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Author: Mr. Qurban Haciyev
Azerbaijan State Oil and Industry University (ASOIU), Azerbaijan

Mr. Karam Safarli
Azerbaijan State Oil and Industry University (ASOIU), Azerbaijan

PROBABILISTIC FRAMEWORK FOR COLLISION RISK MITIGATION IN A CROWDED ORBITAL ENVIRONMENT

Abstract

Managing safety and sustainable operations in orbit continues to be a challenge posed by space debris, and advanced new methodologies will need to be set in place for risk assessment and collision avoidance. An integrated framework for coupling deterministic catalogues with statistical population models for characterizing the current and future debris environment is proposed here. Propagation of uncertainties in debris generation, orbital decay, and fragmentation dynamics through Monte Carlo simulations gives us probabilistic estimates of collision risk for operational spacecraft in our approach.

At the heart of our methodology, we also fuse real-time space surveillance data with long-term statistical trends to enable continuous adaptive updating of risk models. This allows active collision avoidance with appropriate and timely alerts and maneuver advice regarding increasing density and geometry of debris sources. A rich case study demonstrating the framework's capability to track high-risk times and orbits during a congested low Earth orbit situation is carried through with sensitivity analyses identifying the contribution of important parameters, as fragment size distributions and re-entry probabilities.

In addition, our framework allows the evaluation of mitigation strategies such as enhanced shielding and selective debris removal by providing estimates of their potential benefits in terms of how well they would serve to decrease collision probabilities over time. All these show the sign and emphasis on the need for robust uncertainty quantification in debris modeling, thereby offering a broader tool for decision-making for satellite operators and policymakers. This constitutes substantive steps towards proactive risk management practices that will be necessary for guaranteeing the longevity of space operations in an orbit increasingly congested.