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OPTIMAL LOW-THRUST TRANSFERS IN TWO-BODY AND THREE-BODY DYNAMICS

Abstract

Low-thrust propulsion is considered the best option for many interplanetary transfers. Their higher specific impulse, compared to the traditional chemical propulsion, allows an increased spacecraft payload ratio. Moreover, low-thrust propulsion systems can enhance mission feasibility, by exploiting continuous thrust arcs, rather than instantaneous ones. However, this leads to an increase in the control duration and, consequently, the need to model the control variables as continuous functions. Thus, an optimal control problem must be set up and solved. Therefore, the design and the optimization of this kind of trajectories is rather difficult and still represents a challenge for mission designers, despite the numerous techniques developed over the years. Two solution approaches exists: 1) direct methods, which parameterize the optimal control problem through discretization and then use nonlinear programming to find out the optimal solution; 2) indirect methods, which instead formulate the optimal control problem as a boundary value problem, by means of the calculus of variations and the Pontryagin's maximum principle.

Despite the much more accurate results in terms of optimality with respect to direct methods, the convergence domain for indirect methods is smaller and heavily depends on the quality of the initial guesses. Moreover, indirect methods suffer from numerical difficulties that arise during the integration of Euler-Lagrange differential equations, due to their discontinuous nature. This paper describes an efficient and robust indirect optimization approach to solve fuel-optimal low-thrust interplanetary transfer problems. The resulting optimizer is able to deal with different intermediate conditions, such as flybys, rendezvous, or multiple gravity assists. Moreover, within the formulation adopted, no a priori knowledge of the control structure is required. The application of calculus of variations leads to a Multi-Point Boundary Value Problem, characterized by complex inner constraints, which has been solved by means of an indirect multiple shooting method. Effective techniques to increase the robustness of the algorithm and to overcome numerical difficulties are introduced, followed by the presentation of some test cases to assess the overall performances of the software-tool in both keplerian and restricted-three body problem dynamics.