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Building The Control System Tracking Electric Mechanisms at Slow Speed Based on Method Sliding Mode Control and State Observer

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Abstract

In this paper, the authors presents presents a controller synthesis method to controller objects electromechanical actuator slow speed, based on method sliding mode control and status observer. compensate control law. The control law compensates for disturbing components with a state observation set built to evaluate and compensate for nonlinear nonlinear components. Then the chattering reduction techniques of sliding surface are proposed to improve the quality systems. The algorithms are tested on Matlab-Simulink simulation, experimental results with application models adjust directive device antenna.

Keywords: *Robot Position control, sliding mode control, state observer, system tracking electric mechanisms, slow speed.*

I. INTRODUCTION

To ensure extremely short radio wave transmission in signal transmission and transceiver systems, to target the use of passive radar; Two or more transceiver antennas pointed at each other are used. For military equipment, or equipment that works independently, with the goal of improving maneuverability (equipment on mobile vehicles, on ships). So when it comes to collecting information and exchanging data between vehicles, it takes a lot of time.

The feature of the electromechanical traction drive system to adjust the antenna's orientation is that the rotation speed is very slow, corresponding to the small rotation angles (displacement angle), so it is necessary to control accurately. Matters need to be taken into account, in that the role of the position controller is crucial to the quality of the system control.

In this drive system, position control is the last step of the controller. This issue has important implications in ensuring the accuracy of signal reception [1, 2, 3, 5]. In practice, many methods of position tracking control for this drive system have been applied such as PID control, feedforward control, fuzzy control, etc [1, 4, 5, 6, 11, 14].

In [6], the author proposed an algorithm to reduce the adherence error on the rotation axis of the electromechanical attachment system on the basis of the PID control method and the neural network under the friction conditions affecting the system. As mentioned above, the drive system is slow for mobile antenna devices; in the process of operation, there are always impact disturbances such as friction force, the influence of the gap when reversing rotation, reaction, etc affecting the quality of the controller causing error when controlling, [8, 9]. In the control methods mentioned above, the sliding mode control method is considered as a control method with high stability against the impact of noise (constant with disturbance).

With the aim of improving the control quality for the low - speed electromechanical tracking system for mobile antenna equipment, considering the impact of disturbances, this paper presents the problem of improving the quality of the grip controller. The position for the mobile antenna device with the torque input signal on the basis of control in sliding mode and the state observer to evaluate the perturbation nonlinear factor under the assumption of continuously variable impact disturbances, [1, 6, 7, 15]. However, one of the limitations of the sliding controller is that the vibration on the sliding surface affects the quality of the controller. In this paper, a technique to limit oscillation on the slip surface is proposed to overcome the above limitations.

II. THE CONTENT

A. The Build a controller model

On the axis of rotation, the antenna device is carried out separately, so there is no loss of generality when we consider the dynamics of the slow grip system controlling the antenna device as shown in Figure 1.

The after the author has obtained figure 1, the author next examines the model of electromechanical drive system for antenna combination of antenna combination on mobile device as shown in figure 2. In which, in figure 2 includes: 1 pan of antenna, 2 pan base, 3 bars, 4 clamp bar positions, 5 upper rack tabs, 6 u-shaped belts, 7 lead screws, 8 fixed belts, 10 ladders, 11 seat base.

From the antenna dynamics model is depicted in figure 1; figure 2 depicts the antenna structure, considering the slow - speed drive kinetic model of the antenna with the input of the system is torque τ, the output is the position of the linear angle of the antenna device x. Then the block diagram of the drive system from control signal τ to the position of antenna device x is shown in Figure 3, [5, 7, 8, 15].

