Design of motor online monitoring system based on ARM

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Abstract. In order to monitor the operation status of motors accurately in real time, and realize the early warning of abnormal operation of motors, a motor online monitoring system based on ARM is designed. The system uses STM32F103ZET6 microcontroller based on ARM Cortex-M3 core as the control core to monitor the motor temperature, vibration, environmental temperature and humidity and other related parameters, which communicates with the upper computer through wireless transmission, and the upper computer completes data display, storage, processing and alarm. The results show that the motor online monitoring system has the advantages of strong real-time performance, high measurement accuracy, high stability and long transmission distance.

1. Introduction

Motors are widely applied in industrial production. As power equipment, they are frequently used in metallurgy, coal industry, chemical and other industrial field under severe conditions. If the motor faults during operation, it may result in the paralysis of whole production line, which will cause great losses to users [1]. Therefore, the development of a kind of motor online monitoring system to realize the early warning of abnormal operation of the motor is of great significance to ensure the safe operation of the motor and reduce the maintenance cost of the motor.

At present, many motor users generally use off-line detection system to detect the motor running state. This method requires technicians to use hand-held instruments to check the motor running state regularly [2]. If the parameters value detected exceeds the upper threshold, field maintenance will be needed, which is of poor intelligence and low accuracy, and there are no defense measures for the production line fault caused by the sudden abnormal of the motor.

The online motor monitoring system designed in this paper uses the STM32F103ZET6 microcontroller based on ARM Cortex-M3 kernel as the control core, collects and processes the data measured by each sensor, and transmits the data to the upper computer by wireless communication. On the upper computer, a graphical user interface is programmed using LabVIEW to realize the functions of motor data collection, display and alarm.

2. System hardware design

The system consists of STM32F103ZET6 microcontroller minimum system, power conversion circuit, sensors, signal conditioning circuit and wireless transmission module. The system structure is shown in Figure 1.
2.1. STM32 microcontroller
The controller of the system is STM32F103ZET6, a 32-bit microcontroller based on Cortex-M3 kernel designed by ARM. The chip has a maximum operating frequency of 72MHz, 512k byte flash program memory, 64K byte SRAM, three 12 bit analog-to-digital (AD) converters (up to 21 input channels), two 12-bit analog-to-digital (DA) converters, 12 channel DMA controller, up to 112 fast IO ports, up to 11 16-bit timers, 13 communication interfaces and CRC computing unit [3]. The microcontroller can be used in embedded applications with high integration and low power consumption, and can be used in various complex computing control situations to meet the design requirements of the system.

2.2. Power conversion circuit
Figure 2 is the power conversion circuit diagram of the motor online monitoring system, which adopts AMS1117-3.3 and AMS1117-5.0 voltage regulator chips. AMS1117 is a series of Low-dropout Linear Regulator with 1% accuracy and integrated overheat protection and current limiting circuits.
The input port uses DC12V/1A power adapter to filter the 220V electric supply, convert it to 12V DC. Then the circuit input it to AMS1117-3.3 and AMS1117-5.0 voltage regulator chips, which convert it to 3.3 V and 5 V respectively. Among them, 3.3V is mainly responsible for the power supply of STM32 microcontroller, while 5V and 12V are for the power supply of sensors, signal conditioning circuit and wireless transmission module.

2.3. Sensors circuit

2.3.1. Motor temperature measurement circuit.
Pt100 platinum resistance sensors are usually embedded in the three-phase windings, stator core and bearing surface of medium and large motors, so the embedded thermometer method is adopted, while the surface thermometer method is adopted for the air inlet/outlet temperature and the shell surface temperature [4]. The motor temperature measurement is composed of Pt100 platinum resistance sensor and constant current source signal conditioning circuit. The circuit is shown in Figure 3.

