IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (1) (3)

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MULTI-FACETED REFLECTIVITY CONTROL DEVICES: VECTORING SOLAR RADIATION PRESSURE FOR HIGH PRECISION FORMATION CONTROL

Abstract

Achievement and long-term maintenance of precise relative positions is key to most satellite formation flight missions, and remain the bottle-neck for many future concepts. For example, distributed microwave interferometry will require sub-millimetre precision, while distributed infrared and optical telescopes and interferometers can require sub-micrometre precisions. These precisions remain extremely challenging to current thruster-based solutions, with further challenges including limited mission lifetime with the consumption of finite propellant.

For many proposed missions including the examples above, solar radiation pressure (SRP) is the dominant source of differential force. The ability to control this force, therefore, will result in a new approach to formation control with unprecedented thrust precision. Reflectivity Control Devices (RCD) have been demonstrated on board the solar sail demonstrator IKAROS for solar sail attitude control. These devices, however, lack the capability to vector its force, i.e. they can control the SRP in a single degree of freedom. This is insufficient for three-dimensional relative position control.

In this work, the authors propose a modified reflectivity control device with the ability to produce SRP force controllable in three dimensions. The device subdivides conventional RCDs into pixels, each of which can be individually addressed, and is slanted by a unique angle. A satellite equipped with this device will be able to control both force and torque in total of six axes due to SRP. Since the output force of reflectivity control devices are much lower than that of thrusters, much higher thrust precision is expected, while being propellant free, leading to a significant improvement in mission lifetime.

This work explores the capabilities of the proposed device at formation maintenance under external perturbations. First, several configurations of the multi-faceted reflectivity control device are introduced. Then, the stand-alone performance is numerically estimated with raytracing methods. This process finds the device's coefficient of reflection, which is a controllable vector quantity. Then, the device placement is discussed. This discussion is mission-specific, as the satellite geometry, mass and orbit must be taken into account. The total force and torque are linear combinations of the contributions of individual devices, meaning that linear programming can be used for device placement optimization. To constrain the optimization, three representative mission scenarios are explored: geostationary formation flight for microwave interferometry; Sun-Earth L2 formation flight for infrared interferometry; and gravitational wave detection on Heliocentric orbits. Ephemeris-based propagation is used to include gravitational perturbations and assess the device performance.