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ORBIT-ATTITUDE STABILIZATION OF A RIGID SPACECRAFT AROUND AN OBLATE ASTEROID WITH J2 PERTURBATION

Abstract

Space missions to asteroids have drawn more and more attention of the space community due to increasing interest in exploration of these primitive bodies and NEOs hazard mitigation. Several asteroid missions are under development, such as OSIRIS-REx, MarcoPolo-R and Hayabusa 2.

Close proximity-operations are generally necessary during in-situ asteroid exploration and deflection. The orbital radius is very small in close proximity of a small asteroid, and there exists significant gravitational orbit-attitude coupling due to the large ratio of the spacecraft dimension to the orbit radius. The traditional spacecraft dynamics, in which orbital and rotational motions are treated independently, will no longer have a high precision.

For high-precision dynamics and control around an oblate asteroid, we have studied the full spacecraft dynamics in a J2 gravity field. The spacecraft is modeled as a rigid body, and the orbit and attitude motions are within a unified framework with orbit-attitude coupling naturally taken into account. Relative equilibrium of the full dynamics can be used as the nominal motion and a natural orbit-attitude hovering position of the spacecraft. Then, the stabilization of relative equilibrium, i.e., orbit-attitude stabilization of the spacecraft, is necessary during the mission. The non-canonical Hamiltonian structure provides a new geometric viewpoint to stabilize the relative equilibrium.

In the present paper, a Hamiltonian structure-based stabilization approach is proposed and verified, through which orbit-attitude stabilization of the spacecraft is achieved at the unstable relative equilibrium. Since non-canonical Hamiltonian systems commonly exist in celestial mechanics and astrodynamics, this Hamiltonian structure-based stabilization approach will have broad applications in related problems. The proposed feedback control law is consisted of three parts: potential shaping, momentum control and energy control.

The potential shaping modifies the gravitational potential artificially through feedback so that the relative equilibrium is a minimum of modified Hamiltonian on invariant manifold to guarantee the Lyapunov stability. Then for the potential-shaped Lyapunov stable system, the momentum control leads the motion to the same invariant manifold with the relative equilibrium, which is a momentum surface given by Casimir functions. Simultaneously, the energy control introduces the energy dissipation into the system and the motion converges asymptotically to the minimum of the modified Hamiltonian on the invariant manifold, i.e., the relative equilibrium. The feasibility of the proposed Hamiltonian structure-based stabilization feedback control law is validated through a numerical simulation in the case of a space station orbiting around a small oblate asteroid.