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AN ADAPTIVE DISTRIBUTED STOCHASTIC GUIDANCE-CONTROL SCHEME FOR UNCERTAIN GRAVITY FIELD ASTEROID INSPECTION

Abstract

This paper focuses on the design of a reference tracking adaptive Model Predictive Control (MPC) to optimally deal with the stochasticity in the dynamics in close proximity to an irregular-shaped asteroid and the model uncertainties due to the imperfect navigation and inertial measurements of individual distributed inspector mini-spacecrafts. A host/chief spacecraft once aligned to the asteroid's orbit deploys the mini-spacecraft towards the target asteroid after which the guidance-control distributed architecture implemented in the paper robustly assigns and orients individual mini-spacecrafts into re-configurable orbits with the ultimate objective of executing a 3D asteroid inspection without breaking communications between the mini-spacecraft and the host. This method completely eliminates the need for the spacecraft to have a waiting time to gain direct link with Earth, the host spacecraft procures asteroid data without risking itself, and the overall inspection performance is increased compared to single spacecraft inspection. The work is highly focused on constructing a robust Guidance-Control Architecture which firstly involves selection of a suitable gravity model for the asteroid as a nominal dynamics model for the controller. Then, an Unscented Kalman Filter (UKF) is used for nonlinear estimation to realize the stochastic state and actuation distributions that are feed-forwarded to the stochastic MPC control optimization with hard constraints on proximity distance and collision avoidance. The orbit planning control scheme tracks the inspection cost and reconfigures the mini-spacecraft's orbits for optimal output. To deal with possible abrupt shifts in dynamics near asteroids, the receding horizon MPC control is cascaded with a L_1 Adaptive Controller which advantageously separates the fast adaptation rate with the control signal throughput so as to mitigate the actuation saturation solutions from the controller. Overall, in a single control loop, the top-level view of the architecture implements state estimations, orbit planning block, inspection progress-map and cost-map, and control block. The efficacy of the proposed architecture is validated in a simulation of the main-belt asteroid Kleopatra; the mini-spacecraft, deployed from the host, are simulated in MATLAB/Simulink with the proposed individual distributed control scheme. The simulation shows that the proposed controller at best matches the deterministic MPC solutions when a high fidelity gravity model is fed as the nominal dynamics.