 Paper ID: 69882
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IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IPB)

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PSUEDOSPECTRAL OPTIMAL CONTROL OF SPACECRAFT RENDEZVOUS WITH COMBINED DIFFERENTIAL DRAG AND LORENTZ FORCES

Abstract

Trajectory tracking control is a key technology in the research of spacecraft rendezvous missions. The recent importance of decreasing fuel consumption in Earth orbiter spacecraft missions creates the need to exploit the space environment forces in various orbit control applications. In many references, the differential atmospheric drag and Lorentz forces have been utilized separately, where simplified dynamics formulations have been investigated. In this paper, the nonlinear relative equations for satellite constellation in the vicinity of circular and elliptic orbits are stated, and the control action is a combination between the differential aerodynamic drag and the Lorentz forces. Therefore, the optimal control action is derived from solving a nonlinear optimal control problem to minimize the required maneuver time. The main obstruction in constructing optimal feedback laws stems from the difficulty in solving the Hamilton-Jacobi equation, especially with the nonlinear representation of the Lorentz forces and atmospheric drag. On the other hand, direct methods are a family of numerical methods that provide optimal open-loop control by converting the nonlinear optimal-control problem into a nonlinear parameter optimization (nonlinear programming (NLP)) with various transcription schemes. In this paper, we propose obtaining the optimal control for rendezvous missions in low earth orbits (LEOs) by transcribing using Radau Pseudospectral method (RPM), whereas the solution of the NLP is obtained using the sequential quadrature programming algorithm. The RPM bases its quadrature on Radau quadrature for which the (n+1)-node quadrature formula exactly integrates polynomials of degree 2n.

The RPM results are held in comparison with those of the linearized forms of dynamics models with assumptions of small drag plate angles and un-tilted geomagnetic fields. Furthermore, the RPM results with a small relative radius are compared with the linear representations of relative dynamics models in circular and elliptical orbits in Hill–Clohessy–Wiltshire (HCW) equations and Tschauner–Hempel (TH) equations, respectively. This analysis is concerned with the whole system of the relative dynamics models in LEOs. However, it investigates the separated in-plane and out-of-plane motion for special orbit representations as polar and equatorial orbits. Compared with the linear quadratic regulator algorithm, the designed optimal trajectory algorithm has remarkable performance and maneuvers time reduction besides significant improvements with nonlinear dynamics. The numerical simulation results illustrate the effects of the different altitudes and orbital parameters in the performance of the control algorithms.