Control System of IMU Calibration Equipment Based on Multi Control Method

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Abstract. Compared with the previous inertial navigation calibration equipment using a single controller method, the IMU calibration equipment control system based on multiple control methods can be more customized and more flexible. The spindle controller uses a self-developed algorithm. It is realized in real-time control system, which has the advantages of high control positioning accuracy and high rate stability; the automatic turning device controller adopts mature industrial controllers and uses sequential function diagrams to realize the automation process, which is simple, stable and reliable, and can realize complex automation testing process. The two control methods use the way of TCP/IP communication to combine the advantages of the two controllers, shorten the development time, save costs, and achieve high performance, high efficiency and accurate testing.

1. Introduction
The inertial navigation system is an important part of a space vehicle. It plays an important role in national defence system such as space platforms, spacecraft, rockets, and missiles, and reflects the strength of a country's overall national strength. The error of the inertial navigation system is an important factor, affecting the navigation accuracy of the system and will directly determine the direction of the spacecraft rockets. The inertial navigation system mainly measures the angular velocity and acceleration of the carrier relative to the inertial space through IMU (Inertial Measurement Unit), uses Newton's law of motion to estimate the instantaneous velocity and position of the carrier, and uses the acceleration and angular velocity to calculate the attitude and orientation of the carrier[1].

To reduce IMU errors, error compensation technology is usually used to determine the error coefficients of gyroscopes and accelerometers through supporting testing of efficient and reliable inertial navigation test equipment, and compensation is performed in the inertial navigation system. The calibration effect of the inertial navigation system is closely related to the positioning accuracy and rate stability of the calibration equipment, and the calibration efficiency is closely related to the degree of automation of the calibration equipment. The above-mentioned required performance is mainly achieved by the control device of the calibration equipment. At present, most of the IMU test equipment is a three-axis turntable or a single-axis turntable without an automatic test function, which has a single form and low efficiency, and some test equipment have low speed and positioning

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accuracy [2]. Therefore, it is important to design an efficient, high-precision, and reliable inertial navigation calibration equipment control device.

2. Introduction to calibration equipment

2.1 Introduction to system organization

The composition diagram of the IMU calibration equipment system is shown in Figure 1. The system includes two parts: the control system and the mechanical structure. The mechanical structure includes an automatic turning mechanism and a spindle rotation mechanism. The automatic turning mechanism is responsible for turning the IMU device to a different surface for testing. These include the lifting mechanism, the left pushing mechanism, the right pushing mechanism, the turning mechanism and the pressing mechanism. The turning process is: when the main shaft rotates in place, the pressing mechanism rises, the left pushing mechanism and the right pushing mechanism are pushed out to lift and flip, after being turned into place, the lifting mechanism is lowered, the left and right pushing mechanisms are retracted, the pressing mechanism is extended, and the next action is performed. The main shaft rotation structure includes a load disc driven by a direct drive motor, which requires higher assembly processes and machinery.

![Figure 1. IMU calibration equipment system composition diagram](image)

2.2 Introduction to control system

The control system includes two parts: the spindle controller and the automatic turning controller. The integrated control system is responsible for the functional requirements of the control system such as communication, display, fault processing and data processing. The spindle controller is responsible for the control of the spindle motor. It uses a real-time control system and self-developed control algorithms to ensure high positioning accuracy and high rate stability of the spindle. Both the spindle controller and the comprehensive control system run on the equipment industrial computer. The automatic overturning controller adopts mature industrial PLC, which has the features of rich functions, simple programming and stability and reliability. It is suitable for the control of automatic processes. The schematic diagram of the composition of the control system is shown in Figure 2.
3. Multi-control method principle

The control system of the equipment is implemented by dual controllers. The spindle controller uses a self-developed algorithm and is implemented in a real-time control system. It has the advantages of high control positioning accuracy and high rate stability, but the procedure testing is more complicated and needs reliability. The automatic overturning device controller adopts a mature industrial controller and uses sequential function diagrams to implement the automated process. The implementation is simple, stable and reliable, but because the control algorithm is single and the real-time performance is not strong, higher rate stability cannot be achieved. The two control subsystems are connected through communication, combining the advantages of the two controllers, shortening the development time, saving development costs, achieving high-performance and high-efficiency accurate testing.