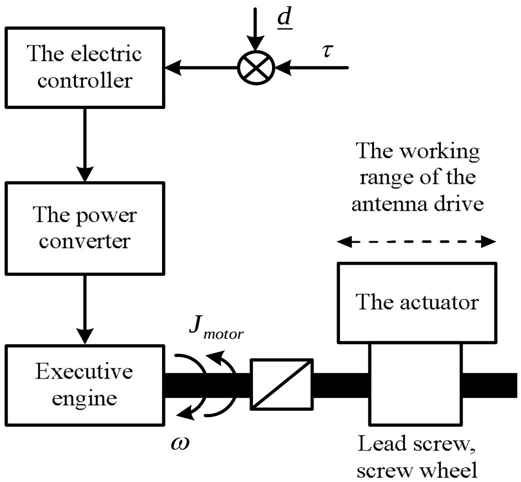

Fig 1: Model of low-speed electromechanical drive system of antenna equipment

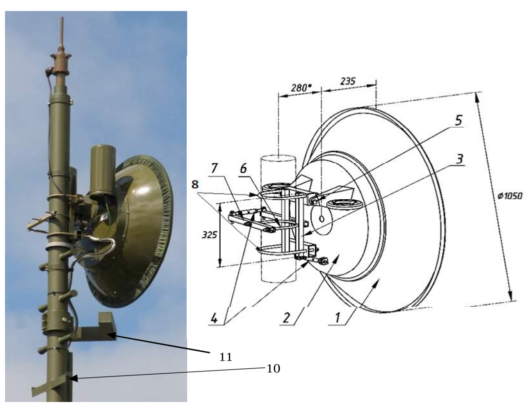

Fig 2: The antenna system structure

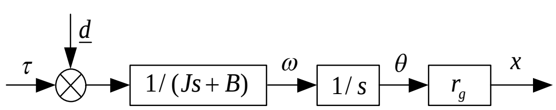

Fig 3: The structure diagram of electromechanical attachment system of the antenna device

In which, the torque of the motor will produce the rotation of the motor shaft with the influence of moment of inertia *J* and viscous friction *B* [6, 7, 10, 12, 13, 14]. Component r_g is the conversion factor from angular speed (or position) of the motor shaft to the translational position of the antenna device, with the following relation.

$$\omega(t)=\frac{\dot{x}(t)}{r_g} \tag{1}$$

From the structure diagram I have:

$$\ddot{x}=-\frac{B\dot{x}}{J}+\frac{r_g\tau}{J}-d \tag{2}$$

set $a=\frac{B}{J}; b=\frac{r_g}{J}; u=\tau$, then we have the equation describing the antenna device axis system as described in the following equation, [2, 3]:

$$\ddot{x}=-a\dot{x}+bu-d \tag{3}$$

Here, with the input control signal of the system being the torque applied to the machine shaft, then the general steps controlling in sliding mode are performed as follows.

B. The synthesize controller in slide mode

Let x_d be the desired trajectory, define $e=x_d-x$ as the tracking error. The control structure here is implemented as a closed loop structure, where only the output net position and output velocity of the antenna device are measured and returned to create control rules.

The selected sliding mode variable is as follows:

$$s=\dot{e}+ce \tag{4}$$

with $c>0$, so have:

$$\overline{s}=\ddot{x}_d+a\dot{x}-bu+d+c\dot{e} \tag{5}$$

Select the Lyapunov function as follows:

$$V_1=\frac{1}{2}s^2 \tag{6}$$

When we have:

$$\overline{V}_1=s(\ddot{x}_d+a\dot{x}-bu+d+c\dot{e}) \tag{7}$$

Select the control signal as follows:

$$u=\frac{1}{b}\left[\ddot{x}_d+a\dot{x}+c\dot{e}+d+ksgn(s)\right] \tag{8}$$

The proposed control law has ensured the convergence of state variables according to Lyapunov's theory. However, because the disturbance signal has an indeterminate value, it is difficult to obtain information about the interference in the above control law. Here we will build noise observe to evaluate noise, create control rules.

III. THE STATE OBSERVER AND EVALUATION NONLINEAR COMPONENT UNKNOWN

A. The design and stability analysis of the state observe

For slow - speed actuators for antenna equipment, depending on the type of antenna, the size of the antenna, etc, during the system's operation with many different weather conditions, there are many types of interference affecting the system such as friction force, gap influence, wind force, processing reaction, etc. In the above types of noise, friction noise and the influence of the gap when there is strong wind (or strong vibration) cause can reduce the rotation speed; also affects the reaction of the reaction when the antenna device interacts with the wind, which always exists and has a great influence on the working quality of the antenna, this type of noise also has many different characteristics to affects the signal reception process. When the antenna is rotating, the noise composition due to reaction impact also has a small variation over time, then we can apply the state observer proposed by [6, 10, 13] as follows:

$$\dot{\hat{d}} = c_1(\hat{\delta} - \dot{x}) \tag{9}$$

$$\dot{\hat{\delta}} = -\hat{d} + bu - c_2(\hat{\delta} - \dot{x}) - a\dot{x} \tag{10}$$

Here $\hat{d}$ is an estimate of d and $\hat{\delta}$ is an estimate of $\dot{x}$, $c_1 > 0, c_2 > 0$.

