A Data Acquisition System in Intelligent Environmental Monitoring Device for Industrial Field

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Abstract. Data acquisition system is an indispensable part in the field of signal processing technology, playing an important role in modern industrial development. Data acquisition system has been developed for a long time. Nowadays, the computers and microprocessors are becoming more and more powerful, so as the data acquisition systems. However, there still exist some disadvantages in the current data acquisition systems, such as high cost, low accuracy, and difficulty to transplant and so on. In this paper, an integrated data acquisition system is designed based on ADUC848, mainly used in an intelligent monitoring device for industrial field. It has 8 differential signal input, each of which has an input range of 0-5V and 16-bits precision. The system communicates with the upper system via RS485. This system will be used in acid regeneration environmental monitoring device of Baosteel for data acquisition.

1. Introduction

It is necessary to collect data in many fields, such as industrial production, national defense and academic research. The collected data can be used to evaluate the system performance in a long period [1, 2]. With more and more attention being paid to industrial environment, many data acquisition systems have been used in environmental monitoring device to process and visualize the environmental variables [3, 4].

Data acquisition is an important part of information technology. The key of information technology is commonly called 3C, which is an abbreviation of collection, communication and computer. Among them, collection is the foundation, and data acquisition is main method of collection [5].

In the past several decades, data acquisition system has experienced great development with the progress of information technology. In 1956, The United States firstly invented a test system used in military, with high speed and flexibility [6]. From the 1960s to the mid-1970s, data acquisition systems are mainly composed of separate semiconductor devices. To the late 1970s and early 1980s, with the development of large-scale and very-large-scale integration, the integration of data acquisition is also increasing [7]. In the late 1980s, data acquisition systems changed a lot. The combination of industrial computer, microcontroller and very-large-scale integration makes data acquisition systems smaller and more powerful. From 1990s till now, data acquisition systems have been widely used in the fields of military, industry and aerospace.

Generally, Higher performance data acquisition system results in higher cost. However, because of the progress of data acquiring technology, more and more data acquisition systems have been used in companies or laboratories, and so the cost of a data acquisition system has become a key factor to be
taken into consideration. Most of the current data acquisition systems are very expensive [8]. In practice, some advanced functions of the systems will not be used, but the need of general data acquisition systems may be huge. So it is quite essential to design a data acquisition system which satisfies the requirements with the lowest cost [9].

Section 2 introduces the functionality of every model in this system. Section 3 and 4 illustrate the methods for choosing models and parameters of devices, as well as PCB designing principles and the experimental results. The paper ends with the future work of the system.

2. System Design
It is critical to understand the exact requirements of a system before designing it, including the problem to be solved and specific functions to be achieved. Only in this way can we design a good system.

2.1. Basic Concepts
Data acquisition is to convert different kinds of measurement values, such as pressure, temperature and humidity, into analog signals by means of corresponding sensors. The analog signals will go through several amplifiers and filters. Then, after the analog-to-digital conversion, the signal will be stored or transferred. The systems to achieve these functions are called data acquisition system.

A complete data acquisition system consists of amplifier, filter, ADC, storage and communication parts. The general structure of a data acquisition system is shown in Figure 1:

![Figure 1. General structure of a data acquisition system](image)

Amplifiers and filters are often referred to as signal conditioning circuits. Signal conditioning is to further process the original signal obtained from the sensors, since the original signal is usually mixed with a variety of harmful interference and noise, which will certainly affect the achievement of information. Signal conditioning circuit amplifies the signal of interest and effectively suppresses the interfering signal. Usually, there may be high-voltage, over-current or surge in industrial signals, which will do great harm to the data acquisition system. So it is necessary to go through a proper signal conditioning circuit.

The signal we get after the signal conditioning circuit is just the signal we want, but it is still an analog signal. As is mentioned in section 1, analog signals have some disadvantages. A common way is to convert the analog signals into digital signals which can be processed and stored by computers or microcontrollers. This process is called analog-to-digital conversion. The corresponding devices are called analog-to-digital converter (abbr. ADC). An analog signal is a signal which is continuous both in time and in amplitude while a digital signal is discrete in these two dimensions. The process of analog-to-digital conversion consists of following three steps: sampling, quantization and encoding, which is shown in Figure 2.

