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Hardware and Software Design of Mine Environmental Monitoring System

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Abstract

A mine environmental monitoring system which is composed of hardware and user software is developed. The functions of the hardware are monitoring the complex coal mine environmental factors, uploading monitoring data and controlling the designed environmental equipment. The user software is programmed by Java and it stores the uploaded data in a database, draws curves, makes predictions and so on. Through analyzing and processing the uploaded data, the user software can makes decisions and sends control commands to the hardware, thus the designed environmental equipments change the environment. Additionally, an improved multi-sensor information fusion algorithm is proposed to improve the stability and accuracy of this system. Finally, an experiment is carried out to test our system.

Keywords: *monitoring system; multi-sensor information fusion; gas filter; user software*

1. Introduction

Mine environmental monitoring system is not only important in the development of coal industry research, but also has an important significance to improve the safety of coal mining. The so-called coal mine environmental monitoring system generally consists of 5 parts: sensors, data acquisition, controller, transmission line and ground control center [1]. From the beginning of the 1960s, a motley variety of techniques and equipment have appeared in this area.

UK developed a computer monitoring system MINOS monitoring system [2]. It is composed of following two parts: aboveground equipment and underground equipment. The main function of this system is to monitor the mine environment and mine machinery. France developed an underground safety centralized monitoring device called CTT63/40 mine monitoring system [3]. It can monitor the mine methane, carbon monoxide gas, temperature, wind speed and so on. In addition, American developed the DAN6400 system. Germany developed the TST system and PROMOS system. China developed a KJ95N system [4] for capsule by Changzhou Institute of Automation. This system can monitor the environment of capsule and control related equipment. However, the traditional monitoring system has the following problems: complex route, difficult to add subsequent modules, unable to change network structure, high manufacturing costs, and high maintenance costs [5]. Some of the shortcomings impede the continued development of the product, limit the scope of application and make the system difficult to operate. Another major problem is the operation of user software cannot be divorced from specific machine, which lead to a limited transplant.

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Aiming at the above problems, this paper insisted on opening principles to design a cost-effective, sustainable development and high degree of automation system which can accurately monitor the environment.

2. MCU Control System Design

Mine environmental monitoring system based on MCU can monitor the environmental factors in certain confined environment. Electronic equipment and related software are the components of this system. The overall design of this system is shown in Figure 1(a).

According to the system function and design target, the function of MCU control system is to monitor temperature, humidity, harmful gases, set parameters, display parameters, alarm when parameter out of bounds, drive stepper motor, etc. So, the main peripheral of the control system is the measurement module of temperature and humidity, gas concentration sensor module, display module, alarm module, clock module, key module, motor module, serial communication module. MCU control system diagram shown in Figure 1(b).

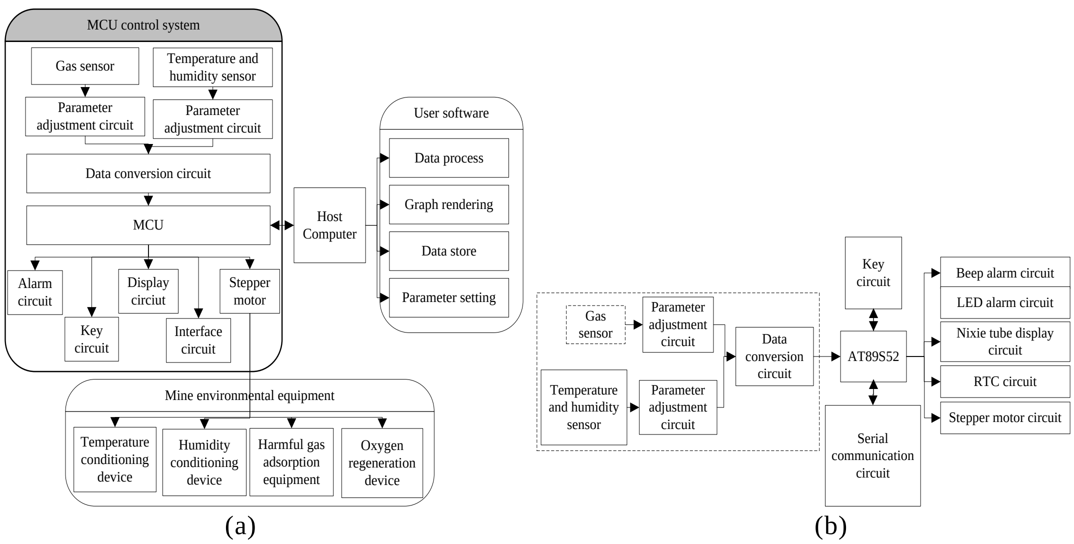

Figure 1. (a) The overall design diagram (b) MCU control system block diagram

Compared to a variety of chips and considering the functions to be realized, we select AT89S52 chip as the control system chip. This not only achieves the purpose of cost-effective, but also makes full use of the chip's resources. In order to improve the measurement accuracy, we choose every 5 sensors as a group. L298N is selected to drive stepper motor group. Through drawing schematic diagram, building circuit, writing program, control system hardware part is realized.