Select the Lyapunov function as follows:

$$V_2 = \frac{1}{2c_1}\tilde{d}^2 + \frac{1}{2}\tilde{\delta}^2 \tag{11}$$

with $\tilde{d} = d - \hat{d}$, $\tilde{\delta} = \dot{x} - \hat{\delta}$. Then get receive:

$$\begin{aligned} \bar{V}_2 &= \frac{1}{c_1}\tilde{d}\dot{\tilde{d}} + \tilde{\delta}\dot{\tilde{\delta}} \\ &= \frac{1}{c_1}\tilde{d}(\dot{d} - \dot{\hat{d}}) + \tilde{\delta}(\ddot{x} - \dot{\hat{\delta}}) \end{aligned} \tag{12}$$

When noise d varies slightly with time and limit, with c_1 having a suitable value, we can get $\frac{1}{c_1}\dot{d} \approx 0$, then with the right choice of c_2, we get: $\bar{V}_2 \le 0$.

So, the noise component d can be estimated by the design of the noise observer, and compensation can be performed in feedback control.

Then we have:

$$\bar{V}_3 = \tilde{d}s - k|s| \le 0 \tag{13}$$

The Lyapunov function of a fully closed system can be expressed as follows:

$$V = \frac{1}{2c_1}\tilde{d}^2 + \frac{1}{2}\tilde{\delta}^2 + \frac{1}{2}s^2 \tag{14}$$

In differential equation (21), we get receive:

$$\bar{V} = \bar{V}_2 + \bar{V}_3 = \frac{1}{c_1}\tilde{d}\dot{\tilde{d}} + \tilde{\delta}\dot{\tilde{\delta}} + s\dot{s} \tag{15}$$

The putting equations of $\bar{V}_2$ and (13) into (15), from there have:

$$\frac{1}{c_1}\tilde{d}\dot{d} - c_2\tilde{\delta}^2 + \tilde{d}s - k|s| \le 0 \tag{16}$$

So we have: $\bar{V} \le 0$.

B. The limit oscillate on the sliding surface

The one limitation of sliding control is the phenomenon of oscillation (chattering) on the sliding surface, it has a negative impact on the system and actuator. To limit the oscillation on the sliding surface, when use the saturation function instead of the sign function in the control law (18), [6].

In fact the process of building the control rule, see that the chattering phenomenon can be eliminated by smoothing out the control interruption within a limit close to sliding surface. An equation describing the saturation function is given as equation (17). A graph of the saturation function is shown in figure 4.

$$sat(s) = \begin{cases} 1, & s > \Delta \\ ks, & |s| \le \Delta, k = 1/\Delta \\ -1 & s < -\Delta \end{cases} \tag{17}$$

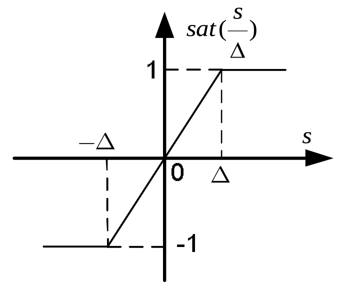

Fig 4: The saturation function

IV. The simulation results and experimentation

A. The simulation results

To get the quality assessment of the proposed controller, the author builds an experimental simulation on Matlab - Simulink for the antenna device with the electric motor which is a DC motor from permanent magnet. The taper combines linear screw model with conventional PID controller and proposed controller.

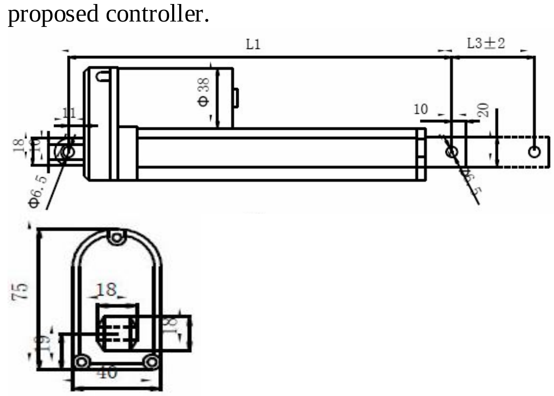

Fig 5: The dimension of superJack's IMD3 linear motor

With the specifications: speed 0-12mm / s, payload 70KgN, fixed aperture: L1 = 158mm, travel distance: L3 = 50mm, maximum length not to mention 208mm joints, 158mm minimum calculated by center of hole.

