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Semi-Analytical Uncertainty Propagation and Conjunction Assessment

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With an increase in space traffic in near-Earth and cislunar regimes, it is important to concentrate new research on development of accurate and efficient Space Situational Awareness (SSA) tools. One of the most significant discussions in SSA today is in accurate state uncertainty representation and propagation, with a direct application in understanding conjunction possibilities. Several analytical and semi-analytical methods have been developed that aim to efficiently achieve an accurate capture of this uncertainty over long periods of time to achieve realistic future locations without recurrent observations so as to alleviate the stress on observation resources.

This study presents a new method of nonlinear uncertainty propagation that combines several existing and complex mathematical tools to capture the non-Gaussian evolution of the distribution. An initial distribution is split into a Gaussian Mixture Model (GMM) to map the distribution piece-wise. This mapping is performed using higher order State Transition Tensors (STTs) that have the ability to capture higher order perturbations of the system dynamics. The STTs used to map the GMM components are calculated using complex dynamical systems that allow realism in the uncertainty propagation. For near-Earth applications, this is achieved using a Simplified Dynamical System (SDS) that incorporates perturbations from J_2 dynamics and Solar Radiation Pressure (SRP). In cislunar space, the Circular Restricted Three-Body Problem (CR3BP) is used in combination with these STTs to achieve the GMM component mapping. The combined mapped GMM components result in a final non-Gaussian distribution.

The GMM-STT uncertainty mapping is combined with analytical conjunction formulas to achieve a system collision probability. The cumulative probability of collision is achieved by combining collision probabilities associated with a GMM component-by-component comparison for the objects in conjunction. The final collision probability is compared to that from a Monte Carlo analysis to confirm validity. The new methods of uncertainty propagation and conjunction assessment presented in this dissertation provide fast, accurate, and realistic results for short and long duration conjunctions in near-Earth and cislunar domains.