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PROBABILITY OF COLLISION OF SATELLITES AND SPACE DEBRIS FOR SHORT-TERM ENCOUNTERS: REDERIVATION AND FAST-TO-COMPUTE UPPER AND LOWER BOUNDS

Abstract

The proliferation of space debris in Low-Earth Orbit (LEO) has become a major concern for the space industry. With the growing interest in space exploration, the prediction of potential collisions between objects in orbit has become a crucial issue. It is estimated that, in orbit, there are millions of fragments a few millimeters in size and thousands of inoperative satellites and discarded rocket stages. Given the high speeds that these fragments can reach, even fragments a few millimeters in size can cause fractures in a satellite's hull or put a serious crack in the window of a space shuttle.

The conventional method proposed by Akella and Alfriend in 2000 remains widely used to estimate the probability of collision in short-term encounters. Given the small period of time, it is assumed that, during the encounter: (1) trajectories are represented by straight lines with constant velocity; (2) there is no velocity uncertainty and the position exhibits a stationary distribution throughout the encounter; and (3) position uncertainties are independent and represented by Gaussian distributions.

This study introduces a novel derivation based on first principles that naturally allows for tight and fast upper and lower bounds for the probability of collision. We tested implementations of both probability and bound computations with the original and our formulation on a real Conjunction Data Message (CDM) dataset used in ESA's Collision Avoidance Challenge. Our approach reduces the calculation of the probability to two one-dimensional integrals and has the potential to significantly reduce the processing time compared to the traditional method, from 80% to nearly real-time.