3.1 Spindle controller

In order to meet the higher control frequency, the spindle controller software uses the "Win32 + RTX" platform, and the software environment of the control system mainly includes Win32 and RTSS. RTX is a real-time extension subsystem from Ardence that works with the Windows kernel. By matching the Windows operating system with the RTX operating system, the timing accuracy can reach 100ns, which can meet the real-time and high-precision requirements required by the control system, and has good human-computer interaction [3-5]. In the control system software program design, data variables and parameter variables are mainly defined in the shared memory area, so the variables defined in the shared memory area can be implemented in Win32 and RTSS environments. Once a task is executed in Win32 and a variable in the shared memory area is changed, in the RTSS environment, the change in the shared memory area will be immediately detected, the control board will perform the corresponding operation and control the motor.

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3.2 Automatic turning controller
The controller of the automatic overturning device is implemented by Schneider Industrial PLC. The controller adopts a modular design, which has a higher degree of integration, is convenient for debugging and maintenance, and has strong anti-interference performance, ensuring that the control system can also work in the field environment with strong electromagnetic interference. The development environment is based on Schneider's own software. The communication method uses real-time industrial Ethernet CanOpen, which can realize sequential function chart programming and meet the requirements of automatic testing.

3.3 Control system workflow
The working process of the calibration equipment control system is as follows: As shown in Figure 4, the integrated control system on the equipment industrial computer exchanges instructions with the control system of the user's industrial computer. The integrated control system is responsible for unified control of the spindle controller and automatic turning controller. Flip to mark different positions. When the user sends a motion instruction, the integrated control system analyzes the instruction and controls the spindle controller to rotate, or controls the automatic flip controller to automatically flip through the ModBus/TCP protocol. During the flip process, certain positions require the spindle to move Angle, the auto flip controller automatically sends motion instructions to the spindle controller to control the spindle to perform the corresponding motion.

4. Experimental results
The main control indicators of IMU calibration equipment have three aspects, including the spindle position control error and rate stability under different rates, and the automatic test function.

4.1 Position control error and rate stability
The auto-collimator and the 23-sided prism are used to measure the steady-state positioning accuracy of the spindle in the rotation range. The drive motor moves and maintains at a fixed distance as a span, and measures it in the forward and reverse directions respectively, reads the data and records it. At each measurement position, the half of the difference between the maximum and minimum readings of
the collimator. That is the steady-state positioning accuracy of the axis. The measurement results show that the position control error is within $\pm 1^\circ$, which meets the requirements of the index.

For the index of rate stability, the frequency meter is used to measure the angle according to the timing measurement method. The results show that the rate stability of the spindle of the IMU calibration equipment meets the index requirements. The results are:

a) When $\omega < 1^\circ/\text{s}$, the relative error of the angular velocity at 1° is not greater than $5 \times 10^{-3}$;

b) When $1^\circ/\text{s} \leq \omega < 10^\circ/\text{s}$, the relative error of the angular velocity at 10° is not greater than $1 \times 10^{-4}$;

c) When $\omega \geq 10^\circ/\text{s}$, the relative error of 360° average angular velocity is not more than $5 \times 10^{-5}$.

4.2 Automated functional testing

Run the human-computer interaction interface, wait for the system is initialized. After the initialization is complete, the system performs self-test on the software and hardware of the host computer and the controller, and waits for the sending of user instructions. When the user sends a movement instruction, the corresponding spindle or automatic turning device starts the corresponding movement and feedbacks the current status information at once. Run continuously for 24 hours without failure, complete the test of three products, and realize automatic unattended testing.

5. Conclusion

Compared with the previous inertial navigation calibration equipment using a single controller method, the IMU calibration equipment control system based on multiple control methods can be customized to a higher degree and combines the advantages of the two controllers. Experiments show that this method can shorten the development time, save development costs, achieve high-performance and efficient precision testing.

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References

[1] Dai S W, Chen Q Q, Nie Z J. Overview of Strapdown Inertial Navigation System Online Calibration [J]. Navigation, positioning and timing, 2018,5(01):12-16.

[2] Tao Y, Guan J, Yuan S M. Review of the development of inertial navigation system error self-compensation technology[J]. Navigation, positioning and timing, 2014,1(01):8-12.

[3] Wang L, Deng H D, Kang F J, et al, Research of avionics integration simulation system based on RTX[J], Chinese Journal of Scientific Instrument, 2011,32(11),2475-2480.

[4] Mike Cherepov, Mike Hirst, Chris Jones, et al. Hard Real-time with Venturcom RTX on Microsoft Windows XP and Windows XP Embedded[R]. Microsoft MSDN, 2002.

[5] Ardence, a Citrix Company. R