One-way LASER Ranging to LRO

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Abstract: One-way laser ranging (LR) to Lunar Reconnaissance Orbiter (LRO) from NASA's Next Generation Satellite Laser Ranging System (NGSLR), and nine satellite laser ranging (SLR) ground stations from the International Laser Ranging Service (ILRS) has been ongoing since commissioning of LRO in June, 2009. Over 1200 hours of ranging data have been collected. The LRO clock oscillator is stable to 1 part in 10^{12} over several hours, and as stable for much longer periods after correcting for a long-term drift rate and an aging rate. Simultaneous ranging to LRO from two, three, or four ground stations allows for relative time transfer among the participating LR stations. Results of new ranging and time transfer experiments using the new time base will be discussed. The increased clock accuracy also provides stronger orbit constraints for LRO POD. The effect of using LR in the OD solution, both alone, and with the S-band tracking will be shown.

Introduction:

The LR flight component on LRO consists of a laser ranging telescope (LRT) attached to the LRO high-gain antenna (HGA), a fiber optic bundle to transmit the pulses from the LRT to the Channel 1 detector of the Lunar Orbiter LASER Altimeter (LOLA) detector, and timing electronics on the LOLA instrument to time stamp the pulse arrival times (*figure 1*). LOLA's Channel 1 detector is designed to receive the LR signal through wavelength multiplexing, with the LR pulses at 532 nm and the LOLA lunar surface returns at 1064 nm. The LOLA timing electronics time stamp both the LR signal from Earth and the LOLA signal from the lunar surface through time multiplexing. (*figure 2*)

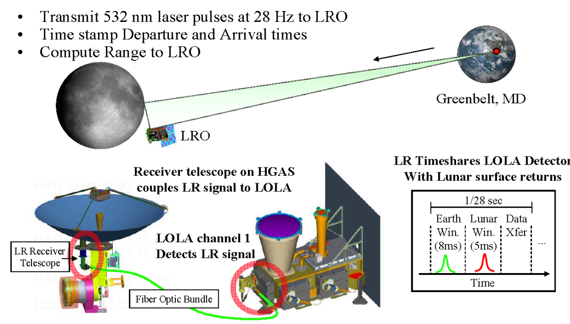

Figure 1: LR diagram

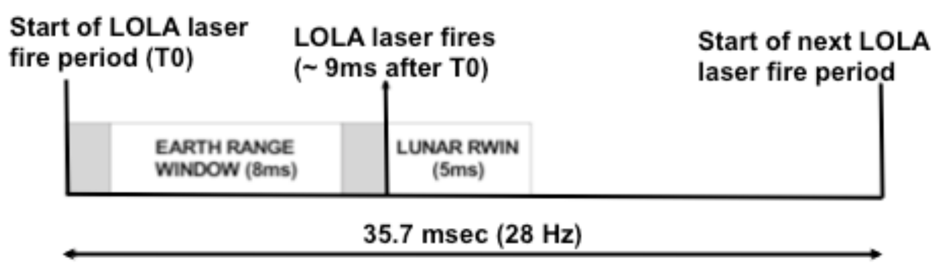

Figure 2. LOLA/LR timing diagram

The LR ground system consists of SLR stations that track the LRO spacecraft as it orbits the Moon, and transmit laser pulses to the spacecraft. The primary ground station for the LR system is NASA's Next Generation Satellite Laser Ranging (NGSLR) station, located at Goddard Space Flight Center in Greenbelt, Maryland. In addition, nine stations from the International Laser Ranging Service (ILRS) have been invited to partner with the NGSLR facility and participate in ranging activities. (*figure 3 and 4*.) From September 20, 2009 through October 5, 2012 these sites have achieved 2,345 hours of LRO tracking. While the single NGSLR station is sufficient to meet the LR objectives, the participation from the ILRS will broaden the ranging coverage and improve the overall LRO tracking coverage and thus data products.

LRO Orbit Determination with LR data:

The primary tracking technology of LRO is S-band. A gravity model derived from the GRAIL spacecraft, GRAIL420 (*Zuber, 2013)* was used to determine the position of LRO in 2.5 day arcs – short enough so that force model errors are not significant at the few meter level. Two-week arcs for LRO were determined in late 2009 and 2010 with LR data only, S-band only, and LR combined with S-band. A comparison of the two-week orbits with the the 2.5 day orbits shows an average total rms difference of 18.3 m, 12.5 m, and 9.6 m, respectively. The LR and S-band orbits show improvement over the individual tracking technologies, and LRO orbits determined with the LR data for two-weeks are good to less than 20 m rms, similar to the precision of the S-band only.

Figure3: Locations of LR tracking sites.

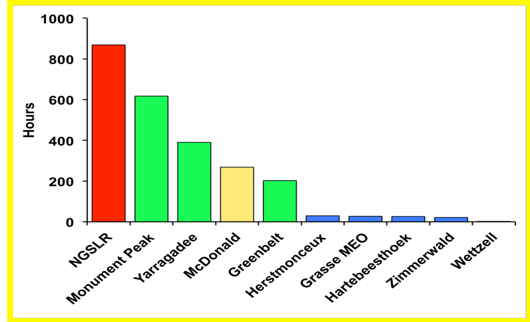

Figure 4: LR data summary from September, 2009 through October, 2012.

LR as Low Data rate Uplink Laser Communication Channel:

Modulation of the transmit time of the laser pulse from the ground station can be used as a code to send data from Earth to LOLA on LRO. A black and white image of Mona Lisa coded into laser firetimes at NGSLR was received at LOLA and sent back via LOLA telemetry.

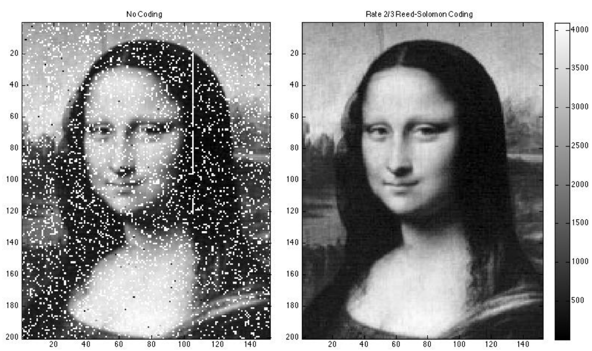

Figure 5. Mona Lisa image encoded at 12 bit grey scale, 1 pixel/laser shot: raw picture (left), after Reed-Solomon reconstruction. (Sun, 2013)

Time Transfer through simultaneous LASER ranging to LRO:

Individual tracking station clocks behave differently, but simultaneous ranging to LRO can achieve time transfer between the ranging sites. Testing of this capability is ongoing at the Goddard Geophysical and Astronomical Observatory (GGAO) with Moblas-7 and NGSLR. The epoch timing from USNO is achieved via GPS All-View receivers to NGSLR event timer. The out-going laser pulses from both stations time-tagged by the NGSLR timer with and epoch time accuracy < 1 ns. Currently, NGSLR & MOBLAS7 time transfer has an accuracy of about 10 ns, whereas current GPS time accuracy is about 10 times that. The goal of this experiment is 0.5 ns accuracy.

Summary:

Data from the ILRS network continues to be taken by the ten participating stations . The quality of orbit determined with only LR data is comparable to using all available tracking data, and the LR data improves knowledge of the LRO orbit from that determined with S-band alone to the level of about 10 m rms. LR has been used to demonstrate low bit rate laser communication to an spacecraft not orbiting the Earth. A time transfer experiment has been demonstrated. LR has demonstrated the ability to effectively perform laser ranging at Lunar distances.

References:

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