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VARIABLE-TIME-DOMAIN NEIGHBORING OPTIMAL GUIDANCE AND ATTITUDE CONTROL OF LOW-THRUST LUNAR ORBIT TRANSFERS

Abstract

Lunar orbit dynamics and transfers at low altitudes are subject to considerable perturbations related to the gravitational harmonics associated with the irregular lunar mass distribution. Onboard guidance and control systems of orbiting spacecraft must be capable of compensating the nonnominal flight conditions related to these perturbations, especially if the transfer duration is relatively long, which is the case if low-thrust propulsion is employed. This research proposes the original combination of two techniques applied to low-thrust lunar orbit transfers, i.e. (i) the variable-time-domain neighboring optimal guidance (VTD-NOG), and (ii) a proportional-derivative (PD) attitude control algorithm. VTD-NOG belongs to the class of feedback implicit guidance approaches, aimed at maintaining the spacecraft sufficiently close to the reference trajectory. This is an optimal path that satisfies the second-order sufficient conditions for optimality. A fundamental original feature of VTD-NOG is the use of a normalized time scale, with the favorable consequence that the gain matrices remain finite for the entire time of flight. The updating formula for the time-to-go and the guidance termination criterion derive from the natural extension of the accessory optimization problem associated with the original optimal control problem. This extension leads also to obtaining new equations for the sweep method, which yield all the time-varying gain matrices. VTD-NOG identifies the trajectory corrections by assuming a thrust direction always aligned with the longitudinal axis of the spacecraft. However, this assumption represents an approximation, and the attitude control system must maintain the actual spacecraft orientation sufficiently close to this thrust alignment condition. Reaction wheels are employed to perform the attitude control action, and a proportional-derivative control law is adopted to drive the actual spacecraft orientation toward the desired one. After identifying the nominal (optimal) low-thrust orbit transfer path, extensive Monte Carlo simulations are performed, in the presence of nonnominal flight conditions related to (i) lunar gravitational harmonics, (ii) gravitational pull of the Earth and the Sun as third bodies, (iii) unpredictable propulsive fluctuations, and (iv) actuation errors. The numerical results unequivocally demonstrate that the joint use of VTD-NOG and PD control represents an accurate and effective methodology for guidance and control of low-thrust lunar orbit transfers. Due to its generality, the unified guidance and control architecture termed VTD-NOG&PD can be applied to aerospace vehicles employed in a wide variety of mission scenarios