The time to complete the journey with maximum speed $t = 4.17s$ with parameters given as: $R_u = 10\Omega$, $L_u = 10\,mH$, $\frac{K}{J} = 1387.63(N/A)/(kgm^2)$. The working structure with converted moment of inertia $J = 0.1kgm^2$.

Simulation diagram: The simulation program built on Matlab - Simulink has the shape as shown in figure 6. The simulation blocks Ctr, CtrC, obsever are built with functions on S - Function.

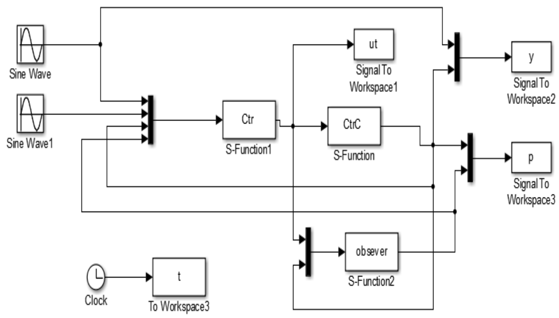

Fig 6: The diagram of simulating the position of the antenna drive system on the basis of sliding mode control with a state observe built on Matlab - Simulink

The simulation parameters: To evaluate the results, we perform the positioning simulation for the antenna device axis with the parameters given as table 1.

TABLE I. The simulation parameters

Parameters	Value	Unit
r_{g1}	0.05	rad/m
J_1	0.003	kgm^2
B_1	0.006	kgm^2/s
k_1	4000	
Δ	0.10	
c	15	
k	5.0	

The simulation results: Simulation results are performed with conventional PID controller.

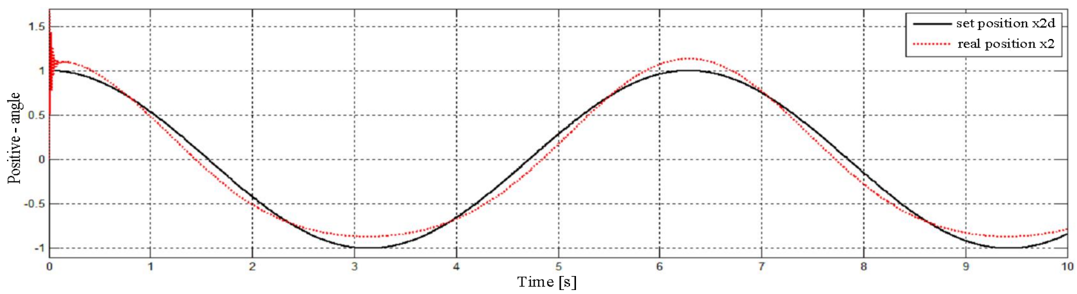

Fig 7: The position of the antenna rotation axis when using the PID controller

Results with sliding mode controller and the observe:

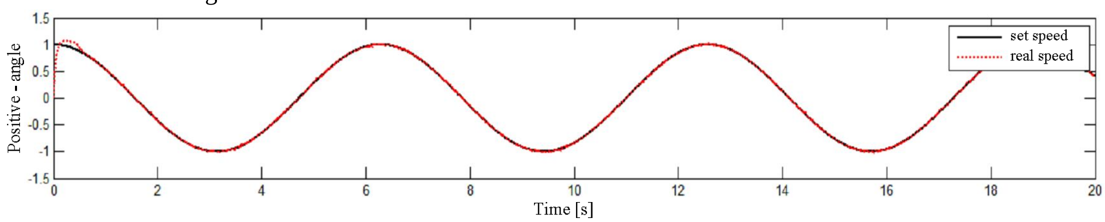

Fig 8: The speed of rotation of the antenna device axis

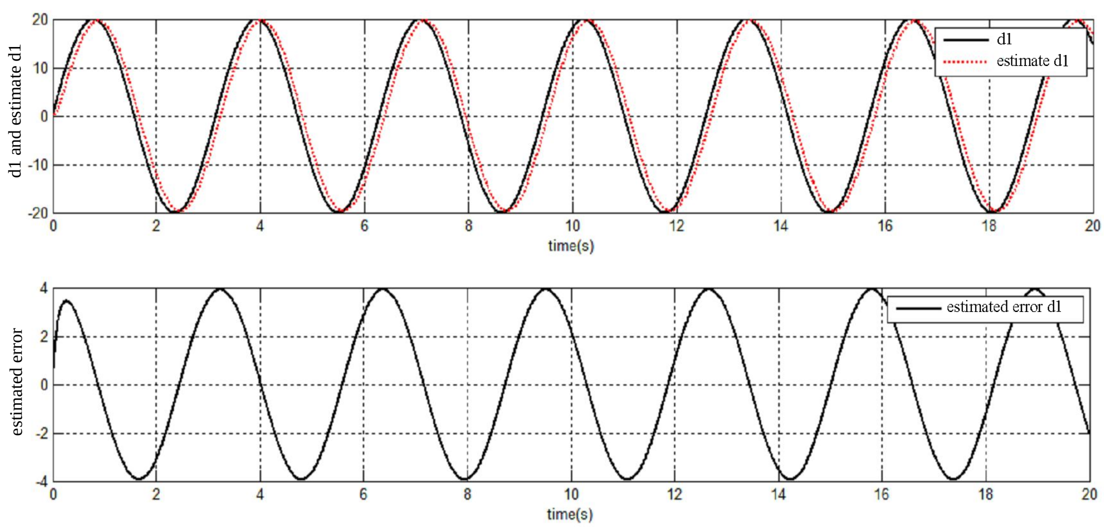

Fig 9: The results estimate the interference signal d1 and estimated error

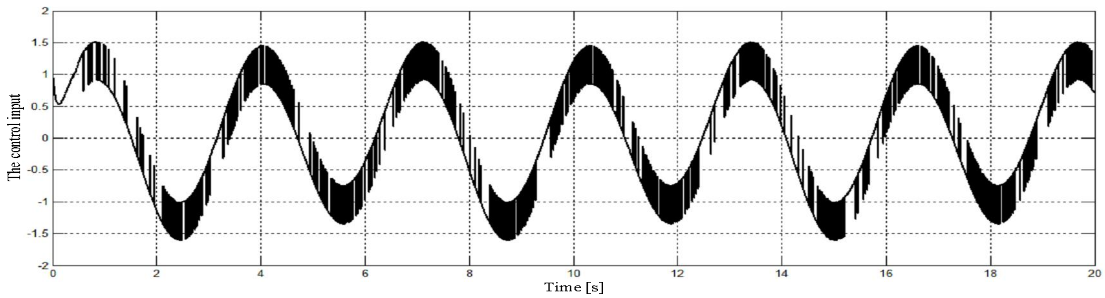

Fig 10: The control signal input u1(t)

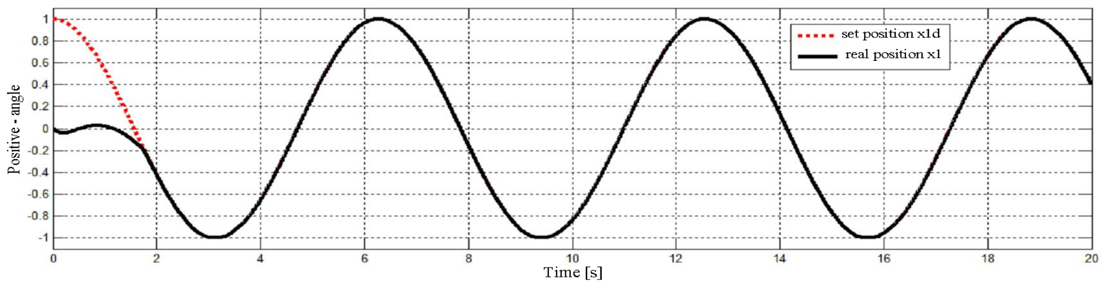

Fig 11: The axial position of the antenna device when using the proposed sliding mode controller

Evaluating the results: Comparing the position sticking value at the axis of the antenna, we find that, with the PID controller, the setting time for the system to follow the set signal is about 0.7s, the correction is 7%, the maximum tracking error is about 12% (Figure 7), with the sliding mode controller combined with the state monitor, we have a set time for the system to follow the speed setting signal and the real speed is always closely related to the set value (figure 8), the estimated noise signal d1 and the estimated error indicate that the observer is working well, providing enough information for the controller, (figure 9).

