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THREE DEGREE-OF-FREEDOM REFLECTIVITY CONTROL DEVICES FOR EXTREMELY 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 propellant consumption. For many proposed missions including the examples above, relative distances between satellites are negligible compared to their distances to gravitating bodies. In these conditions, solar radiation pressure (SRP) becomes the dominant source of differential force, thus controlling this force will result in a new approach to formation control with unprecedented thrust precision. Reflectivity control devices have been demonstrated on the solar sail demonstrator IKAROS, as well as in the upcoming OKEANOS solar power sail mission, where sail attitude has successfully been controlled. These devices, however, lack the capability to vector its force, i.e. they can control the SRP in a single degree of freedom only. 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. A satellite equipped with this device will be able to control both force and torque in total of six axes by 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 and reconfiguration in the presence of external perturbations. Key emphasis will be in the achievable formation precision. First, the thrust output of the proposed device is estimated by raytracing methods. This process describes the SRP force with a single vector coefficient analogous to the reflectivity coefficients, which can be controlled in orbit to alter the SRP force. Nonlinear programming is then used to optimize the placement of these devices to maximize the controllable SRP force. Since this optimization is orbit-specific, two representative mission scenarios are explored: geostationary formation flight for microwave interferometry; and Sun-Earth L2 formation flight for infrared interferometry. With suitable sensor models and feed-back controllers, the device performance is examined by numerical propagation, with ephemeris-based harmonics and third-body gravity as the sources of perturbation.