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MULTI-OBJECTIVE ROBUST TRAJECTORY OPTIMISATION UNDER EPISTEMIC UNCERTAINTY AND IMPRECISION

Abstract

This paper presents a novel method to generate robust optimal trajectories for spacecraft equipped with low-thrust propulsion under the effect of epistemic uncertainty. The uncertainties considered for this paper derive from a lack of knowledge on system's and launcher's parameters. This is a typical situation in the early stage of the design process when multiple alternative options need to be evaluated and only a partial knowledge of each of them is available.

The approach proposed in this work assumes that no single precise distribution can be used to sample the value of the uncertain parameters. In this framework, uncertainties are modelled with probability boxes, or p-boxes, embodying multiple families of distributions without the need to specify any of them. Once the effect of uncertainty is propagated through the system one can calculate the Upper and Lower Expectations on the quantity of interest (for example the mass of propellant). The Lower Expectation defines the worst case effect of the uncertainty when uncertainty is expressed via a p-box. Once the low expectation on the quantities of interest is available a novel efficient computational scheme is proposed to compute families of control laws that are robust against the effect of uncertainty. Robustness is here considered to be the ability to maximise the desired performance, under uncertainty, with a high probability of satisfying the constraints. The computational scheme proposed in this paper makes use of hierarchical surrogate models of the quantities of interest, and of their Lower Expectations, to radically reduce the computational cost of the robust optimisation problem. This is combined with a dimensionality reduction technique, that allows one to construct surrogate models on low dimensional spaces, and an iterative refinement of the surrogate representation. The training points of the surrogate models are evaluated using FABLE (Fast Analytical Boundary value Low-thrust Estimator), an analytical tool for the fast design and optimisation of low-thrust trajectories.

A memetic multi-objective optimisation algorithm is then used to find the set of Pareto optimal control laws that maximise the Lower Expectation in the achievement of the desired values of objective function and constraints. The multi-objective optimisation is performed with Multi Agent Collaborative Search (MACS), an algorithm combining a population-based search with a modified Pascoletti-Serafini refinement of the solutions. The approach proposed in this paper is applied to the design of a multi-flyby mission to a set of Near Earth Asteroids with a small spacecraft with limited resources.