Multi-Channel and Simultaneous Data Acquisition System for Magnetic Tensor Detection

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Abstract. This paper reports the design of a multi-channel and simultaneous data acquisition system (MSDAS). It can collect 12-channel magnetic induction component signals with magnetic tensor information rapidly and simultaneously. The STM32F103RCT6 and a 16-bit AD7606 are used as the MSDAQ’s microcontroller and the analog-to-digital (A/D) converter, respectively. Moreover, FATFS file system and TCP/IP protocol are integrated such that the MSDAS is capable of local storage and network simultaneous data transmission in real time. Experiments show that MSDAS can achieve data acquisition error ≤0.5% with the simultaneous sampling rate up to 500Hz. It is verified that the measurement results of magnetic tensor are basically consistent with the theory.

1. Introduction

Weak magnetic measurement technology is an important detection method, especially in the field of marine environment monitoring and seabed mineral, oil-gas exploration, which can effectively collect, analyse and locate magnetic anomaly signal[1]. With the development of magnetic detection technology, magnetic tensor has become a significant part of low-frequency feeble magnetic field detection due to its strong anti-interference, higher spatial resolution, more complete and abundant magnetic-field information[2]. However, compared with magnetic-field intensity measurement and gradient measurement, magnetic tensor detection usually requires multiple magnetic field sensors to work at the same time, so the processing of large amounts of data, taller synchronization and accuracy of acquisition is essential. Therefore, it is necessary to design a MSDAS with high precision.

A MSDAS based on STM32 microcontroller unit (MCU) and AD7606 converter was designed for the data acquisition of magnetic-field tensor detection. The magnetic tensor detection device mainly consisted of four tri-axial fluxgate sensors with the same performance, which was arranged according to the shape of a cross[3]. Therefore, a total of 12 signals of the magnetic induction component needed to be collected. AD7606 is an A/D converter with 16-bit high precision, eight channels and 200ksps[4]. The combinations of the two data acquisition cards were extended to 16 channels, so the 12 channels of analog inputs could be collected at the same time. The network communication realizes that acquired data could be transferred to the host computer rapidly and in real time for data processing.

2. The Overall Design of Data Acquisition System

As shown in figure1, the data-acquisition system was mainly composed of two data-acquisition cards and the monitoring software. One data-acquisition card primarily consists of A/D conversion circuit, microcontroller, network communication circuit and data-storage circuit, etc.
The 12-channel magnetic signals collected by the A/D conversion circuit are transmitted to the microcontroller via SPI serial bus. The microcontroller processes and packages the data. Two data-acquisition cards have two outputs of network communication, so the network repeater could convert two inputs into one output that connected to host computer, and the data is stored in the SD card.

3. Circuit Design

3.1. A/D Conversion

The AD7606 data acquisition is shown in figure 2. It uses internal precision reference voltage[5] and is connected to STM32 through SPI interface as shown in figure 3. When the DB15 pin is grounded, the data transmission mode is SPI mode. BUSY pin connected to PB5 pin was set as an external interrupt pin, and RST pin was connected to PB6 as the reset pin. The acquisition trigger signal is connected to the CVA and CVB for the start conversion pin. In order to ensure the equal interval of data collection, the PWM working mode of MCU timer is used to generate the start signal of A/D. When the trigger signal is received, AD7606 begins to perform A/D conversion. After the conversion, the BUSY pin triggers the MCU interrupt, then it can read the data in the interrupt handler.
3.2. Network Communication and Data Storage

The network communication circuit’s control unit is W5500. It connects to STM32 via SPI interface, and schematic diagram is shown in figure 4. W5500 supports eight hardware sockets for independent communication. This network acquisition card uses two separate sockets for data port and command port respectively. The two ports work independently, which is helpful to the stable operation of network transmission. In order to make it easy for the client to recognize when it receives data, eight fixed values are added to the header of the data package. After receiving the data, the client verifies the data packet header, then processes, displays and stores the data.

Figure 3. Pin connection diagram

Figure 4. W5500 schematic diagram

Figure 5. SD card schematic diagram.
SD card is used for data storage and used the FATFS file system. During the working process of MSDAS, the AD7606 and W5500’s data communication is faster than that of SD card. So the overall operating speed is limited by the storage speed of the SD card. So the SDIO interface is adopted and shown in figure 5. Compared with SPI mode, the speed of SDIO bus is faster. Then the overall operating efficiency is improved.

