17th International Conference on Innovative Computing, Information and Control (ICICIC2023)
Kumamoto, Japan, August 29-31, 2023

Paper ID: ICICIC2023-SS31-03

Event-Triggered Based Fractional-Order Sliding Mode Control of Flexible Spacecraft Formation

Fan Wu, Jiao Wu* and Ming Liu

Research Center of Satellite Technology, Harbin Institute of Technology, Harbin 150001, P. R. China
*Corresponding author: wn941030@163.com

Introduction

This paper employs the fractional-order sliding mode control law and the event-triggered transmission mechanism to address the attitude coordination for spacecraft formation in the presence of unknown disturbances flexible vibration, and communication constraints. The developed control strategy has a fast convergence rate and low steady-state error compared with the conventional sliding-mode control method. A simulation is carried out to demonstrate the validity of the proposed coordinated attitude control method.

Research Questions

The spacecraft formation flying (SFF) system has the advantages of low cost, high flexibility, and strong reliability. Formation systems are non-linear and exposed to disturbances such as orbital perturbations and random disturbances. As a result, it is difficult to obtain satisfactory formation control performance by applying linear control methods, and non-linear control methods such as fuzzy control or sliding mode control have received substantial attention. In particular, fractional-order sliding mode (FOSM) control has become the frontier of sliding mode control recently due to its advantages of fast response, robustness, and high design freedom. As the scale of the spacecraft formation increases, insufficient communication bandwidth is more likely to occur. Note that the event-triggered transmission mechanism (ETM) is one of the most effective methods for reducing communication burden. Inspired by the above studies, to address the attitude coordination of SFF, this paper studies FOSM-based attitude coordinated control methods under ETS.

Methodologies

The modified Rodriguez parameters are used to describe the attitude motion of a flexible spacecraft

$$\dot{\boldsymbol{q}}_{ei} = \frac{1}{2}\left(\boldsymbol{q}_{ei}^{\times} + q_{0i}\boldsymbol{I}_3\right)\boldsymbol{\omega}_{ei}$$

$$\boldsymbol{J}_i\dot{\boldsymbol{\omega}}_{ei} = -\boldsymbol{\omega}_i \times \boldsymbol{J}_i\boldsymbol{\omega}_i - \boldsymbol{J}_i\boldsymbol{C}_{ei}\dot{\boldsymbol{\omega}}_{di} + \boldsymbol{J}_i\boldsymbol{\omega}_{ei}^{\times}\boldsymbol{C}_{ei}\boldsymbol{\omega}_{di} + \boldsymbol{\tau}_{ui} + \boldsymbol{\tau}_{di} - \boldsymbol{\delta}_i\ddot{\boldsymbol{\eta}}_i$$

$$\ddot{\boldsymbol{\eta}}_i + 2\xi_i\boldsymbol{\Lambda}_i\dot{\boldsymbol{\eta}}_i + \boldsymbol{\Lambda}_i^2\boldsymbol{\eta}_i + \boldsymbol{\delta}_i^{\mathrm{T}}\dot{\boldsymbol{\omega}}_i = 0$$

The fractional-order sliding mode variable is

$$\boldsymbol{s}_i = \lambda\boldsymbol{q}_{ei} + \mathrm{D}^{\alpha}\boldsymbol{q}_{ei} + \dot{\boldsymbol{q}}_{ei},$$

$$\mathrm{D}^{\alpha}\boldsymbol{q}_{ei} = \frac{1}{\Gamma(m-a)}\int_{t_0}^{t}\frac{\left(\frac{\mathrm{d}}{\mathrm{d}u}\right)^m\boldsymbol{q}_{ei}(u)}{(t-u)^{\alpha-m+1}}\mathrm{d}u$$