![Figure 2. Analog-to-digital conversion process](image)

Sampling is to replace the continuous signal with a sequence of signal samples at certain intervals. That is the discretization of the signal on the time domain. The number of samples in one second is called the sampling frequency. In common situation, the sampling frequency should satisfy the Nyquist theorem. The Nyquist theorem illustrates the relationship between the sampling frequency and the signal spectrum, which is the basis for the discretization of a continuous signal. According to the
theorem, the original signal can be reconstructed from the sampled signal series as long as the sampling frequency is higher than twice the highest frequency of the input signal. In practice, the sampling frequency is usually 5 to 10 times the maximum frequency of the input signal.

Figure 2. General structure of a data acquisition system

Quantization is to convert continuous amplitude of an analog signal into a finite number of discrete values of certain intervals. Because the computers use byte as a unit of computing, the number of general quantization bits is 8 or 16. The larger the number of quantization bits, the higher the precision, the lower the error, and the higher the storage cost.

Encoding is to represent the value after quantization with a binary number under certain principles. Encoding makes it possible for computers to store data in a certain format. Besides, it can compress the amount of data using some special algorithm. There are two kinds of compression algorithm, lossy compression and lossless compression. According to the specific application, various compression algorithm can be used, such as, PCM, ADPC, MP3, RA, etc.

After the three steps, an analog signal which is continuous in time and amplitude is converted into a digital signal, which can be directly processed by computers.

2.2. Requirements of the System
The data acquisition system designed in this paper has following requirements: (1) 8 independent differential analog input channels; (2) The input range of each channel should be 0 to 5 volts; (3) The precision of the ADC must be 16 bits or higher; (4) The input signal has a frequency lower than 10 Hz; (5) Signal isolation and surge protection should be introduced; (6) Beside the 8 analog input channels, the system should contain 8 digital input channels (DI) and 8 digital output channels (DO); (7) The system should be able to store and transport data.

2.3. System Design
The core of the system is ADUC848, a microcontroller of Analog Devices, which has eight channels of 16 bits ADC in it, as the core. It also contains the power module, signal conditioning circuit and data communication part. The whole system can meet the requirements listed above.

3. Design of Hardware Schematic
The requirements and the overall framework of the system have been introduced in section 2. Some details about each module in the system will be illustrated in this chapter, including the selection of the devices, determination of circuit form and decision of the parameters.
3.1. Power Module

Common DC power supply voltages in the semiconductor circuit are listed as following: 5V, 6V, 12V, 15V, 18V, 24V and 30V. Considering the further extension of the system, the system is designed to be able to accept negative voltage, which means that the power module has to supply both positive voltage and negative voltage. Finally, considering the requirement of the system and the current condition of my laboratory, I chose ±12V as the DC power supply of the analog part of the system. It’s a very common power supply voltage. It can supply power to all devices used in the system and very easy to achieve. In this part, the main process is decoupling. If not, the high frequency interference and power line interference will be added on the signal through the power line, which may greatly change the signal from the original value. So, the process of decoupling is essential in the power module. The schematic of this part is shown in Figure 3(a).

The way of decoupling is very simple, which is simply adding two capacitors between the positive and negative power supply and the ground. One of them has a larger value (C5, C7 in Figure 3(a)), responsible for the decoupling of low frequency interference. The other one has a smaller value (C6, C8 in Figure 3(b)), responsible for that of high frequency interference. Other capacitors in Figure 3(a) act as separate decoupling units for active devices. On the other hand, since the core processor ADUC848 uses a 5V power supply, and the input range should be limited within 5V, it is necessary to generate 5V power supply. A regulator chip called 7805 is used to convert the +12V power supply into a 5V power supply. The schematic of this part is shown in Figure 3(b).

3.2. Signal Conditioning Circuit

Signal conditioning circuit is an important part of data acquisition system. In the system designed in this paper, there exists a differential to single-ended signal circuit, an amplifier, a filter and an amplitude limiter circuit. The schematic of this part is shown in Figure 3(c): (only one channel).

