Design and Implementation of Automatic Calibration System for MEMS-IMU

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Abstract:: Micro-Electro-Mechanical System (MEMS) IMU has been widely applied into the small inertial navigations. To provide the reliable accuracy of MEMS navigation system, error calibration is necessary before it is put into use, while the efficiency and reliability of its calibration are also taken into consideration. Automatic calibration technology can standardize calibration procedure and reduce human intervention, however, the current automatic calibration systems can only achieve semi-automatization of the calibration. To order to achieve full automation, a new automatic calibration system is designed in this paper. Firstly, the important functions are designed, which includes BISS encoder, serial communication and data acquisition based on FPGA; then the host software is also developed based on LabVIEW, finally the system achieves automatic calibration, data display, processing and calibration report generation. In the calibration of MEMS IMU, results show that the system can significantly improve efficiency of calibration.

1. Introduction

Micro-electro-mechanical systems (MEMS) inertial devices are an important direction in the research of MEMS technology, and also a prerequisite for the development of micro-inertial navigation systems. Because of its small size, low cost, high reliability and long life, MEMS inertial devices have been developed into a mainstream inertial navigation system. It can meet the application requirements of strategic missiles in precision. At the same time, the performance of the gyroscope has approached or reached the level of tactical navigation.

MEMS Inertial Measurement Unit (IMU) is mainly composed of inertial sensors (gyroscopes and accelerometers). The measurement accuracy of inertial sensors and the deterministic error of IMU in the process of mechanical structure design and assembly largely determine the accuracy of navigation[1-3]. Therefore, in order to achieve high-precision measurement, long-term performance testing and accurate

error calibration of inertial devices and IMUs must be carried out to obtain error model coefficients so as to achieve high-precision error compensation and motion information measurement in the process of navigation calculation. IMU calibration experiment includes multi-position static calibration and multi-rate dynamic calibration. In common, the output of IMU is obtained using the fixed input provided by the precision turntable, and the coefficients in the errors model are computed by analytic method[4-6].

Traditional IMU calibration requires manual operation of industrial control computer to control the movement of the turntable, data acquisition and storage also need special operation, the whole process is cumbersome and time-consuming, what's more, the efficiency is low. With the application of automatic test technology, various special inertial navigation system (INS) test systems have appeared one after another, realizing the functions of turntable control, data acquisition and processing, test results output and so on. The authors design an IMU automatic calibration system based on database technology[7]. The system realizes the functions of. However, the system is only designed for a calibration method like automatic data acquisition and storage, generation of calibration results report and so on and does not realize turntable control. In addition, the automation level is not high and the versatility is not good. An automatic calibration and testing system for flexible strap-down INS has been designed, which is based on the existing IMU automatic calibration system and independent turntable system[8]. But the navigation computer in SINS is introduced into the calibration system itself, which increases the hardware composition of the test system. There is no system demonstration and actual experimental results in this paper. For different calibration schemes, the turntable control software needs to be modified, and the system is not universal. Therefore, it is of great significance to design an automatic MEMS IMU calibration system with good versatility and high automation level to further improve the calibration efficiency, reduce the interference of various factors[9-10].

In order to solve the above problems, an automatic calibration system is designed to realize the functions of automatic control of turntable, automatic data acquisition and processing, and automatic calibration report generation. Finally, the validity of the design is proved by the actual test.

2. System Structure

2.1. System Composition

The automatic calibration system designed in this paper is divided into two parts: one is the hardware system, the other is software including the host software based on LabVIEW and embedded software based on VHDL. The hardware system includes a host computer, data acquisition system, turntable system and IMU to be calibrated. The data acquisition system is mainly composed of the minimum system circuit based on FPGA. The minimum system circuit realizes the information exchange among the host computer, the turntable system and IMU. The software realizes the functions of serial communication, time synchronization, data display, data processing, turntable control. The overall scheme of automatic calibration system (ACS) is shown in Figure 1.

