A design of alternating magnetic field analysis and storage module based on embedded MCU

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Abstract. Aiming at the demand of low frequency alternating magnetic field signal extraction function in the background of marine environment, a set of low frequency alternating magnetic field signal processing and storage module is designed based on embedded MCU. The module uses a FatFs file system and a micro SD card with spectrum analysis and line spectrum extraction. Finally, the function of the module was verified by data simulation and Helmholtz coil test.

1. Overview
The background magnetic field of the marine environment includes the geomagnetic field and the low-frequency alternating magnetic field generated by waves, currents and the like. In order to realize the effective measurement and extraction of low frequency alternating magnetic field signals in the background of marine environment, based on embedded MCU, combined with FatFs file system and SD card driver, a set of clock sampling, input conversion, data storage, low frequency intersection is designed. Combined with power spectrum analysis and alternating magnetic field signal line spectrum, the autonomous acquisition and analysis of low-frequency alternating magnetic field signals can be realized, and the ability to test and analyze the low-frequency alternating magnetic field in the marine environment is improved. Utilizing the rich interface and control capabilities of the embedded MCU, communication and signal transmission with other devices can be realized, and the applicability of the module is improved. Finally, the performance of the system was verified by data simulation and Helmholtz coil simulation of alternating magnetic field.

2. System composition
The main function of the low-frequency alternating magnetic field data acquisition and analysis module of the marine environment background is to perform power spectrum analysis and line spectrum extraction on the alternating magnetic field signals collected by the front-end sensor, and the raw data and the analysis extracted results are performed in the Micro SD card. The data processing and storage module designed in this paper has the characteristics of small size, low cost, large data storage capacity, large operating temperature range and strong scalability. It realizes the extraction and storage of low-frequency alternating magnetic field signals in the marine environment background. Using the Micro SD card as the carrier for storing data, data reading is convenient and effective after the collection. The main technical indicators of the module are as follows:

1. The module is powered by battery and the working voltage is +5V.
2. The signal sampling rate is 1Hz, which can realize data processing and storage in real time.
(3) Using the FatFs file system which is easy to transplant, open source and occupying relatively small hardware resources;

(4) The external Micro SD card realizes miniaturization while satisfying the basic functions of the SD card;

(5) The module includes one RS232 bus and one RS485 bus to realize real-time data reception.

The function block diagram of the system is shown in Figure 1. When receiving the data from the sensor, the main control chip saves the original data to the Micro SD card for backup, and performs power spectrum analysis and line spectrum extraction on the other hand. The result of the data processing is then stored in the form of a file on the Micro SD card. The main control chip analyzes the results of power spectrum analysis and line spectrum extraction and reports to the host computer.

![Figure 1: Module functional block](image)

3. Hardware design

3.1. MCU

The system’s main control chip uses the LPC1768 microcontroller produced by NXP, which operating frequency is up to 100MHz. The Cortex-M3 core features a 3-stage pipeline and Harvard architecture with separate local instruction and data buses and a slightly lower performance third bus for peripherals. The peripheral components of the LPC1768 microcontroller include up to 512kB of flash memory, 64kB of data memory, Ethernet MAC, USB master/slave/OTG interface, 8-channel general purpose DMA controller, 4 UARTs, 2 CAN channels, 2 SSP controllers, SPI interface, 3 I2C interfaces, 2-input and 2-output I2S interfaces, 8-channel 12-bit ADC, 10-bit DAC, motor control PWM, quadrature encoder interface, 4 universal timing General-purpose PWM with 6-output, RTC with independent battery power, and up to 70 general-purpose I/O pins.

3.2. Module structure

The hardware structure of the low-frequency alternating magnetic field data acquisition and analysis module of the marine environment background is shown in Figure 2. The module consists of the following sub-function modules: power module, reset module, clock module, serial communication interface, debug interface, and storage module.

