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# An Investigation of the Discrete Sliding Mode Algorithm for On-Board Satellite Antenna Servo System

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## *Abstract*

*A DSP based antenna servo controller is developed to improve its performance. In the servo system, a new discrete sliding mode algorithm based on the exponential trending law is employed. Theoretical analysis and experimental simulations are done with the new algorithm. Results show that the controller and the control algorithm satisfy the demand of stability. Compared with the traditional PID algorithm, the new algorithm has better performance on real-time adaptation. The sensitivity of the servo system to the continuous or unexpected disturbances can be greatly reduced and the robustness is obviously strengthened.*

***Keywords**: Servo control, Satellite antenna, Variable structure control, Robustness*

## 1. Introduction

When vessels are sailing, the platform baseline of the satellite antenna tracking system will offset by azimuth angle, pitching angle and roll angle in three directions. Particularly, the interference should be considered to control antenna directionality and make it point the satellite automatically.

For antenna of earth stations, tracking of the communication satellite primarily adopt the single-pulse mode with high precision. The beam is fairly wide. With the increasing of the signal frequency bandwidth, the beam becomes narrower. Sometimes it even reaches several degrees or even less than one. When disturbed, the narrow beam-width will especially have an effect on the satellite tracking accuracy and communication quality. Increasing demands for satellite antenna servo system are raised. It requires the servo system with high precise, anti-jamming and automatically pointing.

So the satellite earth station should design an advanced automated tracking system that allows the receiving antenna to point the satellite in real time and with high precision [1-5].

Satellite communications antenna servo system is in the host computer and the servo controller. The sliding mode control algorithm is adopted to overcome the lack of servo system to some extent. It is of important engineering value. The algorithm is proposed mainly to aim at friction interference caused by torque. The sliding mode control algorithm can achieve a rate of exponential reaching simulation. Experimental results show that the sliding mode control algorithm has better adaptability for interference than the conventional PID control algorithm.

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## 2. Antenna Servo Controller Design Based on DSP

The experiment platform of satellite communications antenna servo system is based on DSP servo controller speed servo system (speed control system), mainly composed of antenna servo controller, power driver board, DSP2812 board, USB bus, PC host computer and other devices. Its system structure is shown in Figure 1.

The figure shows the antenna servo control system is based on the DSP controller. There are the motor servo controllers, peripherals and memory which are integrated on-chip, reducing the number of system components and improving the CPU's processing ability and system reliability and so on. Moreover, the integrated power driver board is used which set these components in one board : power supply circuits, protection circuits, current detection circuits, an inverter circuit, the motor position detection circuit, a signal isolation circuit, to improve the reliability and accuracy of the system.

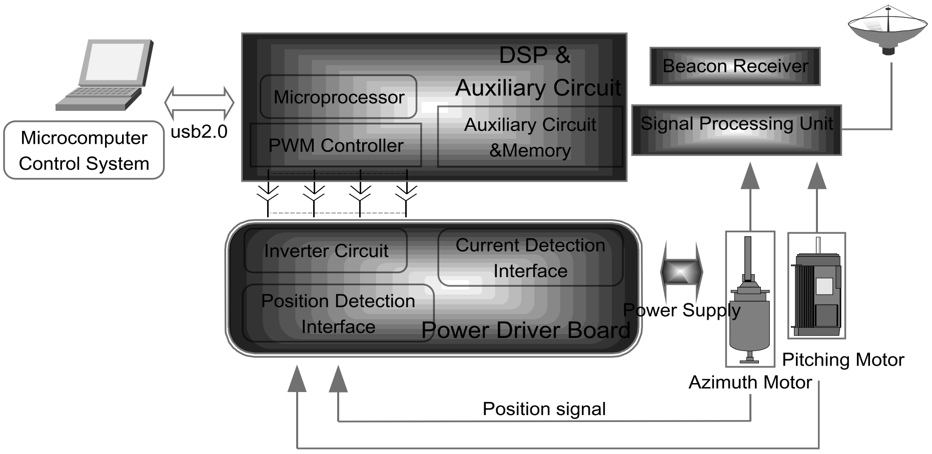

**Figure 1. Antenna Servo Control System Composition Schematic**

DSP servo controller uses USB2.0 bus and TMS 320F2812.It is plug and play and hot swappable, is easy to install and configure; extend the USB I / O capability, the total bandwidth of up to 12Mbs; data transfer rate reaches up to 480Mbps. TMS 320F2812 of TI company is fully functional DSP chips with USB2.0 interface. Its characteristics are : a low-power design, the operating voltage is 3.3V; clocked at up to 150MHz, has 128K of flash memory; motor control peripherals and 12 analog to digital conversion module are integrated; has serial communication peripherals and USB2.0; has advanced simulation debugging function (JTAG).

