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NUMERICALLY EFFICIENT IMPULSIVE AND LOW-THRUST COLLISION AVOIDANCE MANOEUVRES IN CISLUNAR L1-NEAR RECTILINEAR HALO ORBIT

Abstract

The increasing overpopulation of geocentric orbital regimes has led to a growing number of close approach events, posing a significant threat to operational satellites. Mitigating the resulting risk of collisions is crucial to preserve space assets, especially with plans for large-constellation deployment and the trend of satellite miniaturization. In this framework, the cislunar domain looks promising for scientific and commercial applications in the coming years, and policies to limit the space clutter are of utmost importance. Indeed, several missions are currently targeting this region for research activities, with some already operative, like Artemis 1, Capstone and NASA Lunar Flashlight. Among the various families, the Near-Rectilinear Halo Orbits (NRHOs) appear to be the most suitable given their stability properties, absence of Earth occultations and easy access from the Earth and to the Moon. Consequently, in this work a study on Collision Avoidance Maneuvers (CAMs) in the NRHO extends previous research in Low Earth Orbit and Geostationary Earth Orbit. It adopts a pure Circular Restricted 3-Body Problem model with different strategies for electric thrusters, including impulsive, Energy-Optimal (EO) low-thrust, and bang-bang firings. The proposed methods assume constant and uncorrelated covariances, short-term encounters, and a spherical object approximation. CAM planning leverages Chan's Probability of Collision (PoC) and Miss Distance (MD) at the Time of Closest Approach to set safeguard thresholds. The first two CAM algorithms ensure an analytical derivation thanks to motion linearization around the nominal orbit and solve with a Non-Linear Programming and an Optimal Control Problem, respectively. Both the control magnitude and direction are optimization variables. Unfortunately, the EO CAM does not apply to an operative scenario: it outputs a continuously varying unbounded acceleration that may exceed the thruster capabilities. A bang-bang firing overcomes the outlined limitations at the expense of a slight computational overhead by relying on an optimization procedure exploiting the EO solution and Picard–Lindelöf for dynamics approximation. The shut-down time varies to meet tight constraints on the final PoC or MD constraint. At this stage, no additional mission-related bounds are considered on the firing windows. The results show that developed techniques grant reduced computational time and accurate POC/MD targeting. The algorithms are suited for future onboard implementation, large-scale simulations, and sensitivity analysis.