![Figure 2: Hardware structure](image)
The clock module includes two external crystals. One is the main clock oscillator that provides the main clock for the internal circuit operation of the chip, and the size is 12MHz. The other is the RTC oscillator that provides the clock signal for RTC, PLL0 and watchdog timer, which frequency is 32.768kHz. The main crystal oscillator is processed by the phase-locked loop inside the chip and the clock divider to lock the frequency into a stable internal working clock signal. The communication module consists of RS232 and RS485 interfaces and is responsible for receiving and transmitting data and commands. In addition, in the debug mode, the serial communication interface can also be used to receive debugging information of the internal program of the MCU. The function of the storage module is mainly implemented by an external SD card, and the original data and processing results are stored in the SD card. The reset module provides initialization operations for the system. The debug interface uses the SWD mode, which has fewer pins, a simpler structure, and higher reliability than the traditional JTAG mode.

4. Software design

4.1. SD card driver

4.1.1 SPI mode of SD card. The operating protocol of the Micro SD card is identical to the SD card, but the size is much smaller than the SD card. The SD card supports two modes of operation: SD mode and SPI mode. The SD mode data transfer speed is faster than the SPI mode, but the SD mode protocol is complicated. Some low-end, low-cost MCUs do not support the SD interface, but the SPI interface can also be used to communicate with the SD card to achieve data storage requirements. This design uses the SPI mode of the SD card. In the SPI mode, only four pins of the SD card are used: the chip select signal line CS, the serial clock line CLK, the host to card data signal line DI, and the card to the host data signal line DO.

In SPI mode, the SD card works in a "command + answer" mode. For any instruction sent by the host, the SD card always returns a response to the command, and the response structure is divided into 8 or 16 bits depending on the command. An error response is returned even if a data transfer error is encountered.

4.1.2 SD card initialization. The SD card needs to be initialized before the SD card can be read and written normally. The SD card driver designed by this system supports the SD specification standard 2.0 and is compatible with the 1.0 standard. In the process of initializing the SD card, the identification of the SD card type, capacity, and the like is mainly completed. After the SD card is inserted, it enters the SD mode by default. After the card is powered on, it needs to be delayed by at least 74 clock cycles. This includes a process of boosting about 64 clock cycles to achieve the normal working voltage of the SD card, and about 10 clocks. Cycle to synchronize with the SD card. The reset operation and SPI mode selection can then be performed.

4.1.3 R/W of SD card. The read and write operations of the SD card are performed in units of blocks, and the length of the block is generally 512 bytes. The read block operation uses the instruction CMD17. After sending the command, it receives 0x00 as a valid response, then the SD card will send a start token (token) to the SPI bus, the token will follow the valid data, and finally end with the 16-bit CRC. The write block uses the instruction CMD24, and the data format is the same as the read block. Different from the read single block process, after the host sends a block of data to the bus, it also needs to wait for the 8-bit code back of the SD card and the operation completion instruction 0xFF. When the host reads the operation completion command on the bus, it indicates SD. The internal operation of the card ends and the data is written successfully. The multi-block data read instruction CMD18, after receiving the valid response, starts receiving the start token and the valid data. After receiving all the block data, the stop transmission command CMD12 is sent to complete the read operation. Write multiple blocks of data using the command CMD24, after receiving a valid response, start sending data. Each block of
data consists of a start token (0xFC), valid data, and a 16-bit padding. After sending all block data, send 0xFD to stop transmission and complete the write operation.

4.2. Porting of FatFs file system
The FatFs file system is a completely free and open source FAT file system module designed for small embedded systems. It is written entirely in standard C and has good hardware platform independence and portability. FatFs supports FAT12, FAT16 and FAT32, supports multiple storage media, has a separate buffer, and can read and write multiple files. The hierarchy of FatFs is shown below:

![FatFs hierarchy diagram](image)

The top layer is the application layer. You don't need to care about the internal structure of FatFs and the complex FAT protocol. Users only need to call a series of API interface functions provided by FatFs, such as f_open, f_close, f_read, f_write. The system layer implements the FAT file read/write protocol, and can directly include the header file when it is used. Generally, no unnecessary operations are required. What needs to be modified by the user is the underlying structure provided by the FatFs module, which includes the read/write interface of the storage medium and the real-time clock for the modification time of the file creation.

The version of FatFs used in this module is 0.13c. The migration process is divided into two phases:

1. File system configuration. First, configure the ffconf.h file for the actual needs of the project, and perform function clipping on the file system.

