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COUPLED RENDEZVOUS AND DOCKING MANEUVER CONTROL OF SPACECRAFT USING FAST FIXED-TIME SLIDING MODE CONTROLLER

Abstract

Rendezvous and docking maneuver requires simultaneous position and attitude tracking maneuver with high precision. When the distance between the chaser and the target spacecraft is substantial and their orientations differ significantly, it is better to implement rotational and translational maneuver independently as this is more energy efficient. However, if the chaser is in close proximity of the target then carrying out coupled rendezvous and docking maneuver is beneficial and is addressed in this paper. To accomplish this, coupled 6-DOF kinematics and dynamics of spacecraft motion is modeled using Lie group SE(3) with the relative configuration expressed through exponential coordinates. The proposed coupled dynamics of the chaser integrates dynamics of the Double Gimbal Variable Speed Control Moment Gyroscope (DGVSCMG), as a three-axes actuator, along with its gimbal motors. This allows to account for the effect of rotational inertia of the DGVSCMG and its motors, thereby accurately modeling the system for precision control maneuver. Precision maneuver requires a nonlinear robust controller. In the current scenario, a fixed-time sliding mode controller (FTSMC) is used to generate command signals for the actuators. Unlike finite-time SMC, the fixed-time SMC ensures finite-time convergence with settling time independent of the initial states of the system, which is desirable for rendezvous-docking maneuver. However, fixed-time controller often exhibits slow convergence. To overcome this limitation, a time-varying sliding surface based non-singular fast fixed-time SMC is proposed in this paper for the coupled tracking maneuver of the proposed system. To reduce the reaching phase of the sliding mode controller as well as to alleviate the chattering phenomenon, a novel approach is proposed where the slope of the sliding surface is modulated by a time-varying hyperbolic tangent function. This approach involves rotating the sliding surface within the state space in a specific direction resulting in improved tracking behavior. With the proposed controller, faster convergence of the translational and rotational error states is achieved in the presence of external disturbances. The global fixed-time stability of the closed-loop feedback system is proved in the framework of Lyapunov. Simulation results presented support the claims made in the paper. Performance of the proposed SMC is compared against the linear, finite-time, and conventional fast fixed-time SMCs. Interestingly, it is observed that the proposed controller outperforms the conventional fast fixed-time SMC and demands minimal control torque, leading to a reduced energy index for the system.