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UNCERTAINTY PROPAGATION USING HYBRID METHODS

Abstract

The orbital motion of a Resident Space Object (RSO) is influenced by a large variety of external forces, such as the Earth's gravity, which is the principal perturbation affecting the orbit, as well as atmospheric drag, third-body influences, solar radiation pressure, Earth's tidal effects, and, in the case of an artificial satellite, small perturbing forces produced by its propulsion system. Numerical, analytical, or semianalytical techniques are used to solve the nonlinear equations of motion of this complex dynamical system. In order to simplify this system, some of the aforementioned external forces may be removed in function of the scientific requirements for the mission, for example, in the case of maintenance of an Earth satellite or space debris catalogue. The implementation of a solution of this dynamical system in a programming language is called orbit propagator.

In this work, we employ a novel approach called hybrid methodology, which may combine any type of orbit propagator with Statistical Time Series models or Machine Learning methods. This non-invasive methodology allows increasing the accuracy of the orbit propagator for predicting the position and velocity of any RSO, as well as modeling higher-order terms and other external forces not included in the orbit propagator. This new type of propagator is called Hybrid Orbit Propagator.

To illustrate this methodology, we develop an Hybrid Orbit Propagator based on SGP4 and a state-space formulation of the exponential smoothing method as the forecasting technique for the case of Galileo-type orbits. The error terms of the forecasting technique are considered Gaussian noise what allows us to use the maximum likelihood method to estimate the parameters of the exponential smoothing model, as well as computing the point forecast and the reliable predictive intervals. This hybrid version of the SGP4, HSGP4, requires the use of an hybrid TLE, HTLE, which encapsulate the standard TLE and the coefficients of the exponential smoothing method. This study has been applied to 53 different TLEs from the Galileo 8 satellite. The HSGP4 improves the accuracy of the classical SGP4 and is particularly good for short forecast horizons. For instance, the mean distance error of HSGP4 is about 7 km while for SGP4 is about 24 km for a propagation horizon of three days ahead of our set of TLEs.