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KEYNOTE: PAOLO SANTINI'S MEMORIAL LECTURE - STRUCTURAL INERTIAL MORPHING: A NOVEL CONCEPT FOR DESIGNING NEXT-GENERATION AUTONOMOUS SPACECRAFT WITH ENHANCED ATTITUDE DYNAMICS CAPABILITIES

Abstract

The lecture reviews the author's contributions to the development of the Structural Inertial Morphing (IM) - an innovative spacecraft attitude control method, that leverages the deliberate alteration of the spacecraft's inertial properties to manage its motion. IM utilizes simple, low-energy mechanisms to manipulate the spacecraft's inertia.

The fundamental concept of IM involves adjusting the spacecraft's moments of inertia, for example, through "scissors"-type mechanisms that reposition the spacecraft's mass or by deploying appendages that change the inertia properties. These adjustments enable the spacecraft to transition between different motion patterns, such as from tumbling to a regular spin about required axis or from a slow to agile flipping, with minimal control effort. These IM systems can enable spacecraft to perform complex maneuvers, such as 90 and 180 inversions, detumbling, directional coning and agile acrobatic movements, all while using minimal control actions and power. Method is opening up a variety of movement possibilities that can be selected based on mission requirements. For instance, changes in the spacecraft's moments of inertia can directly influence pattern of motion and its period, allowing for tailored agile maneuvering depending on the task at hand.

A key feature of IM is its ability to achieve complex attitude changes with only a small, paltry number of discrete actions. This is done through a process where the non-dimensional angular momentum vector is manipulated by transferring it between different "separatrices" or "polhodes" in the spacecraft's body axes.

The advantages of IM are particularly significant for small and low-cost autonomous spacecraft. These systems can operate with low energy consumption and reduced complexity, making them suitable for long-duration missions where energy efficiency is crucial. Moreover, IM systems can enable spacecraft to perform various critical tasks, such as directional scanning, avoiding space debris by orienting the spacecraft's most vulnerable surfaces away from threats, or efficiently utilizing onboard equipment by optimizing the spacecraft's orientation. Recent studies have demonstrated the feasibility of IM for spacecraft design, showcasing how simple control actions can dramatically enhance directional efficiency. For example, by manipulating the spacecraft's moment of inertia, the directional exposure of various surfaces can be maximized, which is especially important for spacecraft facing potential collisions with space debris or operating in radiation environments.

IM presents a promising concept for spacecraft attitude control. Its ability to enable agile, acrobatic maneuvers with low energy consumption could revolutionize spacecraft design, offering a pathway to more efficient, autonomous, and adaptable space missions.