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DESIGN OF OPTIMAL LOW-THRUST ORBIT-TO-ORBIT TRANSFERS VIA CONVEX APPROACH

Abstract

Recently, low-thrust propulsion such as ion engines and solar sails has contributed to space exploration missions because it has a high specific impulse and can save fuel consumption. Although low-thrust trajectories enhance the efficiency of deep space missions, the optimal design of these trajectories is extremely difficult due to a high sensitivity with respect to initial conditions in the unstable orbital environment. Convex optimization is a powerful tool to design low-thrust optimal trajectories because it can find the global optimal solution and be solved by polynomial-time algorithms. The low-thrust minimum-fuel trajectory optimization problems are usually nonconvex but can be formulated as convex optimization problems by discretization and successive convexification.

This paper proposes the low-thrust minimum-fuel trajectory design method for a phase-free orbit-to-orbit transfers based on the convex optimization framework. In the previous studies, the position and velocity of a spacecraft are fixed on both initial and final points, which means the optimization problem is reduced to a two-point boundary value problem. On the other hand, the proposed method formulates the optimization problem involving the departure and arrival phases as optimization parameters; it optimizes the position and velocity of the initial point along the departure orbit and those of the final point along the arrival orbit, as well as the whole transfer trajectory and control inputs. Moreover, an efficient initial guess generation technique called orbit chaining is introduced to leverage the natural dynamics. With the benefit of the orbit chaining technique, this method can broadly search for the optimal transfers between the departure and arrival orbits. As an example, the proposed method is applied to the design of low-thrust transfers from a halo orbit to a near-rectilinear halo orbit (NRHO) in the Earth-Moon system. The design of halo-to-NRHO transfers is challenging due to the strong nonlinearity of NRHOs. We demonstrate the effectiveness of the proposed method by finding a better optimal solution with lower fuel consumption than the solution obtained by the conventional method. The feasibility of this method is also investigated by applying the acquired optimal solutions to the high-fidelity dynamical model.