Design and on-orbit test of RBF network friction compensation sliding mode control algorithm for Luojia1-01 satellite attitude

Zhi Qu$^{1,2,3}$, Kai Xu$^{1,2,3,*}$, Xin He$^{1,2}$, Zhigang Chen$^3$, Feng Li$^3$, Mengmeng Liu$^3$, Yanhao Xie$^3$

$^1$Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China
$^2$University of Chinese Academy of Sciences, Beijing 100049, China
$^3$Chang Guang Satellite Technology CO, LTD, Key Laboratory of Satellite Remote Sensing Application Technology of Jilin Province, Changchun 130000, China

Abstract. Aiming at the attitude maneuver mode of Luojia1-01 satellite attitude control system, this paper designs an RBF network friction compensation sliding mode control (SMC) algorithm. Firstly, the satellite attitude motion model is derived according to the needs of the imaging working mode. Secondly, a fast Terminal sliding mode control law is designed based on the tracking error motion model described by the error quaternion. Considering the suppression of disturbance, an extended state observer (ESO) is introduced to observe the total disturbance of the system. Then, the RBF network friction compensation system is used to approximate the switching term on line and further reduce the vibration, thereby reducing the switching gain in the sliding mode control law. The simulation results of RBF adaptive control algorithm and RBF network friction compensation sliding mode control algorithm are carried out to prove the perfect effect of the proposed algorithm. Finally, the on-orbit test and summary of Luojia1-01 satellite attitude control system are carried out. The results show that the attitude pointing accuracy is better than 0.02°, the attitude control stability is better than 0.005°/s, and the accuracy of control moment is 0.01mNm. This method satisfies the overall requirements of Luojia1-01 satellite’s working mode.

1. Introduction
On June 2, 2018, Luojia1-01 satellite developed by Wuhan University and Chang Guang Satellite Technology Co., Ltd. (Changchun, China) was successfully launched at the Jiuquan Satellite Launch Center [1]. Luojia1-01 satellite is the first scientific experimental satellite used in nighttime imaging in China. The satellite carries a large field of view high-sensitivity night-light remote sensing camera, as shown in Fig 1, which can provide special products such as China’s and global GDP index, carbon emission index, and urban housing vacancy rate index. At the same time, it has a variety of working modes: push-broom mode, staring-imaging mode, digital transmission mode, inertial space imaging mode, navigation enhancement mode, navigation data down-linking mode. This requires Luojia1-01 satellite attitude control system to have fast maneuverability, high attitude pointing accuracy and attitude stability. Luojia1-01 satellite is a strongly coupled, strongly nonlinear dynamic system with parameter/model uncertainty, and it will be affected by time-varying unknown disturbances or even actuator installation deviations, faults, etc. during orbital operation. These have a significant impact on
the accuracy, stability and reliability of their attitude control systems. Sliding mode control variable structure control has unique advantages in dealing with external disturbances and uncertainties. Sliding mode control theory is widely used in spacecraft attitude control [2,3].

In Reference [4], the author proposed a minimum sliding mode error feedback control strategy based on sliding mode control theory for the attitude control problem of small satellites. The real-time optimal estimation of the equivalent control error is fed back to the sliding mode. The controller makes it better to compensate for the effects of interference and uncertainty in the system, significantly improving the dynamic and steady-state performance of the system. In Reference [5], the author combined adaptive sliding mode control with active vibration control of flexible accessories to design a flexible spacecraft attitude controller to achieve high-precision attitude control while suppressing accessory vibration. In Reference [6], the author discussed the attitude tracking problem of rigid spacecraft in the presence of external disturbances, uses adaptive control algorithm to estimate the interference, and designs the sliding mode controller to ensure the system is asymptotically stable. In Reference [7], the author proposed an adaptive sliding mode control algorithm based on RBF network for the nonlinear problem in the attitude control system of flexible satellites. The neural network makes the uncertainty factors in the modeling process. It is estimated that the neural network parameters are adjusted online by the adaptive law, and the high-performance control of the satellite attitude is realized. In Reference [8], the author used neural network to realize online estimation of nonlinear part, uncertain part and unknown external disturbance of linear system, and realizes equivalent control based on neural network, which effectively eliminates chattering. In Reference [9], the author designed a sliding mode controller based on RBF neural network. The controller is completely realized by continuous RBF function, which cancels the switching term and eliminates chattering. In Reference [10], the author combined BP network learning algorithm with sliding mode control to form a new closed-loop control system, and used the online learning function of BP network to propose a new sliding mode-neural network controller to realize the induction. Adaptive sliding mode control of the motor.

