IAF ASTRODYNAMICS SYMPOSIUM (C1)
Attitude Dynamics (1) (8)

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UNWINDING AND SINGULARITY FREE SATELLITE ATTITUDE CONTROL USING DOUBLE-GIMBAL VARIABLE-SPEED CONTROL MOMENT GYRO AND SLIDING CONTROL

Abstract

Satellite attitude keeping, in the presence of external disturbances, requires continuous attitude control using either inertial or non-inertial control devices. In this paper, a Double-Gimbal Variable-Speed Control Moment Gyro (DGVSCMG) is considered as three axes attitude control can be achieved using only one DGVSCMG unit. This also helps reduce spacecraft size, cost, and control singularities as compared to the other non-inertial actuators which either have more control singularities or saturation problems along with energy consumption issue. The main problems faced while doing satellite attitude control are rotation kinematics related singularities, rotation unwinding, in addition to control singularities associated with the non-inertial devices used onboard. In this paper, all the three issues are addressed and implemented. Singularity free attitude kinematics can be partially achieved using Modified Rodrigues Parameters (MRPs) which have larger singularity free rotation angles, only one singularity at a rotation angle of 2π is present as compared to the Classical Rodrigues Parameters. This also avoids coordinate singularities of Euler angles and holonomic constraints of quaternions also. Another issue related to rotation is unnecessary large angle maneuver done by the satellite, i.e rotation unwinding as mentioned above, to achieve the desired orientation. Unwinding causes extra fuel consumption, extra control efforts and delays in convergence. To completely eliminate the problem of singularity and unwinding, a shadow MRPs set along with the body MRPs set on a unit sphere as switching surface is proposed for describing the attitude kinematics. Satellite dynamics is described assuming a rigid body model equipped with a single DGVSCMG. Attitude control for the nonlinear dynamic system is designed and implemented using a proposed finite-time Sliding Mode Controller (SMC) to avoid gimbal lock. The proposed SMC along with the shadow and body MRPs sets guarantees not only finite time stable convergence while avoiding gimbal lock, but also successfully overcomes the highly undesired unwinding phenomenon and eliminates singularity of the MRPs as well making the system well behaved. Interestingly, the designed controller is robust to 40% uncertainty in satellite inertia and makes the system response 1.5 times faster than that of a conventional SMC. Finally, for the same attitude and control objectives, reduced resultant gimbal angle rotation (inner and outer) is always ensured due to the implementation of the proposed SMC along with the shadow and body MRPs sets. This also reduces extra energy consumption. Simulation results are presented to support the claim made.