The event-triggered mechanism is designed as

$$t_{k_i+1}^{i} = \min\{t \,|\, t > t_{k_i}^{i}, \left\|\boldsymbol{s}_i(t_{k_i}^{i}) - \boldsymbol{s}_i(t)\right\| \cdot \left\|\sum_{j\neq i} a_{ij}\left(\boldsymbol{s}_i(t_{k_i}^{i}) - \boldsymbol{s}_j(t_{k_j}^{j})\right)\right\| \geq \frac{\alpha}{2}\sum_{j\neq i} a_{ij}\left\|\boldsymbol{s}_i(t_{k_i}^{i}) - \boldsymbol{s}_j(t_{k_j}^{j})\right\|^2\}$$

Mathematical Formula

Based on the above methodologies, the event-based fractional-order sliding-mode coordinated control law is designed as

$$\begin{aligned}\boldsymbol{\tau}_{ui} = &-2\boldsymbol{J}_i\left(\boldsymbol{q}_{ei}^{\times} + q_{0i}\boldsymbol{I}_3\right)^{-1}\left(\mathrm{D}^{\alpha+1}\boldsymbol{q}_{ei} + k_1\boldsymbol{s}_i + k_2\,\mathrm{sgn}\,\boldsymbol{s}_i + \sum_{j\neq i} a_{ij}\left(\boldsymbol{s}_i(t_{k_i}^{i}) - \boldsymbol{s}_j(t_{k_j}^{j})\right)\right)\\ &-\lambda\boldsymbol{J}_i\boldsymbol{\omega}_{ei} + \boldsymbol{\omega}_i \times \boldsymbol{J}_i\boldsymbol{\omega}_i + \boldsymbol{J}_i\boldsymbol{C}_{ei}\dot{\boldsymbol{\omega}}_{di} - \boldsymbol{J}_i\boldsymbol{\omega}_{ei}^{\times}\boldsymbol{C}_{ei}\boldsymbol{\omega}_{di} + \boldsymbol{\delta}_i\ddot{\boldsymbol{\eta}}_i\\ &+\frac{1}{2}\boldsymbol{J}_i\left(\boldsymbol{q}_{ei}^{\times} + q_{0i}\boldsymbol{I}_3\right)^{-1}\left(\boldsymbol{\omega}_{ei}^{\times}\boldsymbol{q}_{ei}^{\times}\boldsymbol{\omega}_{ei} + \boldsymbol{q}_{ei}^{\mathrm{T}}\boldsymbol{\omega}_{ei}\boldsymbol{\omega}_{ei}\right)\end{aligned}$$

Figure

A simulation of spacecraft formation (three flexible spacecraft) attitude coordination is carried out to verify the validity of the proposed method.

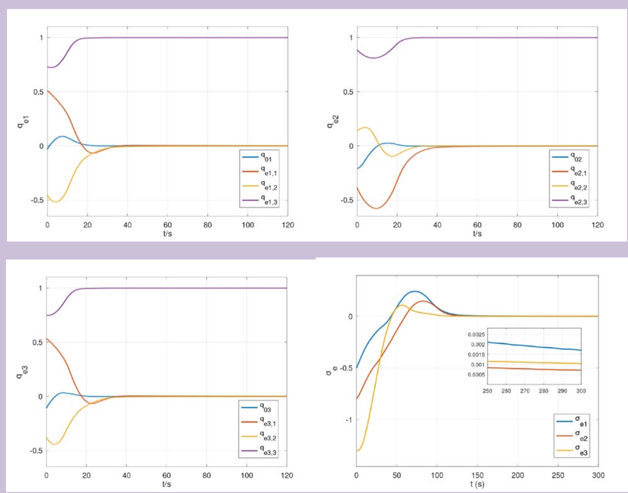

Figure 1. Attitude errors for three spacecraft

Figure 1 shows the attitude error quaternions and error MRPs of three spacecraft. It shows that the attitude coordination of the spacecraft formation flying system achieved at about 260s.

Conclusion

It can be concluded that, for spacecraft formation in the presence of unknown disturbances flexible vibration, and communication constraints, attitude coordination can be achieved with the proposed controller in this paper.