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SHAPE-MEMORY POLYMER (SMP) NETS FOR ACTIVE DEBRIS CAPTURE IN SPACE

Abstract

The growing accumulation of space debris presents a major challenge to satellite operations and space missions. Uncontrolled debris fragments, ranging from defunct satellites to spent rocket stages, pose collision risks that could trigger cascading damage in orbit. This research proposes an innovative debris capture system using Shape-Memory Polymer (SMP) nets, which offer a lightweight, adaptable, and energy-efficient solution for space debris mitigation.

SMPs are smart materials that can change shape in response to temperature variations. The net is designed to remain compact during launch and expand once activated by heat, such as from sunlight or onboard electrical heating. Upon reaching the target debris, the net wraps around it and contracts, securely capturing the object for removal. This self-deploying and shape-recovering behavior is controlled by precise thermal activation and material properties. Unlike traditional rigid mechanical arms, SMP nets are flexible, reducing the complexity and weight of debris capture systems.

The proposed system targets debris ranging from 1 to 10 cm in size within Low Earth Orbit (LEO), where space congestion is most severe. Once the debris is captured, the net can either increase atmospheric drag to facilitate natural reentry and burn-up or guide the object toward a safe disposal orbit. To ensure reliability, advanced computer simulations (Finite Element Modeling) are used to analyze how the net behaves in different space conditions, such as temperature fluctuations and microgravity. Additionally, artificial intelligence (AI) techniques, including reinforcement learning, optimize the net's deployment based on real-time tracking of debris motion.

By providing a scalable and cost-effective approach to space debris removal, SMP nets contribute to long-term sustainability in space operations. Their ability to adapt to different debris sizes and shapes, combined with minimal energy consumption, makes them a promising technology for future satellite servicing and orbital cleanup missions.