![Motor temperature signal conditioning circuit.](image)

Constant current source uses LM317 chip. LM317 is an integrated three terminal voltage regulator with variable output voltage, which is widely used. The principle of the constant current circuit is: The Vin pin of LM317 is connected with 5V supply, and one side of a precision resistor is connected with the Vout pin, while the other side is connected with the ADJ pin as the constant current output. Because of the reference voltage of 1.25V between the Vout pin and the ADJ pin, the current through the resistor can be controlled by setting the resistance value. The constant current source output is

$$I_{out} = \frac{V_{ref}}{R_1} = \frac{1.25V}{125\Omega} = 10mA.$$  \hspace{1cm} (1)

The system uses a 125-ohm precision resistor, which can lead to the output current of 10mA. Then one end of Pt100 platinum resistor is grounded, and the other end is connected with the constant current source output, and connected to the AD conversion channel of STM32. The voltage across the platinum resistor can be measured, and the resistance value and corresponding temperature value of platinum resistor can be obtained. The monitoring positions and corresponding parameter range sampled by the system are shown in Table 1.

| Parameter | Monitoring position            | Parameter range (°C) |
|-----------|-------------------------------|---------------------|
| Motor temperature | Winding (Phase A/B/C)         | -30 ~ 250           |
|           | Bearing surface               | -30 ~ 100           |
|           | Inlet/Outlet                  | -30 ~ 80            |
|           | Case surface                  | -30 ~ 100           |
|           | Stator core surface           | -30 ~ 250           |
2.3.2. Motor vibration measurement circuit.
The vibration sensor used in this system is piezoelectric acceleration sensor, which has the characteristics of easy installation, small volume, wide frequency measurement range and dynamic response range. In this scheme, piezoelectric acceleration vibration sensor is used to measure the vibration of motor bearing pedestal to reflect the vibration state of motor during operation. The measurement of motor vibration is carried out according to the current national standard GB 10068-2008 ‘Measurement, Evaluation and Limit Value of Mechanical Vibration of Motor with Shaft Center Height of 56mm and Above’, fixing the sensor in the horizontal and vertical direction of the bearing seat or bearing cover [5].

The signal of piezoelectric sensor is collected by the built-in AD converter of STM32 chip. In order to ensure the measurement accuracy, the sampling frequency of 400Hz is generally selected. For this system, the rotation rate of medium and large motor is generally not more than 3000r/min, and the vibration sampling frequency is generally more than 4 times of the maximum speed, so the sampling frequency is designed as 400Hz, which can meet the requirements of motor vibration measurement.

2.3.3. Motor rotation rate measurement module.
Rotation rate signal is an important signal of rotating machinery condition monitoring. The commonly used rotation rate measurement methods of motor include photoelectric method, stroboscopic method, Hall sensor method, laser method, etc.

When the Hall sensor is used to measure rotation rate of the motor, there are a number of magnetic steel or convex teeth and concave slots fixed on the motor rotor or coupling. The Hall sensor senses the magnetic steel or teeth on the magnet, which will be converted into a voltage signal. After processing, it will output a stable square wave signal to realize the rotation rate measurement [6]. The microcontroller uses the capture and comparison function of the timer and counter to calculate the motor rotation rate.

2.3.4. Noise measurement circuit.
The system uses KY-037 sound sensor with high precision and good stability. The analog output pin of the module is connected to the AD conversion channel of STM32 microcontroller to measure the output voltage, and then the noise level can be obtained according to the relationship between noise and voltage.

2.3.5. Environmental temperature and humidity measurement module.
The temperature and humidity of the environment around the motor are important for the operation of the motor. The national standard points out that the insulation performance of the motor will decrease when the ambient air is hot and humid [5]. Therefore, it is necessary to monitor the ambient temperature and humidity around the motor. DHT11 digital temperature and humidity sensor is chosen for ambient temperature and humidity data acquisition. It is a single-bus digital signal output sensor using serial peripheral interface [7], whose temperature measurement range is 0~50°C, measurement accuracy is ±2°C, the humidity measurement range is 5%RH~95%RH, and the measurement accuracy is ±5%.

The MCU sends a request to the DHT11 temperature and humidity sensor, and then receives the response from the sensor to get the current environment temperature and humidity.

