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ANALYSIS AND PERFORMANCE EVALUATION OF ZEM/ZEV GUIDANCE AND ITS SLIDING ROBUSTIFICATION FOR AUTONOMOUS RENDEZVOUS IN RELATIVE MOTION

Abstract

Devising closed-loop guidance algorithms for autonomous relative motion is an important problem within the field of orbital dynamics. However, very few closed-loop algorithms have been devised that can autonomously generate feedback trajectories to execute rendezvous in relative motion (e.g. Lopez and McInnes, 1995, JGCD). In this paper, we explore the application of the generalized Zero-Effort-Miss/Zero-Effort-Velocity (ZEM/ZEV) feedback guidance (Guo et al., 2013, JGCD) and its robustified version known as Optimal Sliding Guidance (OSG, Wibben and Furfaro, 2016, ASR) to the problem of closed-loop spacecraft rendezvous guidance.

The ZEM/ZEV feedback guidance has been studied extensively and can be found in the literature for intercept, rendezvous, terminal guidance and landing applications. Such analytical closed-loop guidance has been originally conceived by Battin who devised an energy optimal, feedback acceleration command for powered planetary descent. Ebrahimi et al. (2008, AA) introduced the ZEV concept, as a partner for the well-known ZEM and integrated it with a sliding surface for missile guidance with fixed-time propulsive maneuvers. Furfaro et al. (2011,Advances in Astronautical Sciences) extended the idea to the problem of lunar landing guidance and set the basis for the theoretical development of a robust closed-loop algorithm for precision landing. ZEM/ZEM feedback guidance is attractive because of its analytical simplicity as well as potential for quasi-optimal fuel performance. When robustified by a time-dependent sliding term, the resulting OSG can be proven to be Globally Finite-Time Stable (GFTS) in spite of perturbation with known upper bound.

Here, we study the guided relative motion of two spacecraft for which one of them is executing an autonomous rendezvous via the ZEM/ZEV feedback guidance and its robustifed OSG counterpart. When augmented via time-dependent sliding, the application of Lyapunov stability theory for non-autonomous systems provides the sufficient conditions for GFTS. Indeed, the OSG can be demonstrated to be GFTS for any linear and non-linear relative motion model (e.g. rendezvous in circular orbit or in highly eccentric orbit). Starting from the classical Clohessy-Wiltshire (CW) model, we systematically analyze the ability of the ZEM/ZEV feedback guidance to execute quasi-optimal closed-loop maneuvers and its ability to correct disturbances for precision guidance. Comparison with the OSG counterpart will provide an assessment of the need for robustification as function of different rendezvous conditions (e.g. rendezvous in highly elliptical orbit) and different thrusting constraints (e.g. limited thrust).