The first part, differential to single-ended signal circuit, converts the differential signal achieved from the sensor to a single-ended signal, which is easier to be processed by the microcontroller. AD8422, a chip produced by Analog Devices is the principle device of this part. It is a high performance, low power, rail-to-rail precision instrumentation amplifier. It has a wide range of power supply voltage, from ±1.8V to ±18V. The power supply voltage of my system is ±12V, so it is possible to directly use the system power. The acceptable signal input range of AD8422 is from -Vs to +Vs, that is from -12V to +12V, which is qualified for the requirement of the system. 1in1 and 1in2 are two ends of the input differential signal. The pin number 7 of AD8422 is the output pin, connecting the next part. The resistor between pin number 2 and pin number 3 is used to adjust the gain of AD8422. The second part of the signal conditioning circuit is an amplifier. It is used to adjust the gain of the whole signal conditioning circuit, to make sure the output of this part is exactly same as the input differential signal. It also makes it very convenient to change the input range of the system. The amplifier is based on LF353, in the form of standard inverting amplifier. The third part is a filter. There may be a lot of noises and interferences added on the signal, which will lead to the inaccuracy of data acquisition. One way to solve the problem is to add a filter. A filter is a device which can block part of the input signal spectrum, which is widely used in electronic system. Since the input signal of the system has a frequency less than 10 Hz, I chose to use a low-pass filter to block the power line interference and high frequency noises. The filter here is a first-order passive filter, since the 50Hz power line interference is far from the spectrum of the input signal.

Considering the input impedance of ADUC848, I added a voltage follower after the filter, thus reduce the output impedance of the forestage. This makes it no difference between the signal received by ADUC848 and the original signal. During the operation time of the system, it possible that something unexpected happens, and that may turn the system down. So it's necessary to put some protection on the core devices. The signal input range of ADUC848 is 0 to 5 volts, so I designed an amplitude limiter circuit to guarantee that the input signal is in the safe range. It can make the microcontroller work properly in a safe way. The way I do this is to use two Schottky diodes. Schottky diode is a kind of low power, high speed semiconductor device. It has a low forward voltage drop and
a very fast switching action. The two Schottky diodes are separately connected to AGND and +5V reference. Once the input signal is out of the range, it will be taken back into the range immediately. By the way, the +5V reference is generated by 7805, which is mentioned before.

3.3. Microcontroller
The Microcontroller selected in this system is ADUC848 from Analog Devices. The main factor of choosing it is that it has 8 independent ADCs with 16 bits’ precision. The schematic of this part is shown in Figure 3(d).

The power supply of the microcontroller is the +5V power generated by 7805, which is mentioned before, since ADUC848 can accept +2.7V to +5.25V as the power. Also, decoupling is very important to power module. ADUC848 has three pairs of DVDD and DGND, and a pair of AVDD and AGND. I put a capacitor between each pair of DVDD and DGND, and two capacitors between AVDD and AGND. The ADC embedded in ADUC848 needs a reference voltage, whose value is +2.5V. In order to generate a precise +2.5V reference, I used device of TI named TL431. Using the circuit form shown in Figure 3(d), it can produce the +2.5V voltage with in a very low error rate (typically ±0.4%).
Figure 3. Hardware Schematic of the system:

(a) Decoupling of power supply, (b) Power Supply Generator, (c) Signal Conditioning Circuit, (d) Microcontroller System

4. Experimental Results
In order to take the system designed into practice, the PCB of the system needs to be designed. The PCB is based on the schematic. PCB is a very important component of electronics, which carries the electronic devices on it. PCB is known for its high density, robustness and convenience to design. Nowadays, the PCB manufacturing has been mature and highly standard, which makes it more efficient to design a system. The PCB of the system is shown in Figure 4:

Figure 4. PCB design drawing and the printed PCB

After soldering the component to the PCB, I test the input and output performance of 8 channels. As Table 1 shows, the input DC voltage is 1(V), and I can obtain the measurement from the
oscilloscope. The result shows a good performance and a high accuracy. Considering the input noise and the circuit noise, there is room for improvement.

Table 1. Three Scheme comparing.

| Type           | Channel 1(V) | Channel 2(V) | Channel 3(V) | Channel 4(V) | Channel 5(V) | Channel 6(V) | Channel 7(V) | Channel 8(V) |
|----------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Input Oscilloscope value | 1.000        | 1.000        | 1.000        | 1.000        | 1.000        | 1.000        | 1.000        | 1.000        |
| Result         | 1.011        | 1.039        | 1.003        | 1.021        | 1.055        | 1.032        | 1.007        | 1.034        |

5. Conclusion

In this paper, a system which satisfies certain requirements, used in intelligent environmental monitoring device of industrial manufacturing is introduced. Firstly, the background of the research is introduced. Then every part of the system was illustrated separately. At last, the PCB of the system and test results are displayed. In the future, the software part of the system will be finished soon. After that, a large amount of test will be applied, aiming to find the problems and fix them until it satisfies all the requirements.

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