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RELATIVE DYNAMICS AND SHAPE-BASED METHODS FOR GUIDANCE IN THE RESTRICTED THREE-BODY PROBLEM

Abstract

Increasing attention has been recently brought into deep space missions by both the Space Industry and the Academia, with particular interest in the cis-lunar environment, where long-term humankind space activities are planned to be established within this decade. Such activities, exemplified by the Lunar Gateway, are in need of a larger space infrastructure, for which autonomous proximity operations are mandatory. While near-Earth missions may be completely covered by perturbed Keplerian dynamics, deep space missions require of a different modelling approach, where multi-body gravitational interactions play a major role. To that end, the Restricted Three-Body Problem has proved as an insightful first modelling strategy for early mission design purposes, retaining major dynamical transport structures while still being relatively simple. In addition, the trajectory design of these new space challenges and global orbital infrastructures is totally comprised with costly optimization processes, in which the rapid generation of accurate initial guesses may be crucial for the early development of the initial mission phases. Among proposed solutions, shape-based methods have gained increasing favorable interest within the astronautical community in these past years, with successful applications to low-thrust trajectory design.

In this work, a Hamiltonian derivation of the Restricted Three-Body Problem relative dynamics is revisited, exploiting its phase space solutions and intrinsic structures for rephasing, rendezvous and general proximity operations missions. This analytical and its associated numerical approach is further combined with shape-based methods for rapid transport trajectory design between Libration Point Orbits, with particular emphasis on low-cost mission optimization. Compared to previous work, our relative motion approach reduces the complexity and dimensionality of the orbital targeting Guidance problem, in which the relative phase space shall be studied. In addition, it demonstrates and exploits intrinsic homoclinic and heteroclinic relative orbit trajectories between absolute periodic and quasi-periodic LPOs, stemming from a relative center manifold and associated relative orbit families. Shape-based methods are then employed to construct a semi-analytical trajectory design algorithm, based on this inherited orbital manifold structure, with direct applications to rapid, optimal and initial trajectory design for general proximity operations missions.

The proposed algorithms and techniques are demonstrated and validated within several end-to-end low-cost Guidance mission design cases, including rendezvous, rephasing and orbital disposal within an autonomous resupply chain for an Earth-Moon L_2 space station.