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Author: Mr. Gaurav Kumar
Indian Institute of Technology Kanpur, India, grvk@iitk.ac.in

Dr. Dipak Kumar Giri
Indian Institute of Technology Kanpur, India, judipakkumar@gmail.com
Prof. Shashi Ranjan Kumar
Indian Institute of Technology, India, srk@aero.iitb.ac.in
Mr. Arya Das
Indian Institute of Technology Kanpur, India, aryadas98@gmail.com

ON-TRACK OPTIMAL RENDEZVOUS AND DOCKING OF SPACECRAFTS USING HYBRID COULOMB CONTROL

Abstract

The use of electrostatic actuation for formation flying and on-orbit proximity operations has been gaining attention in the Aerospace community in recent years. This method utilizes variable spacecraft charges developed using ejection of negative (electrons) or positive charge (ions) to generate Coulomb forces and torques, which control the relative motion between the spacecraft. With its high specific impulse and low plume impingement, this method of propulsion provides a sustainable and efficient way for proximity maneuvers. This paper investigates the dynamics of on-track rendezvous and docking of two spacecraft and stabilization using hybrid Coulomb control. Chaser spacecraft is modeled to be a general spacecraft shaped like a cylinder, while the target shape is assumed to be spherical because of its little influence on the system's dynamics. Modeling electrostatic forces and torques to control complex spacecraft geometries like a cylinder is challenging. Point mass assumption of the spacecraft that disregards the chaser attitude dynamics will lead to errors in force estimation during the terminal docking phase, resulting in a mission failure due to collision. This paper uses the effective sphere method to model Coulomb interactions between the chaser and the target, which provides a computationally efficient way to compute electrostatic forces and torque in real-time. This method replaces the cylindrical target with an ellipsoid which is then used to analyze these interactions. The method is coupled with the chaser's tumbling motion about its body axis to develop a relation between electrostatic force and attitude. The relative attitude dynamics of the chaser is then derived and incorporated into the system dynamics. Differential gravity and hybrid thruster are used to stabilize the relative attitude of the two bodies. Charge-voltage relations are used to compute potential variations for the Coulomb control. Optimal linear quadratic tracking control is designed for tracking a reference trajectory generated using solutions of Clohessy-Wiltshire-Hill's equations. Numerical simulations are carried out for both non-linear and linear models of dynamics demonstrating time propagation of tracking error and docking angle to validate the proposed concept. Results have also been compared with an existing voltage feedback controller to demonstrate the merits and challenges of electrostatic actuation for docking over the existing ones.