EFFICIENT STATION-KEEPING FOR SEMI-AUTONOMOUS CLUSTER FLIGHT

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ABSTRACT

A key challenge of guidance, navigation, and control for clustered satellite flight is long duration station-keeping of the cluster. The secular perturbations that force the cluster to drift apart must be corrected periodically, and the satellites must maintain safe relative orbits. Furthermore, the station-keeping should be semi-autonomous to the point that the ground crew required for the mission is similar to that required for a traditional monolithic satellite performing the mission. This paper describes several cluster station-keeping strategies and analyzes their performance over 500 orbits using a high-fidelity simulation. The strategies were down-selected based on the results of this trade study and implemented into flight software for DARPA's System F6 (Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange) program. This program seeks to address the challenge of developing future space systems via fractionated architectures wherein wirelessly networked modules would communicate, collaborate and share resources to accomplish their mission.

The station-keeping strategies build on the concept of receding horizon control (RHC), which is common in controls literature. The strategies are intended to provide maneuver time windows and specific targets to a robust maneuver planner, which is available in the high-fidelity simulation but is not discussed in this paper. First, RHC is directly applied as a solution to maintain a specified cluster formation. Then, several innovations are developed that preclude the generic proofs of stability for RHC but significantly improve the performance of long-term station-keeping. The first innovation is the addition of control regions to the RHC strategy, which are specified using relative orbit elements (ROEs) [Ref. 1]. The intention is to reduce the frequency of burns while maintaining passive safety by updating maneuver plans only when necessary. The analytical results for the secular drift of ROEs due to J2 are used in the design of the control regions. This approach is similar to the traditional station-keeping control strategy used for geostationary satellites using control box regions defined in terms of classical orbital elements. For our station-keeping strategy, the control box concept has been applied to ROEs in the relative space instead.

The receding horizon approach is a very efficient and effective approach, but it does not provide a guaranteed convergence time. The second innovation to our station-keeping

strategy modifies the control horizon such that the maneuver window deadline no longer recedes into the horizon. Instead, a fixed horizon approach is adopted, which plans new maneuvers within a reduced window based on the time remaining until the target deadline. This improves the convergence time of the algorithm, but it often results in larger and more frequent burns within the reduced maneuver window.

The trade study described in the paper also considers the flocking controller station-keeping strategy described in Ref. 2. In this strategy, the satellites do not maintain a specified cluster formation and only perform maneuvers to prevent secular perturbations from causing the cluster to drift apart and to maintain safe relative orbits.

Performance metrics for each station-keeping strategy are evaluated using Monte Carlo analysis over 40 runs of 500 orbits. Each of the 500 orbits runs simulates approximately four weeks of station-keeping. The mean results over 500 orbits are extrapolated to determine the fuel requirements for a nominal six month mission. The efficiency of the strategies is evaluated using multiple metrics that represent the fuel requirements, burn frequency, safety, and consistency.

[Ref. 1] Lovell, T. A and S. G. Tragesser, “Guidance for Relative Motion of Low Earth Orbit Spacecraft Based on Relative Orbit Elements,” AIAA 2004-4988, AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Providence, RI, 16-19 August 2004.

[Ref. 2] Schwartz, J., et al, "The Flocking Controller: A Novel Cluster Control Strategy for Space Vehicles," AIAA Guidance, Navigation, and Control and Co-located Conferences and AIAA Infotech@Aerospace 2013, Boston, MA, 19-22 Aug 2013.