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INTEGRATED 6-DOF SPACECRAFT ORBIT-ATTITUDE DYNAMICS MODELING AND ITS APPLICATION IN HOVERING CONTROL OVER AN ASTEROID

Abstract

Recent studies have shown that orbital and attitude motions of spacecraft are dynamically coupled in close proximity of small asteroids through the gravity. Generally, the gravitational orbit-attitude coupling is more significant with a larger ratio of the spacecraft's size to the orbital radius. More importantly, the close-proximity operations about asteroids usually require that the relative position and attitude of the spacecraft follow the reference trajectory simultaneously. Therefore, integrated 6-DOF orbit-attitude control yields better performance than the classical separate control scheme in terms of both accuracy and agility.

One challenge in the design of integrated 6-DOF orbit-attitude motion control is to find an adequate unified mathematical representation for the 6-DOF motion, which must be amenable for the application of nonlinear control theories, and is also required to be free of singularities and be applicable to a wide range of close-proximity operations. As for the representation of the 6-DOF orbit-attitude motion, the spacecraft can be considered as a rigid body, and the configuration space is the Lie Group SE(3), which is the set of position and attitude of the spacecraft. Recently, exponential coordinates of the Lie Group SE(3) have been used in the representation of the 6-DOF rigid body motion and the controller design. Exponential coordinates have several advantages: Free of singularity, has a vector form, convenient for the controller design, and can achieve almost global convergence in the controller. However, exponential coordinates of SE(3) have been used only in the spacecraft's kinematics, that is, only the relation between the first-order time derivative of exponential coordinates and the spacecraft's (angular) velocity has been given.

In this paper, we will improve current modeling method by using exponential coordinates of SE(3) on the dynamical level further, that is, by giving the relation between the second-order time derivative of exponential coordinates and the spacecraft's (angular) acceleration. By using this relation on the dynamical level, the system can be written as a second-order system with a compact form. Then, it becomes more convenient for controller design, and many control theories can be easily applied to this second-order system. Finally, based on the second-order system, a controller for hovering over an asteroid with almost global convergence and robustness is designed by using sliding mode control, and is verified by using numerical simulations.