Design of Shipborne Radar Turntable Servo System

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Keywords: Servo Turntable; Triple Closed Loop; PID Control.

Abstract: In view of the high attitude stability requirements of shipborne radar turret under sea conditions, the hardware and software of the two-axis shipborne radar turret servo control system were designed.DSP chip TMS320F2812 and FPGA chip were used as the servo control core for controller design, and Copley motor drivers were used to drive the motors. The control software used the "current + speed + position" triple closed loop control method and PID control algorithm was developed with CCS3.3 development platform. The system triple closed loop control model was established and simulated with the Simulink module of Matlab, and the result of 30 ms response time of the system was derived. Finally, the experimental verification shows that the design of shipborne radar turntable servo control system meets the design specifications.

1 PREFACE

The ocean is an important battlefield for the current global power game, and the number and advancement of warships are concentrated expression of its competitiveness. Shipborne radar plays an important role in target detection and early warning. The warship is generally equipped with high-precision shipborne radar. The radar antenna is installed on the servo turret, and the sway of the hull is isolated by the movement of the turret, so that the radar antenna obtains stable relative inertia space, and the target is searched, positioned and tracked under the control command. The servo control system is an important part of modern shipborne radar, and its performance directly affects the radar detection and tracking accuracy (Wang Yuqian, Gu Weijie and Li Guiqiu, 2017).

Ji Wei, from Southeast University, conducted theoretical research and experimental verification on the techniques of visual axis stability control and search tracking in the gyro stabilized photoelectric tracking system (Ji Wei, 2006). Xu Tao, from Changchun Institute of Optics and Mechanics, Chinese Academy of Sciences, proposed an initial calibration method for target tracking turntable based on coordinate transformation, which is used to improve the tracking accuracy of the moving base photoelectric tracking system (Xu Tao and Li Bo, 2013). Ji Dong, from Aerospace Science and Technology Second Research Institute, adopted a method of adding disturbance observers on the gyro speed loop to reduce the speed deviation caused by the frictional interference of the turret and the carrier disturbance, ensuring the stability of the stable platform speed (Ji Dong, 2013).

2 SYSTEM BASIC COMPOSITION AND WORKING PRINCIPLE

The turntable servo control system is mainly composed of mechanical structure, servo controller, driver, servo motor, detection component, and display control (Liu Sheng, Peng Xiafu and Ye Guizhen, 2001). The shipborne radar turret is a two-axis servo turret, azimuth axis and pitch axis. The servo control loop consists of two independent control systems, the azimuth control system and the pitch control system. The basic composition of the turret is shown in Fig.1.

Zhao, C., Liu, J. and Tang, Y.
Design of Shipborne Radar Turntable Servo System.
DOI: 10.5220/0008385802990305
In *Proceedings of 5th International Conference on Vehicle, Mechanical and Electrical Engineering (ICVMEE 2019)*, pages 299-305
ISBN: 978-989-758-412-1

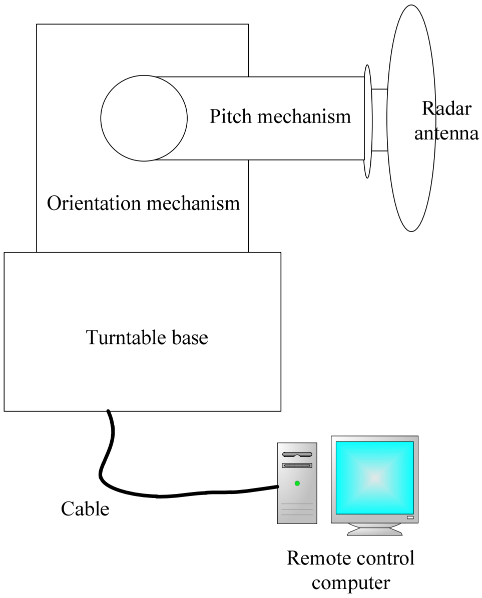

Figure 1. Block diagram of the stable platform.

