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Entitled

DEVELOPMENT OF GUIDANCE, NAVIGATION, AND CONTROL SYSTEMS FOR MULTI-SPACECRAFT ASSEMBLY IN PROXIMITY OPERATIONS

by

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Abstract

This thesis presents the development of Guidance, Navigation, and Control (GNC) algorithms for multi-spacecraft assembly in proximity operations. A 3-DOF mathematical model of spacecraft relative translational motion is derived using the Euler-Lagrange method. Additionally, a 6-DOF mathematical model of spacecraft relative translational and rotational motion is derived using the twistor method, with consideration for the kinematic coupling effect. A new Linear Time-Invariant (LTI) model is developed based on the twistor-based model, which is utilized in the design of the GNC systems. LTI Model Predictive Control (MPC) and Linear Time-Varying (LTV) MPC algorithms are employed to develop a Guidance and Control (G&C) systems using the 3-DOF translational model. These algorithms consider mission constraints such as collision avoidance, Line-of-Sight (LOS), and input saturation. A novel linear representation of the LOS constraint is developed using the Taylor method to simplify the optimization problem while avoiding ambiguity. Furthermore, a decentralized G&C systems are developed using the Discrete-Time Periodic Riccati (DTPR) method, based on a discrete-time Linear Time-Periodic (LTP) model of spacecraft relative translational motion. The stability of the system and the synchronization of the members are analyzed using the Lyapunov method. In addition, a new technique is developed to prove the stability of multi-agent discrete-time LTP systems under input saturation using the invariant-set method. On the other hand, the twistor-based model is utilized to design G&C systems using decentralized MPC and Linear Quadratic Regulator (LQR) methods. The optimal trajectories of the spacecraft are generated using Lagrange method, and the results are compared to identify the most efficient method. Regarding the navigation systems, the Unscented Kalman Filter (UKF) is employed to develop two relative navigation systems for spacecraft relative 6-DOF motion. First, the Taylor method is utilized to obtain the residuals of the state covariance and measurement noise covariance matrices. Second, the State Noise Compensation (SNC) method is utilized to determine the first-order approximation of the residuals, while the Stirling Interpolation Formula (SIF) is employed to evaluate the second-order approximation. The integrated GNC systems are verified through real-time testing using dSPACE SCALEXIO LabBox, demonstrating the ability to apply the proposed systems in practical applications.

Keywords: Spacecraft relative motion, guidance, navigation, control, model predictive control, discrete-time periodic Riccati method, invariant-set method, energy-optimal trajectory, unscented Kalman filter, state noise compensation, Stirling interpolation formula