Ethernet Based Embedded Precision Acceleration with Temperature and Humidity Acquisition System

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Abstract. This paper proposes an efficient precision acceleration with temperature and humidity acquisition system based on 24-bit A/D Converter, IIC temperature and humidity sensor, Ethernet controller and microcontroller. This paper expounds in detail the realization of acquisition hardware, UDP protocol in microcontroller, the acquisition software as well as many other important aspects of the system. On the basis of the foregoing, build the entire acquisition system and apply it to the road roughness measuring instrument. Through the practice of the vehicle-mounted environment inspection, experimental results show that this system can stable operation for a long time and have a good application prospect.

1. Aims and background
The High-speed High-accuracy and long-time data acquisition of accelerometer signal is an important aspect of the road roughness measurement system [1, 2]. In practical engineering application, the traditional method to digital accelerometer output signal uses voltage to frequency converter ADC (i.e. AD650)[3]. But this method has many disadvantages: the conversion rate is not fast enough, exists blind area for weak signal, exists temperature drift, system volume is larger, and is difficult to improve the measurement precision etc.

With the performance improvement of the technology, the accelerometer output signal is more and more sensitive and weak. Acceleration acquisition system is increasingly demanding more precision ADC. Traditional voltage to frequency methods have been difficult to meet the needs of the measurement, whereas the current fastest growing 24-bit Δ-Σ A/D converter is a kind of very good solution [4]. This paper from the practical point of view, using the 24-bit Δ-Σ A/D converter LTC2440 combined with Ethernet controller RTL8019AS, IIC temperature and humidity sensor HTU21D and enhanced 8051 series microcontroller W77E58, design and realize the 10 Mbit/s Ethernet interfaced acceleration and temperature and humidity data collection scheme, and apply it in vehicle-mounted road roughness measuring system [5, 6].

2. Hardware system
Hardware system uses two LTC2440 chips to separately collect two acceleration sensor output signal. Microcontroller reads the digitized data from LTC2440, then drive Ethernet controller RTL8019AS to send data to the computer via UDP protocol. System data flow is shown in Figure 1.
2.1. System structure

Two pieces of LTC2440 are respectively connected to P1.0 ~ P1.2 and P1.3 ~ P1.5 of the microcontroller via Serial Peripheral Interface (SPI). The microcontroller starts two LTC2440's A/D conversion process and collects the resulting data at a fixed frequency. Then use connected to the microcontroller bus network chip RTL8019AS to send the data to the host computer via UDP network protocol. Furthermore, in order to improve the stability of the system, the system also uses a watchdog chip MAX813L and feeds the watch dog pulse to P1.6 of the microcontroller. For temperature and humidity data, use P1.7 and INT1 connect with IIC temperature and Humidity sensor SHT25 to measure the temperature and Humidity of the environment, the system structure is shown in figure 2.

2.2. Current to voltage conversion

Acceleration sensor signal current to voltage conversion can be simply achieved by connecting a precision resistor between the output signal and GND. But the resistor will take a greater impact on the acceleration signal, leading to the presence of a large deviation between the measured value and the true value, so this method is not desirable. In this paper, using the operational amplifier built a current to voltage conversion circuit, its principle is shown in figure 3. The op-amp working on negative feedback status, so the op-amp output voltage is as as in equation (1).

\[ U_{out} = -I_{in} \times R_f \]  

Therefore we can adjust the gain of the circuit by changing the value of resistor \( R_f \).
2.3. A/D conversion

The core of high-precision data acquisition is the selection of A/D chip. In this application, the selection of A/D chip is mainly based on input polarity, effective resolution and conversion time to determine.

Input polarity. Due to the application of the accelerometer output bipolar signals, thus require A/D chip can support dual polarity of the input signal.