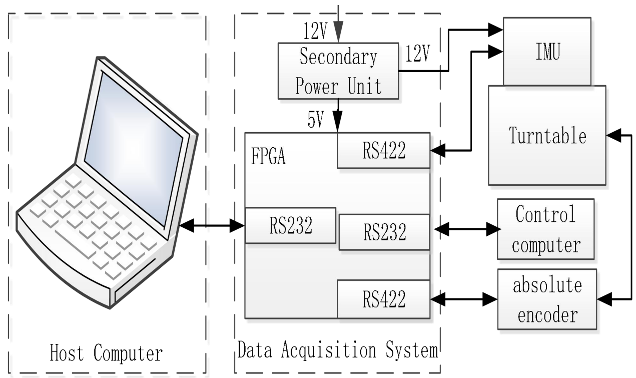

Figure 1: Automatic calibration system

2.2. System Workflow

The process of ACS is as follows: Firstly, the system is built and the correct electrical connection is confirmed. After the serial port is set up, the host software automatically run. Read instructions sequentially and test them according to instructions. If the test instructions require the turntable to move in position, the control instructions of the turntable are sent out by the test computer and transmitted to the turntable control computer through the minimum system circuit to realize the control of the turntable; the minimum system circuit collects the output data of the equipment to be tested and the feedback data of the turntable and sends them to the test computer in real time, and then executes them. After all the test instructions, the test software calls the data processing subroutine, calculates the target parameters, generates the test report, and records the test process and test results.

2.3. Design Of Hardware

The data acquisition system is based on XC3S400 FPGA designed by Xilinx and the corresponding peripheral circuit, in which RS422 interface is used to send MA clock, receive SLO position data from absolute encoder and navigation data of inertial navigation system, and respectively communicate with control computer of the turntable and host computer through RS232 interface. The XCF02S is selected as the FLASH chip, and the crystal oscillator with frequency of 25MHz is selected as the clock source of the system, as shown in Figure 2.

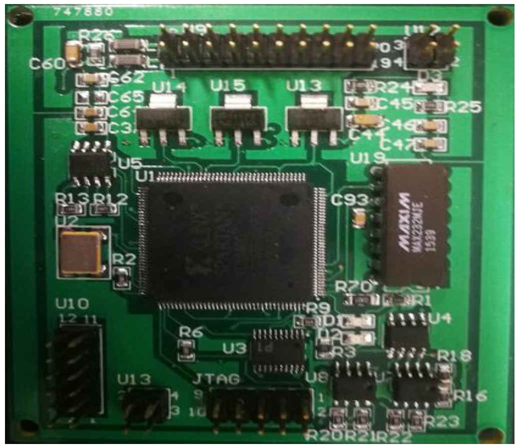

Figure 2: The data acquisition system

2.4. Design of Software

The host computer software is based on LabVIEW. The software mainly includes: serial communication module, data display module, turntable control module and calculation and result output module.

Serial port communication module receives IMU data and BISS data sent by the minimum system circuit of the FPGA and sends the control command of the turntable at the same time; data display module displays the output data of MEMS IMU under test in real time. The automatic calibration module sets up the corresponding instructions. The calculation and result output module realizes the comprehensive calculation of the test data and writes the calculation results into the specified files.

In order to complete the automatic test, it is necessary to control the turntable accurately. The motion of turntable is mainly position motion and speed motion, and the general test scheme is based on the above two kinds of motion. Position testing requires the turntable to rotate in multiple positions and remain stationary in a specific position. Rate testing requires the turntable to rotate around the rotation axis at different angular rates, and to keep the angular rate stable.

2.5. Experimental Verification

In order to verify the practicability and reliability of ACS designed in this paper, the system is applied to the IMU calibration experiment. The automatic calibration experiment of MEMS IMU is carried out by using the traditional twelve-position (equipment non-directional) test and calibration method. MEMS IMU is fixed on the inner axis of turntable, as shown in Figure.3. The calibration experiment of MEMS IMU is carried out at room temperature. The experimental process is as follows.

