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SOLAR-SAIL-BASED CISLUNAR NAVIGATION CONSTELLATION: BOUNDED TRAJECTORIES BY HAMILTONIAN STRUCTURE-PRESERVING CONTROL

Abstract

Recently, with the cislunar navigation constellation playing an increasingly important role in the positive cycle of the cislunar navigation and communication, the existing libration-point satellite cislunar navigation systems gradually show the localizations. For instance, the number of the classical Lagrangian points is limited and all the satellites in navigation systems are restricted in the same plane, which is not conducive to perform high-quality navigation. Motivated by it, this paper proposes to assign solar sails around the artificial Lagrangian points (ALPs) to construct the constellation. Different from the previous studies, the perturbation from lunar gravity is taken into consideration, which leads to the instability around the ALPs. To stabilize the perturbated dynamical system, the Hamiltonian structure-preserving (HSP) controller using position feedback is developed to make the motions of sails bounded.

Firstly, due to the Hamiltonian property owned by the dynamics of the Sun-Earth-Moon-sail system, i.e., a four-body problem, a HSP controller formulized in the three-body problem is implemented to stabilize the motion near ALPs by changing the lightness number and sail's attitude. Then, to make sure three-body HSP controller can work well in the four-body problem, the KAM theory is employed to prove the stability, just as did for the one of the natural triangular points, i.e., L_4 and L_5, in the full four-body problem. The topological property near ALPs controlled in the Sun-Earth system is investigated with the lunar gravity being regarded as the perturbation in the Hamiltonian system. The controlled dynamics with HSP is transformed to the Hamiltonian form equilibrating at the origin. To convert the above Hamiltonian function into Brikhoff's normal form, the symplectic transformation is developed based on the generation function. In addition, it is proved that the motion near ALPs is non-resonant and the frequency map satisfies the Kolmogorov non-degenerate conditions. Therefore, based on the KAM theory, there are invariant tori around ALPs in the controlled three-body problem, which indicates that the Moon's perturbation will not influence the stability around ALPs.

The proposed controller for bounded trajectories is practical in engineering, which is verified numerically by an achievable lightness number of solar sail. Thus, the developed constellation is expected to benefit not only the lunar exploration, but also the future interplanetary missions.