At present, many RBF neural network control results for nonlinear systems have been published. This method is rarely applied in the engineering of attitude stabilization control of agile satellites, and there is no on-orbit experiment. Therefore, our team design an RBF network friction compensation sliding mode attitude control algorithm for the working modes of Luojia1-01 satellite attitude control system: attitude maneuver and staring-imaging working mode. A fast Terminal sliding mode control law is designed based on the tracking error motion model described by the error quaternion. An extended state observer is introduced to observe the total disturbance of the system, reduce the switching gain in the sliding mode control law, and weaken the system chattering. The RBF network friction compensation adaptive system is used to approximate the switching term on line and further reduce the vibration.
2. The kinematics modeling and control theory basis of Luojia1-01 satellite

The kinematics equation of the satellite described by the attitude quaternion \( q \):

\[
\dot{q} = \frac{1}{2} \Omega(\omega)q = \frac{1}{2} A(q) \omega = \frac{1}{2} \left[ -q^T \omega I_{3 \times 3} - q \right]
\]

(1)

In Equation (1), where \( q \) is the attitude quaternion, \( \omega = \) the scalar of the attitude quaternion, and \( \Omega \) is the vector of the attitude quaternion transformation. \( \omega \) is the attitude angular velocity vector of the satellite relative to the inertial coordinate system; \( \ddot{q} \) is the cross-multiplication operation of the vector \( \dot{q} \).

According to the momentum moment theorem, the attitude dynamics equation of a flexible satellite is given as

\[
\begin{align*}
J \ddot{\omega} + \delta \ddot{\eta} &= - \omega^T (J \omega + \delta \eta) + u + T_d \\
\dot{\eta} + C \dot{\eta} + K \eta &= - \dot{\omega} \dot{\omega}
\end{align*}
\]

(2)

In Equation (2), where \( J \in \mathbb{R}^{3 \times 3} \) is the moment of inertia matrix of the satellite's overall positive symmetry; \( \eta \in \mathbb{R}^{3 \times 3} \) is the modal coordinate of the flexible structure; \( \delta \in \mathbb{R}^{3 \times 1} \) is the coupling array of the satellite rigid body attachment; \( u \in \mathbb{R}^{3 \times 1} \) is the control torque applied on the three axes of the satellite body; \( C = \text{diag} \{ 2 \varepsilon \omega_i, i = 1, 2, 3, 4 \} \) is a damping matrix; \( K = \text{diag} \{ \omega_{\text{e}_i}, i = 1, 2, 3, 4 \} \) is a stiffness matrix; \( \omega_{\text{e}} \) is the flexible mode vibration frequency of the solar array; \( \varepsilon \) is the flexible mode vibration damping ratio of the solar array; \( T_e \in \mathbb{R}^{3 \times 1} \) is the space environment disturbance torque. The space environment disturbance torque mainly includes: Solar radiation pressure interference torque, gravity gradient interfering torque, driving torque of solar cell array, the torque generated by the rotating parts of the payload, the torque generated by the installation error of the flywheel and the magnetic torque device, and the friction torque that cannot be accurately model.

