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TRAJECTORY OPTIMIZATION, GUIDANCE AND CONTROL OF LOW-THRUST ORBIT TRANSFERS FROM THE LUNAR GATEWAY TO LOW LUNAR ORBITS

Abstract

The Lunar Gateway will represent a primary space system useful for both the Artemis program, Earth-Moon transportation, and deep space exploration. It is expected to serve as a staging location and logistic outpost on the way to the lunar surface. This study focuses on low-thrust transfer dynamics, from the Near-Rectilinear Halo Orbit traveled by the Gateway to a specified Low-altitude Lunar Orbit (LLO). More specifically, this research addresses two closely-related problems: (i) determination of the minimum-time low-thrust trajectory and (ii) design, implementation, and testing of a guidance and control architecture, for a space vehicle that travels from the Gateway to LLO. Orbit dynamics is described in terms of modified equinoctial elements, with the inclusion of all the relevant perturbations, in the context of a high-fidelity multibody ephemeris model. This includes the gravitational attraction due to Earth, Moon, and Sun, as well as several harmonics of the selenopotential. The minimum-time trajectories from the Gateway to different lunar orbits are detected, through an indirect heuristic approach, which uses the analytical conditions arising in optimal control theory, in conjunction with a heuristic technique. However, future missions will pursue a growing level of autonomy, and this circumstance implies the mandatory design and implementation of an efficient feedback guidance scheme, capable of compensating for nonnominal flight conditions. This research proposes nonlinear orbit control as a viable and effective option for autonomous explicit guidance of low-thrust transfers from the Gateway to LLO. This approach allows defining a feedback law (for the thrust direction and magnitude) that enjoys quasi global stability properties - under certain conditions related to the dynamical environment - without requiring any offline reference trajectory. The overall spacecraft dynamics is modeled and simulated, including attitude control (carried out using a globally stable nonlinear feedback law) and actuation. The latter is demanded to an array of reaction wheels, arranged in a pyramidal configuration. Guidance, attitude control, and actuation are implemented in an iterative scheme. Monte Carlo simulations demonstrate that the guidance and control architecture at hand is effective in nonnominal flight conditions, as well as in case of temporary unavailability of the propulsion system. The numerical results also point out that only a modest propellant penalty is associated with the use of feedback guidance and control in comparison to the minimum-time optimal trajectory.