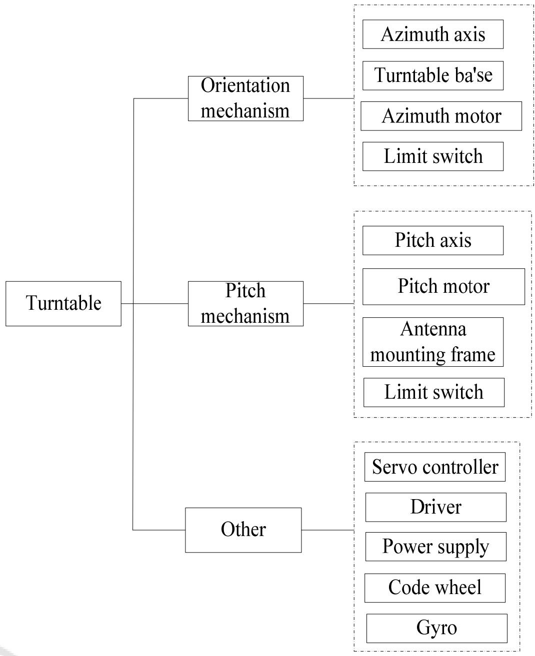

Figure 2. Overall block diagram of the servo system.

The two-axis shipborne turntable controller controls the motion state of the servo motor by receiving the off-target amount transmitted by the host computer and the feedback signals of the code wheel and the gyro to realize the search and tracking function of the target Zheng Yanwen, Wang Yuyu, Lin Lin, Huang Yuxin, Fan Genxin, 2013). In this design, the radar needs to detect and locate the air target, and the positioning accuracy of the turntable is high. The performance requirements of the turntable are shown in Table 1.

3 SERVO SYSTEM DESIGN

The azimuth control system is composed of a servo controller, a driver, a servo motor, a code wheel and a gyro. The pitch control system is composed of a servo controller, a driver, a servo motor, a code wheel, a gyro, and a limit switch. The overall block diagram of the servo system is shown in Fig.2.

3.1 Servo Controller Design

The controller is based on DSP and FPGA chips. The main functions of the servo controller include control algorithm, signal acquisition, communication with the terminal, and control of peripheral devices. The DSP uses TI's TMS320F2812 with a clock frequency of 150 MHz, an on-chip 128K×16 Flash, integrated the motor control peripheral event manager (EVA and EVB), serial communication peripherals and a 12-bit 16-channel ADC with 56 general purpose I/O (GPIO). In order to achieve high-precision control, the 12-bit ADC of DSP is used as a backup. The 16-bit AD7656 is selected as the sampling AD to collect the gyro signal. The 16-bit DAC7744 is selected as the DA output to control the Copley controller to drive the servo motor. The servo control circuit diagram is shown in the Fig.3.

Table 1. Shipborne radar turntable performance indicators.

Structure Type	Rotation Range /(°)	Range of Rotation /((°)·s^{-1})	Maximum Angular Acceleration /((°)·s^{-2})	Positioning Accuracy /(°)
Azimuth Axis	0~360	0.1~25	30	0.02
Pitch Axis	-10~100	0.1~20	30	0.02

