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TRAJECTORY OPTIMIZATION FOR JOVIAN MOON EXPLORATION USING SINGLE AND MULTI-OBJECTIVE BEAM SEARCH

Abstract

The Jovian System, home to Jupiter and its four Galilean moons, offers profound insights into early solar system phenomena. Exploring this system holds significant importance, driving groundbreaking missions such as ESA's JUICE mission and NASA's Europa Clipper. Both of these missions employ a moon-tour trajectory, throughout which the spacecraft encounters the moons of interest by means of close flybys, which allow to study specific regions of the surface of the moon. This enables the probe to modify its orbital energy while remaining in orbit around the central body. Within the context of a mapping mission of the Jovian System, the trajectory is defined as a sequence of flybys around Io, Europa, Ganymede and Callisto. The optimal sequence of flybys lies within an extremely vast search space generated by all the possible combinations of feasible maneuvers. Utilizing resonant orbits, which enable consecutive encounters with the same target, the problem is conceptualized as a graph made up of nodes interconnected by edges. The nodes represent resonant orbits concerning a specified celestial body, while the edges correspond to flyby maneuvers that allow to jump from one orbit to the other. Consequently, the problem is turned into a search within the tree graph structure, whose exhaustive exploration is computationally infeasible due to its vast size. This extensive search space can be explored using heuristic pruning algorithms, such as Beam-Search algorithms, which simplify the exploration by imposing a beam width constraint. This paper focuses on the implementation of such algorithms for the design of optimal ballistic trajectories aimed at exploring the Jovian System. In particular, the study employs and compares two distinct approaches: a single-objective optimization and a multi-objective optimization, where the implementation of the algorithms is done using different beam widths to observe the effect it has on the quality of the solutions found and the computational performances. Finally, the set of tools is applied to the GTOC 6 problem, a challenge proposed by the Jet Propulsion Laboratory (JPL) in 2012, whose primary objective is to map the four Galilean moons of Jupiter by means of close flybys. The comparative study between single and multi-objective Beam-Search provides insights into the strengths and limitations of each methodology, leading to a conclusion on which approach best fits this problem. The high scores achieved highlight the potentiality of these tools to navigate extremely vast and complex search spaces in the field of trajectory optimization.