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NUMERICALLY EFFICIENT METHODS FOR LOW-THRUST COLLISION AVOIDANCE MANEUVERS DESIGN IN GEO REGIME

Abstract

The rapid growth of the space debris population is leading to an increment in satellite proximity events. The Geostationary Orbit (GEO) region is less populated than the Low Earth Orbit (LEO) regime, but the debris density is still high, despite the difference in the absolute number of satellite belonging to the two regions. In particular, the increasing number of spacecraft reaching their end-of-life and the existing debris, such as rocket bodies, could threaten operative satellites and may require onboard Collision avoidance Maneuver (CAM) planning in the near future. Moreover, in this peculiar regime, spacecraft are subjected to gravitational perturbations that cause satellites to cross the assigned geostationary slot delimited by sharp latitude and longitude limits. To overcome this issue, ad-hoc control strategies are adopted to keep the spacecraft within the specified boundaries through station-keeping maneuvers. Currently, the state-of-the-art treats CAMs and station-keeping as separate problems. This paper illustrates how to embed both maneuvers, executed with a low-thrust propulsion system, into an analytical and time-efficient design policy. First of all, an extension of previous similar work in LEO has been carried out to GEO considering a pure Keplerian motion. Several firing strategies have been envisaged such as the North-South and East-West energy-optimal maneuvers, typical of station-keeping. Then, with the inclusion of geopotential perturbation in the CAM design, a station-keeping maneuver has been formulated as a Multi-Point Boundary Value Problem (MPBVP) with specific constraints on Probability of Collision (PoC) at Time of Closest Approach (TCA) and final state. The idea is to leverage the motion linearization by way of the state transition matrix (STM) and transform the energy-optimal control problem into an Initial Value Problem. In particular, the problem-solution can distinguish between two possible scenarios. On one hand, station-keeping alone is enough to ensure a PoC lower than a safeguard limit. On the other hand, when this requirement is not met, the algorithm autonomously identifies the best strategy for commanding CAM and station-keeping by imposing an arbitrary PoC at TCA. Results show that the maneuver is designed with a reduced computational time burden suitable for onboard CAM planning and the required equivalent v is strongly influenced by the maneuvering time windows.