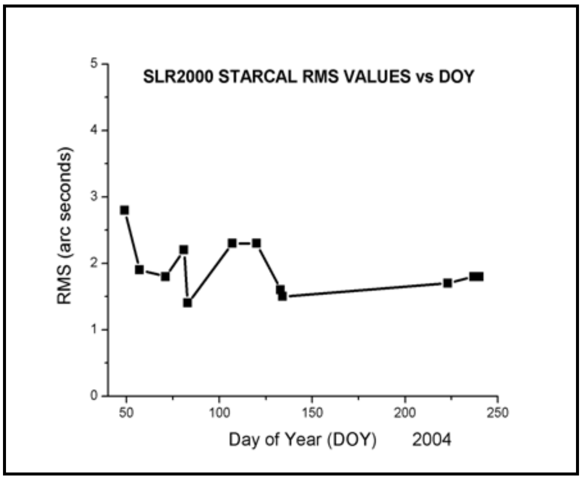

Figure 2: **Star calibration RMS model fit versus day of year.**

Star Calibrations

Star calibrations are performed routinely. The system pointing is at the arcsecond level and the mount model appears good for several days after the data has been taken. The current 22 term mount model provides a good fit (~ 2 arcsec) for elevations between 10 degrees and 90 degrees. Once the dome is open the star calibration executes completely autonomously and takes approximately 30 minutes to accumulate information for 66 stars. The solution is calculated from a least squares fit to the 22 term trigonometric model. Figure 2 shows the RMS values of all star calibrations for the current version of the mount model.

The mount model corrections can reach a sizeable fraction of a degree. Figure 3 shows model corrections for the star calibration on May 13, 2004, which are typical for SLR2000.

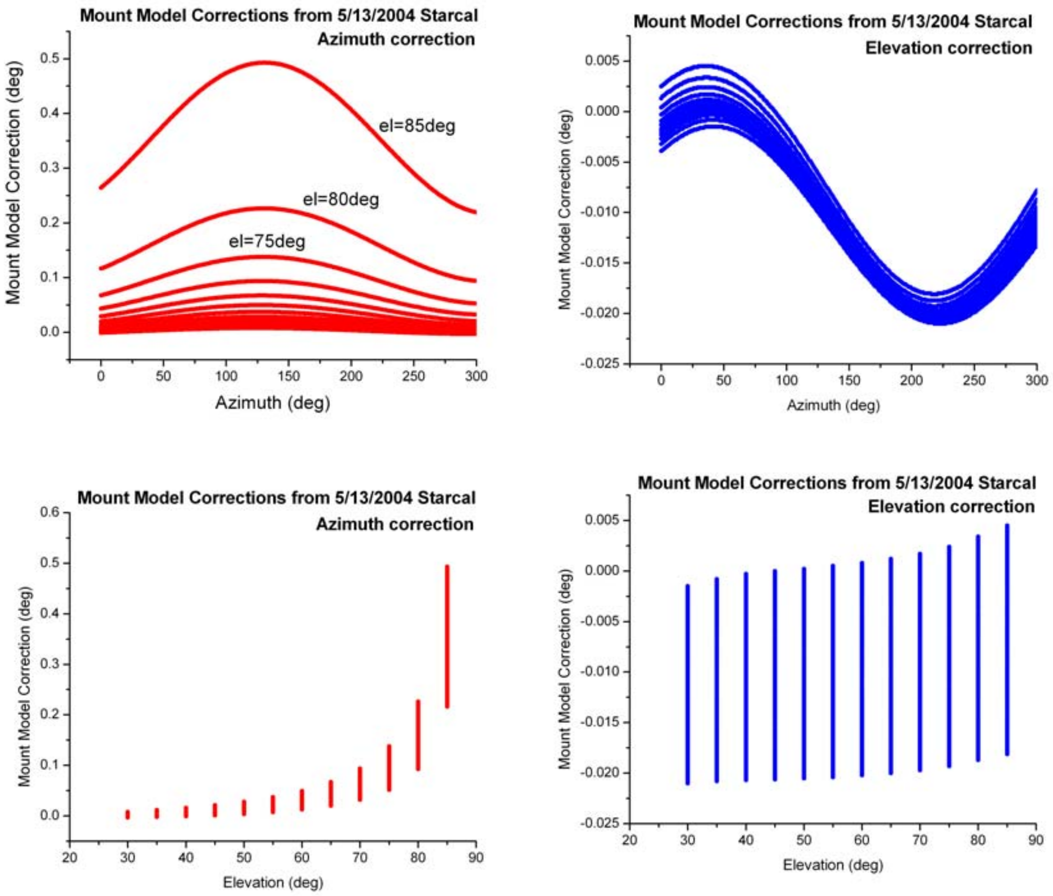

Figure 3: Mount model corrections calculated from May 13, 2004 star calibration. Top plots give azimuth and elevation corrections versus mount azimuth. Bottom plots show same corrections as a function of mount elevation.

