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FUEL-OPTIMAL LOW-THRUST TRAJECTORY OPTIMIZATION OF MULTIPLE ASTEROID EXPLORATION MISSIONS

Abstract

Low-thrust trajectory design and optimization of multiple asteroid exploration missions have been attracting great attention in recent years. The 2nd-5th Global Trajectory Optimization Competition (GTOC) all focused on this type of problem. When preliminarily designing multiple asteroid exploration missions, the patched-conic and impulsive approximation are adopted to generate candidate asteroid sequences and then the best sequence is divided into several legs to be optimized using low thrust. The whole trajectory is found by connecting each locally optimized subsequence, which has the risk of missing the globally optimal solution. In this work, the intermediate asteroid rendezvous or flybys are considered as time-varying inner constraints on the position and velocity vectors of the spacecraft. The low-thrust trajectory optimization of multiple asteroid explorations is formulated as fuel-optimal control problem with boundary and inner constraints (equality and inequality). The solution to the optimal control problem is difficult to obtain because of the discontinuous integrated function for bang-bang control, the small convergence radius, the sensitivity of the initial guess and the existence of locally optimal solutions. To handle these numerical computation difficulties, the homotopic approach that solves the fuel-optimal problem of low-thrust trajectory by starting from the related and easier energy-optimal problem is applied. Moreover some effective techniques are presented to reduce the computational time and increase the probability of finding the globally optimal solution. Multiplying the performance index by a positive numerical factor, the Lagrange multipliers and initial costate variables are normalized on a unit hypersphere to avoid the unbounded guessing for the initial costate variables. The switching function detection and the Runge-Kutta integration with fixed step are employed to insure the integration accuracy for the discontinuous bang-bang control. Based on the impulsive evaluation results, Particle Swarm Optimization (PSO) increases the probability of getting the globally optimal solution. Two examples, multiple asteroid sample return mission and multiple asteroid flyby mission, are given to illustrate the efficiency of the presented approaches.