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MIXED-INTEGER GLOBAL OPTIMALITY FOR MULTIPLE FLY-BY MISSIONS WITH GRAVITY ASSIST

Abstract

This work describes a methodology to design optimal trajectories that visit multiple orbital waypoints, namely asteroids and/or planets in the Solar System, with a single spacecraft launch. The trajectory design of these missions is complicated by the fact that the visiting order of these objects is not known a priori but is the objective of the optimization problem itself, resulting in a complex Mixed-Integer Non-Linear Programming Problem (MINLP), on which discrete/combinatorial optimization is coupled with optimal control theory. Current approaches to solve these problems require computing time that rises with the number of control parameters, as the visiting objects sequence length, as well as rely on a-priori knowledge to define a manageable design space (i.e., departing dates, hyperbolic excess speeds, etc.). For these reasons, current approaches usually struggle to identify the global minimum.

With the present paper, a method is presented that is based upon a dynamic programming approach, guaranteeing global optimality to transfers that aim to pass-by many objects, on overall multiple fly-by missions. The model implemented uses Lambert problem solutions over a grid of departure dates at one object and range of time of flight to the next object, allowing a quasi-systematic scan of the search space. Discontinuities between incoming and outgoing Lambert arcs are in part compensated by the fly-by of the celestial body. If required, an additional Δv manoeuvre is added on the given leg of a body-to-body transfer, representing the defect between incoming and outgoing spacecraft relative velocity with respect to the object. The solutions are then refined by leveraging the defects with Deep Space Manoeuvres between two consecutive close passages with celestial objects.

This study has been developed in support both to Icarus and CASTAway Asteroid Spectroscopic Survey mission proposals, which are to be submitted to the latest ESA's fast and medium size call, respectively. In particular, Icarus aims to explore a never-visited orbital region by performing the rendezvous with a low-perihelion asteroid, to observe its disruption mechanisms when passing close to the Sun. CASTAway explores the Main Asteroid Belt aiming at performing a succession of fly-bys with asteroids and planets. The methodology developed has enabled the exploration of the design space for both the missions proposed, while maintaining reduced computational effort, and guaranteeing global optimality for the discrete/combinatorial aspect of the design.