Let the expected target quaternion be \( q_0 = \left[ q_{00}, \ddot{q}_{e} \right]^T \), the attitude tracking error of the satellite ontology coordinate system relative to the expected target coordinate system is \( \dot{q}_e = \left[ 0, \ddot{q}_{e} \right]^T \), Luojia1-01 Satellite’s motion equation that based on the error quaternion can be described as

\[
\dot{q}_e = \frac{1}{2} \left[ -q_0^T \dot{\omega}_a + \ddot{\eta}_e \right] \omega_a
\]

(3)

In Equation (3), where \( \omega_a = \omega - A_{\omega}^\#(q_a) \omega_b \) is an angular velocity deviation; \( \omega_b \) is a desired target angular velocity. \( A_{\omega}^\# \) is a coordinate transformation matrix.

Since the whole moment of inertia of Luojia1-01 Satellite is \( J \in \mathbb{R}^{3 \times 3} \); \( J_r \) is the rotational inertia array of the satellite body, \( J_e \) is the rotational inertia array of the flywheel, \( \Omega \) is the rotational angular velocity relative to the main body, and \( A \) is the flywheel mounting matrix. The relationship is as follows:

\[
J = J_r + AJ_r A^T
\]

(4)

The control torque of a single reaction wheel is:

\[
a = J_\omega (\Omega + A \dot{\omega})
\]

(5)

The control torque provided by the flywheel is:

\[
u = A a
\]

(6)

The relative motion equation (7) of Luojia1-01 satellite is obtained by equation (2)(4)(5).

\[
J_r \dot{\omega}_a + \delta \ddot{\eta} = - \omega^T (J_\omega + AJ_\omega \Omega) + u + T_d + J_r (\omega_a^\# A_{\omega}^\# (q_a) \omega_b - A_{\omega}^\# (q_a) \dot{\omega}_b)
\]

(7)
3. Design of RBF network friction compensation sliding mode attitude controller

In ordinary sliding mode control, a linear sliding plane is usually selected, so that after the system reaches the sliding surface, the tracking error gradually converges to 0, and the progressive convergence speed can be achieved by adjusting the sliding surface parameters, but the effect is not good [11]. Therefore, Luoji1-01 Satellite attitude control system selects the fast terminal sliding mode control strategy. In this study, we choose $x1 = q$, $x2 = \omega$, and the sliding surface is selected as

$$ s = \dot{q} + \alpha \dot{q}^{\prime \prime} + \beta \dot{q}^{\prime} $$

(8)

Where $p$, $q$, $h$, $h$ is positive odd number.

Then the satellite attitude tracking error dynamics equation can be expressed as

$$
\begin{align*}
\dot{x1} &= \frac{1}{2}A(q_1)\omega_5 + \frac{1}{2}A(q_1)x2 \\
\dot{x2} &= J^{-1}_{s}\left[-\omega^T(J\omega + AJ_\omega \Omega) - \delta^T \hat{\eta} + u + T_d + J_s(\omega^T A_y^b(q_4) \omega_5 - A_y^b(q_4) \omega_6 - \delta^T \dot{\eta})\right]
\end{align*}
$$

(9)

The sliding mode control law can be designed as

$$ u = u_q + u_k $$

(10)

Where $u_q$ is the equivalent control when $s = 0$, and $u_k$ is the switching control.

When $s = 0$, then

$$ u_q = -J^{-1}_{s} \frac{q}{2bp} A(q_4) \omega_5^{\prime} \left( I + \frac{ag}{h} q_5^{\prime} \right) + \omega^T(J\omega + AJ_\omega \Omega) - J_{s}^{-1}(\omega^T A_y^b(q_4) \omega_5 - A_y^b(q_4) \omega_6 - \delta^T \dot{\eta}) $$

(11)

At the same time, take: $u_k = -B \text{sgn}(s) - ks$, where: $B = \text{diag}(B1, B2, B3)$.