2.3.6. Combustible gas measurement module.
For flammable and explosive dangerous places, MQ-2 combustible gas sensor is selected for the system, which has high sensitivity to methane, propane and hydrogen. The analog output pin of MQ-2 sensor is connected to the AD conversion channel of the microcontroller to measure the output voltage of the sensor module. If the measured voltage is higher than the threshold, an alarm signal will be sent out.
2.4. Wireless transmission module
The system adopts Lora data communication using SX1278 wireless transmission module, and in order to deal with the serious interference in the field environment, it is equipped with high gain antenna. The working frequency of the module is 410-441MHz, and the transmitting power is 100MW, and the maximum communication distance is more than 3km, including general mode, wake-up mode, power saving mode, signal strength mode and AT command configuration mode [8]. The RXD and TXD pins of the wireless transmission module are connected with PB10 and PB11 pins of USART2 of the microcontroller which sends and receives data through the wireless transmission module. The AUX pin is used as the working status pin being connected with the external interrupt input pin of the microcontroller.

3. System software design
The software of the system is mainly composed of upper computer and microcontroller.

3.1. Upper computer software
The upper computer software of the system is programmed in LabVIEW, whose functions include the display, storage, processing and alarm of motor parameters, as shown in Figure 4.

Figure 4 Software functions of upper computer.

3.2. Microcontroller software
The microcontroller software is mainly responsible for data acquisition and storage of each sensor and data communication with the upper computer. The software flow chart is shown in Figure 5.

3.3. Communication protocol
The system mainly works in the industrial field environment, where the environment is severe and electromagnetic interference is strong. In order to prevent packet loss and bit error in the wireless transmission process, the system uses Modbus RTU protocol, using CRC check to ensure the correctness of the data transmission. The structure of Modbus RTU message frame is shown in Table 2.

Table 2 Modbus RTU message frame.

| ADDRESS | FUNCTION | DATA(SENSORS) | CRC CHECK |
|---------|----------|---------------|-----------|
| 8 BITS  | 8 BITS   | n×8 BITS      | 16 BITS   |
4. System test

In order to verify the effectiveness of the system, field experiments are carried out. The experimental object is a three-phase asynchronous motor with rated power of 1.5KW and rated rotational speed of 1400r/min. The graphical user interface and some of the data are shown in Figure 6, and Figure 7 shows some historical data stored. Experiments show that the system can realize the monitoring of motor parameters effectively.

5. Conclusion

In this paper, an online motor monitoring system based on ARM is designed. The system uses 32-bit ARM Cortex-M3 microcontroller as the control core to realize the real-time acquisition of motor temperature, vibration and other parameters. After processing, it is sent to the upper computer through the wireless transmission module for display, storage, processing and alarm. The system can efficiently collect the relevant data of the motor in real time with good stability and anti-interference, which can effectively realize the early warning of abnormal operation of the motor, ensure the safe operation of the motor, and help users reduce the maintenance cost of the motor.

References

[1] Hmida M A, Braham A. An On-Line Condition Monitoring System for Incipient Fault Detection in Double-Cage Induction Motor[J]. IEEE Transactions on Instrumentation and Measurement, 2018:1850-1858.
[2] Gb C. ELECTRIC MOTOR MONITORING SYSTEM[J]. EP, 2005.
[3] STM32F101xx, STM32F102xx, STM32F103xx, STM32F105xx and STM32F107xx Advanced ARM-based 32-bit MCUs RM0008 Reference Manual, STMicroelectronics, Jun. 2009.
[4] Jiang S L, Cheng W M. Motor Temperature Based on Lora and Virtual Instrument Online Monitoring System Research[J]. Agricultural Equipment and Vehicle Engineering, 2021, 59(03):93-97.
[5] Interpretation of GB14711-2013 General Safety Requirements for Small and Medium Sized Rotary Motors[J]. Electrical Engineering, 2014(3):55-58.
[6] Kia Motors Corporation; Patent Issued for Method Of Calculating Motor Position Using Hall Sensor (USPTO 10,720,862)[J]. Energy & Ecology, 2020.
[7] Ahsan Ullah, Sadia Akhtar, Nipa Sutar, Rafsan Kabir, Afzal Hossain. Cost Effective Smart Hydroponic Monitoring and Controlling System Using IoT[J]. Intelligent Control and Automation, 2019, 10(04).
[8] Dala Aliyu, Arslan Tughrul. Design, Implementation, and Measurement Procedure of Underwater and Water Surface Antenna for LoRa Communication[J]. Sensors (Basel, Switzerland), 2021, 21(4).