Ground Calibrations

Successful real-time signal processing of ground target range data is now routine. The automated search and acquire also works well. Currently the range returns are manually centered on the quadrant detector, but implementation of closed loop tracking using the quadrant detector information will soon make the ground calibrations semi-autonomous. System setup for ground ranging, including adding required ND filters and setting appropriate gating for the PMT, is still manually performed.

A system delay is calculated for each of the four quadrants independently. The nominal system delay for quadrant 1 is 45 nanoseconds. To overcome the 100 nanoseconds deadtime in the

Event Timer, each quadrant's return is delayed 100 nanoseconds relative to the previous one using a fixed delay line. Thus quadrant 2's system delay is ~145 nsec, quadrant 3 is ~245 nsec, and quadrant 4 is ~345 nsec. In photon-counting mode, the range data RMS should mimic the convolution of the transmitter pulsewidth and the receiver impulse response, and the observed high values are consistent with the 300 psec pulsewidth of the current laser. The plots in Figure 4 show the measured return ranges minus a fixed relative range for all four quadrants. In this plot each of the quadrants has been corrected with its corresponding system delay. For those viewing this document in color, quadrant 1 is black, 2 is red, 3 is green, and 4 is blue. As viewed from behind the detector on the transceiver bench, quadrant 1 is upper right, quadrant 2 is lower right, 3 is lower left, and 4 is upper left.

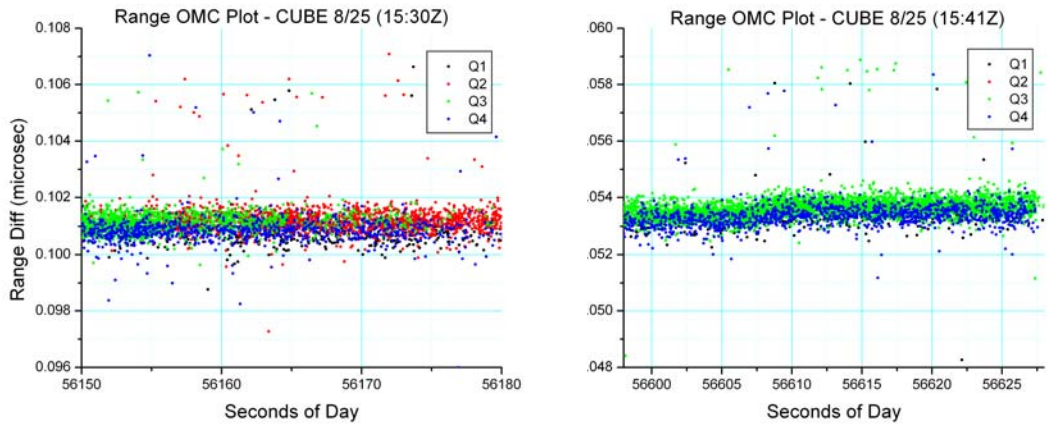

Figure 4: Measured minus fixed relative ranges to the ground target versus seconds of day. All data has been corrected using system delays for the relevant quadrants.

Satellite Laser Ranging

SLR2000 has tracked segments of about a dozen Low Earth Orbiting (LEO) satellite passes, including AJISAI, TOPEX, STARLETTE, and BEC. The current laser on SLR2000 is the preliminary version and outputs only about 120 microJoules of green energy (60 microJoules out of the telescope), which is 40% of the required laser transmit energy. Satellite ranging is, unfortunately, not routine yet, and our ability to get returns appears to be related to the orientation of the pass. Some problems in the receive optics have been identified, and will be corrected during the fall of 2004. This combined with a higher power laser and the addition of closed loop tracking should make satellite ranging much easier.

