Reduction, analysis and application of one-way laser ranging data from ILRS ground station to LRO

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Abstract:
One-way laser ranging is being performed routinely from International Laser Ranging Service ground stations to the Lunar Orbiter Laser Altimeter, an instrument onboard NASA's Lunar Reconnaissance Orbiter. We developed software to process this novel type of tracking data and gathered information e.g. on characteristics and distribution in a preliminary analysis. By incorporating the high accuracy spacecraft range measurements into orbit determination, one expects the positioning and thereby the accuracy of further derived data products to improve. We used the one-way laser ranging measurements within an estimation software based on the Tudat library for carrying out an orbit determination for the Lunar Reconnaissance Orbiter. Thereby the results from the preliminary analysis on tracking data coverage, quality and quantity were used for inputs into the estimation and for evaluation of the results.

1. Introduction:

The one-way LR (Laser Ranging) experiment provides high-accuracy range measurements over lunar distances between ILRS (International Laser Ranging Service) ground stations and the LOLA (Lunar Orbiter Laser Altimeter) instrument onboard NASA's LRO (Lunar Reconnaissance Orbiter). Furthermore, this data can be used for characterizing the LRO clock and monitoring the long-term behavior as well as referencing the MET (Mission Elapsed Time) to TDB (Barycentric Dynamical Time). Unlike ranging experiments to reflectors or transponders, LR to LRO is a one-way measurement (Figure 1). A ground station fires a laser pulse to LRO at a certain time and the received pulse is time stamped by the satellite. An optical receiver is attached to LRO's HGA (High Gain Antenna), which is always pointed towards Earth, and incoming laser pulses are transmitted into the LOLA laser detector by a fiber optic cable.

This permits ranging measurements to LRO simultaneously while LOLA is ranging to the lunar surface [1]. By calculating the light travel time between the receiving and the firing time, a high precision range measurement with a typical RMS of 10 to 30 cm in case of this experiment is derived [3]. Currently the OD (Orbit Determination) for LRO is based on radio as well as altimetric crossover data and is provided in the form of the LRO SPK's (Spacecraft Positioning Kernels) with an accuracy of ≈ 14 m in total spacecraft positioning [2]. This, as well as the quality of Lunar remote sensing data products, is expected to improve with a successful incorporation of the LR data to the LRO nominal navigation data [1].

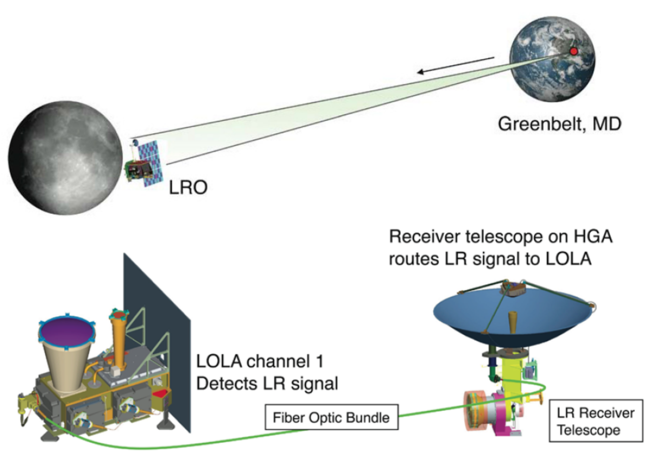

Figure 1: LR to LRO [1]

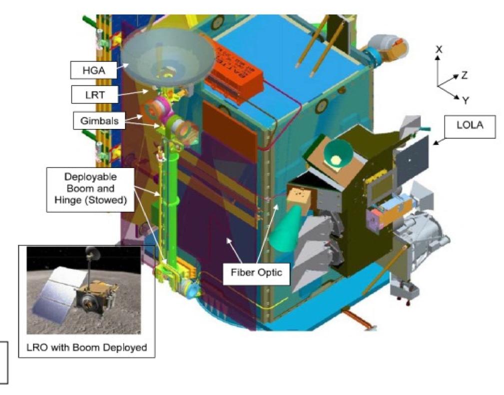

Figure 2: Fiber optics cable [1]

2. Data Processing and Application:

Beginning with data obtained during a LR to LRO campaign from the ILRS station in Wettzell Germany, we have developed an independent matching program at DLR Berlin. This software relates the separated station laser fire times to the LOLA laser receive times and has been extended to process a large number of passes automatically. Beginning with the LRO commissioning phase, we now have processed and analyzed data until the end of ES03 mission phase (July 2009 until December 2012). From that preliminary analysis we derived information on the LRO clock as well as tracking data coverage, quantity and quality by using the LRO SPK. The mean per pass measurement RMS value of 13.4 cm that we obtain from this analysis agrees with the LOLA instrument accuracy.

In order to make use of those high accuracy measurements in an OD, we used the one-way laser ranging data within an estimation software based on the Tudat library [4]. Thereby we used the state of the art GRAIL gravity field of the Moon up to Degree and Order 150.

