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# A HOMOTOPIC APPROACH FOR ROBUST LOW-THRUST TRAJECTORY DESIGN THROUGH CONVEX OPTIMIZATION

**Abstract**

The space industry has recently witnessed a significant decrease of the overall costs of space missions, thanks to the miniaturization of satellites and their components. CubeSats have granted institutions and small companies access to space. However, space operations are still entirely performed from ground, limiting the potentiality of such spacecraft. Enhancing the autonomy of satellites, for example enabling on-board guidance, represents thus an interesting research challenge.

The low control authority and little on-board resources of CubeSats require a new trajectory design paradigm. Optimization methods can be compared in terms of sustainability (a measure of the computational load), optimality (the quality of the solution found), and feasibility (the capability of converging to a feasible solution). State-of-the-art approaches lack of on-board sustainability, as powerful computers can be used to design the fuel-optimal trajectory of a spacecraft offline. Convex optimization represents instead a sustainable approach when real-time applications are considered due to the limited resources required to solve convex programs. This technique has been recently applied to different space-related problems, including powered descent and landing, entry and low-thrust trajectory optimization.

Yet, robustness of current convex approaches is not sufficient to have a flyable guidance algorithm. In fact, robustness issues are encountered due to the discontinuous optimal thrust profile in minimum-fuel transfer trajectories. In indirect optimization, this problem is circumvented by means of smoothing techniques, such as the homotopic approach. It consists of solving a sequence of simpler problems until the original, discontinuous one is eventually solved.

This paper presents a Sequential Convex Programming (SCP) algorithm based on a Legendre-Gauss-Lobatto discretization scheme with nonlinear control interpolation to solve the minimum-fuel space trajectory optimization problem; the collocation scheme has been adapted to the convex programming environment. Moreover, an adaptive second-order trust region radius change mechanism is developed to reduce the overall computational time. Finally, the SCP is combined with the homotopic approach to increase robustness of the method. The effectiveness of the approach is shown by means of numerical simulations with poor initial guesses. The present work is framed within the EXTREMA project, awarded an ERC Consolidator Grant in 2019.