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DETERMINISTIC AND STOCHASTIC EXPLORATION OF LONG ASTEROID FLY-BY SEQUENCES EXPLOITING TREE-GRAPH AND OPTIMAL SUBSTRUCTURE PROPERTIES

Abstract

In the past, space trajectory design was limited to the optimal design of transfers to single destinations. However, new technologies, and a somewhat more daring approach to space, are today making the space community to consider missions that visit, with one single spacecraft, a multitude of celestial objects; examples of this include CASTAway and MANTIS, which have proposed to ESA and NASA, respectively, to visit 10 or more asteroids in a quick succession of asteroid fly-bys.

The design of these so-called asteroid tours is complicated by the fact that the sequence of asteroids is not known a priori, but is the objective of the optimisation itself. This leads to a complex mixed-integer non-linear programming (MINLP) problem, on which the decision variables assume both continuous and discrete values. Beyond the obvious complexity of such problem formulation, preliminary mission design requires not only to locate the global optimum solution but, also, to map the ensemble of solutions that lead to feasible transfers.

This paper analyses the complexity of such search space, which can be efficiently modelled as a tree-graph of interconnected Lambert arc solutions between two consecutive asteroids. This allows to exploit the optimal substructure of the problem and enables complete tree traverse explorations for limited asteroid catalogues (<50 asteroids). Nevertheless, the search space quickly grows in complexity for larger catalogues, featuring a labyrinthine multi-modal structure and extreme non-linearities. This underlying complexity ultimately renders common stochastic metaheuristics, such as Ant Colony Optimization or Genetic Algorithm, rather inefficient. Mostly, due to the fact that the metaheuristic processes are not able to gather any real understanding, or knowledge, such that they can efficiently guide the search. Instead, an astrodynamics-lead heuristic based on the distance between spacecraft and asteroid at the asteroid's MOID-point crossing epoch, enables an efficient pruning of the asteroid catalogue. Then, deterministic processes based on dynamic programming and beam search can be efficiently be applied, providing solutions to both the global optimum and the constraint satisfaction problem.