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CLOSING THE LOOP BETWEEN MISSION DESIGN AND NAVIGATION ANALYSIS

Abstract

In the mission design phase, the robustness and reliability of the reference trajectory are typically evaluated a posteriori through a navigation analysis. Thus, the trajectory design is deterministic and decoupled from the uncertainty quantification step. With this approach, numerous time-consuming iterations and handovers between the trajectory design and navigation analysis teams are needed to improve the mission robustness and reliability. Furthermore, navigation analysis is typically tackled as a Monte Carlo simulation of operations since diverse sources of uncertainty affect the spacecraft trajectory. The slow convergence is often tackled by the introduction of a number of approximations and assumptions to reduce the computational burden, e.g. dynamical linearisation and Gaussian uncertainties. However, although the larger admissible number of samples reduces the estimator error, the estimated quantity may differ from the true sought one because of the approximations introduced. In other words, the Monte Carlo simulation may deliver accurate statistics of a possibly inaccurate operational scenario. To overcome these issues, the paradigm of mission design and analysis under uncertainty has been investigated in recent literature. This research presents a contribution to this modern field by proposing a nonlinear navigation analysis approach to deliver accurate statistics in a competitive computational time, i.e. such that it can be employed directly for uncertainty quantification within trajectory optimisation. Specifically, the developed approach is constructed around a novel epistemic sequential filtering scheme, where the uncertainty is propagated directly through the nonlinear equations of motion, and updated at each observation time. Epistemic uncertainty models different observation realisations by employing a likelihood function with epistemic mean within the prior support. Furthermore, such approach can handle epistemic uncertainty over the initial and model parameters distributions. Therefore, the output distribution is obtained by directly pushing forward the input uncertainty through the navigation scenario, rather than reconstructing it by Monte Carlo simulations. This approach enables nonlinear mission analysis to be computationally tractable while solving for the true operational scenario, therefore returning more accurate estimates overall. Furthermore, the generalisation to epistemic uncertainty enables the use of a broader range of uncertainty models which may better characterise the available knowledge during the different mission design phases. The developed approach is tested for the navigation analysis of several flybys of the Europa Clipper trajectory. First, a full nonlinear Monte Carlo is performed to construct the baseline solution. Then, the developed analysis is compared against the reference solution and classical ones both in computational time and accuracy.