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LOW-THRUST LUNAR TRAJECTORY OPTIMIZATION USING CANONICAL TRANSFORMATION

Abstract

It is well known that the optimal low-thrust transfer between near-Earth and Lunar orbit passes through the vicinity of libration point EML1 of the Earth-Moon system. In this regard, the libration point EML1 has been used as a junction point for the geocentric and selenocentric segments of trajectory in several studies. This technique allows us to obtain the results of near-optimal trajectory with insignificant losses in the cost function (transfer duration or fuel consumption). However, a discontinuity appears in the co-state variables at the junction point of the two segments, since two separate optimization problems are solved. This also leads to a discontinuity in the optimal control, including in the thrust vector control program of electric propulsion system. The aim of study is to analyze the lunar trajectories with the optimal junction point of geocentric and selenocentric segments to ensure the continuity of co-state variables. The proposed method is based on the application of maximum principle and continuation method to solve all the boundary value problems. To transform co-state variables between geocentric and selenocentric coordinate systems, it is proposed to use the canonical transformation of co-state variables. We use the system of differential equations of geocentric and selenocentric motion of spacecraft in modified equinoctial elements (MEEs) and the auxiliary longitude as an independent variable. However, the transformation from the geocentric coordinate system to the selenocentric one (or vice versa) is conveniently performed in the Cartesian coordinate system (CCS). The proposed scheme for the transformation from the geocentric coordinate system to the selenocentric one is as follows: 1) transformation from geocentric MEEs to geocentric CCS; 2) transformation from geocentric CCS to selenocentric CCS; 3) transformation from selenocentric CCS to selenocentric MEEs. The possibility of using obtained canonical transformations to solve the optimization problem of low-thrust trajectories to the Moon with the optimal junction points of geocentric and selenocentric segments is demonstrated. For the initial guess, the libration point EML1 is used as a junction point and the transformation to the optimal junction point of these segments, which ensures the continuity of the dependence of co-state variables on the independent variable, is carried out using the continuation method and canonical transformations. Numerical examples of low-thrust transfer from elliptical Earth orbit to circular Lunar orbit taking into account the full ephemeris model are given and comparison is made between the trajectories with optimal junction point and the trajectories with intermediate EML1 rendezvous.