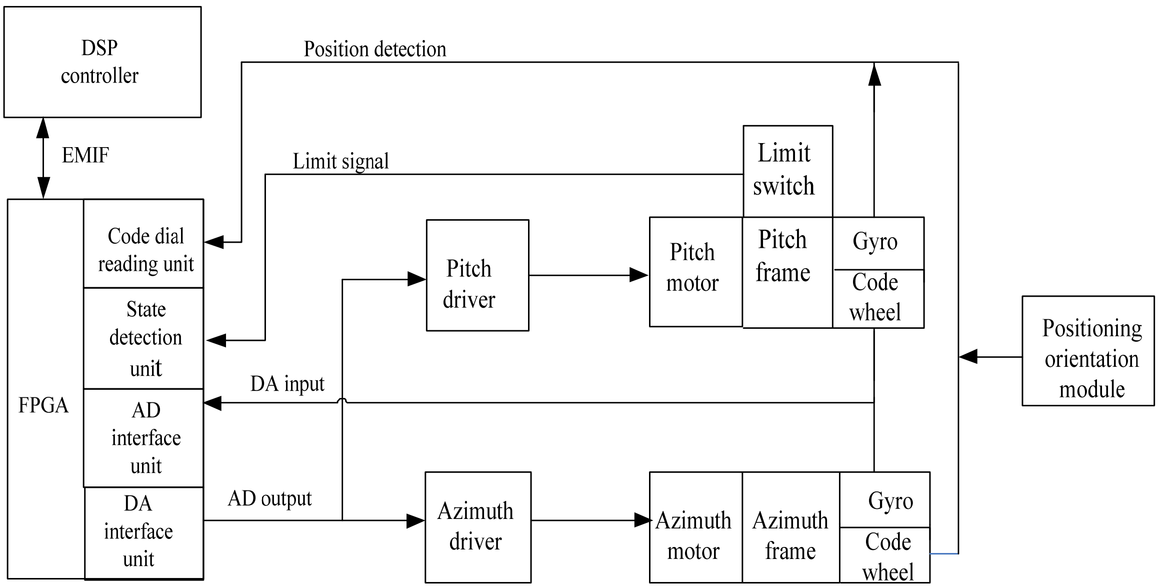

Figure 3. Schematic diagram of servo control circuit.

The servo controller sends the generated control quantity to the driver through the DA port, and the driver power-amplifies the signal to drive the servo motor to drive the platform to perform corresponding motion. The photoelectric encoder is installed as the speed sensor and the position sensor at the end of the platform swing mechanism. The gyro measurement base motion information is installed on the platform base. The positioning orientation system is installed to obtain the angle information of the stable platform in the inertial space, and the limit function is realized by the photoelectric switch.

3.2 Servo Drver Selection

The servo drive is one of the cores of the servo control. Copley's industrial servo driver is selected. The analog signal output from DA is transmitted as a control command to the Copley servo driver, and the position information and speed information returned by the drive are accepted. The main interface is the motor control interface, RS232 communication interface, CAN communication interface, dual encoder interface, 9 IO input interface, 4 IO output interface, and its characteristics are as follows:

1) It has a dual encoder interface (motor encoder interface and load encoder interface);

2)The drive control system adopts triple closed loop structure (current loop, speed loop and position loop), each closed-loop system parameter can be set, and the maximum value of the parameter can be limited to facilitate safe debugging;

3) It has strong environmental adaptability, and the working environment temperature is -25 °C ~ 70 °C.

3.3 Servo Control Software Design

The software design of the controller mainly includes the communication software of the upper computer and the control software of the lower computer (Wu Tianzhu, 2010). In this study, the PID control algorithm is used to realize the "current+ speed+ position" triple closed loop control, so that the response speed and tracking accuracy of the turntable control system meet the performance requirements.

The servo control software is based on DSP system development, and the development tool software is CCS3.3. The main program mainly includes two parts of initialization and loop running program. The initialization includes hardware and system initialization and servo running environment initialization. The main flow chart of the servo control program is shown in Fig.4. It mainly includes the main function modules such as serial communication module, motor control module and servo control module.

