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EARTH-TO-MOON LOW ENERGY TRANSFER USING TIME-DEPENDENT INVARIANT MANIFOLDS

Abstract

In recent decades, there has been a growing interest in applying the theory of circular restricted three-body problem (CR3BP) to astrodynamics. Previous work has demonstrated the usefulness of the stable and unstable manifolds of certain periodic orbits for understanding the transport phenomena in the CR3BP. One famous example is the Hiten-like trajectory, i.e. the low energy trajectory from the Earth to the Moon. By utilizing this innovative trajectory, the amount of on-board fuel can be lowered by about 20% compared to Hohmann transfer.

The Sun-Earth-Moon-spacecraft bicircular model (BCM) is an extremely useful model for the study of Earth-to-Moon missions. In the past studies, the BCM is approximated as two coupled three-body systems, and the invariant manifolds in these three-body systems are used as building blocks for the design of the Hiten-like trajectory. Apparently, a direct approach for constructing Hiten-like trajectory in non-autonomous systems, say, BCM or even Ephemeris, would produce a more accurate solution. To achieve this goal, a tool for understanding the time-dependent invariant manifolds should be developed firstly.

Lagrangian coherent structures (LCS), a concept that widely used in fluid mechanics, have excellent performance in analysis of the phase space of dynamical systems. Behaving as separatrices of sets with qualitatively different fates, LCS were defined as ridges of finite-time Lyapunov exponent (FTLE) fields by Haller, and can be used as substitutes of time-dependent invariant manifolds even in systems with arbitrary time dependence. Recent years, researchers have been devoted to the effective computation of LCS and its applications to astrodynamics.

In the present investigation, three specific tasks are accomplished. First, the time-dependent invariant manifolds in the Sun-Earth-Moon-spacecraft bicircular model are investigated using LCS as substitutes. Numerically implemented simulations indicate that, these manifolds are not only separatrices but also invariant sets. The second task is to automatically extract the LCS. Dichotomy proves to be a very cost-effective algorithm for LCS extraction. Finally, the application on constructing Earth-to-Moon low energy transfer in non-autonomous system is presented. As a simple example, the Hiten-like trajectory is reproduced by patching two portions together, with one computed in the Sun-Earth-spacecraft three-body system and the other in the integrated Sun-Earth-Moon-spacecraft bicircular system. A small mid-course ΔV of 42 m/s at the patch point is necessary. This technique may represent an important capability in more accurate models.