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A HYBRID MULTIPLE-SHOOTING APPROACH FOR COVARIANCE CONTROL OF INTERPLANETARY MISSIONS WITH NAVIGATION ERRORS

Abstract

Future interplanetary missions will require unprecedented autonomous guidance capability to cope with scientific tasks of increasing difficulty and severely tight mission budgets. In this context, small-satellite missions are extremely appealing as they allow for significant costs reduction, given the possibility of using standardized design procedures and off-the-shelf components. A careful optimization of the trajectory is thus crucial to reduce propellant consumption and mitigate risk of mission failure.

Traditional methods for trajectory design usually consist in finding a nominal open-loop control law that minimizes a given performance index (e.g., propellant consumption), while respecting a prescribed set of deterministic constraints. Additional propellant is then reserved for correction maneuvers, which compensate for trajectory deviations due to dynamics uncertainties and stochastic disturbances. Empirical iterative and time-consuming procedures are commonly employed to ensure a sufficient degree of robustness to the trajectory, resulting, in turn, to the definition of sub-optimal control strategies and over-conservative margins. The presence of navigation errors poses an additional challenge. In particular, for small-satellite missions, where low-cost embedded navigation components limit the accuracy on position and attitude measurements, this issue becomes critical.

This manuscript proposes a systematic approach for the design of a nominal robust trajectory and an associated closed-loop control law, where quantitative information concerning uncertainty on the system dynamics and stochastic navigation errors are directly accounted for in the optimization process. More precisely, a linear feedback control law is sought in order to steer the probability distribution of the spacecraft state towards a target distribution at an assigned final time. A hybrid multiple-shooting approach is used, where the mean trajectory and the open-loop controls are optimized according to a multiple-shooting scheme, while a single-shooting scheme is adopted for propagating higher order statistical moments of the spacecraft state distribution, which varies according to the closed-loop feedback gains to be optimized.

The proposed approach is applied to the analysis of the extended mission phase of the future JAXA mission DESTINY^{+}, a medium-class mission to fly by the Geminids meteor shower parent body (3200) Phaethon and additional asteroids. Given the high sensitivity on the state accuracy for this delicate portion of the mission, such this scenario is the ideal test case to improve the robustness of the trajectory by means of the proposed method, whose results are expected to reduce the final dispersion on the state of 1-2 orders of magnitude, with an increase of fuel consumption of less than 5%.