IAF ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (1) (4)

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DIRECT OPTIMIZATION FRAMEWORK FOR COLLISION AVOIDANCE OPERATIONS OF LOW-THRUST SATELLITES IN LOW EARTH ORBIT

Abstract

The main goal of this research is to optimize low-thrust collision avoidance maneuvers for both the probability-of-collision among satellites and the propellant expenditure, considering a J2 perturbation model in the LEO regime. The probability-of-collision (Pc) is a common metric used in collision avoidance for measuring the conjunction risk and one of the most important pieces of data that is evaluated by the satellite operators. Currently, three Pc categories exist: high risk, moderate risk, and low risk. Operationally, a conjunction event is tracked over time for a few days before the time-of-closest-approach (TCA). If the Pc is consistently in the high-risk zone, necessary steps are taken to generate an avoidance maneuver plan. To improve collision avoidance maneuvers capabilities among satellites using low-thrust propulsion systems, we propose using a direct control method, considering the J2 perturbation effects, as it allows one to minimize the objective function involving the propellant expenditure of satellites at the nominal time of closest approach and probability of collision thresholds. The common method available for the computation of Pc approximates its value semi-analytically using 2-D numerical integration at TCA. The 2-D Pc approximation relies on simplifying assumptions that allow the complex 3-D non-linear and time varying conjunction event to be modeled as a simpler 2-D linear, Gaussian, and time-invariant event. Furthermore, objects are modeled as hard spheres. Consequently, Pc is computed by integrating over the closed region defined by the hard body radius (HBR) – the sphere enveloping the two objects – and the combined uncertainty ellipsoid centered on one of the bodies and projected on the impact plane. We apply numerical and semi-analytical propagation techniques to efficiently compute optimal low-thrust trajectories with the goal of risk mitigation in probability-of-collision involving two or more satellites. The goal of the proposed work is to show that a semi-analytical propagator (i.e., Draper Semi-Analytic Satellite Theory (DSST)) embedded in a direct solver will supply more optimal maneuver plans to space mission operators when compared to the same software implementation using a numerical propagator. Efficiency, accuracy, robustness, and computational speed tradeoffs between these propagation techniques are analyzed and discussed in this paper. This research has numerous guidance and control applications for achieving mission success and safety in autonomous operations.