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LATENT FORCES MODEL APPROACH TO OBSERVATION-BASED SPACE OBJECT STATE AND UNCERTAINTY PROPAGATION

Abstract

Numerous attempts of using machine learning to improve the state-of-the-art orbit prediction accuracy, on one hand, show promise in certain cases, and on the other hand suffer from the lack of sufficient publicly available data and poor generalization. In the line of purely mechanistic approach there exist high-fidelity orbit propagators, however, they also have their limits as it might not be possible to identify and specify all forcing terms as well as identify all the systems parameters.

In this work we employ Latent Force Models (Alvarez et al., 2009), which is a hybrid technique that combines mechanistic modeling principles (i.e., physical models) with non-parametric data-driven components into one framework allowing joint inference of the parameters and state of non-linear equations of satellite orbital motion with unknown forcing terms (latent force). The approach employs recent advances in approximate inference for deep Gaussian processes, and stochastic variational inference for approximate Bayesian inference.

The non-linear latent force models can be represented as non-linear white noise driven state-space models, that is, partially observed non-linear stochastic differential equations. The known part of the equation of motion is represented by the gradient of geopotential (keeping the first terms to the degree and order 8), whereas all other forces of the gravitational nature (including tidal effect and third-bodies gravity pull), atmospheric drag force and the solar pressure force are accounted as latent forces and their components in the satellite's orbital frame are assumed to be quasi-periodic with the additive white noise. Following prior research (Ward et al, 2020) we use black-box variational inference and construct a neural network-based representation of the joint solution, i.e. the dynamical system evolution and model parameters, given noisy observations.

Two use-cases of LEO satellites, for which we had representative observation and GPS data, have been considered to validate the approach. Preliminary numerical experiments show that the inferred model can be employed for fast and relatively accurate propagation of the satellite's state and its uncertainty. Further research is needed to see how the approach generalizes to other space objects and orbits, however it appears that even in its its current state the technique can be employed in collision avoidance systems for preliminary assessment of possible conjunction events as it is computationally lighter than high-fidelity propagators and besides does not require Monte-Carlo simulations to estimate the uncertainty.