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MINIMUM WARNING TIME ANALYSIS FOR LOW-THRUST COLLISION AVOIDANCE MANOEUVRES WITH STEERING LAWS

Abstract

The presence of space debris in Earth orbits has become an important factor to consider for day-to-day spacecraft operations. Future trends regarding the number of satellites, number of space debris objects and tracking capabilities of these objects suggest that satellites in low-Earth orbits will continue to require collision avoidance manoeuvres (CAM's) on a regular basis within their lifetime to resume operational activities safely. At the same time, low thrust satellites are becoming more popular in space flight, especially for (mega)-constellations, replacing conventional chemical propulsion systems with more efficient electrical ones. While propellant consumption is reduced using low-thrust propulsion system, CAM design becomes more challenging. Smaller thrust levels go hand in hand with both less manoeuvrability as well as a more required time to perform manoeuvres. This constraint is more evident for satellites which do not possess an on-board engine, since these satellites rely on attitude control systems and environmental accelerations to perform collision avoidance manoeuvres.

This study will explore the minimum time required to safely avoid a collision using low-thrust propulsion through a novel algorithm based on rate-of-change maximisation of the mutual distance at the time of closest approach. Rather than minimising fuel or Delta V, the time required to avoid a collision is minimised. Analyses are performed for a variety of conjunction geometries, thrust magnitudes and other simulation settings. Additionally, the behaviour of the time of closest approach under the influence of control is investigated. The results from the locally optimal algorithm introduced in this study are compared to a variety of common CAM techniques for various test cases in order to showcase its performance.

The results of this study have important implications for situations where the notification for a potentially dangerous conjunction is late and action time is limited. Examples include just-in-time collision avoidance, late detection of space debris, propulsion systems malfunctioning mid-manoeuvre and satellites without active propulsion systems. Additionally, situations where satellite operation time is valuable, such as Earth-observation missions, an algorithm like introduced in this study can be of relevance.