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GEOMETRIC FAULT-TOLERANT SATELLITE ATTITUDE CONTROL USING DOUBLE-GIMBAL VARIABLE-SPEED CONTROL MOMENT GYRO

Abstract

One unit of Double Gimbal Variable Speed Control Moment Gyro (DGVSCMG) provides three axes satellite attitude control. The majority of the current body of research on attitude control of satellites using a DGVSCMG primarily focuses on parameter uncertainties and operates on the assumption that defects or breakdowns in the satellite system components are highly unlikely to transpire. The fulfillment of this assumption is infrequently observed in practical scenarios, as catastrophic failures can arise from many problems, especially to the actuator. In the absence of fault tolerance capacity, the attitude controller inability to mitigate faults related problems would lead to significant deterioration in performance and system stability, ultimately resulting in mission failure. The existing fault tolerant attitude control architectures have primarily a singularity-avoidance steering logic along with a fault-tolerant attitude controller. However, this architecture is not robust against the fault present in the servo motor system of the DGVSCMG, as no gimbals and rotor motor control systems are incorporated into this architecture. Thus, it may not ensure stability of the closed-loop system in practice under such a faulty DGVSCMG. To address this issue, a novel single-loop and singularity-free fault-tolerant attitude control architecture is proposed in this paper to capture uncertain faults in the servo motor system. The proposed fault-tolerant control architecture is more computationally efficient and robust than the existing steering-law based fault-tolerant control architecture as there is no requirement to design the singularity-avoidance and fault-tolerant steering logic separately. To accomplish this, a novel mathematical fault model of the system is proposed and developed in the framework of geometric mechanics to account for uncertain faults occurring in the motor servo system of the DGVSCMG. The satellite attitude dynamics is considered to be evolving on the special orthogonal matrix group SO(3) for achieving global, unique, and kinematic singularity-free attitude representation. A novel predefined-time sliding manifold for the attitude control system on the Lie group $\mathrm{SO}(3)\times\mathbb{R}^3$ is proposed and proved to be a Lie subgroup, along which the reduced order dynamics is shown to be almost globally predefined-time stable. Furthermore, a single-loop adaptive fault-tolerant geometric predefined-time sliding mode controller (AFTPTSMC) is designed for the system, which guarantees robustness against satellite inertia uncertainty, motor bearing frictional torque, and actuator partial failure. The efficacy of the proposed AFTPTSMC to the attitude control problem of a satellite equipped with a DGVSCMG under various types of servo motor system faults is demonstrated through numerical simulations.