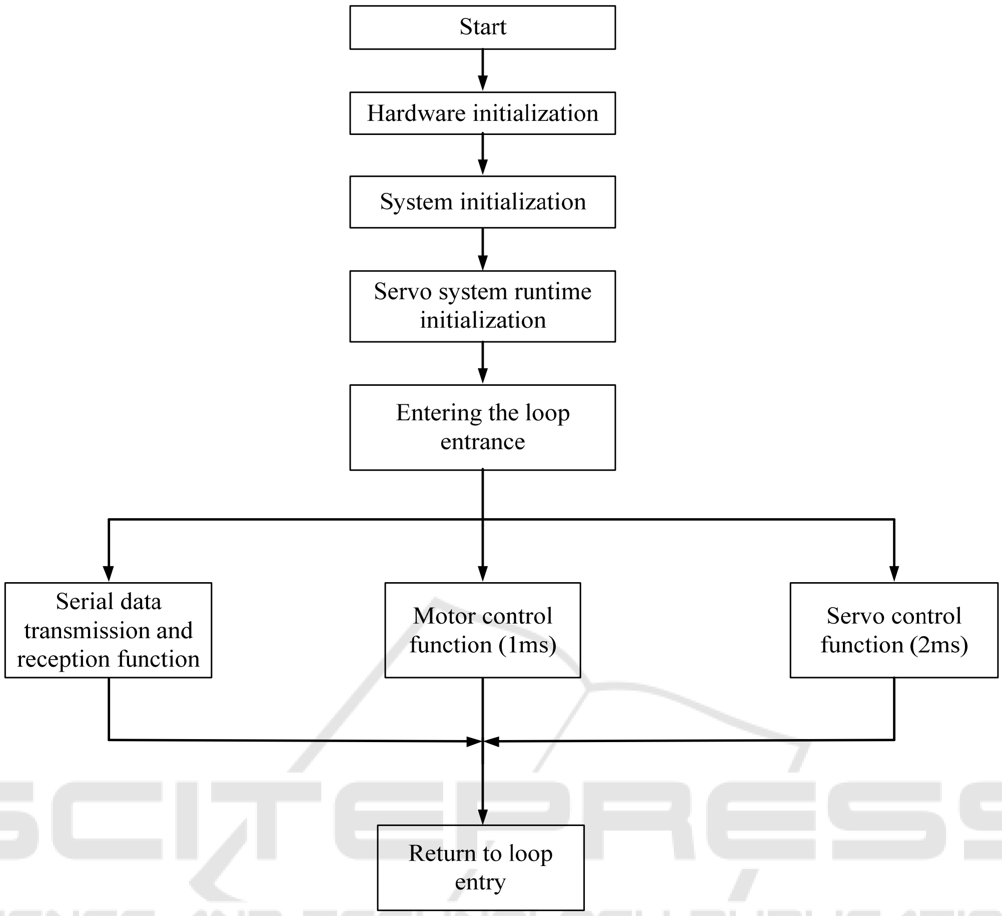

Figure 4. Servo control software main program flow char.

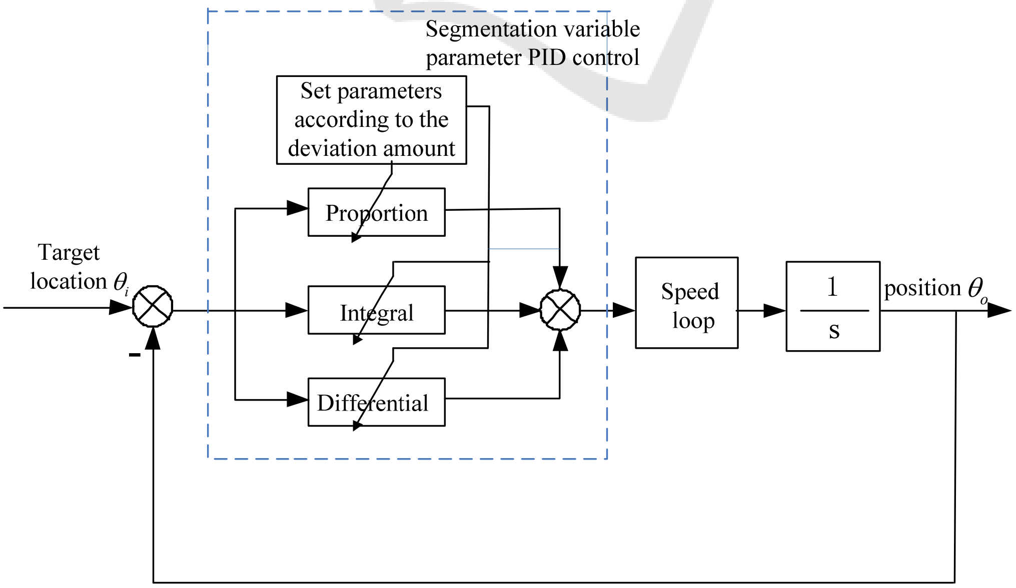

Figure 5. Schematic diagram of segmentation variable parameter PID control.

