Singularity Avoidance/Passage Steering Logic for a Variable-speed Double-gimbal Control Moment Gyro Based on Inverse Kinematics

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Recently, many challenging missions using microsatellites have been conducted. Microsatellites are valuable in that they enable low-cost and short-term development. On the other hand, they impose low-volume requirements for all components. One solution is to employ a variable-speed double-gimbal control moment gyro (VSDGCMG) for an attitude control actuator. The actuator has 3 degrees of freedom because it is composed of a variable-speed wheel, an inner gimbal orthogonal to the wheel axis, and an outer gimbal orthogonal to the inner gimbal axis (Fig.1). Thus, a satellite can conduct three-axis attitude control using only one VSDGCMG. This reduces volume for attitude actuators compared with the use of traditional three reaction wheels.

Several studies about steering logic for a VSDGCMG have been conducted; however, there has been little study about avoiding singular states where it cannot generate torque to arbitrary direction. Two singular states exist when using a VSDGCMG. One is the state where wheel speed is zero and the other is where the wheel axis coincides with the outer gimbal axis. Tsukahara et.al. proposed a steering logic which can avoid (not trapped in the singular state) or pass (trapped in the singular state once and leave from it) the latter singular state [1]. The method automatically determines whether avoiding the singular state or passing it. If the approximate variation of the outer gimbal angle is larger (smaller) than a threshold, avoidance (passage) is conducted. Although their research is valuable in that it is the first study about the singular state of a VSDGCMG, there is still much room to be studied about it.

In this presentation, we propose a novel steering logic for a spacecraft using a VSDGCMG based on inverse kinematics. Inverse kinematics is to calculate wheel speed and gimbal angles from an angular momentum vector. Inverse kinematics of a VSDGCMG has two solutions with different gimbal angles. Selecting the solution close to the present gimbal angles is a nominal choice and can avoid the singular state. Outer gimbal rate extremely exceeding rate limitation is sometimes required to avoid it and that results in large attitude error. At the time, selecting the other solution is desirable because it can pass the singular state with low gimbal rate and reduce attitude error.

To decide the action near the singular state automatically, we define cost functions for avoidance and passage respectively. If the system is near the singular state and the cost function for the passage is smaller than that for the avoidance, passage is conducted and otherwise avoidance is conducted.

Using the proposed method, the VSDGCMG can generate accurate torque close to reference torque when avoiding the singular state. This is because the previous method inserts a correction term into the steering logic to avoid or pass the singular state and the proposed one not. In addition, the proposed method employs cost functions including gimbal angular rate limitation explicitly for the avoiding/passage decision. The decision is dependent on the gimbal angular rate limitation (if limitation does not exist, avoidance should be always selected) and therefore the proposed method can precisely decide the action.

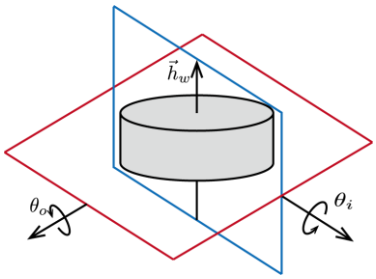

Fig. 1. VSDGCMG Configuration

References

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