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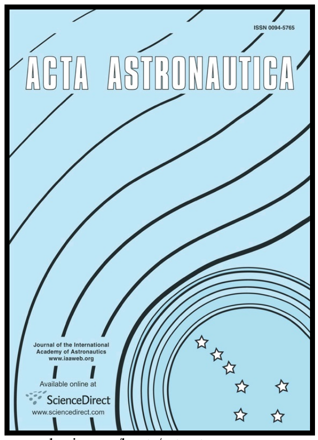

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A Satellite Formation Flying Approach Providing both Positioning and Tracking

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Abstract

A magnetic field approach is presented whereby a large number of closely located satellites can be positioned and oriented relative to each other, but can also be tracked in six degrees of freedom. This is accomplished by using frequency-multiplexed magnetic fields where coils are placed on each satellite to allow them to generate magnetic fields, to interact with the magnetic fields from other satellites, and to sample the surrounding magnetic fields. By doing this, a satellite can choose which alternating field to push or pull against, to provide torque about, or to sample in order to determine its location and orientation relative to the other satellites. Theory is provided demonstrating the capability of this approach along with its advantages and limitations. An experimental system allowing 3 degrees-of-freedom was constructed and used to demonstrate a feedback and control system where a satellite is told to move to a location and it does this by interacting with the surrounding satellites to both generate forces and torques and to track its position and orientation.

Keywords: Spacecraft formation flying, satellite swarms, satellite propulsion, satellite tracking, satellite positioning

1. INTRODUCTION

There is continued interest in developing close range satellite formation flying systems, or satellite swarms, as indicated by the demonstration of the Synchronized Position Hold, Engage, Reorient Experimental Satellites (SPHERES) project on the International Space Station [ISS] [1]. This system demonstrates an electromagnetic formation-flying concept developed over several years by MIT researchers [2, 3, 4, 5] where coils on satellites produce constant magnetic fields whose dipole moments can be controlled. By adjusting the direction of the dipole moments in a cluster of satellites the orientation and position of the satellites can be controlled within the formation. However, due to the limited number of degrees of freedom in this approach, adjusting one satellite requires that all of the other satellites in the formation be adjusted as well, leading to control difficulties [6]. One way to alleviate this complexity is to frequency multiplex the magnetic fields produced by the satellites; a technique we described in a previous paper [7]. Each coil on each satellite can generate an oscillating magnetic field at a unique frequency so that it can produce synchronous oscillations with whichever other satellite coil it needs to interact, allowing it to yield the appropriate force or torque to achieve a given formation. This decouples the formation problem allowing forces and torques to be directed as desired throughout the swarm.

However, a satellite formation requires more than the production of forces and torques, it also requires a tracking and global communications system whereby each satellite knows its position and orientation relative to the other satellites in the formation. SPHERES uses an ultrasonic transmission system to provide position and attitude information [8], which is possible because SPHERES is operated within the air-filled portion of the ISS, but of course this approach will not work in the vacuum of space. Space applicable, relative navigation technology development for precision formation flying is called out in the NASA Roadmap on Communication and Navigation Systems [9]. Technologies such as image processing and laser rangefinders are suggested as possibilities, but image processing may not provide the accuracy needed for many applications and laser rangefinders become complicated and expensive when applied to a swarm with a large number of satellites.

In this paper, we describe an alternative relative navigation approach that uses the induced voltage in coils attached to satellites to determine their relative position and orientation. A key advantage of this approach is that it utilizes the same coils used to generate forces and torques, thereby minimizing additional structure to the formation flying system. Also, significant redundant information is available, helping to ensure the reliability of this approach, but the key performance issue is whether the positional and angular resolution and accuracy that can be achieved with magnetic induction is sufficient. This will be discussed below. Then we will demonstrate a system where a mock-satellite, allowed to move in two dimensions and rotate about one axis, is located between four coils representing nearby satellites. In this system, forces and torques can be generated and the magnetic fields from the nearby satellites can be sampled to provide positional and angular information. The mock-satellite can be told to move to a given location and by using a feedback and control process, it determines how far it is from its goal and generates corresponding forces and torques to move to and then hold its position.

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