## 3. Discrete Sliding Mode Control Algorithm Design

The main idea of sliding mode control is: to make the system state move as the sliding mode surface preset. Before the system state variables trajectory don't move to the sliding surface or switching function $s = 0$, forcing system state variables move toward the slip plane by the switch control variable , once reaching the sliding surface, the system state will have to slide along the sliding surface to the end. When sliding the state trajectory of the system is determined by the parameters of sliding surface [6-10].

Also considering PWM produces the circuit gain of $K_A$, you can get the ratio of the instantaneous speed of the motor by the PWM duty ratio transfer function [6], as follows:

$$\frac{\omega(s)}{D(s)} = \frac{K_A K_t}{(Ls + R)(Js + B) + K_t K_e} = \frac{\frac{K_A K_t}{JL}}{s^2 + \frac{BL + JR}{JL}s + \frac{K_t K_e + RB}{JL}} \tag{1}$$

Consider the system:

$$\frac{\omega(s)}{D(s)} = \frac{6788489813}{s^2 + 7917.67s + 718448.5} \tag{2}$$

The experiment is the real-time control systems of the computer, so it is necessary to converts a continuous system represented by formulate (2) to a discrete system. In this experiment, the sampling time control system is set as $T = 0.00005s$, *i.e.* the system sampling frequency is 20KHz. Z-transform method is used to discrete a continuous system in formula (1) , specific operation is calculating by using MATLAB function c2dm () , the second-order discrete system state equation of the control object is got, as equation (3) below:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = A \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + Bu \tag{3}$$

In this experiment, PWM signal generated by the DSP chip, the adjustment range of duty ratio is 0~1. The circuit gain $K_A = 24$ generated by PWM can be obtained according to the supply voltage $U_N = 24V$ .

Antenna servo system is a multi-loop feedback control system, its tracking performance depends largely on the design of the control algorithm. Motor speed servo system (*i.e.*, speed control system) system structure is shown in Figure 2.

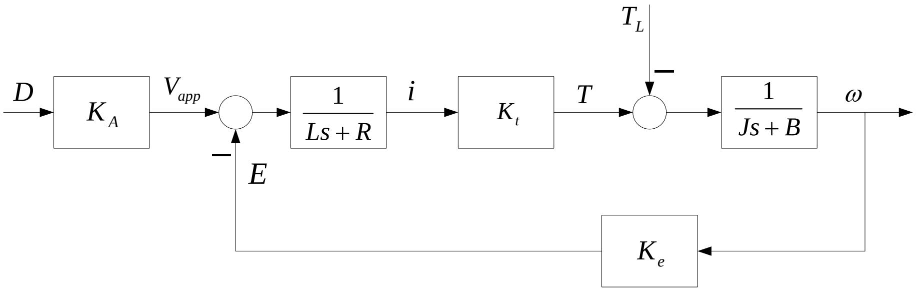

**Figure 2. Servo System Motors Modeling Composition Schematic**

In the discrete sliding control, the switching function is taken as the form shown in the formula (3)

$$s_e(k) = C_e x_e(k) = C_e(R(k) - x(k)) \tag{4}$$

Which, $C_e = \begin{bmatrix} c & 1.0 \end{bmatrix}$, it can be obtained by pole configuration method.

According ideas of the reaching law, based on the switching function by the formula (3) and the second-order discrete system in formula (2), $s_e(k + 1) - s_e(k)$ is calculated with the following formula:

$$\begin{aligned}
& s_e(k+1) - s_e(k) \\
& = C_e x_e(k+1) - C_e x_e(k) \\
& = C_e(R(k+1) - x(k+1)) - C_e(R(k) - x(k)) \\
& = C_e R(k+1) - C_e A x(k) \\
& - C_e B u(k) - C_e R(k) + C_e x(k)
\end{aligned} \tag{5}$$

Exponential reaching law designed by Gao Wei-bin is expressed as the following equation [5]:

$$\begin{gathered}
s_e(k+1) - s_e(k) = -qTs_e(k) - \varepsilon T \operatorname{sgn}(s_e(k)), \\
\varepsilon > 0, \quad q > 0, \quad 1 - qT > 0
\end{gathered} \tag{6}$$

Then according to equation (4) and (5), are:

$$\begin{aligned}
& C_e R(k+1) - C_e A x(k) - C_e B u(k) \\
& - C_e R(k) + C_e x(k) \\
& = -qTs_e(k) - \varepsilon T \operatorname{sgn}(s_e(k))
\end{aligned} \tag{7}$$

