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GUIDANCE AND CONTROL FOR AERODYNAMIC BASED NANOSAT MULTI-STATIC SAR FORMATION FLYING MISSION AIMED AT SUB-MILLI-METER SPACE DEBRIS CHARACTERIZATION.

Abstract

Low earth orbits (LEO) and very low earth orbits(VLEO) are important regions for space-based applications like Earth observation, Telecommunication, and Astrophysics. Understanding and modeling the Space debris in this region is of utmost importance for space situational awareness. Specifically, due to the limitations of ground-based sensor systems, the detection and characterization of sub-millimeter-level objects require an in-situ sensor system. In these regions, the effect of aerodynamic force is significant, as a result, utilization of this force for position control is very attractive, especially for nanosats. This will enable nanosats not to carry propulsion system leading to increased available size, weight, and power (SWAP) for mission outputs such as science data by increasing the payload quality and mission redundancy via extra sensors and actuators.

In this work, we are proposing a guidance and control methodology for a novel aerodynamics-based nanosat formation flying mission. As the size and shape of the debris are not known a priori, the multi-static synthetic aperture radar (MSSAR) technique is considered to detect and characterize the sub-millimeter debris particles. The proposed guidance generates coupled translation and attitude trajectories that are optimized in terms of coverage area thereby increasing the detection and characterization of debris particles in different regions. Constraints specific to this mission such as maximum separation distance, position and attitude accuracy, and traditional constraints like collision avoidance are integrated into the guidance method. Moreover, the dynamics model includes co-rotation of the atmosphere with respect to earth, perturbation effects until the order smaller than aerodynamic forces ($O(10^{-5} \sim 10^{-6}) m/s^2$), for example until J3 for non-spherical effects. The controller considered is an adaptive controller that takes care of the model uncertainties and accounts for the errors coming from sensors and actuators. Furthermore, a learning-based polynomial density model is used for guidance. It utilizes the NRLMSISE-00 reference model and can adapt to new information. For the adaptive controller, a receding horizon-based estimator (RHE) estimates density with the latest available information. If the error exceeds a threshold, guidance trajectories are regenerated with updated information, ensuring the framework's robustness and reliability in changing environmental conditions. High-fidelity numerical simulation campaigns demonstrate the feasibility and effectiveness of the developed guidance and control methodology for different MSSAR formation flying configurations.