We incorporated 36 passes covering the time from the 25th until the 30th of July 2010 in Nominal Mission 12 for the OD. During that timeframe the stations GO1L in Greenbelt MD USA, MONL in Monument Peak CA USA and YARL in Australia did track LRO with 1-way LR successfully. Thereby in case of the full data ≈96% of the matched shots are coming from the GO1L station due to its capability of firing synchronously with the LOLA 28 Hz cycle. In order to balance the amount of data coming from the various stations in the OD, we developed station specific weights.

To verify whether the results were reasonable, we evaluated the RMS of the measurements with respect to the derived trajectory. In addition, the results from the preliminary analysis were used as a reference to check on the total value and the variation of the estimated parameters.

3. Results:

We present the results of two estimation cases, whereby we derived a continuous trajectory and estimated the

- LRO clock parameters per pass & initial state (referred to as per pass)
- LRO clock parameters per day & initial state as well as ground station clock parameters once (referred to as per day).

Figure 3 shows the RMS of the measurements with respect to the derived trajectory in blue for per pass and in red for per day. Figure 4 and 5 show the estimated clock parameters for drift and aging, per pass in blue and per day in red, as well as the results from the preliminary analysis in black. Table 1 shows the RMS, the mean value and the variation of the derived parameters as well as their deviation with respect to the values of the preliminary analysis .

When the LRO clock parameters are estimated as often as per pass they absorb orbit errors, which is the reason that this case has the largest variations and deviations with respect to the preliminary analysis for drift and aging (see Table 1). Even though with 0.45 m the RMS is almost at measurement accuracy level, which is expected and a verification of the estimation itself, it does not represent the actual orbit accuracy.

When switching to an estimation of the LRO clock parameters per day and including the estimation of ground station clock parameters as well, we retrieve less variation and deviation with respect to the preliminary analysis results (see Table 1). Due to this, we consider those values to be more reasonable than those from the case per pass. Now that the orbit errors are absorbed less by the clock parameters, the RMS of the measurements goes up to 4.55 m. The derived aging value of -2.00±5.83e-17 s/s² for this case is actually in quite good agreement with the value of ≈1.2e-17 s/s² estimated in previous analysis for that point in time [3]. With that we consider, that the estimated values of the case per pass, where we included ground station clock parameters as well, are more reasonable than the those of the case per day and thus represent an improvement in our application.

As we are currently trying to improve our software, the setup and the formulation, we are working towards the usage of clock parameters for a longer period e.g. one week as a next step. Thereby we want to maintain a low overall RMS and reasonable values for the estimated parameters, taking these two criteria as an indicator for good orbit quality. Furthermore we consider the usage of Normal Point Data within the OD, simultaneous LR observations to LRO from multiple ground stations, as well as various type of tracking data in order to provide additional reference. With that we are trying to work towards a successful application of the 1-way LR data into OD.

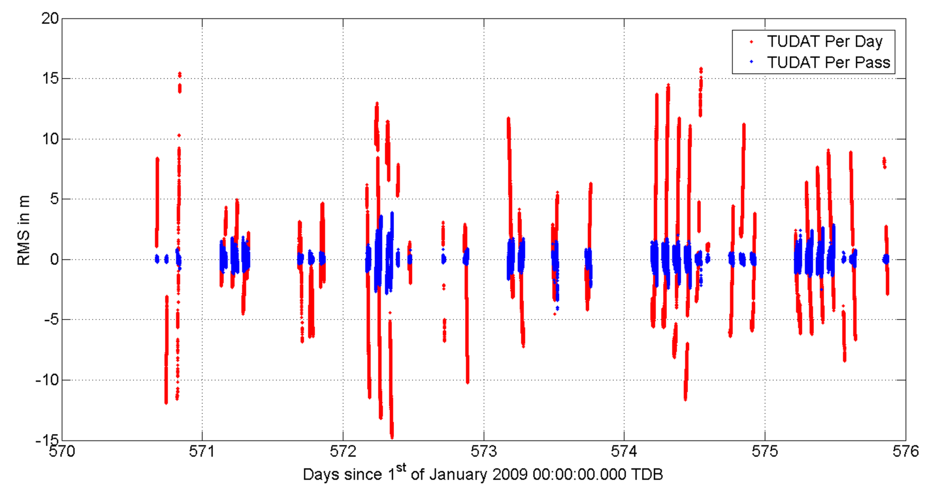

Figure 3: RMS of the measurements w.r.t. the derived trajectory

Case	Mean RMS in m	Mean value and variation (STD is w.r.t. to a linear fit to the data)		Deviation of mean value to mean value of preliminary analysis	
		Drift in s/s	Aging in s/s²	Drift in s/s	Aging in s/s²
Preliminary analysis	-	- 7.1108e-08 ±3.53e-12	+2.96e-15 ±6.90e-16	-	-
Per pass	0.45	-7.1129e-08 ±2.04e-11	+1.27e-14 ±1.00e-14	2.10e-11	9.74e-15
Per day	4.55	-7.1103e-08 ±3.22e-12	-2.00e-17 ±5.83e-17	5.00e-12	2.98e-15

