Performance Study of Sliding Mode Attitude Controllers for Low Earth Orbit CubeSat

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ABSTRACT

This paper pertains to the design of attitude control system actuated with reaction wheels for low Earth orbit CubeSat. The control system is implemented based on sliding mode approach, in which two control modes are proposed: sign mode and smooth mode. The smooth function is utilized to reject chattering effect and prevent torque saturation for reaction wheels. An evaluation study has been conducted to see, if the investigated control modes provide a benefit in performance and convergence behavior under the presence of external disturbances.

Keywords: CubeSat, Sliding mode control, Reaction wheel

1 Introduction

Cube-Satellites (CubeSats) are a category of research spacecraft called nanosatellites that are often utilized for low Earth orbit applications. Many CubeSats missions have been designed recently for technological demonstration, astronomical research, or aerospace education projects [1]. The mission requirements and system restrictions must be considered when using attitude control systems for small satellites.

Concurrently, many control approaches have been implemented to stabilize the attitude of rigid body, such as Quadrotor and spacecrafts, one of them is Sliding Mode Control [2], [3], which is a nonlinear control method that is developed to effectively account for parameter uncertainty and the presence of unmodeled dynamics. However, standard sliding mode controller might cause high-frequency oscillations in the input command signal leading to severe consequences. This phenomenon, known as chattering, is a well-known issue that can occur in sliding mode control. Thus, this problem can be solved by applying an approximated smoother function in the standard sliding mode control rule.

In this paper the possibility of using a sliding mode control approach is examined in order to stabilize a 3U CubeSat, with a specific focus on the elimination of the chattering effect. The attitude controller presented in this study is implemented based on sign and smooth modes. A performance analysis is conducted to determine whether it can effectively eliminate the chattering effect and stabilize a 3U CubeSat attitude.

2 Mathematical Dynamic Model

The attitude dynamic equations of a CubeSat can in general be expressed in the following form [4].

$$I_s\,\dot{\omega} = -\,\omega \times I_s\omega + u_c + u_d \tag{1}$$

and

$$\begin{cases} \dot{q}_0 = -\frac{1}{2} q_v^T \omega^o \\ \dot{q}_v = \frac{1}{2}(q_0 I_{3\times3} + q_v^{\times})\omega^o \end{cases} \tag{2}$$

with

$$\omega^o = \omega + A(q)\Omega_0 \tag{3}$$

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where I_s is the satellite inertia matrix, $\omega = [\omega_x, \omega_y, \omega_z]^T$ is the angular velocity of the satellite, u_c is the control torque, u_d is the total disturbance torque, ω^o is the orbital angular rate of the satellite, Ω_0 is the orbit rate vector, $A(q)$ is the attitude transformation matrix and $q_v^\times$ is the skew-symmetric matrix of q_v .

3 Sliding Mode Controller for Attitude Control

In this work, sliding mode controller based on two different modes is developed to select the suitable one for controlling the attitude of the CubeSat. The general sliding mode control law is designed as

$$u_c = \omega \times I_s\omega - I_s\dot{A}(q)\Omega_0 - I_s\rho\dot{q}_{ve} - u_d + \begin{cases} -k_{sgn}sgn(s) \\ \\ -k_{sth}sth(s) \end{cases} \tag{4}$$

such that

$$s = \omega^o + \rho\, q_{ve} \tag{5}$$

where s is the sliding mode surface, q_{ve} is the three components vector error, sgn and sth denote the sign and smooth functions, respectively, ρ, k_{sign} and k_{sth} are positive constant gains.

4 Simulation and Results

Figure 1 presents the obtained time responses of Euler angle control errors for sign and smooth sliding mode controllers. The designed controller successfully converges to the required attitude using the two suggested modes. Applying the smooth function in the control rule reduces the chattering effect and allows the system to achieve the desired reference attitude accurately with a lower energy consumption.

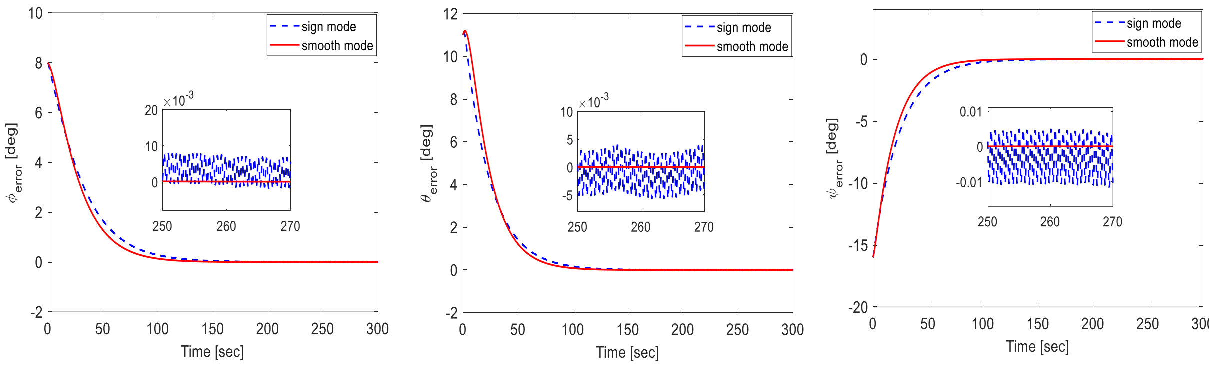

Figure 1: *Response curves comparison for Euler angle control errors.*

5 Conclusion

In this paper, a sliding mode control approach has been implemented based on sign and smooth modes for addressing the rigid CubeSat attitude control problem. The simulation results show that when the smooth function is adopted, the output of the system exhibits a considerable reduction in chattering effect leading to the good stability performance with respect to the attitude control accuracy.

How to Cite

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References

[1] J. Bouwmeester and J. Guo, "Survey of worldwide pico-and nanosatellite missions, distributions and subsystem technology," Acta Astronautica, vol. 67, pp. 854-862, 2010.

[2] H. Bang, C.-K. Ha, and J. H. Kim, "Flexible spacecraft attitude maneuver by application of sliding mode control," Acta Astronautica, vol. 57, pp. 841-850, 2005.

[3] B. Nasri, A. Guessoum, A. Adnane, and L. Mostefai, "Fault Tolerant Attitude Estimation Strategy for a Quadrotor UAV under Total Sensor Failure," Control Engineering and Applied Informatics, vol. 25, pp. 79-89, 2023.

[4] A. Adnane, A. Bellar, M. A. S. Mohammed, J. Hong, and Z. A. Foitih, "Adaptive Attitude Controller Design for a Rigid Satellite with Feedback Linearization Approach," The Journal of the Astronautical Sciences, vol. 67, pp. 1445-1469, 2020.

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