To prove that $s^T \dot{s} < 0$, select the Lyapunov function:

$$ V = \frac{1}{2} s^T s $$

(12)

Deriving the time $t$ and bringing the control law into:

$$ \dot{V} = \frac{bp}{q} s^T \omega^T J_{s}^{-1}(J_s (\dot{\Omega} - \delta^T \dot{\eta}) - B \text{sgn}(s) - ks) $$

(13)

Assumption 1: In the attitude dynamics equation (13), the time-varying external disturbance $\dot{T}_d$ is bounded and satisfies $\|\dot{T}_d\| \leq b_0$, $b_0 > 0$.

Assumption 2: In the attitude dynamics equation (4), the 2-norm of the coupling effect term $-\delta^T \dot{\eta}$ satisfies the inequality $\|\delta^T \dot{\eta}\| \leq b_1 + b_2 \|\dot{\eta}\|^2$, where $b_1 > 0$, $b_2 > 0$.

Definition $\phi = 1 + \|\dot{\eta}\|^2$, $\|T_d\| + \|\delta^T \dot{\eta}\| \leq b_0 + b_1 + b_2 \|\dot{\eta}\|^2 \leq \rho \phi$ can be obtained from assumption 1 and assumption 2, where $\rho = \max(b_0 + b_1, b_2)$.

The disturbance moments received by the orbiting spacecraft mainly include gravity gradient moments, solar radiation moments, aerodynamic moments, and geomagnetic moments. Although they have time-varying characteristics, they are bounded.

$$ V = \frac{bp}{q} s^T \omega^T J_{s}^{-1}(J_s(\rho \phi) - B \text{sgn}(s) - ks) $$

(14)

If $B > |J_s \rho \phi |$, then $s^T \dot{s} < 0$ is satisfied. However, $B$ determines the size of the vibration of the sliding mode control, so it will affect the stability of the satellite.
3.1. Formatting the title Second-order ESO design

The switching gain in the control law is affected by the parameter perturbation and unknown disturbance, so the control precision is reduced. The sliding mode controller is introduced into the extended observer (ESO), and the high gain error feedback makes the dynamic response of the observer much higher than the dynamic response of the system, which is equivalent to the fast-changing subsystem in the system, which can ensure that the observation error of fast convergence and high enough estimation precision, thus providing angular velocity signal available for feedback.

The state variable \( x = \omega_x + K\eta \) taken by ESO derives the state variable: \( \dot{x} = \omega_x + K\eta \), then bring (9) into:

\[
\dot{x} = J^{-1} \left[ -\omega^T (J\omega + AJ\omega) + u + (\hat{\eta} - \delta^T \eta^\prime) \right] + (\omega^T A^b(q_o)\omega_b - A^b(q_o)\dot{\omega}_b)
\]

Then the expansion equation of Luojia-01 Satellite dynamic system is:

\[
\begin{align*}
\dot{x} & = ax + bu + f(t) \\
y & = cx
\end{align*}
\]

In Equation (16):

\[
f(t) = J^{-1} \left[ -\omega^T (J\omega + AJ\omega) + \rho \dot{\phi} \right] + (\omega^T A^b(q_o)\omega_b - A^b(q_o)\dot{\omega}_b)
\]

The expansion observer is designed to:

\[
\begin{align*}
\dot{\hat{x}1} & = \dot{x}2 + \alpha1 / \epsilon(y - \hat{x}1) \\
\dot{x}2 & = bu + \alpha2 / \epsilon^2(y - \hat{x}1)
\end{align*}
\]

In Equation (17), where \( \hat{x}1 \) and \( \hat{x}2 \) are the observer state, \( \alpha1 \) and \( \alpha2 \) are positive real numbers. Then the observer output \( \hat{x}2 \) is close to \( x \) and \( \hat{x}1 \) is close to \( \rho \dot{\phi} \).

