Design and development of rotary machinery vibration monitoring system

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Abstract. This paper designs and develops a monitoring system for rotary mechanical vibration. The system uses ARM+FPGA dual processor combination, FPGA control signal acquisition and data transmission, ARM transplantation embedded Linux system with touch screen to complete signal analysis and time domain, frequency domain curve display. The vibration signals of multiple positions on the mechanical device are synchronously sampled, and the FFT analysis of the signals is completed on the terminal, and the vibration waveform diagram and the spectrum diagram of each channel are displayed. At the same time, the system combines current IoT technology and cloud diagnostic technology to provide wired and wireless network communication solutions. The monitoring system can connect to the cloud server through the Ethernet interface and the WiFi interface to perform cloud diagnosis on the device.

1. Introduction
The mechanical equipment in modern industrial production is developing towards large-scale, complicated, high-speed, automation and high-power. The coupling degree between different parts of the equipment is more compact, and one component fails, which may cause the entire production process to terminate, resulting in Major accident [1]. The rotary machinery and equipment occupy a considerable proportion in the industrial sector and are the key equipment in the factory. The monitoring and analysis of the rotary machinery and equipment can not only find the fault of the equipment in time, but also effectively prevent the occurrence of faults and facilitate the timely maintenance of the equipment. To extend the life of the device. The early workers judged the cause and location of the mechanical failure based on the noise level and vibration degree of the rotary machine. This method is easy to cause misdiagnosis or missed diagnosis, and the experience of workers is very high [2]. Aiming at this problem, this paper designs a revolutionary vibration monitoring terminal based on the Internet of Things. The terminal can not only perform on-site signal analysis and display, but also provide a network transmission interface and cloud platform docking function, which can use powerful cloud computing capabilities to conduct a more in-depth diagnosis for the device.

2. System overall design
The vibration monitoring system can be divided into two parts, one is the design of the communication scheme based on the Internet of Things, and the design of the monitoring terminal scheme.

For communication with the cloud server, the system uses WIFI communication and Ethernet communication to complement each other. When the wireless transmission interference is large, the Ethernet interface is used, and the WIFI interface is used when the wiring is troublesome. After the monitoring terminal establishes a connection with the cloud server, receiving the read command of the
cloud platform uploads the state data of the device during the period, and allows the cloud server to analyze the vibration signal to complete the diagnosis. When the vibration amount of the device exceeds the alarm value, the terminal will not only issue an audible and visual alarm, but also upload the fault data of this stage to the cloud server [3].

Regarding the design of the monitoring terminal scheme, the monitoring system should complete the functions of multi-channel acceleration signal high-speed synchronous sampling, FIR filtering, multi-interface data transmission, signal processing and display, as shown in Figure 1 below.

![Vibration monitoring system internal workflow](image)

3. System hardware design

The hardware circuit design of the vibration monitoring system can be divided into three parts. The first part is the selection of the acceleration sensor and the corresponding power supply circuit and amplifier circuit design. The second part is the signal acquisition and transmission circuit design with FPGA as the control core. The third part is the design of the display processing circuit of ARM as the main control chip. The overall structure is shown in Figure 2.

![System hardware overall structure](image)

3.1. Acceleration sensor selection

This paper chooses to measure the acceleration signal of the gearbox and bearing, using a piezoelectric sensor, which can convert the acceleration of the measurement object into a proportional voltage or charge. After considering factors such as sensitivity, frequency range, range, internal structure, and installation environment, two types of unidirectional HD-YD-232 and three-way HD-YD-213 sensors are selected. The sensitivity is 100mV/g, the frequency range is 0.5~6KHz, and the maximum allowable...
acceleration is $5 \times 1\text{00m}\cdot\text{s}^{-2}$. The acceleration of the gearbox and bearing of the machine under test does not exceed 10g, and the vibration frequency is within 2KHz, so the range and frequency range of the sensor meet the requirements. The sensitivity of the two sensors also meets the measurement accuracy requirements of the system.

3.2. Processor selection

3.2.1. FPGA chip selection
The system selects the EP4CE10F17C8 chip from ALTERA's Cyclone IV series. The chip has a low-cost, low-power FPGA architecture, 10320 logic cells, and 414Kb of embedded memory. Users can use up to 179 I/Os, and their I/O supports programmable bus hold, programmable pull-up resistors, programmable delay, programmable drive capability, and programmable slew-rate control for signals Integrity and optimization of hot swap.

3.2.2. ARM selection
The vibration monitoring system uses the embedded Linux system to complete the data analysis and display work. Considering the power consumption, development difficulty, cost and applicability, the S3C6410 chip based on the ARM1176JZF-S core is selected. It provides a variety of hardware peripheral interfaces, such as TFT liquid crystal display control interface, 4-channel UART, 32-channel DMA, SPI bus interface, USB, etc., which can effectively reduce the development difficulty.

3.3. Signal Conditioning Circuit Design
The signal of the sensor can be converted into a standard signal through the conditioning circuit to access the AD chip. In this paper, a constant current source circuit is needed to supply power to the sensor, and the signal needs to be amplified and filtered. This paper uses software filtering, so only the signal amplification circuit is designed.

