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CLUSTER FLYING ALGORITHM FOR SPARSELY CONNECTED SATELLITE SWARMS

Abstract

The concept of cluster flying, initially introduced in DARPA's System F6 program, has garnered increasing attention in the field of distributed satellite systems. According to this concept, relative drift caused by higher-order orbital disturbances is permissible as long as the distances between satellites stay within the range supported by cross-links, and collision avoidance can be guaranteed. Since precise positioning between satellite pairs is not required, this approach is particularly well-suited for emerging space architectures, such as satellite swarms, disaggregated satellites, or fractionated spacecraft.

Despite significant advancements in cluster flying algorithms in recent years, most existing studies rely on a common assumption: that satellites within the cluster maintain a fully connected communication network throughout the mission. In the literature, this assumption is termed "cluster flight," which requires that all member satellites should keep bounded relative distances for the entire mission duration. However, in practice, the wireless network in a satellite swarm often functions as a loosely connected multi-hop mesh network, as demonstrated in NASA's Starling CubeSat Swarm program last year.

Consequently, the challenge of ensuring that each satellite in a cluster operates within a sparsely connected network while avoiding collisions persists as an unresolved issue that has yet to be extensively studied. To address this gap, this paper proposes a detailed cluster flying strategy tailored for sparsely connected satellite swarms.

Firstly, to facilitate network topology management for the satellite swarm, a cluster-tree network architecture is adopted based on Relative Orbit Elements (ROE), which parameterize the relative motion between satellite pairs. Nextly, a cooperative guidance methodology is introduced to generate nominal ROE sets that satellite members should adopt when risks to cross-link connectivity or collisions arise. Specifically, cross-link connectivity risks are mitigated by cooperatively adjusting the semi-major axis differences between satellites to regulate relative distances along the flight direction. Meanwhile, collision avoidance is achieved by coordinating the relative eccentricity/inclination (E/I) vectors between at-risk satellite pairs to ensure passive safety in the plane perpendicular to the flight direction. Finally, a novel triple-impulse maneuver scheme is proposed to achieve the target nominal ROE.

Simulations involving seven nanosatellites demonstrate that 25 grams of propellant are sufficient for each satellite to be kept in a sparsely connected swarm with the cluster-tree network topology for one month, using low specific-impulse thrusters.