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A SWARM-DRIVEN SOLUTION FOR SPACE DEBRIS REMOVAL: INSPECTION, CAPTURING, AND CONTROLLED DE-ORBITING

Abstract

The increase in number of the space debris has emphasized the need for effective concepts and technologies to clean orbits, minimizing the risk of collisions with operational satellites. Different concepts were discussed in literature for active debris removal (ADR) such as robotics arm, drag sails, harpoons and nets. There are missions, such as RemoveDEBRIS, that demonstrate ADR technology, and the upcoming mission ClearSpace-1 by ESA, which is designed to remove in-space debris. The existing approaches mainly rely on single-satellite servicers, which offer certain advantages but also come with several limitations and challenges.

This study investigates the potential of a swarm-based approach for space debris mitigation. In this concept, a mother spacecraft carries a set of small satellites for multiple debris removal activities. The mother spacecraft provides the maneuvering capability for large orbital transfer to the targeted debris. Based on the determined ejection and commissioning activities, it releases a swarm of small satellites, which autonomously executes the de-orbiting mission. Initially, the small satellites, equipped with multi-axis electric thrusters, establish distributed bounded motion around the debris, enabling detailed characterization through vision-based navigation. The swarm of satellites coordinate together to provide the full picture on the debris physical and dynamical properties in preparation for the capturing phase.

The satellites are equipped with a capturing mechanism that can absorb the first impact and maintain the attachment with the debris throughout the mission. Once the debris is captured by the swarm of satellites, the final stage involves its de-orbiting. The multi-axis thrusters are used to de-tumble the debris before proceeding with the de-orbiting phase. Since the satellites are attached at different points on the debris, a decentralized communication system is necessary for decision-making and task allocation. This system determines which satellites should activate their thrusters for the de-orbiting maneuver and which ones should control the debris attitude throughout the de-orbiting phase.

This paper examines the feasibility of the proposed approach by discussing potential technologies and mission scenarios. The primary goal is to evaluate the benefits of using a satellite swarm over a single satellite for debris inspection and removal in terms of efficiency, cost, timeline, and complexity. Additionally, it aims to identify the conditions in which a swarm is more advantageous, considering factors such as debris size and orbital characteristics. The study also explores the sizing of the swarm and mother spacecraft to optimize environmental benefits and mission costs for multiple ADR missions.