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Attitude-Orbit Coupled Fault-Tolerant Control for Flexible Spacecraft without Velocity Measurement

Ruichao Fan*, Jian Chen and Ming Liu

Research Center of Satellite Technology, Harbin Institute of Technology, Harbin 150001, P. R. China
*Corresponding author: ruichao_fan@163.com

Introduction

This paper proposes a velocity-free fault-tolerant attitude-orbit coupled controller for flexible spacecraft with disturbances, unknown velocity information, and actuator failures. In this design, an extended state observer is designed to estimate the velocity and actuator failures of the flexible spacecraft. By using the estimated velocity and fault value, a terminal sliding mode controller is developed to achieve finite-time attitude-orbit coupled tracking of the flexible spacecraft. The control scheme proposed in this paper can tolerate partial failure of the actuator and is robust enough to overcome the effects of external disturbances as well as the flexible vibrations.

Research Questions

High precision attitude and orbit control system is core of accomplishing complex space missions and has attracted extensive attention in the past few decades. Due to sensor limitations and measurement errors, velocity information may not be accurately measured in practical spacecraft systems. Another factor to be aware of when developing a controller is the health of the actuators. It is, therefore, of essential practical significance to design a velocity-free fault-tolerant control scheme that can provide attitude-orbit coupled tracking for flexible spacecraft.

Methodologies

In the case of actuator failures, the expression for the control input is as follows

$$\hat{T}_u = \hat{P}_u \odot \hat{T}_v + \hat{T}_f$$

Then the attitude-orbit coupled error kinematic and dynamic model of the flexible spacecraft can be obtained as follows.

$$\begin{cases} \dot{\hat{q}}_e = \frac{1}{2}\hat{\Xi}_e \cdot \hat{\omega}_e \\ \hat{J}^*\dot{\hat{\omega}}_e = -\hat{J}^*\left(\hat{Q}_e^* \circ \dot{\hat{\omega}}_d \circ \hat{Q}_e\right) + \hat{J}^*\hat{\delta}_1 + \hat{C}\cdot\left(\hat{T}_v + \hat{T}_g\right) \\ \ddot{\eta} + 2\xi\Lambda\dot{\eta} + \Lambda^2\eta + \left[\hat{B}\middle|\dot{\hat{\omega}}\right] = 0 \end{cases}$$

A finite-time ESO is constructed to estimate the velocity and the actuator failure of the spacecraft.

$$\begin{cases} \dot{\hat{z}}_1 = \frac{1}{2}\hat{\Xi}_e \cdot \hat{z}_2 - \hat{x}_{e1} \\ \dot{\hat{z}}_2 = \hat{z}_3 - \left(\hat{Q}_e^* \circ \dot{\hat{\omega}}_d \circ \hat{Q}_e\right) + \hat{J}^{*-1}\cdot\hat{C}\left(\hat{T}_u + \hat{T}_g\right) - \hat{x}_{e2} \\ \dot{\hat{z}}_3 = -\hat{\beta}_3 \odot \hat{x}_{e2} - \hat{\beta}_4 \odot \mathrm{sgn}\left(\hat{x}_{e2}\right) \end{cases}$$

Mathematical Formulas

On the basis of the ESO, a terminal sliding mode control law is developed as follows.

$$\hat{T}_v = \hat{f}\left[\hat{J}^*\left(\hat{Q}_e^* \circ \dot{\hat{\omega}}_d \circ \hat{Q}_e\right) - \hat{J}^*\hat{z}_3 - \alpha\hat{J}^*\left(\mathrm{diag}\left(\hat{\lambda}_i \odot \left|\hat{\Gamma}_{ei}\right|^{\alpha-1}\right)\odot\hat{Z}_{\Omega_e}\right)\right] - \hat{T}_g - \hat{f}\left[\left(\frac{d}{d\varepsilon}+\varepsilon\right)\left(\hat{k}\odot\hat{s} + \hat{\beta}\odot\mathrm{sgn}\left(\hat{s}\right)\right)\right]$$

With the application of the above controller, the flexible spacecraft system will converge to the desired state within finite time.

Figures

The simulation results under the attitude-orbit coupled fault-tolerant controller are shown in Figure 1-Figure 3.

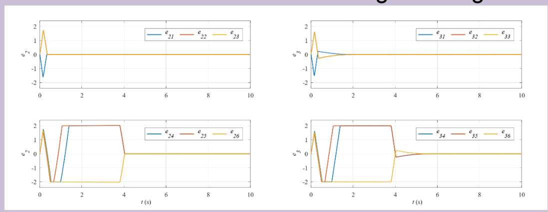

Figure 1. The observation errors

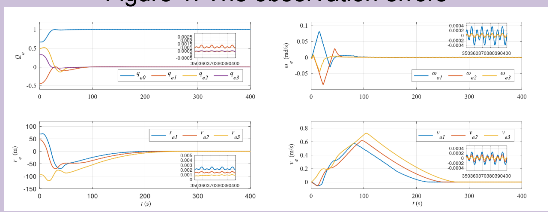

Figure 2. The motion state errors of spacecraft

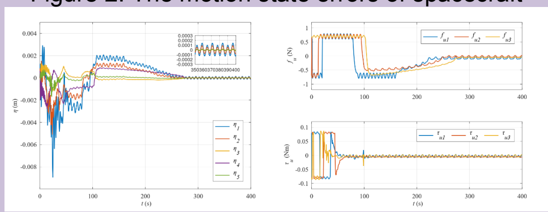

Figure 3. The flexible modal variable and control input

The simulation result verifies the effectiveness of the flexible spacecraft attitude-orbit coupled fault-tolerant controller based on the ESO designed in this paper.

Conclusion

This paper investigates the finite-time attitude-orbit coupled controller of flexible spacecraft without velocity information over faulty actuators. The performance of the numerical simulation has shown the effectiveness of the control scheme.