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TISSERAND GRAPH EXPLORATION WITH ANT COLONY OPTIMIZATION FOR PRELIMINARY MULTIPLE GRAVITY ASSIST TRAJECTORY DESIGN

Abstract

Multiple-gravity assist (MGA) trajectories are used in interplanetary missions to change the spacecraft orbital energy by exploiting the gravity of celestial bodies. This allows the spacecraft to reach regions in the Solar System that otherwise would be extremely demanding in terms of propellant. However, if a trajectory seeks to benefit from a long MGA sequence, it is necessary to solve a complex mixed integer programming problem in order to find the best swing-by sequence among all combinations of encountered planets and dates for the various spacecraft manoeuvres.

Tisserand graphs provide an efficient way to tackle the combinatorial part of the MGA problem, by allowing a simple computation of the effect of different sequences of gravity assists, based only on energy considerations. Typically, the exploration of Tisserand graphs is performed via a comprehensive Tree Search of possible sequences that reach a specific orbital energy and eccentricity (e.g. Langouski et al.). However, this approach is generally directed by heuristic techniques aimed at finding duration limited, low Δv transfers without formal optimization or time constraint.

This paper presents a more comprehensive strategy involving the use of multi-objective, global optimisation. Extra realism in the mission duration evaluation is achieved by the consideration of planetary resonance when stepping along an infinity velocity contour, as well as adding small Deep Space Manoeuvres (DSMs) to ensure feasible transfer durations.

The proposed approach leads to a large search space of discrete variables and an Ant Colony Optimization (ACO) is used in order to efficiently explore the discrete search space. The ACO exploration allows to identify a large number of potential MGA transfers requiring different time of flights and total Δv to reach a target orbit. This entails a multi-criteria approach to the ACO exploration in order to generate an optimal Pareto front of solutions with Δv and time of flight as its cost functions. Lastly, all the solutions identified by the ACO-generated Pareto front are validated by re-optimizing the complete MGA trajectories as sequences of swing-bys, DSMs and Lambert Arc transfers intersecting the real positions of the planets involved. Several mission scenarios are used as test cases to validate and demonstrate the accuracy of the Tisserand-based first-guess solutions, as well as the capability of the ACO exploration to find the global optimum.