52nd IAF STUDENT CONFERENCE (E2)
Student Conference - Part 2 (2)

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CONVEX OPTIMIZATION OF CISLUNAR TRANSFERS EXPLOITING BALLISTIC CAPTURE TRAJECTORIES

Abstract

The advancement of space exploration is heavily reliant on spacecraft autonomy, with on-board real-time trajectory design solutions representing a critical area of research. Recent studies have highlighted sequential convex programming as a reliable and computationally efficient methodology for guidance and trajectory optimization. Moreover, missions including Artemis 1 and Capstone, are actively conducting research in the cislunar domain, which is strategically and economically significant as a testing ground for future space exploration. Trajectory design within the Earth-Moon circular restricted three body problem (CR3BP) environment presents challenges due to high non-linear and potentially chaotic dynamics. In this setting, convex optimization techniques are employed, with the aim to investigate the connections between ballistic captures (derived from the energy transition domain) and periodic orbits. Extending previous methodologies from deep-space missions to the cislunar domain, this study analyses both impulsive and low-thrust fuel optimal transfers. The proposed approach adopts a multiple-shooting method, with initial guesses obtained through bi-impulsive non-linear optimization. A sequential convex programming algorithm is used, leveraging automatic differentiation (AD) to compute a second-order Taylor expansion of the equations of motion. This allows us to linearize the dynamics and define a non-linearity index to determine a state-dependent trust region. An adaptive scaling further aids the convergence of the algorithm. The optimality of the solutions is verified using primer vector theory. In addition to the constraint of the final state belonging to a period orbit , the optimization algorithm is formulated including a time variable to obtain the optimal selection of the impulse timing. Preliminary results show that the state-dependent trust region allows a swift convergence of the algorithm to a sufficiently accurate solution and both the multi-impulsive and low-thrust trajectories are improved with respect to the initial guess. Once the method is verified, the research is then extended to the generalization of the transfer trajectories. This is achieved by investigating the arrival conditions having imposed a more general bounded motion to the states and applying the algorithm to high-fidelity dynamical models. The current study demonstrates the applicability of sequential convex programming within the complex framework of the Earth-Moon system, providing a broader understanding and possible applications to future missions in this challenging domain.