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LOW-THRUST NONLINEAR ORBIT CONTROL USING NONSINGULAR EQUINOCTIAL ELEMENTS

Abstract

During their lifetime, orbiting satellites often perform corrective maneuvers, for the purpose of avoiding excessive performance degradation, related to perturbations inherent to the space environment, namely (i) aerodynamic drag, (ii) solar radiation pressure, (iii) Earth gravitational harmonics, and (iv) pull of Sun and Moon as third bodies. The definition and implementation of an effective orbit control strategy thus represents a crucial issue, in order to compensate these perturbation actions, as well as possible errors at orbit injection. This research proposes a general, systematic approach to real-time, feedback orbit control, under the assumption that the satellite of interest is equipped with a low-thrust ion propulsion system. Lyapunov stability theory, in conjunction with the LaSalle's invariance principle, supply the theoretical foundation for the definition of a feedback control law that includes saturation and is capable of driving the dynamical system at hand toward the desired operational conditions. These are expressed in a rather general form and are associated with an invariant set that belongs to the attracting set of the controlled system. The feedback strategy at hand can be regarded as near-Lyapunov-optimal. Two different operational Earth orbits are considered: (a) a very-low-altitude, circular orbit and (b) a medium-altitude elliptic orbit. For each case, the relevant orbit perturbations are modeled. The stability properties and the overall performance (in terms of propellant expenditure) are investigated for scenarios (a) and (b). In each case, the attracting set is identified, and is proven to contain the invariant set associated with the operational conditions. For mission scenario (a), the sufficient conditions for stability are proven to hold on average, whereas they are satisfied instantaneously for scenario (b). As a result, convergence and stabilization in the proximity of the desired operational conditions is demonstrated, albeit for case (a) short-period oscillations cannot be avoided and represent the ultimate, non-compensated effect of Earth gravitational harmonics. Suitable tolerances on the desired operational conditions allow substantial propellant savings, because propulsion is switched on only when the flight conditions are beyond some specified bounds. As a further effort to model real scenarios with enhanced fidelity, satellite eclipsing is also considered. In this case, the numerical simulations demonstrate that the tolerances on operational conditions are occasionally violated in some limited time intervals (where the ion propulsion is unavailable), while the overall propellant consumption exhibits a moderate – yet still completely acceptable – increase.