The ESO observation \( \hat{x}1 \) is compensated into the control law, and the control law is designed as follows:

\[
u = -J^{-1} q A(q_o)\alpha^T \left( I + \frac{ag}{h} q^2 \right) + \omega^T (J\omega + AJ\omega) - J^{-1} \dot{\hat{x}}1 - B \text{sgn}(s) - ks
\]

3.2. RBF network friction compensation system

Sliding mode control combined with RBF neural network approximation is used in Luojia-01 Satellite attitude control system. The RBF network friction compensation model is used to realize the adaptive approximation of the unknown part, which can effectively reduce the fuzzy gain. The friction compensation system of RBF network is derived by Lyapunov method, and the stability and convergence of the whole closed-loop system are guaranteed by the adjustment of adaptive weights.

The RBF network friction compensation system introduced in this paper approximates the symbol function term, and its input plane is \( s \), and the output symbol term estimated value \( u_f = \Gamma \delta(x) \), then the RBF network input algorithm is given as

\[
h_j = \exp \left( \frac{x - c_j}{2\delta_j} \right)
\]

\[
\delta = W^T h(x) + \epsilon
\]
$\dot{\delta}$ is the network output; $\hat{W}$ is the estimated weight of the neural network. Then the network output is:

$$\delta = \hat{W}^T h$$

The control law is designed as

$$u = -J^T \frac{q}{2 hp} A(q_e) \omega_e^T \left( I + \frac{ag}{J} A_e \omega_e^T \hat{W}^T \right) + \omega^T (J \omega + AJ \omega) - J^T$$

(21)

The Lyapunov function can be used to derive the adaptive law of adaptive adjustment parameters, and the Lyapunov function can be established as

$$L = \frac{1}{2} s^2 + \frac{1}{2} \gamma \hat{W}^T \hat{W}$$

(22)

$$\dot{V} = s \dot{s} + \gamma \hat{W}^T \dot{\hat{W}} = -\eta |s| + s dt - sbe + \hat{W}^T (sbh + \gamma \dot{\hat{W}})$$

(23)

Take the adaptive law as

$$\dot{\hat{W}} = \frac{1}{\gamma} s J^T h$$

(24)

Then $\dot{V} = -\eta |s| + s(dt - be) \leq 0$.

Take $\dot{V} = 0$, then $s = 0$, according to the LaSalle invariant set theorem, when $t \to \infty$, $s \to 0$.

4. Numerical simulation of attitude control system

In order to verify the effectiveness of the control algorithm proposed in this paper, numerical simulation verification is carried out. Relevant parameters are shown in Table 1.

Table 1. Parameters for simulation

| Parameters                        | Values       |
|-----------------------------------|--------------|
| Satellite mass $M$ / kg           | 20.873       |
| Earth radius / km                 | 6378         |
| Gain for quaternion normalization | 1.0          |
| Angular velocity of the earth's rotation $(rad/s^{-1})$ | $7.292115 \times 10^{-5}$ |
| $dt$ / s                          | 0.0125       |
| $\delta$                          |              |
| $\omega_0$ / $(rad / s)$          | [0.45637 0.27841 0.15629; -0.25619 0.91756 -0.67264; 0.11687 0.48901 -0.83674; 0.23637 -0.6581 -0.12503] |
| $J$ / $(kg \cdot m^2)$            | [0.31838 0.014595 0.025140; 0.014595 0.869047 0.004149; 0.025140 0.004149 0.891924] |
| $J_a$ / $(kg \cdot m^2)$          | diag (0.45, 0.55, 0.45) |
| $J_m$ / $(kg \cdot m^2)$          | diag (0.1, 0.1, 0.1, 0.1) |