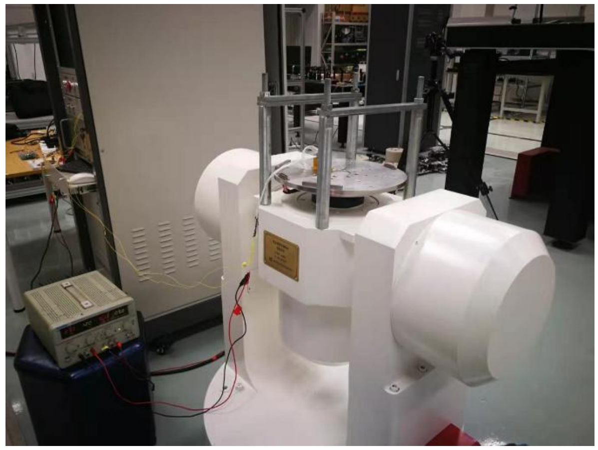

Figure 3: The turntable and MEMS IMU

1) Complete the electrical connection of hardware system;
2) Running host software;
3) The twelve-position test scheme is designed as automatic process;
4) According to the calibration method, the data collected in the calibration process is processed and the corresponding calibration parameters are calculated through calling MATLAB script in LabVIEW;
5) Output the calibration result file and end the calibration.

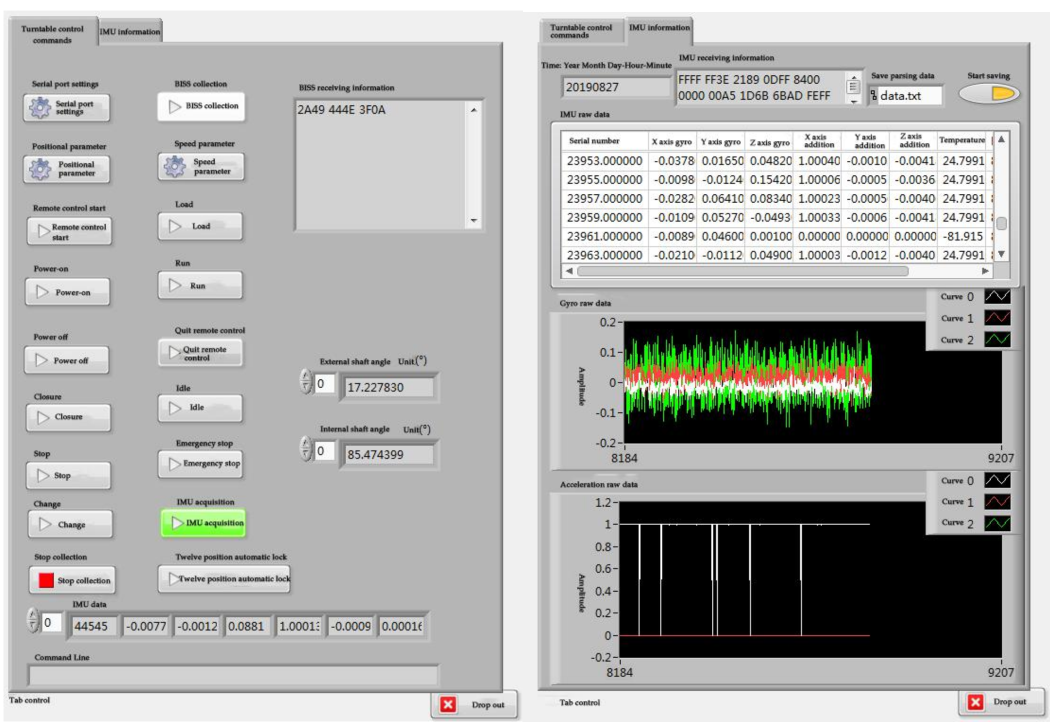

Figure 4: The interface of the host software

The main interface of the host software is shown in Figure 4. It mainly includes the following modules:

1) Setting up the module of communication serial port. Before the test starts, first select and open the communication port;

2)Real-time display module of IMU output data, displaying three gyroscopes, three accelerometers and multi-channel temperature information in IMU;

3)Manual operation module of turntable (for manual control of turntable, automatic calibration process is not used);

4)Real-time position information display module of turntable;

5) Automatic calibration display module.

