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ESTIMATION OF ATTITUDE AND MODAL COORDINATES FOR SPACECRAFT ATTITUDE CONTROL WITH NON-COLLOCATED SENSORS AND ACTUATORS

Abstract

Attitude control of spacecrafts with flexible components is a critical field of spacecraft design and operation. Especially when non-collocated sensors and actuators are considered, attitude control of flexible spacecraft becomes a very challenging problem.

Comparing with the collocated case, attitude control of spacecraft with non-collocated sensors and actuators is more difficult, for the spacecraft dynamics model is now a non-minimum phase (NMP) system with unstable flexible mode interactions. Methods such as notch filter, non-minimum phase filter, linear-quadratic-gaussian method, and nonlinear direct adaptive control, etc. are proposed to such NMP systems. However, degradation of the control performance, and even divergence is still indispensable when severe model parameter uncertainty exists.

In an alternative perspective, forementioned difficulties is attributed to that the inputs of the proposed attitude controllers are attitude states that described under the sensor fixed reference frames. Consequently, controller inputs from the sensors and outputs to the actuators are non-collocated for flexible spacecrafts, which makes the non-collocated control problem inevitable.

This article presents an approach to the problem by designing a novel estimation scheme for the control process. Based on nonlinear Bayesian estimation theory, measurements under the sensor fixed reference frame are used to estimate both reference attitude states and flexible modal coordinates of the spacecraft. Since the reference attitude states are defined under the actuator fixed reference frame, input and output of the controller are collocated to the actuator fixed reference frame when using the reference attitude states as input to the attitude controller. Thereupon, collocated control methods can be applied, which leads to greater convenience in designing control systems with higher accuracy and robust level.

Observability is essential to feasibility and performance of the estimation scheme. First, observability of the estimated system states is verified by investigating observability matrix with Lie-derivative calculation. Second, quantitive degrees on observability of each estimated state are shown using the singular value method. According to the degrees, states with poor observability are eliminated to improve filter stability and to save computing cost.

With typical PID control and model adaptive control methods, the proposed estimation scheme is applied to numerical simulation of attitude control system of a large-scale spacecraft with non-collocated star tracker and control momentum gyros. With attitude estimation accuracy (1σ) on the level of 10 arcsec and 0.1 arcsec/sec, advantages of the proposed scheme including guaranteed accuracy, reduced fuel cost and improved control stability are demonstrated.