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Dynamical Realism and Uncertainty Propagation

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In recent years, Space Situational Awareness (SSA) has become increasingly important as the number of tracked Resident Space Objects (RSOs) continues their growth. One of the most significant technical discussions in SSA is how to propagate state uncertainty in a consistent way with in the highly nonlinear dynamical environment. In order to keep pace with this situation, various methods have been proposed to propagate uncertainty accurately by capturing the nonlinearity of the dynamical system. We notice that all of the methods commonly focus on a way to describe the dynamical system as precisely as possible based on a mathematical perspective.

This study proposes a new perspective based on understanding dynamics of the evolution of uncertainty itself. We expect that profound insights of the dynamical system could present the possibility to develop a new method for accurate uncertainty propagation. These approaches are naturally concluded in goals of the study. At first, we investigate the most dominant factors in the evolution of uncertainty to realize the dynamical system more rigorously. Second, we aim at developing the new method based on the first investigation enabling orbit uncertainty propagation efficiently while maintaining accuracy.

We eliminate the short-period variations from the dynamical system, called a simplified dynamical system (SDS), to investigate the most dominant factors. In order to achieve this goal, the Lie transformation method is introduced since this transformation can define the solutions for each variation separately. From the first investigation, we conclude that the secular variations, including the long-period variations, are dominant for the propagation of uncertainty, i.e., short-period variations are negligible. Then, we develop the new method by combining the SDS and the higher-order nonlinear expansion method, called state transition tensors (STTs). The new method retains advantages of the SDS and the STTs and propagates uncertainty analytically and nonlinearly.