Assume $C_e B$ reversible, so, discrete sliding control law based on exponential reaching law can be obtained by formula (6), now represents as the formula (7):

$$\begin{aligned}
u(k) = (C_e B)^{-1} (& C_e R(k+1) - C_e A x(k) \\
& - C_e R(k) + C_e x(k) \\
& + qTs_e(k) + \varepsilon T \operatorname{sgn}(s_e(k)))
\end{aligned} \tag{8}$$

Or it represents as the formula (7):

$$u(k) = (C_e B)^{-1} (C_e R(k+1) - C_e A x(k) - s_e(k) - ds_e(k)) \tag{9}$$

Where: $ds_e(k) = -qTs_e(k) - \varepsilon T \operatorname{sgn}(s_e(k)))$; $\varepsilon > 0,\ q > 0,\ 1 - qT > 0$

The formula is the realized form of the discrete sliding mode variable structure control law based on exponential reaching.

## 4. Simulation Results Analysis

The whole control system take the TI's TMS 320F2812 DSP chip as the core, Mitsubishi IPM intelligent as drive module. Experimental conditions are: when the speed is 5000r / min, Agilent oscilloscope is taken. According to the parameters of the model of the control object and sliding mode control, system simulation is carried on in the CCS integrated environment.

For servo control object, sliding mode control and classical PID control were simulated respectively [11]. Changing the parameters of the control object and adding a successive interference or a sudden load torque to the object, response curves of the two algorithms were compared. The simulation results with parameters before and after are compared.

(1) Disturbed by continuous interference, the robust performance of the two strategies are observed. motor speed reference value is set to 5000rpm under the circumstances, the hand-held motor shaft is used to increase its friction, it is approximately equivalent to the working situation of the torque disturbance of the equivalent motor or sudden load torque, to observe the robustness performance curve of PID algorithm and the discrete sliding mode control algorithm based on the exponential approaching. System sampling time interval is $T_s = 0.00005s$, the robust performance of the speed loop of antenna servo controller is studied by using PID control strategy and that based on exponential law

approaching respectively when it is in successive interference. The real-time operational data obtained from CCS graphics displays window were shown in Figure 3- Figure 5:

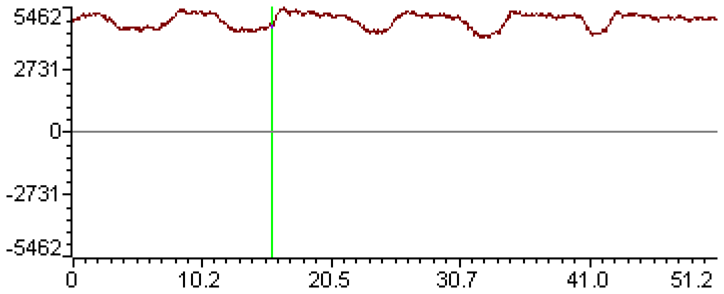

**Figure 3. Robust Performance Simulation Curve during PID Control**

PID Parameter settings : $K_p = 1.5$; $T_i = 0.3$, $T_d = 0.0001$, $T_C = 0.2$

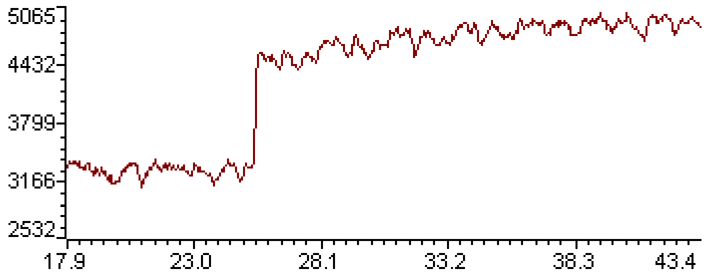

**Figure 4. Robust Performance Simulation Curve during PID Control**

PID Parameter settings : $K_p = 1.5$; $T_i = 0.3$, $T_d = 0.001$, $T_C = 0.2$

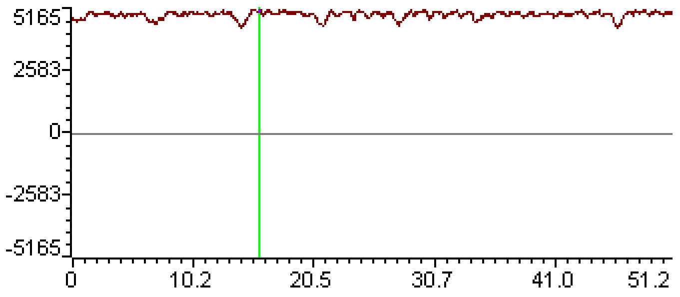

**Figure 5. Robustness Simulation Curve during the Discrete Sliding Mode Control Based on the Exponent Reaching Law. Sliding Control Parameters:** $c = 2000$; $q = 4000$; $\xi = 100$; $Sat = 1.0$