A constant current source is a current source whose output current does not change as the load and ambient temperature change. In order to obtain a high-precision, stable and reliable constant current source, the device for building the circuit should not be too much, and the connection method should be as simple as possible [4]. This system uses LM334 to form a constant current source circuit. However, the output current of the LM334 changes with temperature. To prevent the temperature change from affecting the output current, a diode and a resistor are added outside the LM334 to cancel the temperature dependence of the chip.

The sensitivity of the sensor is 100mV/g, and the vibration acceleration of the machine under test is less than 10g, which means that the voltage output of the sensor is between ±1V. The AD chip used in this article is input at ±5V, so the design is a five-fold amplification circuit.

3.4. Communication interface circuit design
The vibration monitoring terminal needs to transmit the signal data to the cloud server through the Ethernet network or the WiFi network, and transmit it to the PC through the serial port and the USB port. The various interface circuits are described below.

3.4.1. 232 interface circuit design
This paper chooses RS232 interface, which can achieve two-way data transmission, full-duplex communication, and is widely used in short-distance transmission. The FPGA pin input and output are TTL level, and the RS-232 uses a negative logic level, so a level shifting chip is required. The circuit diagram is shown in Figure 3.
The vibration terminal communicates with the host computer through the serial port. The baud rate, the number of data bits, the number of stop bits, and the presence or absence of parity bits need to be consistent. Otherwise, a reception error will occur.

3.4.2. USB interface circuit design

The USB chip selected in this article is FT245 produced by FDTI, which is USB independent for parallel FIFO bidirectional data transmission interface.

The chip has a data transfer rate of up to 1MB/s. The chip connection circuit is shown in Figure 4.

4. System software design

The vibration monitoring system performs analysis and display functions on the signal data using an embedded Linux system. This article uses the Tiny6410 development board, transplants the embedded Linux system on it and builds a cross-compilation environment on the PC, writing drivers and applications in C++ and C.

4.1. Device driver design

In this paper, the system needs to read the sensor signal data from the FPGA. It also needs to pass the sampling frequency and alarm information to the FPGA. The application program cannot directly operate the hardware, so it is necessary to design the corresponding driver. There are three kinds of device drivers under Linux, namely character device driver, block device driver and network device driver. This paper designs the character device driver, as shown in Figure 5 below.
After the application calls open, read, write, etc., the library file executes the swi instruction to cause the CPU to be abnormal, so that it enters the kernel smoothly, and then the kernel finds the corresponding driver and executes it, thus completing the operation of the peripheral [5]. For the slow transfer of bulk data and insufficient storage space, this article uses mmap memory mapping to solve.

### 4.2. Fast Fourier Transform

In vibration monitoring, only observing the time domain waveform of the device is not enough to analyze the current state of the device. Each fault has its own unique frequency. If you look at the frequency domain, you can roughly see that the device has appeared. What kind of failure. FFT is an efficient algorithm based on discrete Fourier transform, which can switch a signal from time domain to frequency domain. Therefore, FFT is often used in signal analysis [6]. In this paper, the FFT is used to extract the frequency domain data of the vibration signal and draw the spectrum image.

### 4.3. Qt application design

This paper requires the vibration monitoring system to display the time domain and frequency domain curves of the eight-channel sensor signal, so you need a control that can draw the axis. The workflow of the designed Qt application is shown in Figure 6.
5. System test
In order to verify the correctness of the waveform display, the Tiny6410 development board is turned on, set to 3-channel display, channel 1 (blue line) is connected to the signal generator, and the signal generator generates a sinusoidal signal with a frequency of 21.23 Hz and a peak-to-peak value of 6V. The channel (red line) is grounded, and the 3 channel (green line) is connected to a 3.3V power supply. As shown in Fig. 7, the red and green lines are straight lines, which correspond to a fixed voltage, and the blue line is a wavy line, which corresponds to a sinusoidal signal. Channel 1 shows a frequency of 21.48 Hz with an error of 1.18%. Channels 2 and 3 have a frequency of 0, which is consistent with the actual.

Figure 6. Qt application flow chart

Figure 7. Sine wave result graph
6. Conclusion
Based on the actual requirements of vibration monitoring of rotating machinery, this paper designs a multi-channel vibration signal monitoring system based on the Internet of Things. The system can not only perform signal analysis on the lower computer, but also transmit data directly to the cloud server through the WiFi or Ethernet interface for cloud diagnosis, or transmit it to the PC through the serial port and USB interface for analysis.

References
[1] Wang Lirong. (2008) Research on equipment vibration monitoring analysis and diagnosis system. North China Electric Power University, Beijing.
[2] Zhao Zhihong. (2012) Research on Mechanical Fault Feature Extraction and Diagnosis Based on Vibration Signal. Beijing Jiaotong University.
[3] Song Xinchao. (2013) Design and development of production data collection and management terminal based on WIFI technology. Nanjing University of Science and Technology.
[4] Sha Changyuan. (2015) Research on ship vibration signal acquisition and data analysis. Shanghai Jiaotong University.
[5] Wei Dongshan. (2008) Complete Manual for Embedded Linux Application Development. People's Posts and Telecommunications Press.
[6] Atoui I, Meradi H, Boulkroune R, et al. (2013) Fault detection and diagnosis in rotating machinery by vibration monitoring using FFT and Wavelet techniques. International Workshop on Systems. IEEE, 2013:401-406.