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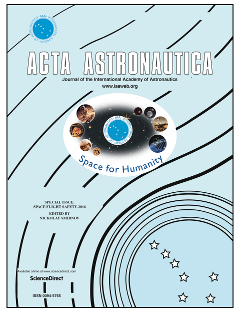

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A Low-complexity Attitude Control Method for Large-angle Agile Maneuvers of a Spacecraft with Control Moment Gyros[☆]

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Abstract

This study examines a low-complexity control method that satisfies mechanical constraints by using control moment gyros for an agile maneuver. The method is designed based on the fact that a simple rotation around an Euler's principal axis corresponds to a well-approximated solution of a time-optimal rest-to-rest maneuver. With respect to an agile large-angle maneuver using CMGs, it is suggested that there exists a coasting period in which all gimbal angles are constant, and a constant body angular velocity is almost along the Euler's principal axis. The gimbals are driven such that the coasting period is generated in the proposed method. This allows the problem to be converted into obtaining only a coasting time and gimbal angles such that their combination maximizes body angular velocity along the rotational axis of the maneuver. The effectiveness of the proposed method is demonstrated by using numerical simulations. The results indicate that the proposed method shortens the settling time by 20–70% when compared to that of a traditional feedback method. Additionally, a comparison with an existing path planning method shows that the proposed method achieves a low computational complexity (that is approximately 150 times faster) and a certain level of shortness in the settling time.

Keywords: Spacecraft, Attitude control, Agile maneuver, Control moment gyro

1. Introduction

Recently, micro satellites[1, 2] and spacecrafts[3] (weighing less than 100 kg) were launched and various space missions were conducted. Several missions, including the observation of transient objects and ground targets, require a spacecraft to rapidly reorient its attitude [1]. With respect to agility requirements, the single-gimbal control moment gyro (CMG) is considered as a promising actuator as it generates high torque.

Single-gimbal CMGs correspond to internal-torque actuators for spacecrafts and generate high torque when compared to reaction wheels. The principle of the mechanics of CMGs is as follows. A single-gimbal CMG consists of a wheel and a gimbal. The wheel rotates at a high speed in a spacecraft. The gimbal rotates the wheel around an axis that is orthogonal to the wheel's rotation axis. This results in a high gyro-torque for a CMG, and its reaction torque affects the spacecraft attitude. However, the output-torque direction of a CMG varies with its gimbal angle, and thus, the CMG system that consists of several CMGs generally experiences a singular state problem. That is, it cannot always generate torque about specific directions. Thus, studies were performed to analyze singularity[4, 5] and develop singularity-avoidance steering laws[6, 7, 8, 9, 10].

Several studies on agile attitude control using CMGs focused on feedforward control. For example, existing studies proposed an attitude trajectory planning method using an optimization theory[11], a method introducing the piecewise linear gimbal angular accelerations as design parameters[12, 13], and a low-complexity suboptimal control method based on insights obtained from time-optimal solutions[14]. However, the first two methods are time-consuming and the last method is unable to satisfy mechanical constraints (for example, gimbal angular accelerations) of CMGs. Hence, the development of a low computational complexity algorithm that can be calculated on an onboard computer improves spacecraft autonomy and enables advanced space missions. Additionally, if an algorithm can satisfy angular acceleration constraints, then this guarantees the tracking of the generated trajectory. This characteristic is especially significant for an agile maneuver in which gimbals are rapidly accelerated. Thus, this study examines a low-complexity control method that uses CMGs to satisfy mechanical constraints for an agile maneuver.

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