The resolution. A/D chip can measure the minimum voltage variation. This can be calculated by using equation (2).

\[
\frac{U_{FSR}}{U_{\text{min}}} = 2^N - 1 = 2^N - 1 \Rightarrow N \geq \log_2 \left(1 + \frac{U_{FSR}}{U_{\text{min}}} \right)
\] (2)

In the formula, \(U_{FSR}\) is full range of chip. \(U_{\text{min}}\) is the A/D chip minimum detect voltage. \(N\) is the A/D chip output length of bits. Then available:

The input range of acceleration of this application system is -10g~+10g, the minimum resolution is 0.0001g. So as in equation (3).

\[
\frac{U_{FSR}}{U_{\text{min}}} = \frac{10 - (-10)}{0.0001} = 2 \times 10^5 \Rightarrow N \geq \log_2 \left(1 + 2 \times 10^5 \right) \approx 18 \quad \text{(round up)}
\] (3)

So the system must ensure that the final measurement result has 18 bits precision. Because the system supply voltage drift, temperature drift, other conversion error. Therefore the A / D conversion process should reach at least 20 actual conversion accuracy.

Conversion time. Because the system requirements for accelerometer measurement update rate is output once every 2.5ms, i.e. 400Hz. At the same time considering every 5 ~ 6 time of collection can perform the arithmetic average filter to the data, so the A/D chip conversion rate should be above 2400 Hz.

At present, 24 bits A/D conversion chip mainly include two companies (ADI and TLC) products, their typical models are AD7710 and LTC2440 respectively. The comparison of two kinds of chips are shown in Table 1.

| Devices  | Input Range | Bits | Resolution (100Hz) | Resolution (100Hz) | Maximum sampling frequency |
|----------|-------------|------|---------------------|---------------------|---------------------------|
| AD7710   | -5~5V       | 24   | 0.596 uV            | 18                  | 1KHz                      |
| LTC2440  | -2.5~2.5V   | 24   | 0.298 uV            | 21                  | 2.3 uV                    | 3.5KHz                    |

Visibly, in terms of high frequency acquisition LTC2440 has greater advantages than AD7710. At 100Hz frequency acquisition LTC2440 can still achieve an effective resolution of 21 bits, for the present application is a better choice. LTC2440 through 3 line digital interface communication with microcomputer, contain the serial data output (SDO), the serial clock (SCK) and chip enable (CS). According to SPI protocol MCU read 32-bits data from LTC2440, the 3rd as a sign bit, 4 to 27 for the 24 bits of A/D conversion (bit 4 is high, bit 27 is low). So total data of one LTC2440 are 25 bits. LTC2440 operation timing is shown in Figure 4.
Using high-precision A/D chip for data acquisition can give a more bits code, and convert the raw sensor signals into more bits digital data. Then using MCU simple arithmetic average processing can further improve the accuracy of the system and reduce noise.

Temperature and Humidity measurement. This system uses the integrated temperature and humidity sensors to measure temperature and humidity of the environment. Acquisition temperature to modify the collected acceleration data and acquisition environment humidity to maintain the reliability of the detection instrument. Nowadays, there are many temperature and humidity sensor produced by many different companies. The Table 2 shows the temperature and Humidity sensor chips that are popular at present.

Table 2. Temperature and Humidity sensor chips [9,10,11,12].

| Chip    | Temperature Range | Temperature Accuracy | Humidity range | Humidity Accuracy |
|---------|-------------------|----------------------|----------------|------------------|
| SI7021  | -10~85°C          | 0.4°C                | 0~100%RH       | 3%               |
| SHT25   | -40~120°C         | 0.2°C                | 0~100%RH       | 1.8%             |
| HIH9131 | -40~125°C         | 0.6°C                | 0~100%RH       | 1.7%             |
| HTU21P  | -40~125°C         | 0.3°C                | 0~100%RH       | 2%               |

As can be seen from the table, the comprehensive performance of SHT25 is better than the others, so the SHT25 is selected for the measurement of temperature and humidity in this project. SHT25 temperature measurement range is -40°C~120°C, its accuracy can up to 0.2°C of temperature and 1.8% of humidity. In this application, every time INT0 interrupt signal is received, the microcontroller collected once the current temperature and humidity using I2C Protocols, every time can gather 26 bits of data (RH : 12bits, T : 14bits), the data is sent along with the A/D conversion data of acceleration to the host computer. PC software receives, calibrates and stores data [13].

