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Simulation of Interplanetary Laser Links

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Abstract

Interplanetary laser ranging (ILR) could enable highly accurate measurements of the range from Earth-based stations to interplanetary spacecraft and landers. A software framework that simulates these interplanetary laser links in a bottom-up manner, combining mission, system and environment characteristics in a transparent and controllable way, is being set up in the context of the ESPaCE project. Using these simulations, we will analyze the potential capabilities of such a system for improving the science return of planetary missions. The first part of the simulations has been validated using data from, among others, the LAGEOS satellites. Currently, data from the LRO satellite is being used to validate the combined mission and hardware models. Subsequently, the added value of a one- or two-way laser ranging system, either as a stand-alone system or supplementing existing radiometric systems, will be analyzed.

1. Introduction

Current estimates of the attainable range measurement precision of ILR are at the mm- to dm-level, a potential orders of magnitude improvement over current radiometric methods. The concept of one- and two-way laser links for ILR has evolved from reflector laser ranging to Earth-orbiting satellites, modified with active laser transmitter/detector systems on both the ground and space segments, allowing sufficient signal strength to be retained over interplanetary distances [1]. These high-accuracy range measurements have potential applications in planetary science missions, for instance the measurement of tidal deformation of extra-terrestrial bodies, the improvement of planetary ephemerides or gravity fields, tests of general relativity and precision deep space navigation. Such measurements could be performed by a dedicated instrument or an existing payload such as the GALA laser altimeter onboard the JUICE spacecraft.

2. Simulation

To ascertain the potential of ILR, bottom-up simulations of the laser links are performed within the Tudat software framework. These simulations will combine the hardware and mission characteristics of both the space and ground segment and the optical noise signals that are detected along with the laser pulses. In addition, the dynamical simulations and orbit determination process will be done in the same framework. By taking this approach, the performance of the ILR systems follows not from an assumption on the attainable precision of the measurements, but instead directly from the hardware characteristics and the specific mission geometry. In this manner, a clear mapping can be made from system and mission properties to attainable science return. By performing all simulation steps within the same framework, consistency between models can be ensured and the influences of specific parameters can be reliably determined.

3. Validation

Internal consistency of the software has been shown, in that using the exact same environment models for measurement simulation and orbit determination, using perfect measurements, results in the estimation procedure converging to a residual that approaches machine precision. The estimation procedure can incorporate various combinations of spacecraft or celestial body states, as well as a number of scientific parameters, such as spherical harmonic coefficients, deformation love numbers and body rotational characteristics.

The development of the dynamical simulations and orbit determination was validated using, among others, two-way laser ranging data to the Earth-orbiting geodetic LAGEOS satellites. Although these satellites employ reflector laser ranging, many of the characteristics are similar to those of ILR, allowing for its use in validation of a number of the models that are used. The orbit over an eight-day arc was estimated, including a set of empirical accelerations. The mean residual of the estimated orbit with the observations is at$\sim$5 cm, which is at the level that is to be expected at present. Remaining unmodelled effects are dominated by ground station motion and hardware-related matters, such as satellite signature and ground station time/range bias, which are of limited interest in simulation studies. Improved hardware models are currently under development, which is expected to result in a decrease of the residual.

The LRO satellite orbiting the Moon makes use of a one-way laser ranging system, which is used to supplement the radiometric tracking methods. As the only satellite currently employing this method operationally, it constitutes an excellent test case for the link simulations. These laser ranging measurements from the ground stations and the spacecraft have been processed and matched [2] and will be compared, in the statistical sense, to simulated data. This validation step will provide an estimate of the capabilities of the software to simulate one-way laser ranging links. This, along with the succesful validation of the orbit determination process, will provide confidence in the robust simulation of one- and two-way interplanetary laser links.

4. Application

Several applications of the laser link simulations are forseseen, which will provide a detailed investigation of the possible advantages of one- and two-way laser ranging links over interplanetary distances. Firstly, a laser-only mission will be simulated, for instance for a laser system on Phobos or a Jovian moon. Both one- and two-way laser ranging systems will be simulated, with a variety of hardware and mission caracteristics, to fully explore the design space. It will allow a selection of the most cost-effective architecture from a given set of science requirements, providing a robust estimate of the competitiveness between one- and two-way systems.

The final goal of the simulations is to simulate a mission using both radiometric (Doppler and VLBI), as well as laser tracking of an interplanetary spacecraft. Radiometric systems will not be simulated in a bottom-up fashion, but *a priori* assumptions will be made on the attainable precision and accuracy of these systems, which can be done reliably due to their extensive heritage. By performing such simulations, the added value of each of the tracking systems can be analyzed, where the focus will be on the added value of different types of laser systems and mission architectures. However, also the added value of VLBI tracking, which is not yet commonplace on interplanetary missions, will be addressed. Mission concepts and systems with dedicated interplanetary laser ranging systems will be used in one set of simulations to ascertain the cutting-edge possibilities of the technology. Additionally, the use for interplanetary tracking of existing and near-term laser altimeter systems, such as the GALA instrument onboard the JUICE mission, will be simulated. By using this analysis, it can be determined whether it could be worthwhile to use the laser altimeter to this end and assist in determining the optimal planning of possible laser ranging arcs.

5. Summary and Conclusions

Interplanetary laser ranging is being investigated in the ESPaCE project [3] as a future technology to enable highly accurate range measurements over interplanetary distances, supplementing the existing radiometric tracking techniques. A simulation tool, capable of performing bottom-up link simulations of laser range measurements without *a priori* assumptions on their precision, is being developed. Using the simulated data in an orbit determination process witin the same software framework will allow us to ascertain the added value of a one- or two-way laser ranging system, with and without Doppler and VLBI measurements, as well as the synergy with these systems. Upcoming simulations will allow us to determine the potential of both the use of existing laser altimeter systems for tracking purposes, as well as that of dedicated missions with purpose-designed hardware.

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References

[1] Degnan, J.: Journal of Geodynamics, 34(3-4):551-594, 2002

[2] Bauer et al., : Reduction and analysis of one-way laser ranging tracking data from Wettzell ground station to LRO, Vol. 7, EPSC Abstracts, 2012

[3] Thuillot, W. et al. : ESPACE, European Satellite PArtnership, EPSC Abstracts, Vol.6, EPSC-DPS Joint Meeting, 2011.