3.4 Code Disk Position Loop Control Strategy Design

The position and position control adopts the segmentation variable parameter PID control algorithm in Fig. 5, which has the advantages of simple algorithm, good robustness, and the ability to balance both fast performance and stability performance.

In order to achieve precise positioning of the turntable, a segmentation variable parameter PID control algorithm is adopted in the positioning control, and the error is divided into three segments according to different sizes of position errors during positioning.

(1) When $\left|e(k)\right| \geq \varepsilon_1$, the P controller is used at this time, $K_p = k_{p1}$, so that the response time of the system is faster and the overshoot is small.

(2) When $\varepsilon_2 \leq \left|e(k)\right| \leq \varepsilon_1$, use the PD controller, $K_p = k_{p2}$, $K_{\mathrm{i}} = k_{\mathrm{i}2}$, to speed up the system adjustment speed, shorten the system adjustment time, and reduce the steady state error.

(3) When $\left|e(k)\right| \leq \varepsilon_2$, use PID controller, $K_p = k_{p3}$, $K_i = k_{i3}$, $K_d = k_{d3}$, to improve the overall control accuracy of the system.

Among them, $k_{p1} > k_{p2} > k_{p3} > 0$, $k_{i2} > k_{i3} > 0$, $k_{d3} > 0$.

4 SYSTEM SIMULATION AND ANALYSIS

In order to facilitate the analysis of the relevant performance of the shipborne servo radar turntable control system, the motor model and the three closed loop control model of the azimuth axis are established, and the model is simulated and analyzed.

4.1 Motor Model

According to the selected servo motor, driver parameters and the magnitude of the received torque, the transfer function of the azimuth motor current and angular velocity is:

$$G_i(\mathrm{s}) = \frac{1}{0.0015s + 10} \qquad (1)$$

4.2 Triple Closed Loop Control Model Simulation

The step response model of "current + speed + position" triple closed loops and the sinusoidal signal tracking curve are established in the Simulink module of Matlab software. The sinusoidal signal tracking simulink simulation model is shown in Fig. 6.

Set the input signal to a sinusoidal signal with a magnitude of 1°, a frequency of 0.5 Hz, and a simulation time of 6 s. The sinusoidal signal tracking curve of the system can be obtained through simulation, and the sinusoidal signal tracking curve is shown in Fig. 7. According to the image display, the system tracking performance is good.

Set the input step signal to 1°/s, and perform mathematical simulation on the system. The step response diagram is shown in Fig.8. It can be seen that the speed loop response time is 30 ms, the rise time is 3 ms, the peak time is 6 ms, the transition time is 25 ms, and the overshoot is 2.25%.