Ethernet data communication. MCU synchronously acquires the data of two A/D chips, and also reads the state of external interrupt pin INT0. When the INT0 signal arrives, the microcontroller performs arithmetic average filter to recent five groups acquisition data, and collects the current temperature and humidity(26 bits), then adds 4 bits as packet ID, consisting of an 10-byte packets. As is shown in Figure 5.

| Data Index | Temperature and humidity | AD results | AD results |
|------------|--------------------------|------------|------------|
| 4 bits     | 26 bits                  | 25 bits    | 25 bits    |
| 10 bytes of data |

Figure 5. Packet Content.

The system uses a 10Mb/s Ethernet chip RTL8019AS to send the collected data to the computer, the circuit connection is shown in Figure 6.
Collect and transmit data flow is: MCU collects multiple sets of data into the RAM buffer, and group packages based according to UDP protocol, while setting each UDP package can only have a maximum of 50 groups of collected data (10 bytes for each group, 50*10= 500 bytes). Package format is shown in Figure 7, the MCU controls RTL8019AS through remote DMA operations to write the package data to RTL8019AS internal SRAM, and then sent to the Ethernet via RJ45 interface. The computer uses UDP protocol to receive and store data.

As can be seen from Figure 7, using UDP protocol to establish data package needs to add additional 42 bytes Ethernet header, which includes IP header and UDP header (14 + 20 + 8 = 42). The front 40 bytes are fixed number, only the last two bytes (16-bit UDP checksum) needs to be calculated based on the collected data. Therefore, the speed of the microcontroller group package is fast when using UDP protocol, which can increase the communication speed.

MCU program design. The main parts of the microcontroller software include: read LTC2440 data, INTO interrupt process, arithmetic average filter, read temperature and humidity, group UDP package, UDP package transmission and other parts. The main program flow is shown in Figure 8.
3. Software Develop

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MCU collects and sends data to the computer via the UDP protocol, so we need to develop the software systems in the computer to receive and store the collected data, the focus of software work includes data correction and data storage.

3.1. Data correction

MCU collected voltage is 25-bits signed binary number. It can be assumed that at a fixed temperature, there is a linear relationship between the acquired voltage $M$ and the measured acceleration $A$. i.e.

$$A = kM - b$$

(4)

Wherein $k$ is the slope of the calibration model, $M$ is the measured digital voltage, $b$ is the intercept of the calibration model. When the temperature changes, the intercept $b$ can be considered constant, only slope $k$ is changed, and $k$ varies quadratic relationship with temperature. That is as in equation (5).

$$A = \left(cT + dT^2 + e\right)M - b$$

(5)

By the way of experiments, we can get many group datas of $A, T, M$. Based on these datas, we can set up equations and solve to get $c, e, d, b$. So we can obtain at a temperature $T$ of the environment and acquire value of $M$ corresponding to the acceleration $A$.

3.2. RESULTS

By using the VC++.net 2010, a software development platform, we developed a data collection and storage system [14]. In the system, UPD protocol is used to communicate with computer, so as to collect data transmitted by accelerometer real-timely, then the data are corrected by conversion Eq.(5). The system can operate stably in specific instrument for detecting roughness of road. What's more, the detection accuracy can reach 98% and the data errors repeatedly measured in different temperature are below 2%. The interface of data collection software is shown in figure 9 and the road roughness measurement vehicle is show in figure 10.
4. Conclusions
This paper designs and implements the accelerometer with temperature and humidity acquisition program with an Ethernet interface, very suitable for the accelerometer signal acquisition correction and storage in road roughness measurement system. Through the practice of the vehicle-mounted environment inspection, experimental results show that this system can stable operation for a long time and have a good application prospect.

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