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ADAPTIVE ONLINE BAYESIAN STOCHASTIC MODEL UPDATING FOR THE REDUCTION OF EPISTEMIC UNCERTAINTY IN SATELLITE ATTITUDE PREDICTION

Abstract

With a boom in commercial satellite deployment capabilities, Earth's orbits are becoming heavily populated with satellites. Expensive and sparse attitude observations mean measurements may only be generated for a subset of assets at a time - leaving gaps between observation points which must be filled via numerical models. When performing such analyses, there are inevitable uncertainties between the model results and real-world performance, especially within the highly non-linear domain of aerospace. Taking such uncertainties into account for engineering models is an important step to better correlate simulations and enable more informed analyses. One can account for the inherent process noise, also known as aleatory uncertainty, via a probabilistic framework which incorporates precise uncertainties in model parameters. Bayesian model updating techniques are well established for the inverse propagation of uncertainty in model parameters.

Such frameworks rely on a well-defined likelihood, in practice however such a derivation can be intractable. Further, they work under the assumption of a large enough availability of data to create precise distributions. As is typical of aerospace applications, measurement data can be sparse while also prohibitively expensive to obtain, leaving uncertainty to be characterized by imprecise representations such as intervals or probability-boxes, introducing epistemic uncertainty into analyses. Hence exists a desire to use sparse measurements to update and refine the uncertainty in models. Approximate Bayesian computation (ABC) based approaches bypass the direct evaluation of the likelihood function, where statistical distances between the measurements and model are used to approximate a likelihood. Such approaches have proven to provide effective stochastic model updating, but their extension to online, adaptive, non-linear settings is not clear.

In this work we develop an approach to tackle the online updating of epistemic uncertainty, with adaptability enabling the tracking of changes within the underlying uncertain parameters. First, we introduce an efficient Gaussian-Mixture based Unscented Transform forward propagation to generate the Bayesian likelihood, negating the use of ABC. Secondly, a Sequential Monte Carlo sampler with occasional Markov-chain resamples enables efficient online sampling while avoiding sample degeneracy, ensuring samples correctly follow the posterior. Lastly, an online change-point algorithm enables adaptive updating and the tracking of changing aleatory uncertainty in the measurements. The approach is demonstrated against a semi-analytical satellite attitude propagation example to track changes in the stochasticity of the attitude model - demonstrating the approach's effectiveness against the non-linear domain of aerospace models and its enablement of reduced uncertainty in attitude predictions.