The same, the quality of the antenna position at the axis of the antenna device when using the sliding mode controller with (figure 11) is also better than the conventional PID controller in (figure 7).

From the results of the antenna trajectory we see, with conventional PID controller, the position adjustment is large, the time is too great, the end point trajectory error is large; for the sliding controller combined with the proposed state monitor, we find that the trajectory adhesion quality is highly accurate, the actual trajectory of the antenna device has followed the set trajectory with very error small (≈ 0), time transient is small, degree of transition is small.

From the simulation results we have comments:

The control quality of the proposed controller is much higher than that of the conventional PID controller in terms of transient time, transient correction and traction error.

The position and speed of the antenna device shaft has adhered to the position and the set speed with a small traction error after a short time, so the position of the antenna device always follows the set trajectory with error very small, it proves that the quality of the controller has met the control requirements with high precision.

On the basis of the built state observer, the results show that the observer has evaluated the value of the impact noise with a small adherence error, from which we implement the law of sliding control combined with noise compensation ensure the stability of the system with the proposed control laws.

With the above results, we can apply to synthesize the position tracking algorithm for antenna equipment or a certain device in industry, military and civil; such as the electric drive systems of secvo motors in production lines.

B. The experimental results

The after building off - line simulation model in Matlab - Simulink, we get results to support the analysis above. The convergence of friction error, results of stable adherence when changing parameters of friction torque.

Research on experimental model: in this study, the specific experimental object with the adjustment system orientation of antenna device is as follows:

On the basis of the given theory, we conduct experiments with the transmission system closely working at slow speed, which is the model of the antenna system to transmit signals in the military, we go to research to build. This close drive system with the measurement and control devices on the physical model as shown in figure 12, figure 13, figure 14. To prove the correctness of the algorithm just synthesized, on the basis of quality assessment model: With actuator is considered as a permanent magnet DC motor controlled through a speed changer, combined with measuring system, noise filter and many modern equipment other.

Fig 12: The practical antenna system

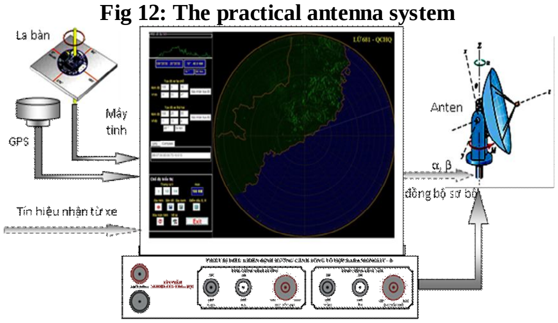

Fig 13: The model connection with antenna system

The model describes the connection with antenna equipment as shown in figure 13.

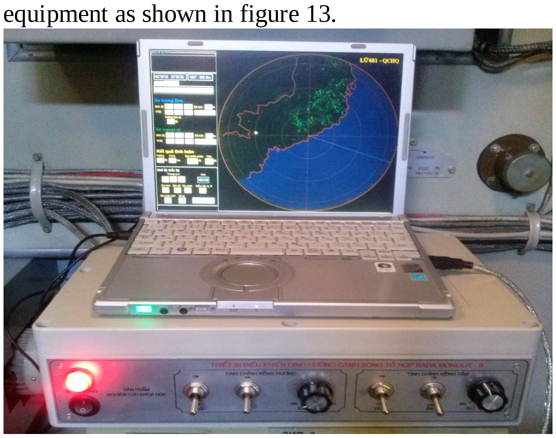

Fig 14: The conect the antenna device to a signal collection device

After connecting the controller with the antenna orientation adjustment system, we get some positive results on the screen obtained from the computer. The obtained signal is much better than before without using the proposed control algorithm.

The objective of the experimental process is to demonstrate that the built - in position controller not only works well in the Matlab Simulink simulation but also works well in the real - time system environment.

V. CONCLUSIONS

The paper has synthesized the position tracking algorithm for the antenna device based on the control in sliding mode and the state observe with high control quality, small tracking error. The output quantity is always tracking related to the set value at the balance process. The control law is proved based on the theory of stability Lyapunov. The simulation results based on Matlab - simulink software have proved the correctness of the proposed algorithm. In addition, the above algorithm can be applied to improve the quality of position control for many industrial, military and civil equipment in turbulent conditions affecting the system. With this result, construction has been applied on practical antenna combination equipment.

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