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Reduction, analysis and application of one-way laser ranging data from ILRS ground stations 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). We developed software to process this novel type of tracking data and perform 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 LR measurements within the estimation software TUDAT for doing an orbit determination of LRO. To select a certain timeframe we looked at the size of the jumps at the LRO SPK (Spacecraft Positioning Kernel) merge points and the tracking data coverage, quality and quantity. Furthermore the results taken from the preliminary analysis were used for various inputs into the estimation.

Background

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). The experiment provides high accuracy spacecraft range measurements over interplanetary distances. Furthermore it 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 Coordinated 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 optics cable. This permits ranging measurements to LRO simultaneously while LOLA is ranging to the lunar surface [1].

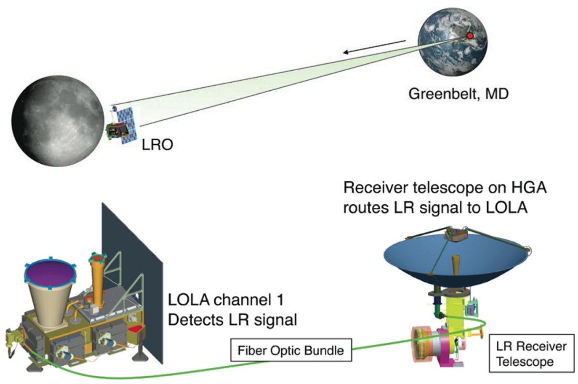

Figure 1: LR to LRO - basic principle [1]

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 spacecraft positioning [2]. This, as well as the quality of further derived data products, is expected to improve with a successful incorporation of the LR to LRO data [1].

Data processing

Beginning with data obtained during a LR to LRO campaign from the ILRS station in Wettzell Germany, we have developed a matching program at DLR Berlin independently. This software is relating the separated station laser fire times to the LOLA laser receiving times and has been extended for being able 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. The mean measurement RMS value of 13.4 cm estimated from this analysis, thereby agrees with the LOLA instrument accuracy.

Application

In order to derive the proposed improvement in positioning via an OD, we used the one-way laser ranging data within the estimation software TUDAT [4]. We selected a certain timeframe for a first estimation by looking at the magnitude of the jumps at the LRO SPK merge points. Since the orbit in the SPK's consists of many partial trajectories, one can see jumps of the position and the velocity at the times where they are merged together. Throughout the analyzed timeframe we saw a mean jump size of ~ 83 m. While looking for timeframes with small jumps we also took the tracking data coverage, quality and quantity into account. Since the tracking data is not evenly distributed due to station characteristics, we used these informations to develop station specific weights. Likewise we also developed and provided apriori covariance to the estimation, in order to stabilize the solution.
We defined several cases, to check our approaches, the simulation setups and the validity of the results. We did that by assessing what the impact of changes of the setups, the used models (e.g. clock), the weights and apriori covariance was doing to the estimated parameters and their attainable accuracy. In addition to that the results from the preliminary analysis were used as a reference to check on the total values of the estimated parameters.

Results and Outlook

The results showed variation of the measurement RMS with respect to the derived trajectories from 5 to 150 m on average. While we consider the first number not being representative due to it's certain case setup and the far too optimistic value, the latter number shows that the currently achieved positioning is yet not better to what is already provided [2].
Some of the models that are currently employed in the estimation software are too simplistic as for example the radiation pressure model that is implemented via a 'Cannonball-model'. Due to the mismodeling the resulting trajectories are not very realistic, which causes high RMS values with respect to the real measurements and lowers the attainable accuracy of the estimated parameters. Thus one of the next steps is to improve the realism and the accuracy of the included models.
Furthermore we saw high correlations between state and clock in all results, which indicates that an independent estimation with our current approach is not yet possible. This is probably caused by the one-way setup of the LR experiment and the fact that we did do an estimation with one-way LR

data only. Applying apriori covariance and weights to the estimation did help improving the results and lowering the correlations but not yet to the desired level of accuracy.
By introducing a further referencing, we expect to be able to lower the correlations and yield the desired positioning improvement. If we can do that referencing for example by the incorporation of radio tracking data or if we have to develop other approaches is currently under research.

Summary

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 and carried out a preliminary analysis. With that software 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 putting the processed data into the estimation software TUDAT, we successfully combined two independent research approaches in order to derive an improvement of the LRO positioning. Thereby we compared, validated and improved the incorporated models as well as the results coming from the respective software systems. The results from the preliminary analysis were used to develop station specific weights for balancing the tracking data and apriori covariance in order to stabilize the estimation solution.
We were able to identify critical issues that arise during an application of the one-way measurements within an OD and furthered our understanding of this novel type of tracking data, even though we did not yet derive an improved positioning of LRO. By improving the incorporated models and introducing further referencing we intend to overcome the issues that are associated with this type of data and the experimental setup.

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