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ANALYTICAL ASSESSMENT OF THE IMPACT OF UNCERTAINTIES IN LOW-THRUST MANEUVERS ON COLLISION PROBABILITY

Abstract

Significant advantages of electric propulsion systems compared to chemical systems, such as reduced fuel consumption, led to a frequent deployment on spacecraft in recent years. Examples include the Starlink constellation as well as several CubeSats, such as UWE-4. Even though these engines provide only low thrust, they are also used for collision avoidance maneuvers. Due to the increasing number of active satellites and debris objects, fast and autonomous systems are crucial for future conjunction assessment and maneuver planning. In this process, not only the outcome of the maneuver itself must be considered but also the impact of expected uncertainties due to imprecise thruster performances. These additional uncertainties are often neglected when determining the post-maneuver collision probability. This can lead to an inaccurate prediction of the efficiency of the risk mitigation strategy which results in insufficiently or unnecessarily performed maneuvers. For autonomous systems this is particularly critical because maneuvers might only be triggered when the collision probability can be reduced below a specific threshold. Thus, these additional uncertainties are crucial for the autonomous decision-making.

In this paper, the impact of thrust uncertainties on the post-maneuver collision probability is assessed. Therefore, an analytical approximation is derived that determines state uncertainties due to an unknown thrust magnitude. Since low-thrust maneuvers cannot be approximated by an impulsive velocity change, these uncertainties are considered by assessing the continuously change of the specific orbital energy due to the exerted force. These additional uncertainties can then be added as process noise to the state covariance which allows more precise maneuver planning. The analytical approximation is compared with Monte-Carlo simulations to assess its accuracy.

Results show that these errors influence the post-maneuver collision probability. Especially, when uncertainties in thrust magnitude of several percent are expected, it is crucial to include this effect in the planning process. It can be shown that particularly the error in in-track direction grows significantly while it has only minor impact on the radial and out-of-plane components. Thus, especially for conjunction events where the in-track uncertainty considerably affects the collision probability the assessment of thrust errors is necessary for accurate maneuver planning.