Title: "**Guidance and Navigation Algorithms for Spacecraft Low-Thrust Proximity Operations: Formation Flight in Circular Relative Orbit**"

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The increasing complexity of multi-satellite missions necessitates the development of advanced autonomous GNC strategies for proximity formation flight. This thesis investigates the use of Circular Relative Orbit (CRO) in Earth-orbiting missions, with particular emphasis on their feasibility for LEO operations. The primary challenges addressed include collision risk, control limitations, and the design of effective guidance strategies to ensure stability and mission success. This research explores the CRO tracking problem by framing it as a velocity tracking task. Stability conditions are derived in relation to the maximum allowable tracking error, which is constrained by actuator limitations.

Two guidance approaches are compared: Optimal Guidance and the Lyapunov Guidance Vector Field (LGVF) method. Optimal Guidance allows for precise maneuver planning while accounting for actuator constraints and collision avoidance, but its application in low-thrust scenarios is limited by its high computational cost. On the other hand, LGVF provides a computationally efficient solution, but exhibits reduced robustness in the presence of model uncertainties and actuator constraints. To overcome these limitations, an Adaptive-LGVF strategy is introduced, offering a balance between computational efficiency, robustness, and stability. The CRO guidance algorithm is subsequently integrated with an Artificial Potential Field strategy to enable formation control, resulting in a robust and unified guidance framework for formation flight missions in CRO.

A critical aspect of successful CRO tracking is accurate state estimation, which directly impacts control performance and formation stability. To address this problem, an adaptive observer-based navigation framework is proposed. The framework improves state estimation accuracy in the presence of sensor noise and dynamic

uncertainties, and includes adaptive gain tuning to ensure rapid convergence while minimizing chattering effects. By carefully tuning velocity feedback gains, the navigation framework enables the system to balance responsiveness and CRO tracking accuracy under realistic mission constraints.

Simulation results were conducted to assess the performance of CRO tracking in various orbital models, including circular and elliptical reference orbits, as well as within the Restricted Three-Body Problem. These simulations allowed for the verification of closed-loop system performance under realistic perturbations and actuation limits. After establishing the tracking performance, the analysis was extended to formation flight scenarios. The impact of formation deployment strategies and orbital altitude on mission safety and feasibility was investigated. Single-phase deployments, where all spacecraft are released simultaneously, introduce high collision risks and require strict coordination. In contrast, multi-phase deployments, where spacecraft are released sequentially, reduce these risks and enable more controlled reconfiguration.

The study also explores the influence of orbital altitude on formation flight. In LEO, strong perturbations such as atmospheric drag and gravitational variations limit feasible formation sizes and impose stringent tracking accuracy and control authority requirements. Higher altitudes, such as MEO and GEO, offer reduced perturbative effects, improving maneuverability and formation stability. However, weaker gravitational forces in these regimes reduce natural observability, increasing reliance on accurate state estimation. As a result, observer performance becomes critical in these higher altitudes for ensuring accurate guidance and control.

The proposed guidance and control framework is demonstrated to achieve formation flight with millimeter-level relative position accuracy, even in the presence of sensor noise, control saturation, and environmental perturbations. This level of precision is critical for missions requiring high-resolution payload alignment, coordinated sensing, or interferometric measurements. Moreover, the proposed framework enables the achievement of various formation flight missions, offering scalability and reconfiguration capabilities within a compact and efficient implementation. The results confirm the feasibility of using CRO-based strategies for advanced multi-satellite missions in Earth orbit, paving the way for future autonomous space missions.