2. Interface function writing. After configuring the ffconf.h file, write the interface functions in the diskio.c file, including obtaining the disk state function disk_status(), the disk initialization function disk_initialize(), the read data function disk_read(), the write data function disk_write(), and the disk control function disk_ioctl() and time information function get_fattime() to achieve the coupling between the file system and the SD card driver function. Then you can read and write to the SD card by calling the API interface function provided by FATFS.

4.3. Signal spectrum analysis and extraction method
The power spectrum of the signal reflects many important characteristics of the signal. Using the line spectrum and continuum characteristics of the signal power spectrum to identify and classify the target is an important part of signal processing in the fields of sonar, radar and noise analysis. The power spectrum of the ocean environment magnetic field is a superposition of the typical low frequency line spectrum and continuum spectrum, reflecting the characteristics of the background magnetic field from two aspects. The advantage of obtaining the power spectrum according to the fast Fourier transform (FFT) of the signal is that the operation is simple, the speed is fast, and the physical meaning is clear, but this will result in a large dimension of the generated feature data, and the need to generate a lower-dimensional feature vector. Further lower the dimensions. When doing classical spectrum analysis, the algorithm of the direct cycle diagram method is shown in the figure below.
The periodic map estimation algorithm of the N-point data x(n) is as follows:

1. Segmenting the N-point data x(n), the length of each segment is set to L, if there is no overlap in each segment, there are 88 segments, and if each overlaps, there are 88 segments;

2. The data of each segment after segmentation shows xi(n), i=1, 2, 3, ..., M, n = 1, 2, 3, ..., P, select P point window function w(n), find yi(n)=xi(n) * w(n) for each window function segment;

3. Find the fast Fourier transform Yi(k) of point P yi(n);

4. Calculated power spectrum

\[ P_i(k) = \frac{1}{P} |Y_i(k)|^2 \]

5. Find the average period map

\[ p(k) = \frac{1}{MU} \sum_{i=1}^{M} P_i(k) \]

where \( U = \frac{1}{L} \sum_{n=1}^{P} w^2(n) \) is the normalization factor.

The detection, tracking and recognition of the characteristics of line spectra play an extremely important role in the use of sonar. People have studied this, including the criteria and criteria of line spectrum, the generation mechanism of line spectrum, and the characteristics of line spectrum. Extract and so on. Underwater target signals have many line spectral components that contain a lot of useful information. From the spectrum point of view, the line spectrum is characterized by a much higher amplitude than the adjacent one, and the width is also narrower. Through this feature, it can be searched out from the power spectrum by some methods, as follows:

1. Define a width value and an amplitude value. The so-called width value is the minimum of the multiple of the line spectrum amplitude higher than its adjacent amplitude; the so-called amplitude depreciation is the maximum value of the line spectrum width. The width value is affected by the resolution, and as the resolution increases, the width depreciation decreases; the resolution decreases as the width depreciation increases. The amplitude depreciation used in this system is 6pT, which means that when the line spectrum amplitude exceeds 6pT, the width depreciation is 7df Hz (df = fs/512).

2. Search whether there is a line spectrum point that satisfies both the amplitude depreciation and the width depreciation in the entire frequency interval, and if so, records the position and amplitude of the line spectrum point that satisfies the condition.

5. Performance verification

During the actual simulation test of the low-frequency alternating magnetic field data processing and storage module, the main control chip LPC1768 is set to operate at a frequency of 100 MHz, and a Kingston Micro SD card with a capacity of 2G is used. The Matlab software and Helmholtz coil are used to simulate the low-frequency alternating magnetic field environment in the marine environment. The test results show that at 1 Hz sampling frequency, the module can successfully acquire data and perform power spectrum analysis and line spectrum extraction. The data processing results are accurate and the storage is normal. The module can work continuously for more than 48 hours.

6. Conclusion

In this paper, based on the requirements of effective measurement and extraction of low-frequency alternating magnetic field signals in the marine environment, a set of functions based on embedded MCU, combined with FatFs file system and SD card drive, spectrum analysis and extraction with low-frequency alternating signals are designed. Data processing and storage modules. The analysis and storage function of the low frequency alternating magnetic field signal in the marine environment is realized. The data simulation and Helmholtz coil test are carried out. The test results show that the
module can stably complete the analysis and storage function of low frequency alternating magnetic field data.

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