4. The Software Design
The overall flow of software work is shown in figure 6. Firstly, the hardware devices are initialized. Then the TCP/IP parameters of W5500 were set and working mode is the server. Secondly, two sockets were initialized, and one is used as a data port and the other as a command port. The next step is to wait for the command sent by the client. After receiving the command, the interrupt handler is triggered, and corresponding tasks according to the command format were performed, such as setting the collection rate, starting collection, stopping collection, reading SD card and so on.

The computer monitor interface is made out with C# programming language. The software is regarded as a windows-based server. The host computer integrates the function of selecting and sending instructions, setting the storage path, real-time collection and display of multi-threaded and multi-client data, and data processing, etc.

Start

- hardware initialization
- set param of TCP/IP, SOCKET initialization

Wait for the request of client

- Is the client request received?

- Are command parameters received?

Judgement of the command format

- Set the collection parameters and start the collection
- stop
- Stop collecting and read data of SD card

Figure 6. Software workflow

5. Experimental Result

5.1. The Voltage Acquisition
Input voltage value and test the accuracy of measured voltage. The test results are shown in table 1. The maximum measurement error of the eight channels is less than 0.5%, which can meet the system measurement requirements.
5.2. Magnetic Tensor Measurement

The MSDAS is designed for the magnetic-field data acquisition. So we have performed an experiment to test. The magnetic sensor probe consists of four same fluxgate, which arranged in the shape of a cross. The effect of data collection was tested by measuring the external magnetic field. The experimental flow design is shown in the figure 7.

The magnetic tensor detection device is an open-loop system. In order to reduce the influence of geomagnetic field, we used a signal generator to generate 45Hz ac signal with an effective current value of 80mA, and the Helmholz coil would generate a magnetic field to be measured. Four fluxgate sensors are placed on a 3d-printed cross structure. After the sensor is powered, the detection signals of 12 magnetic induction components are appeared. The sensor body converts the magnetic-field signal into the voltage signal then outputs through the port. The analog voltage signals are passed into the data acquisition card and transmitted to the host computer for display via the cable.
Figure 8. Partial raw data

Figure 9. Data spectrum analysis

When the data acquisition has been finished, the storage files can be read and processed. The data of one channel partly showed in the figure 8. It is obvious that the frequency of data is mainly direct flow and 45Hz component as shown in figure 9. So it is useful for us to get more accurate results in a band-pass filter. There are 12 storage files corresponding to the 12 channels. The magnetic tensor can be calculated by the 12 signals from twelve channels at the same time.

The magnetic tensor contains nine elements, and the number of independent elements is five [6]. So the 12 signals are enough to get five elements of the tensor.
Table 2. Calculation results (unit/(μT/m)).

| Element     | $\frac{\partial B_x}{\partial x}$ | $\frac{\partial B_x}{\partial y}$ | $\frac{\partial B_y}{\partial x}$ | $\frac{\partial B_y}{\partial y}$ | $\frac{\partial B_z}{\partial x}$ | $\frac{\partial B_z}{\partial y}$ |
|-------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Theoretical value | 101.48                            | 4.35                              | 27.10                             | -29.70                            | 0.43                             |
| Actual value  | 101.05                            | 4.30                              | 27.22                             | -32.39                            | 0.44                             |

In fact, the position of the tensor probe has deviation. So the position offsets less than 1 cm is considered in theoretical calculation, then the real value is close to the theoretical value as shown in table 2. According to the results, the MSDAS could detect the weak magnetic field effectively, and the magnetic tensor is related to the relative location of the sensor and the magnetic-field source.

6. Conclusion

In order to detect magnetic tensor of the weak magnetic field, the MSDAS with 16 channels was designed and tested. Data-acquisition system could collect signals of 16 channels simultaneously. From the results, measurement agrees with theory, and the interference of environmental magnetic field does not affect the measurement. MSDAS could detect the weak magnetic field with low frequency available. The data-storage files are completely and orderly, which is important to further signal processing or analysis. Algorithm of magnetic tensor will be programmed and solidified in the following study.

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