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ENHANCED CONVEX OPTIMIZATION STRATEGIES IN 6-DOF NON-COPLANAR ORBITAL MANEUVER TRAJECTORY DESIGN

Abstract

Non-coplanar orbital maneuver is an important phase in numerous space missions where a single spacecraft conducts complex operations, such as active debris removal and on-orbit services. Depending on the specific application, these maneuvers should be optimized to minimize the time or propellant required to change the spacecraft orbit with on-board and real-time computation.

Non-coplanar and broad-range orbital transfer trajectory design has been addressed by several authors in the literature, yet it remains a topic worthy of further research due to the following reasons: First of all, due to the widespread adoption of electric propulsion systems in many spacecrafts, which possess low thrust capabilities, broad-range orbital maneuvers necessitate multiple revolutions to accomplish. However, traditional trajectory optimization methods, including both indirect and direct approaches, encounter challenges when solving multi-revolution orbital maneuver problems. On the one hand, the indirect method faces issues including extreme sensitivity of the costate initial variable to the number of orbital revolutions and the requirement of high computational complexity. On the other hand, the direct method fails to achieve global optimal solutions. Henceconventional trajectory optimization methods are incapable of facilitating on-board and real-time computation. In addition, the guidance system must count for the coupling between attitude and orbit, which is also known as 6-degree-of-freedom(6-DoF) optimization problem. Several research endeavors focusing on 6-DoF trajectory optimization in various contents have been completed, such as rocket powered landing, collision avoidance, and spacecraft rendezvous.

The problem of 6-DoF non-coplanar orbital maneuver trajectory design is addressed using an enhanced convex optimization-based approach. The Third-order Flourier Series method is utilized to establish a reference landing trajectory, accounting for the J2 term of the Earth's gravitational field model, with minimal computational resources. Additionally, an enhanced optimization method combining lossless relaxation methods and successive linearization techniques is proposed. Furthermore, the Legendre-Gauss-Radau discretization method is employed during the linearization process yielding accurate and fast solution. With this optimization approach, the original highly-constrained optimal control problem is transformed into a convex form, facilitating rapid solution using the Interior Point Method. We conduct a comparative simulation experiment between our optimization strategy and the Gauss pseudospectral method. The simulation results indicate that the orbital maneuver trajectory generated by the proposed optimization strategy exhibits reduced fuel consumption and computational time compared to alternative methods. The robustness of the proposed algorithm is then investigated by means of Monte Carlo analysis varying the number of orbital revolutions.