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AUTOMATED COMPUTATION OF OPTIMAL SPIRAL TRAJECTORIES IN THE CIRCULAR RESTRICTED THREE-BODY PROBLEM

Abstract

Increasing interest in low-thrust, high-efficiency propulsion has led to the development of new methods for computing optimal (or near optimal) long duration, many-revolution (i.e., spiral) trajectories. These approaches commonly employ orbital element sets, which are not applicable to the Circular Restricted Three-Body Problem (CRTBP) model, and therefore concepts useful for cis-lunar trajectory design, such as periodic orbits and their associated invariant manifolds, cannot be easily employed.

Indirect optimal control techniques have been successfully applied to compute low-thrust transfers to cis-lunar periodic orbits or their invariant manifolds. Nevertheless, the successful application of indirect optimal control techniques for low-thrust trajectory design in the CRTBP model remains difficult when considering acceleration levels achievable by current low-thrust propulsion technology (typically on the order of 10^{-2} to 10^{-5} m/s^2), as the radius of convergence about the optimal unknown variables is very small for this class of problems. Moreover, acquiring a guess for the unknown variables that lies within this radius of convergence is not trivial, as the set of unknowns typically includes co-state variables with little physical significance.

In this work, a methodology for the automated computation of optimal spiral trajectories from an Earth-centric elliptical orbit (e.g., a Geostationary Transfer Orbit) to the stable manifolds associated with periodic orbits within the cis-lunar region is proposed. First, Particle Swarm Optimization (PSO) is employed to compute a guess for the unknowns of the minimum-time transfer two-point boundary-value problem. PSO-based co-state initialization is greatly improved through a exploit of the mass co-state and its final time transversality condition, such that the unknown transfer time need not be determined by PSO. This leaves only the initial co-state variables as unknowns, which are restricted to the unit hypersphere via normalization. After a PSO generated guess has been acquired, the minimum-time problem is solved employing the Trust-Region algorithm. Next, a continuum of minimum-energy transfers is acquired by solving the minimum-energy transfer problem for increasing time-of-flight, beginning with the minimum-time solution. Finally, energy-to-fuel continuation is employed to transition the longest duration minimum-energy solution to that of minimum-fuel. Through the removal of the transfer-time from the set of unknowns that must be guessed, preliminary results indicate solutions to the minimum-time transfer problem can be acquired directly (without continuation) for transfers involving a spacecraft with an initial thrust-to-mass ratio of 2×10^{-4} m/s^2 and over 130 revolutions about the Earth.