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NONLINEAR SEMI-ANALYTICAL UNCERTAINTY PROPAGATION FOR CONJUNCTION ANALYSIS

Abstract

Propagation of uncertainty in space is an essential part of Space Situational Awareness (SSA) work. Most defunct satellites and other debris have significant uncertainties in their states, as their orbits are determined using only occasional observations from satellites and ground observatories. Therefore, Monte Carlo simulations are usually used to find their future locations and to perform conjunction analyses. In these simulations, millions of points from within the region of uncertainty are propagated individually. This is very computationally expensive and depending on the propagation time, can take a significant amount of time to run.

Linearized dynamics and analytical uncertainty propagation models have been shown to produce inaccurate results that don't align with the real-world motion of these Resident Space Objects (RSOs). Therefore, developing nonlinear uncertainty propagation models has become an important focus of research in the area of SSA. Two methods have been used recently in this area: state transition tensors (STTs), which are an extended higher order version of the state transition matrices, have been used to non-linearly propagate the state probability density function (PDF); Gaussian Mixture Models (GMM) have been frequently used to enable an ensemble of simple Gaussian distributions to define the uncertainty, enabling rapid evaluation of conjunctions.

In a recent paper, Fujimoto and Scheeres (JGCD 38(6), 2015) use these two tools in combination to perform conjunction assessment for short-term encounters. These encounters are considered instantaneous and a snapshot of covariance is used to define the uncertainty at the time of closest approach (TCA). The conjunction plane is defined using the relative position and velocity between the two RSOs. The PDF of the state uncertainty is then propagated using the combined STT-GMM model to find the probability of collision at the TCA.

This work aims to further examine the accuracy of this model over a wide range of conjunction scenarios, including a variety of orbital elements for the RSOs, a range of propagation times to observe the model limits, and extremely close to distant encounters, to test the spatial limits. Testing this model with these wide-ranging scenarios allows us to explore a number of encounter geometries.

We also leverage the rapid computations of this approach to explore repeated instances of short-term conjunctions when objects return to the same spot periodically. This provides an interesting study which can be used as the basis for deeper studies into conjunctions between RSO in similar orbits, which can have repeated close encounters.