Table 1: RMS and deviation of the estimated parameters to the results of the preliminary analysis

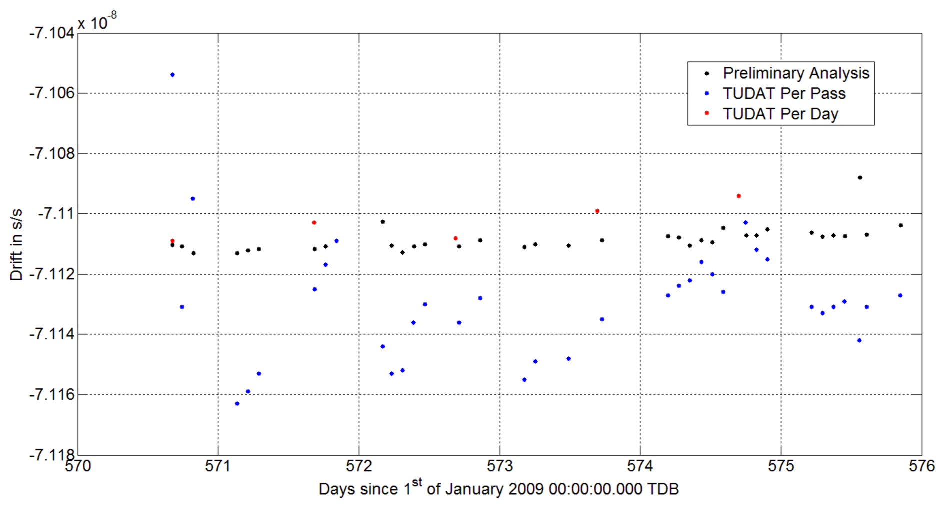

Figure 4: Estimated drift values

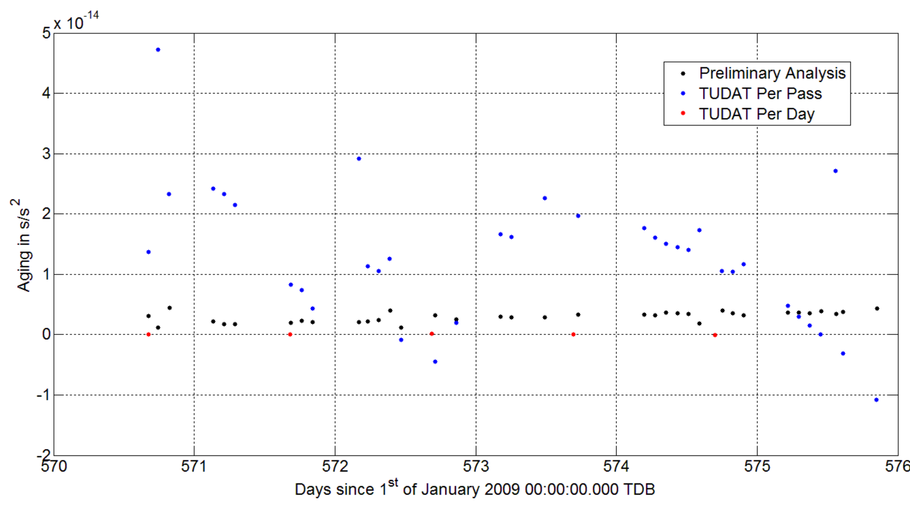

Figure 5: Estimated aging values

4. Summary and Conclusions:

Beginning with the participation in an observation campaign at the Fundamentalstation Wettzell, we developed software to process one-way LR data from ground stations to LRO. We derived information on the LRO clock behavior as well as tracking data coverage, quality and quantity over a timeframe from beginning of CO until the end of ES03 mission phase (July 2009 until December 2012).

By incorporating the processed data into an estimation software based on the Tudat library, we made an attempt to use the high accuracy LR data for the estimation of the LRO position. The results from the preliminary analysis were used to develop station specific weights for balancing the tracking data.

As shown with the comparison to the results from the preliminary analysis, the parameters become more reasonable when changing the estimation of the LRO clock parameters from per pass to per day, while incorporating ground station clock parameters as well. Thereby the RMS of the measurements with respect to the derived trajectory is still good. As we are currently trying to work towards longer arcs, we want to maintain reasonable results on the RMS and the estimated parameters. By working on the setup, the approach and the incorporation of Normal Point data as well as other passes and data types, we intend to enable a successful application of the 1-way LR data into OD.

Acknowledgements:
This work has partially been funded by the DFG (German Science Foundation). S. Bauer is partially and D. Dirkx completely financed by the FP7 ESPaCE project, financially supported by the EC FP7 Grant Agreement 263466. 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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