The maximum output of the flywheel control is 2mNm; the control output is -0mNm between -0.1mNm and 0.1mNm; the control delay is 0.5s; the whole star uses a control period of 0.5s. We make the simulation for the different mission modes of Luoji1-01 satellite. For the two imaging task modes of Luoji1-01 satellite, the RBF network friction compensation sliding mode attitude controller designed with the extended state observer is simulated and verified. The specific parameters of controller and expansion observer are shown as the following Table 2.
Table 2. Parameters of controller and expansion observer

| Parameters | Values          |
|------------|-----------------|
| $\alpha, \beta, p, q$ | 6.27, 3.33, 8.65, 3.33 |
| $a, b, c$   | 1.11, 0.78, 0.66 |
| $\alpha_1, \alpha_2$ | 1, 0.6         |
| $k, e, \gamma$ | 1, 0.03, 7.88   |

4.1. Theoretical simulation of attitude maneuver mode

For the attitude maneuver mode, the initial attitude angle in the simulation is $0^\circ$. When the ground speed is maneuvered, the target values can be showed $x$-axis maneuver to $172.5^\circ$, $z$-axis maneuver to $52.5^\circ$, and $y$-axis constant speed $0.63^\circ/s$ push-broom. The initial attitude angle of the satellite is set to [0 0 0]. The theoretical simulation and the deflection simulation are carried out. The RBF friction compensation sliding mode control algorithm is introduced into the simulation model, and the two sets of simulation results are compared. At the initial attitude angle and angular velocity, the simulation analysis of the attitude maneuver mode without the depolarization is performed without considering the measurement error of the measuring component and the influence of the mounting matrix error.
It can be seen from the angle of the inertial system that since the selected flywheel angular momentum is large enough, it can provide an angular velocity of 1°/s, and the maneuvering time is about 130 s. It can be seen from Fig 2 (c)(d)(e) that the system pointing accuracy is better than 0.1°, the attitude control stability is better than 0.001°/s, and the accuracy of control moment is 0.01mNm.

4.2. Pull-off simulation of attitude maneuvering mode based on RBF network friction compensation sliding mode control

In order to realistically simulate the actual on-orbit state of the satellite, the influence of the installation and measurement error of the measuring components such as the gyro and the star sensor on the system control accuracy and stability is further considered in the system simulation stage. The RBF network friction compensation term is introduced for the sliding mode controller to further approximate the switching gain. RBF friction compensation parameters are selected as shown in Table 2.
Figure 3. Pull-off simulation results of attitude maneuvering mode based on RBF network friction compensation sliding mode control: (a) Attitude angle under the inertial frame; (b) Angular velocity; (c) Angular deviation under the inertial frame; (d) Angular velocity deviation; (e) Control torque

Compared with the theoretical simulation, the control accuracy and stability after the pulling are reduced, but still can be meet the requirements of control accuracy and stability from Fig 3(a)(b)(c)(d). The results show that the attitude pointing accuracy is better than 0.2°, the attitude control stability is better than 0.005°/s, and the accuracy of control moment is 0.01mNm. The sensors error is introduced into pull-off simulation, and the friction gain is weakened by the RBF network friction compensation system, so that the satellite attitude control system can still maintain a good effect in the maneuver process.

4.3. Pull-off simulation of attitude maneuvering mode based on RBF adaptive control
To further demonstrate the effectiveness of the RBF network friction compensation sliding mode controller. The RBF adaptive controller is applied to the attitude control system of the Luojia1-01 satellite with the same parameter model. The satellite attitude control stability parameters are visualized, and the simulation results are shown in Fig 4.
Figure 4. Pull-off simulation results of attitude maneuvering mode based on RBF adaptive control: (a) Attitude angle under the inertial frame; (b) Angular velocity; (c) Angular deviation under the inertial frame; (d) Angular velocity deviation; (e) Control torque

