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REUSABLE CUBESAT CONSTELLATION FOR (99942) APOPHIS 2029 OBSERVATION AND BEYOND

Abstract

The 2029 close approach of asteroid (99942) Apophis offers an exceptional opportunity to test novel planetary defense strategies. Traditional single-spacecraft missions face significant challenges, including limited observational perspectives, susceptibility to mission-critical failures, and inadequate flexibility for transient asteroid encounters. To overcome these issues, this paper introduces a reusable CubeSat constellation mission concept designed to provide comprehensive, multi-angle imaging of Apophis.

The proposed constellation leverages a genetic algorithm to optimize the number and formation of CubeSats, balancing imaging coverage, maneuver complexity, and overall mission feasibility. Each CubeSat in the constellation operates autonomously, equipped with adaptive six-degree-of-freedom (6DOF) formation control, which integrates Relative Orbit Elements (ROEs) with precise attitude control. This enables each spacecraft to accurately position itself and align its camera system, forming a coordinated imaging network around Apophis to ensure full surface coverage and high-resolution stereoscopic imaging capability during the flyby.

A critical aspect of this mission is its advanced post-observation retrieval strategy. After completing observations, each CubeSat executes carefully planned impulsive maneuvers to return safely to the carrier spacecraft. The redocking procedure employs clearly defined approach corridors, collision avoidance techniques, and precise timing, utilizing state-of-the-art docking adapters. Successful redocking facilitates the secure transfer of collected imaging data, alongside CubeSat inspection, refurbishment, and refueling, significantly extending the mission's lifecycle.

The modularity and reusability of this CubeSat constellation enable rapid adaptation and deployment for future near-Earth object (NEO) encounters beyond Apophis. The proposed approach enhances Earth's ability to promptly address newly identified asteroid threats, significantly improving planetary defense readiness. This reusable CubeSat constellation thus represents a versatile and sustainable advancement in asteroid surveillance and planetary protection, extending its utility well beyond the 2029 Apophis flyby.