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Author: Mr. Chandrakanth Venigalla
University of Colorado Boulder, United States, chve1854@colorado.edu

Prof. Daniel Scheeres
Colorado Center for Astrodynamics Research, University of Colorado, United States, scheeres@colorado.edu

NUMERICAL AND ANALYTICAL REACHABLE SET APPLICATIONS TO COOPERATIVE AND NON-COOPERATIVE MULTI-SPACECRAFT TRAJECTORY COORDINATION

Abstract

Coordination of multiple in-space assets is becoming increasingly important to the successful planning and execution of space missions. This is true both in a cooperative sense and in a non-cooperative sense. Examples of cooperative missions include formation flying missions, on-orbit assembly, and manned rendezvous flights. Non-cooperative scenarios include not only active pursuit and evasion between multiple spacecraft, but also planning mission operations around defunct satellites that are not well understood. Understanding optimal evasion strategies in the pursuit/evasion problem actually gives the “safest” evasion strategy for avoiding a space debris object with unknown forces and torques acting upon it. These issues are of prime importance for satellite constellation management, rendezvous and docking, spacecraft servicing and recycling, and more.

This paper extends previous work that explored the use of single spacecraft reachable sets for coordinating multiple spacecraft trajectories. Previously, we have explored the application of two-dimensional (semimajor axis and eccentricity), time-free reachable sets for the purposes of rendezvous and pursuit/evasion[1]. By analyzing the intersections of individual reachable sets for two separate spacecraft in orbital element space, we could find optimal rendezvous and pursuit/evasion trajectories. In this paper, we further investigate these set intersections for three-dimensional (semimajor axis, eccentricity, and inclination) time-free reachable sets. Examining these set intersections will illuminate rendezvous and pursuit/evasion strategies in a three-dimensional, time-free context.

We will also further analyze both two-dimensional and three-dimensional rendezvous and pursuit/evasion cases on an analytical basis using delta-V optimal multi-impulse transfers. Analyzing delta-V optimal transfers for a limited number of impulses will not only simplify analytical analysis, but will also allow us to generate exact reachable sets with which to compare to other methods of generating reachable sets. This will further validate previous results, and give more insight into coordination strategies. Preliminary results using this type of analysis have validated previously found planar pursuit/evasion strategies, and have given greater insight into the relative advantages and disadvantages of the pursuing and evading spacecraft. Finally, we will use both the numerical reachable set results and analytic results to help derive finite-time implementations of orbit transfers in a J_2 perturbed environment. These finite-time transfers will provide conditions for spacecraft to use judicious control policies in conjunction with natural dynamics in order to coordinate actions between multiple spacecraft with minimal delta-V.

[1] Venigalla, C. and Scheeres, D. “Spacecraft Rendezvous and Pursuit/Evasion Analysis Using Reachable Sets.” *2018 Space Flight Mechanics Meeting.* 2018.