IAF SPACE EXPLORATION SYMPOSIUM (A3)
Small Bodies Missions and Technologies (Part 2) (4B)

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MULTI-STATIC RADAR TOMOGRAPHY OF SMALL BODIES WITH MICRO-MINIATURE SOLAR SAILS

Abstract

Capabilities of picosatellites to aid or lead deep-space exploration are rapidly materialising in the recent years, with cubesat missions demonstrating formation-flight as well as operations beyond Earth orbit. If landers are included, asteroid exploration is also demonstrated. Furthermore, miniaturisation of solar sails has reached cubesat scales with advanced orbit control techniques. In this light, we propose an innovative concept exploring the surface and interior of a small body (an asteroid or a comet) using a fleet of kg-class micro-miniature solar sail probes. Solar sails are uniquely suited for small body exploration for their ability to achieve stabilised trajectories under irregular gravitational fields. The probes are transported to a target by a Deep-Space Orbital Transfer Vehicle (DSOTV), where they are released and independently manoeuvre into their target orbits, forming a constellation. Multi-static radar tomography explores the interior structures, and high-resolution global surface mapping is conducted at low orbits.

This concept is newly enabled by two key innovations. Firstly, a new solar sail antenna is introduced, where the antenna pattern is etched directly onto the sail membrane material. This integrates the desired radar antenna into the sail membrane with no thickness, weight, or complexity penalties, giving the probes radar functionalities within the weight and size constraints. Secondly, an active membrane shape control technique for spin-type sails is introduced, giving the probes propellant-free force and torque authority. This allows the probes to achieve long-term stabilised trajectories around the target by controlling solar radiation pressure forces.

This paper explores the implications of these innovations with an example mission scenario. Radar tomography prefers low frequencies (100 MHz or under) for their penetrative ability, and wide bandwidth for acceptable range resolution. Under these requirements, conventional antennas would be prohibitively heavy for pico-satellite platforms, and the antenna would interfere with the sail. The new solar sail antenna concept addresses both these issues. Since the proposed sail is circular, a circular loop antenna is selected, with a wide active element to expand the bandwidth, and parasitic elements to maximise sail reflectivity. The feasibility of this concept is explored with simulation and experimental results.

Suitable orbits are explored that satisfy mission requirements for radar tomography. Active shape control of the sail greatly expands the available orbits. The expected quality and quantity of data is assessed against mission constraints such as power and stability. Propellant consumption is not a factor since the proposed method requires none.