71st International Astronautical Congress 2020

Paper ID: 59535
oral
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation & Control (3) (3)

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FINITE-TIME REACHABILITY OF THRUST-LESS RENDEZVOUS MISSION UNDER INPUT CONSTRAINTS

Abstract

Space environmental forces are invested as one of the main methods to reduce the chemical thrusters-dependency for satellite missions. They were theoretically tested as alternative control actions instead of thrusters for specific missions. In the last three decades, the controllability analysis for the orbit control missions in low earth orbits (LEOs) using differential atmospheric drag has been studied for various orbits with different formulations.

In this paper, we aim to specify the boundaries of the reachability closure using a differential atmospheric drag control action subject to input saturation. This analysis can predict the boundaries of the reachable space within restricted time intervals and restricted control actions. It is implemented to acquire the practical limits for the saturated actuators with nominal satellite parameters. The paper estimates the finite-time reachability closure based on different formulations of the rectilinear relative states for circular orbits. The linearized relative equations for satellite constellation in the vicinity of a circular orbit are stated based on the Hill–Clohessy–Wiltshire (HCW) with a low formation radius. The boundaries sets are evaluated theoretically and numerically by the estimation of the closure to the allowable initial states for the rendezvous mission.

The paper illustrates two main approaches to estimate the finite-time reachability of the in-plane motion considering saturation in the rotation angles of the satellites' drag plates. The first approach is a theoretical derivation to achieve generic reachability analysis for the linearized relative dynamics models using differential drag by utilizing the eigenstructure of the dynamical systems. The paper presents a bang-bang control action to derive a theoretical approach with the pseudo-inverse of the state matrices. It is stated to denote the boundary for the closure of reachability sets for the singular state matrices with linear time-invariant (LTI) system of the normalized HCW equations. The second approach implements an applied technique that states the finite-time reachability for a restricted nonlinear relative dynamics models for different altitudes. This approach is designed based on the numerical solutions of Hamilton-Jacobi (HJ) for the partial differential equations (PDE) of the nonlinear dynamics by maximizing the general performance index of the optimization problem. The numerical simulations results ensure the effectiveness of this analysis by showing that all trajectories lie within the theoretical boundaries of the initial state vectors for the linear formulation of the relative equations.