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SPACE OBJECTS CONJUNCTION ANALYSIS VIA ORBITAL ERROR PROPAGATION

Abstract

With the advancement of human space exploration activities, the quantity of space objects has risen substantially, creating significant hazards for the safety of on-orbit spacecraft. Particularly under the constraints of limited computational capabilities onboard, the efficient evaluation of orbital uncertainty propagation and the prediction of conjunction risks have emerged as critical challenges requiring immediate attention. This holds substantial practical and application-oriented significance for rapidly determining orbital states and their statistical characteristics at designated time interval.

This study applies a framework combining gaussian mixture models (GMM) and differential algebra (DA) to precisely propagate the state uncertainties of space objects, thereby facilitating conjunction risk assessment. Initial uncertainties are split using GMM, followed by the application of DA to derive a high-order Taylor expansion of the uncertainty propagation from the initial to the final state. Highly accurate collision probabilities are then obtained by calculating the integrals in the elliptic domain of the isotropic probability density functions corresponding to space objects at the conjunction moment. The performance of the method is evaluated using several representative orbital dynamics models, including two-body motion, J2 perturbations and solar radiation pressure effects. The first case applies the method to the dynamics of the two-body problem, the second one adds J2 long-term perturbation effects, and the last one includes full perturbation and solar radiation pressure dynamics effects.

Numerical experiments show that the collision probability converges to the true value derived from Monte Carlo simulations as the number of mixtures increases. And the method takes into account the effect of higher-order terms in the propagation process, effectively capturing the non-Gaussian component of the uncertainty, which allows the probability density to be propagated accurately.