From Figure 5, it shows, the differential coefficient reflects the tendency of the deviation signal, *i.e.*, preventing the occurrence of deviation. It is depending derivative time constant. Comparing Figure 1 and Figure 2, it is concluded when the derivative time constant $T_d$ is for 0.0001s and 0.001s, the greater is the $T_d$. As shown in Figure 4, it will speed up the movement of the system, reducing adjusting time, help to reduce overshoot, overcome oscillation. However, by comparing Figures 3 and 5, it is concluded that it is sensitive to interference and is not conducive to the robustness. The integration time constant $T_i$ is used to eliminate static error and improve the system's no difference degree, when for 0.3s, the greater is Ti, the weaker will be the integral role , which can reduce the overshoot of the system, but at another hand the response process of the system will be slowed down .

In terms of robustness, curve fluctuates obviously in Figure 3. Comparison of the experimental results in Figure 3 and Figure 5 shows that: for interference torque, traditional PID control algorithm is less effective, reflecting the motor speed fluctuations and having no conducive to the actual motor operation. When system is subjected to same strong continuous interference, for the same size torque interference, the control strategy based on exponential reaching law, its curve has the smaller fluctuations and it is concluded the robustness performance is better.

(2) In the case of sudden load, the robustness performances of the two strategies are observed. System sampling time interval is still set as $T_s = 0.00005s$ , the robust performance of the speed loop of antenna servo controller is studied by using PID control strategy and that based on exponential law approaching respectively when a sudden interference is added .The real-time operational data obtained from CCS graphics displays window were shown in Figure 6- Figure7:

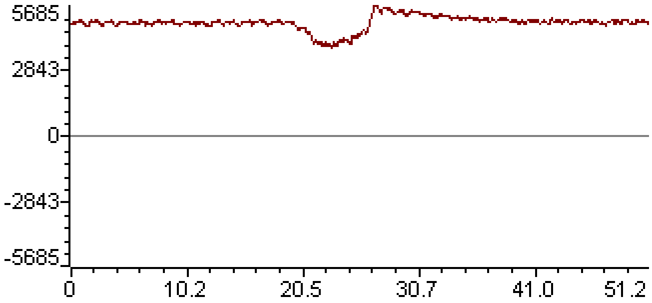

**Figure 6. Robust Performance Simulation Curve during PID Control**

**PID Parameter Settings:** $K_p = 1.5$; $T_i = 0.3$; $T_d = 0.0001$; $T_C = 0.2$

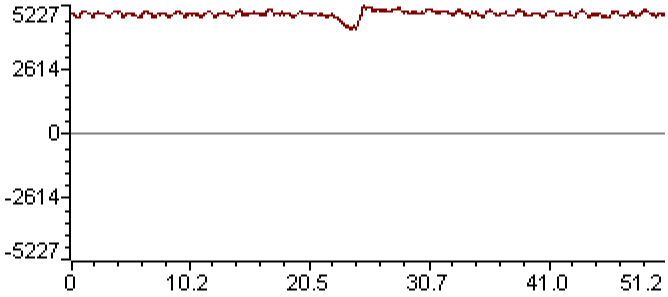

**Figure 7. Robustness Simulation Curve during the Discrete Sliding Mode Control Based on the Exponent Reaching Law. Sliding Control Parameters:** $c = 2000$; $q = 4000$; $\xi = 100$; $Sat = 1.0$

From the above two figures, in the subject to the same sudden disturbance torque, simulation waveform of Figure 7 is smaller ups and downs compared with that in Figure 6. Figure 6 also reflects the time of system control adjusting at the sudden disturbance is too long by using the conventional PID control algorithm. Robustness curve shows the speed fluctuation is far less than that under conventional PID control sliding mode control curve shows the algorithm is anti-integral windup. Moreover PID control parameters applied here have been a number of debugging and optimization. Experimental results show: compared to conventional PID control strategy, the discrete sliding mode control

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algorithm based on index reaching law, the sensitivity for interference is weakened and the robustness is enhanced. It has better real-time adaptability.

## 5. Conclusion

Aiming at the problem that the shipboard satellite antenna servo system may be disturbed by some interference, a new discrete sliding variable structure control algorithm based on the index approaching rate is studied to improve the adaptability of the servo system. The comparison with the traditional PID control strategy was done on the algorithm performance. Simulations are done in the TI's experimental platform with the core of TMS 320F2812 DSP chip. Experimental results show that the feasibility of the discrete variable structure control algorithm applies to the ship-board satellite antenna servo system. The continuous interference and sudden interference caused by the instability during ship's sailing are verified. Interference sensibility is reduced for the sliding mode control algorithm compared with PID control algorithm. The system has better robustness and prospective in engineering applications.

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