Reduction and analysis of one-way laser ranging data from Wettzell ground station to LRO

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Abstract:

One-way LR (Laser Ranging) is being performed routinely from ILRS (International Laser Ranging Service) ground stations to LOLA (Lunar Orbiter Laser Altimeter), onboard NASA's LRO (Lunar Reconnaissance Orbiter). This rather new experiment provides high accuracy spacecraft range measurements over interplanetary distances. Furthermore it can be used for monitoring the LRO clock long-term behavior and referencing the MET (Mission Elapsed Time) to UTC (Universal Time Coordinated) precisely. We present the current status of our effort to process, analyze and utilize selected LR data for LRO clock characterization, orbit determination and gravity field estimation.

Introduction:

Satellite LR has being used to track Earth satellites since 1964 and has reached an accuracy of a few millimeters nowadays. The high precision positioning enables the development of greatly improved Earth gravity field models and constraints for fundamental physics [1]. For the LRO mission LR supports the development of an accurate global lunar geodetic grid [4] which will be the basis for future lunar exploration missions [3]. In addition to that LR to LRO can be used for keeping track of the time drift of the LRO USO (Ultra stable oscillator) with respect to ground station clocks and confirmed the long-term stability which has been estimated in preflight ground tests. LR also enables a referencing of the LRO MET (Mission Elapsed Time) to UTC (Universal Time Coordinated) with higher precision than provided by the NASA flight dynamics facility SCLK (Spacecraft Clock Kernel) which is accurate to 3ms by definition [5].

LR to LRO:

Unlike various ranging techniques, such as retro reflector or two-way transponder, LR to LRO is a one-way measurement and Figure 1 shows the basic principle of this experiment. A ground station fires a laser pulse to LRO at a certain time and the received pulse is time stamped by the satellite. By calculating the light travel time between the receiving and the firing time, it is possible to derive a high precision range measurement with a RMS of 10 to 30 cm [5]. An optical receiver is attached to the HGA (High Gain Antenna), which is always pointed towards Earth; incoming Earth range pulses are transmitted into the LOLA laser detector by a fiber optics cable. This permits LR tracking of LRO simultaneously while LOLA is ranging to the lunar surface.

Wettzell Ranging Campaign:

Among the ILRS stations, the fundamental station Wettzell in Germany is routinely engaging in LRO LR campaigns. Here we analyze data from two successful Wettzell passes, with dates and times listed in Table 1. Both passes have a duration of about 35 minutes, while the laser was firing at a 14 Hz rate. After receiving the station laser fire times for these two passes, we paired them with the LOLA laser receive times.

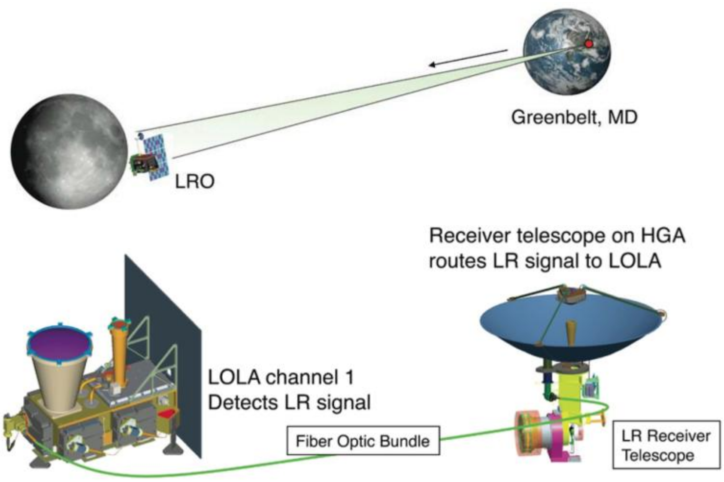

Figure 1: LR to LRO - basic principle [3]

Pass	Tue 15th Nov 2011	Wed 16th Nov 2011
Begin	1:49 am CET	4:02 am CET
End	2:24 am CET	4:37 am CET

Table 1: Wettzell LR to LRO passes

Matching:

The results are shown in Figure 2 and 3. We used the NAIF SPICE toolkit to predict light travel times for certain shots to then find the receive times that match those predictions best. Currently, no relativistic or atmospheric corrections are applied to the light time. In order to retrieve a predicted spacecraft position, we used LRO SPICE kernels, produced by inversion of radio tracking and Laser crossover analysis [4]. Figure 2 shows the predicted light travel time from SPICE and the best matched shots for the pass of the 15th November 2011. We successfully matched a total of 3267 out of 26711 (≈12.2 %) station laser fire times with corresponding LOLA laser receive times taken from the RDR (Reduced Data Record) files. Figure 3 shows the deviation between the predicted light time in SPICE and the matched shots. The linear fit shows an offset of about 5.346e-4 s (≈160.27 km) and a trend of roughly 1.447e-6 s (≈439 m) of the matched shots with respect to the prediction during the pass of approx. 2000 seconds. The offset is most probably due to the offset of the LRO MET with respect to UTC and currently under our investigations as well as its curve shape and the trend.

A polynomial fit of the order of 4 to the matched shots reveals statistical variations around a mean trend. The matched shots have a RMS of 3.3e-10 s (≈9.89 cm) with respect to that fit, whereby they are not averaged to normal points. This is the accuracy that is achievable with 1-way LR to LRO [4] and therefore our results look promising.

Following our investigations, the effect of the unusual grouping of the matched shots during the second half of the pass, is associated with a hardware frequency issue of the Wettzell laser system which has been resolved recently. Beside weather condition and telescope pointing this issue is also a reason for the low ratio of matched to total number of laser shots.

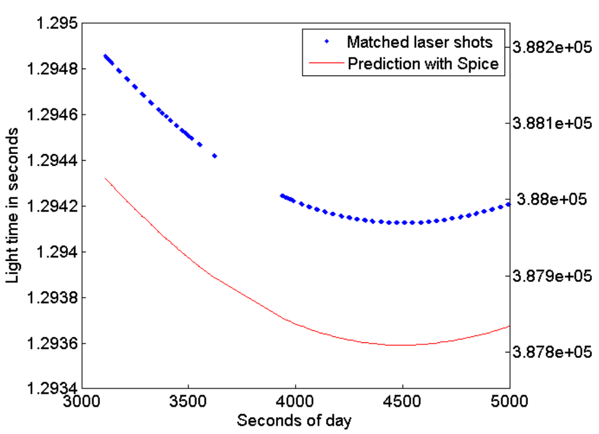

Figure 2: Predicted light time and matched shots

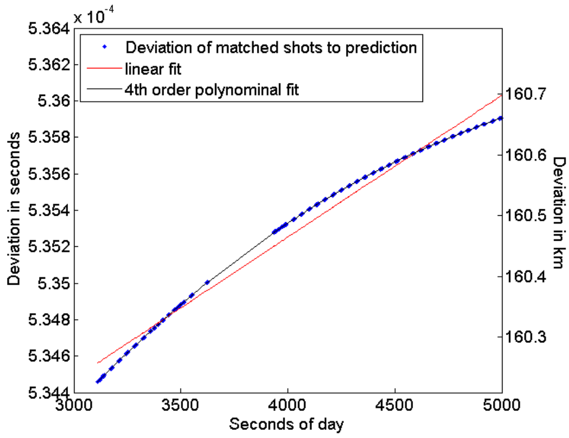

Figure 3: Difference between prediction and shots

Summary and Conclusions:

We have received LR data from two successful passes from Wettzell ground station to LRO and matched the station laser fire and LOLA laser receiving times. The results show the accuracy that is achievable with 1-way LR to LRO and remaining deviations are under our investigation. Recently the work on processing all LRO LR passes has begun with the development of an automated data processing and shot matching capability at DLR in Berlin. Currently LR to LRO data is being processed, whereby the results show promising RMS values, for example on average around 13.4 cm for all participating stations from commissioning phase until science mission 23 (≈ June 2009 until June 2012). This new type of tracking data will be used to improve the knowledge about the LRO clock behavior, as well as the orbit determination of LRO and gravity field estimation in future [cf. 4].

Acknowledgements:

This work has partially been funded by the DFG and the FP7 program of the European Union. Much of this work was carried out while the first author very much enjoyed a research visit at NASA Goddard Space Flight Center (GSFC).

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