Figure 5 shows the measured range minus the predicted range (OMC) plotted versus seconds of day for various SLR2000 satellite tracks. The upper left plot (AJISAI 5/13/2004) is from a daylight track taken around 11:00 am local time. The rest of the plots are from nighttime tracks. All of the satellite, as well as ground target data, shows an as yet unidentified noise signature

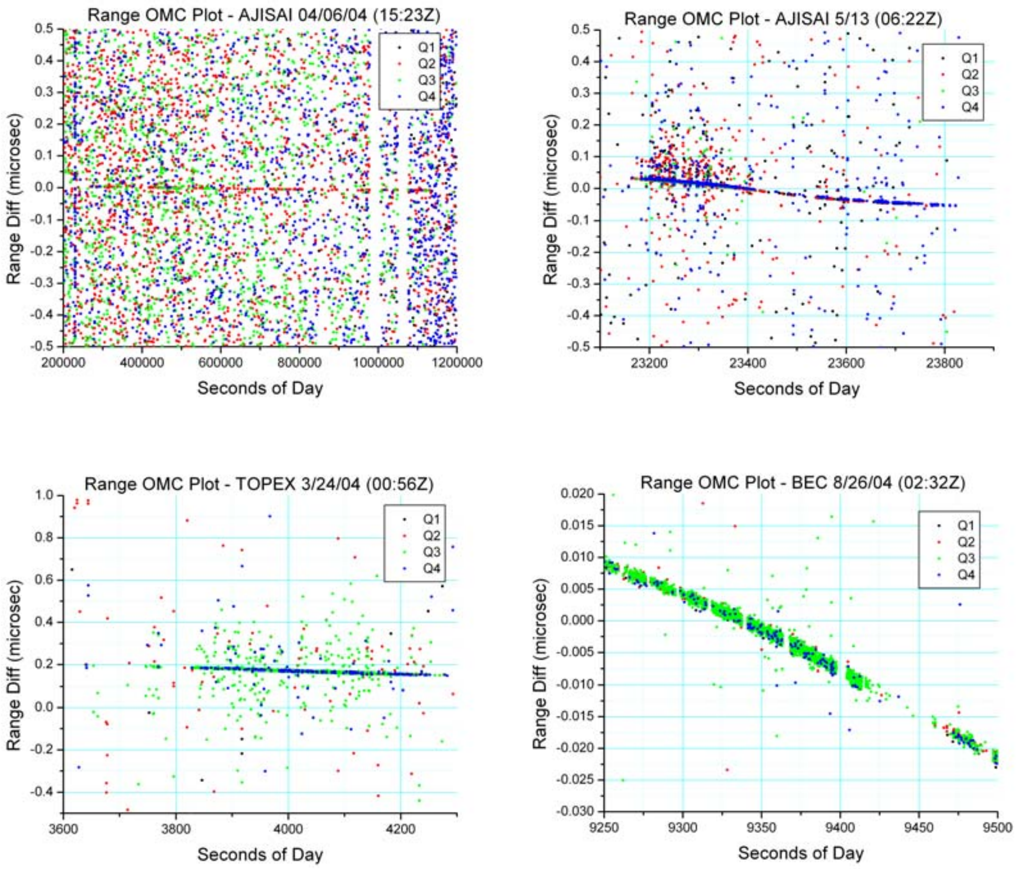

Figure 5: Observed minus calculated (OMC) ranges versus time for various SLR2000 satellite tracks. Measured ranges have been corrected for corresponding quadrant system delay.

which seems to be proportional to the signal strength. It can be clearly seen in the upper right hand plot (AJISAI 5/13/2004) as the bloom in the noise near the start of the plot when the signal strength is high. It disappears as the signal strength decreases. The envelope of this noise is several hundred nanoseconds. We currently believe this problem resides in the detector but more testing is needed to determine this conclusively.

Summary and Future Work

The SLR2000 system has finally become a reality. The system open loop pointing appears to be very good and very stable, the realtime signal processing works as expected, and segments of approximately a dozen satellite passes have been tracked. There is still much work to be done. The current goal for the SLR2000 prototype is to complete the major technical challenges within the next year and arrive at a semi-automated satellite laser ranging system that can track all of the current SLR targets. To accomplish this the following activities must be completed:

1) Operational laser must be completed by Q-Peak or developed in-house.
2) Receiver optics must be upgraded to include:appropriate daylight / twilight bandpass filters, adjustable iris field of view stop, and more angularly sensitive focusing to support quadant detector closed loop tracking.
3) High noise signature problem must be resolved and corrected.
4) Transmitter point-ahead must be implemented. The telescope will be pointed behind and the transmitter will be offset pointed using a Risley Prism pair to steer the beam ahead to where the satellite will be when the light reaches it.
5) Closed loop tracking using information from the quadrant detector must be added.
6) Automated realtime scheduling and realtime signal processing parameter update must be completed, making use of the system knowledge of the sky conditions and background noise.
7) Normal point generation from SLR2000 data needs to be analyzed.

We plan to complete the first six of these items within the next year. The system will then be collocated with MOBLAS-7 and used to collect data for Normal Point algorithm analysis.

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