After completing all position tests and speed tests, the data calculation and result output module of the software is invoked. The calculation method of the coefficients in the mathematical model of six-position test calibration is compiled with reference to document. Three zero offset, scale factor, installation error coefficients of gyroscopes, three constant offset, scale factor and installation error coefficients of accelerometers are calculated respectively. The corresponding coefficients of accelerometers as shown in Figure.5.

	zero offset	
0.000593370415018	0.033681749039272	0.008550557003381
	scale factor	
1.000085197079397	1.017092788879723	1.002874827978505
	installation error coefficients	
0.999983323979291	0.005041650605697	-0.002816650936487
0.000386998350173	0.993980486112874	0.109556576521408
0.000440849367617	-0.185021108136057	0.982734447954248

Figure 5: The results of the accelerometers

The calibration results show that the system can realize the calibration automation, simplify the calibration steps and improve the reliability of the calibration results. For the same twelve-position calibration scheme, ACS designed in this paper is used for calibration. The average time of a complete calibration experiment is reduced from 60 minutes to 30 minutes, which significantly improves the efficiency of MEMS IMU calibration.

3. Conclusions

This paper designs and implements an automatic calibration system for MEMS IMU. The automatic calibration system significantly improves the universality, scalability and efficiency of calibration. The calibration experiment of MEMS IMU is carried out using the automatic calibration system designed in this paper. The experimental results show that the system can automatically accomplish the task of MEMS IMU calibration, significantly improve the calibration efficiency, meet the requirements of calibration, and be of practical value.

Acknowledgments

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References

[1] LiuBaiqi, angJiancheng. Modified hybrid calibration method for IMU without orientation [J]. Chinese Journal of Scientific Instrument, 2018,29(6):1250-1254.

[2] YangGuoliang, WangWei, XuYefeng, FengPeide. Research on installation error analysis and calibration for LSINS based on rotation modulation [J]. Chinese Journal of Scientific Instrument, 2011,32(2):302-308.

[3] HONG Zhenchun，LIU Zhanchao，GU Bin.Design and implementation of a general automatic test system for POS[J]. Modern Electronics Technique,2016,39(2):95-100.

[4] ZHANG Hongliang,WU Yuanxin,ZHA Yabing,WU Meiping,HU Xiaoping.Calibration Errors of High-precision Inertial Measurement Units[J].Journal of National University of Defense Technology,2010,32(1):142-146.

[5] Aggarwal P , Syed Z , Niu X , et al. A Standard Testing and Calibration Procedure for Low Cost MEMS Inertial Sensors and Units[J]. Journal of Navigation, 2008, 61(02):323---336.

[6] Wang L , Hao Y , Wei Z , et al. A calibration procedure and testing of MEMS inertial sensors for an FPGA-based GPS/INS system[C]. International Conference on Mechatronics & Automation. IEEE, 2010.

[7] Bekkeng, J. K . Calibration of a Novel MEMS Inertial Reference Unit[J]. IEEE Transactions on Instrumentation and Measurement, 2009, 58(6):1967-1974.

[8] MORROW R B, HECKMAN D W. High precision IFOG insertion into the strategic submarine navigation system[C]. Position Location and Navigation Symposium，IEEE. Palm Springs, CA, USA：IEEE,1998:332-338.

[9] Aydemir G A , Saranl? A . Characterization and calibration of MEMS inertial sensors for state and parameter estimation applications[J]. Measurement, 2012, 45(5):1210-1225.

[10] Aslan G , Saranli A . Characterization and calibration of MEMS inertial measurement units[C]. European Signal Processing Conference. IEEE, 2008.