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MANIFOLD DYNAMICS IN THE EARTH-MOON SYSTEM VIA ISOMORPHIC MAPPING

Abstract

Recently, manifold dynamics has assumed an increasing relevance for analysis and design of low-energy missions, both in the Earth-Moon system and in alternative multibody environments. With regard to lunar missions, exterior and interior transfers, based on the transit through the regions where the collinear libration points L1 and L2 are located, have been studied for a long time and some space missions have already taken advantage of the results of these studies. Some examples are the European Smart-1, the Japanese Hiten, and the recent NASA GRAIL missions. This paper is focused on the definition and use of a special isomorphic mapping for low-energy mission analysis. A convenient set of cylindrical coordinates is employed to describe the spacecraft dynamics (i.e. position and velocity), in the context of the circular restricted three-body problem, used to model the spacecraft motion in the Earth-Moon system. This isomorphic mapping of trajectories allows a visual, intuitive representation of periodic orbits and of the related invariant manifolds, which correspond to tubes that emanate from the curve associated with the periodic orbit. Homoclinic (i) or heteroclinic (ii) connections, i.e. the trajectories that belong respectively to both the stable and the unstable manifolds of the same periodic orbit (i) or two distinct periodic orbits (ii), can be easily detected by means of this representation. This paper illustrates the use of isomorphic mapping for finding (a) homoclinic connections between trajectories emanating from the Lyapunov orbit at L1, (b) heteroclinic connections between trajectories emanating from two Lyapunov orbits, the first at L1, and the second at L2, (c) heteroclinic connections between trajectories emanating from the Lyapunov orbit at L1 and from a particular unstable lunar orbit, (d) heteroclinic trajectories emanating from the Lyapunov orbit at L2 and from a particular unstable lunar orbit. Homo/heteroclinic trajectories are asymptotic trajectories that are travelled at zero-propellant cost. In practical situations, a modest delta-v budget is required to perform transfers along the manifolds. This circumstance implies the possibility of performing complex missions, by combining different types of trajectory arcs among (a)-(d). This work illustrates two examples of such missions. The same isomorphic mapping has also a straightforward use in determining the optimal velocity impulse eventually needed to inject the spacecraft into a specified lunar (stable) orbit. In summary, this research proposes and successfully employs an original isomorphic mapping for lunar mission analysis, and proves its utility with reference to a variety of mission profiles.