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A MULTIFIDELITY APPROACH TO ROBUST ORBIT DETERMINATION

Abstract

Accurate Uncertainty Propagation (UP) in orbital dynamics requires a careful modeling of both initial and high-frequency uncertainties on the orbit state. The latter arise from unmodeled or mismodeled forces and are introduced in the dynamics as a stochastic acceleration. Uncertainties in drag perturbations, e.g. atmospheric density model and time evolution of the ballistic coefficient, and thrust laws realizations represent the major contribution to the aforementioned uncertainty. In applications such as Orbit Determination (OD), stochastic accelerations are usually neglected since their contribution is negligible in presence of dense tracking data and large uncertainties in the observed states. However, inclusion of high-frequency uncertainties is paramount to preserve uncertainty realism over longer propagation time spans and in the context of robust OD. Other applications that benefit from an accurate handling of unknown accelerations include collision probability computation and trajectory design under significant uncertainty. A novel technique to compute the effects of process noise on high-order statistical moments of the propagated state Probability Density Function (PDF) is thus proposed. This algorithm is combined with a multifidelity UP method developed by the authors to preserve the uncertainty realism on the propagated orbit state. In the last, Differential Algebra (DA) techniques are employed to approximate the propagated state PDF as a multivariate Gaussian Mixture Model (GMM). The initial distribution is modeled as a single Gaussian kernel and a measure of nonlinearity is introduced to detect deviations from linearity in the neighboring dynamics. A recursive splitting algorithm is then employed to adapt the number of kernels such that the aforementioned index remains bounded within each component's domain. The recursive scheme is run on a low-fidelity model for maximum efficiency while its accuracy is restored with a posteriori correction of the kernels' means in high-fidelity dynamics. Thanks to the GMM approximation, only the contribution of stochastic accelerations on the components' covariances needs to be studied. The process noise is modeled either as uncorrelated white noise or as a Gauss-Markov process and treated with a variation of the State Noise Compensation (SNC) or Dynamic Model Compensation (DMC) algorithms respectively. The methodology developed for the concurrent propagation of initial uncertainties and the computation of process noise effects is applied to robust OD with initial uncertainties drawn from real observation data of the TAROT network. The numerical results demonstrate the increased realism enabled by the proposed method with respect to techniques that neglect the effects of mismodeled accelerations.