The simulation results of RBF adaptive control when the satellite is in attitude maneuvering are shown in Fig 4. Compared with the RBF network proposed in this paper, the attitude control index under the friction compensation sliding mode control is poor. Since the adaptive term has a longer convergence time for stability and a poor generalization ability, it has no good effect on satellite attitude control. Finally, the control algorithm under the attitude maneuver mode is compared. The RBF network friction compensation sliding mode control has better attitude control effect. The comparison results are shown in Table 3.
Table 3. Comparison of algorithm simulation results

| Algorithm                                           | Stabilization time | Attitude pointing accuracy | Attitude control stability | Accuracy of control moment |
|-----------------------------------------------------|--------------------|----------------------------|----------------------------|----------------------------|
| RBF network friction compensation sliding mode control (theorical simulation) | 130s               | 0.1°                       | 0.001°/s                   | 0.01mNm                    |
| RBF network friction compensation sliding mode control (pull-off simulation) | 130s               | 0.2°                       | 0.005°/s                   | 0.01mNm                    |
| RBF adaptive control                               | 250s               | 1°                         | 0.006°/s                   | 0.025mNm                   |

5. Luojia1-01 satellite attitude control system on-orbit test

The telemetry quaternion in the telemetry data is analyzed. First, the quaternion is converted into Euler angle, then the data is fitted, and then the standard deviation of the residual is obtained to get the attitude determination accuracy and attitude maneuverability of the system.

In the closed-loop test, the satellite orbit is quadratic. Fig 5(a) shows the maximum maneuvering angular velocity of the satellite is 1°/s. Satellite control accuracy is an evaluation of the satellite attitude control system capability and can be extracted by the actual control deviation information of the satellite. During the test phase, multiple domestic telemetry data are recorded and analyzed, and the statistical results of the deviation quaternion in the telemetry data are obtained to verify whether it meets the satellite control system control accuracy requirements. The test results show that the control accuracy of the satellite control system meets the requirements of the index. The attitude pointing accuracy is better than 0.02°, and the attitude control stability is better than 0.002°/s.
In the closed-loop test, the satellite orbit is quadratic. Fig 5(a) shows the maximum maneuvering angular velocity of the satellite is $1^\circ /s$. Satellite control accuracy is an evaluation of the satellite attitude control system capability and can be extracted by the actual control deviation information of the satellite. During the test phase, multiple domestic telemetry data are recorded and analyzed, and the statistical results of the deviation quaternion in the telemetry data are obtained to verify whether it meets the satellite control system control accuracy requirements. The test results show that the control accuracy of the satellite control system meets the requirements of the index. The attitude pointing accuracy is better than $0.2^\circ$, and the attitude control stability is better than $0.005^\circ /s$.

6. Conclusion
In this paper, we aim at the attitude maneuver mode of the Luojia1-01 satellite attitude control system, and design RBF network friction compensation sliding mode attitude control algorithm. The conclusions are as follows:

(1) The fast terminal sliding mode control law is extended to the attitude control system of the Luojia1-01 satellite, which makes the strong nonlinear flexible satellite attitude control system achieve better control index.

(2) Through theoretical derivation, the extended state observer is introduced to observe the total disturbance of the system, and the switching gain in the control law is reduced. Combined with the RBF network friction compensation system, the system chattering is effectively weakened.

(3) The results of theoretical simulation and pull-off simulation are compared for attitude task modes of Luojia1-01 satellite, and the comparison experiment between RBF adaptive control algorithm and RBF network friction compensation sliding mode control algorithm is sufficient. The results show that the application of RBF friction compensation sliding mode control algorithm can reduce the switching gain in the sliding mode control law, and weaken the chattering of the system. The algorithm is applied to the in-orbit test, which verifies the effectiveness of the algorithm and improves the application efficiency of the satellite.

The on-orbit test results show that the attitude pointing accuracy is better than $0.2^\circ$, the attitude control stability is better than $0.005^\circ /s$, the accuracy of control moment is $0.01mNm$, and the maximum
maneuvering angular velocity of the satellite is 1°/s, indicating the method satisfies the overall requirements of the Luojia1-01 satellite working mode and has certain engineering practical significance.

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