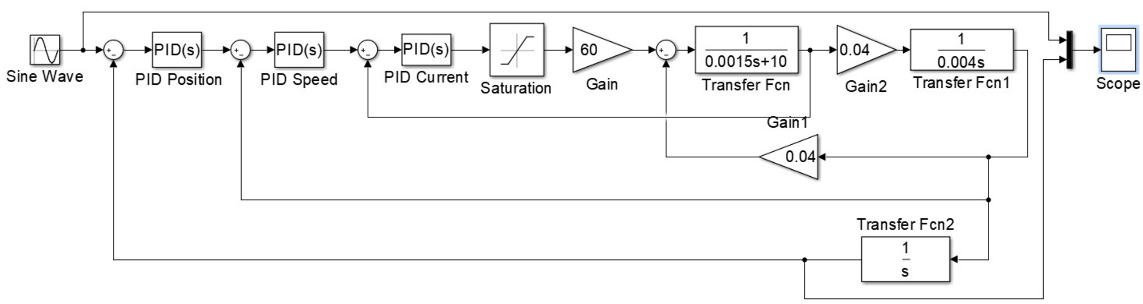

Figure 6. Sinusoidal signal tracking simulink simulation model

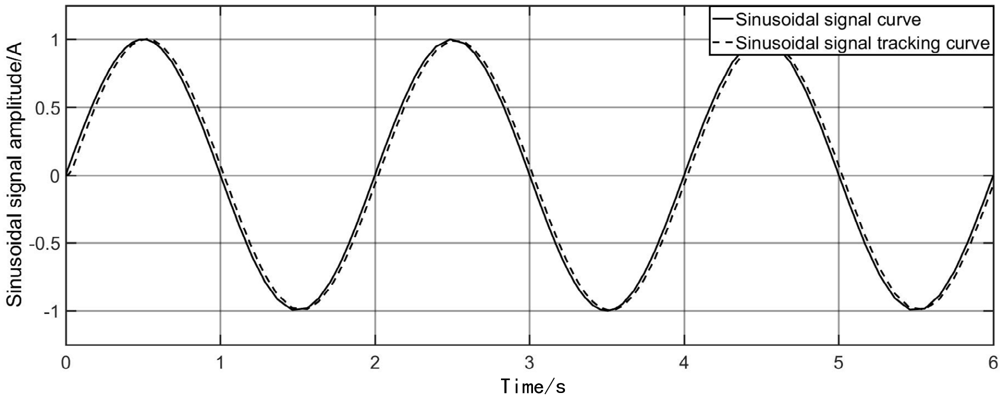

Figure 7. Sinusoidal signal tracking curve

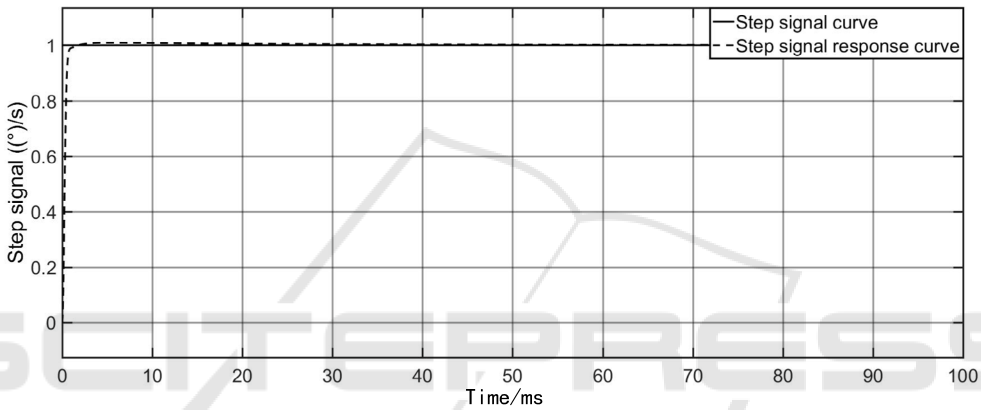

Figure 8. Step signal response curve.

5 CONCLUSION

This paper introduces the hardware and software design of the shipborne radar servo turntable control system, adopts the "current + speed + position" triple closed-loop control mode, and uses the "TMS320F2812+FPGA" chip as the servo control core to design the controller through Copley. The selection of the motor driver realizes the driving of the motor; through the segmentation variable parameter PID control algorithm, the high-precision positioning requirements of the shipborne radar turntable are realized, and the relevant control software design is carried out by using the CCS3.3 development platform.

The mathematical model of the servo system of the turntable is established. In the simulink module of Matlab, the three-closed control model of the system is simulated mathematically, and the response time of the step signal of the system is 30 ms. by simulating the tracking of the sinusoidal signal, the tracking performance of the system is verified.

At the same time, the relevant indicators are verified through experiments, and the actual indicators meet the requirements of the design indicators.

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