IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation & Control (3) (5)

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THE EXTREMA AUTONOMOUS GUIDANCE ALGORITHM FOR LOW-THRUST INTERPLANETARY SPACECRAFT

Abstract

In recent years, the advent of CubeSats revolutionized the space sector. These platforms, originally thought as technological demonstrators for Universities, allowed more and more small companies to launch and operate their own satellite around the Earth due to their reduced development and integration costs with respect to larger spacecraft. The tendency is to use them for deep-space exploration missions as well. However, the costs required to operate do not depend on their size. Therefore, operating CubeSats is currently as expensive as operating traditional spacecraft, hence partially jeopardizing the benefits brought by miniaturized spacecraft. Consequently, increasing the level of satellites autonomy is becoming paramount. In particular, this work presents the architecture of the autonomous guidance algorithm that is being tested in hardware-in-the-loop simulations in the context of the EXTREMA project at Politecnico di Milano. The optimal spacecraft trajectory is computed by means of a convex optimization-based guidance algorithm, consisting of a three-step process: first, a problem is solved which computes the optimal trajectory from the current spacecraft state as estimated by the navigation algorithm to the target celestial body. In general, this first step considers a fixed time of flight optimization. However, if the spacecraft state has diverged significantly with respect to the planned trajectory, it may be the case that no feasible solutions can be found. In that case, the guidance algorithm autonomously solves a free-final-time problem instead. The second step of the guidance algorithm consists of refining the solution found at the first step for the next duty cycle. In this phase, the duty cycle constraints (a thrust arc maximum duration of n days and a m-day-long coast arc to allow for autonomous navigation) are also imposed and the time of flight is fixed to n+m days. Finally, the third step transforms the thrust commands found by the convex optimization algorithm such that the thrust angles are expressed as single arbitrary-order polynomials in each thrust arc. This last step allows for the transformation of the algorithm output into actual executable commands by the thruster and the attitude control system. The algorithm is run on relevant hardware to test whether the computational time and precision are suitable for onboard use and the computed commands are executed by the thrust test bench ETHILE, a facility developed within the ERC project EXTREMA. Extensive simulations and results are presented and discussed.