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LARGE-SCALE MAPPING AND ANALYSIS OF COLLISION AVOIDANCE MANOEUVRES WITH SEMI-ANALYTICAL MODELS

Abstract

The continuous increase in space traffic and the accumulation of space debris means a growing stress on space traffic management (STM) and space situational awareness systems. This is a multi-faceted challenge, requiring sustained advances in a diverse set of fields like space surveillance and tracking, policy and regulations, debris mitigation, and collision avoidance (COLA). For what regards COLA activities, recent developments have focused on dealing with the increasing number of close approaches (CAs) by introducing a higher level of autonomy through artificial intelligence (either to assist ground operations or introduce on-board capabilities), the challenge of managing large constellations, updating the tools and models to account for the adoption of low-thrust propulsion, and improving the characterization of uncertainties, among other topics. In many of these cases, large-scale simulations are required to train, inform, or validate the models, which can be a challenge particularly in low-thrust scenarios.

This work presents a systematic mapping of collision avoidance manoeuvres (CAMs) in different operational scenarios both for impulsive and low-thrust propulsion systems, including sensitivity analyses for the key physical parameters affecting the manoeuvre design and performance. This large-scale mapping is enabled by the high-performance analytic and semi-analytic models in the MISS (Manoeuvre Intelligence for Space Safety) software developed by Politecnico di Milano. First, the different models, based on the single-averaging of the equations of motion, are presented. For the low-thrust case, arbitrary thrust directions are managed through the superposition of solutions for the tangential and normal directions. Both for impulsive and low-thrust CAMs, manoeuvre design methods for miss distance minimization and probability of collision maximization are described. Then, these models are used to construct the maps for a set of representative scenarios, leveraging publicly available historic data on CAs. From the analysis of these maps, key conclusions on the CAM's behaviour are drawn. Finally, the use of these maps for applications like machine learning models training or surrogate model design for on-board applications is briefly discussed.