3. Harmful Gas Adsorption Equipment Design

The harmful gas adsorbent should have such advantages: a large internal surface area, dense pore structure, chemically stable, good adsorption property, small air resistance and uneasy to broken. Common absorbents have artificial zeolites, activated carbon, silica gel and alumina. But any gas adsorbent has an upper limit. When the adsorbent reaches saturation, its

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adsorption effect will be greatly decreased. There are two ways to improve the adsorption effects after saturation:

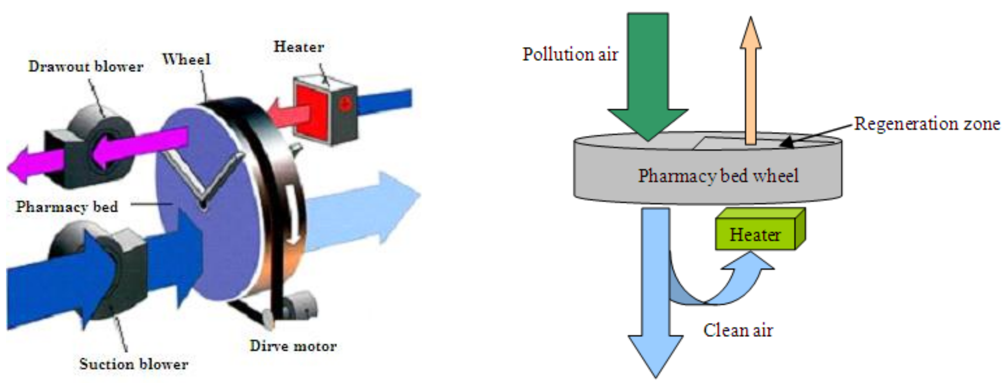
Replace adsorbent: This method is very waste adsorption of pharmacy and it is not convenient in some case. The biggest defect is not advantage for equipment automation.

Adsorbent regeneration: By heating, ventilating, the harmful gas in the saturated adsorbent detachment, so the adsorbent can be reused.

We improved the performance of existing apparatus, use fixed adsorption pharmacy and recyclable wind filter out harmful gases. Zhejiang University Haitao Liu [6] designed a filter device suitable for indoor harmful gas. The schematic diagram of the device is shown in Figure 2(a).

This device is made up of pharmacy bed, fans and heating device. Pharmacy bed is installed in the middle of the device, driven by a special motor, so it can rotate at a fixed rate. On one side of the wheel is installed a suction blower and a drawout blower. On the other side is a heater which can heat the regeneration section of pharmacy.

Because of the power shortage environment underground, the use of two fans will increase energy consumption. So the filter device needs to be simplified and improved. A simple way is lead a part of the purified air to the regeneration region, thus the drawout blower eliminated. Change the fixed speed controller of drive motor to adjusted speed controller. The air flows of modified filter device shown in Figure 2(b).



(a) (b)

Figure 2. (a) Harmful gas filter device; (b) The modified harmful gas filter device air flows

The core of the harmful gas filter device is a constantly rotating wheel. Pharmacy bed on the wheel is divided into two parts: regeneration zone and non-regeneration zone. The proportion of each is 25% and 75%. When the device is working, the not clean air flow from one side to the other side, harmful gas in it is absorbed by the pharmacy bed. A part of clean air blow back to the bottom of heater through a special conduit. So the air blown to the regeneration zone is heating clean air, this is the reason why the saturated absorbent regenerated. Under the control of adjusted speed controller, the drive motor speed according the concentration of harmful gas in the air to make appropriate adjustment.

The structure of pharmacy bed wheel is shown in Figure 3.

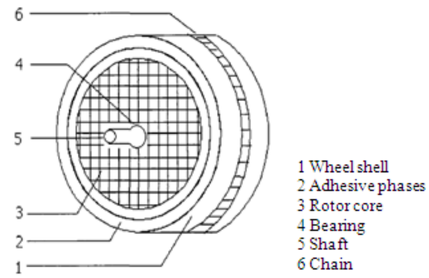


Figure 3. Pharmacy bed wheel structure

4. Filter Device Parameters Calculated

Assume that the radius of rotor core is R, the bearing radius is R_0, the effective absorption area is S_1, the area of non-generation and regeneration zone is S_2 and S_3. The formula is shown as following:

$$\begin{cases} S_1 = \pi \times (R^2 - R_0{}^2) \\ S_2 = \dfrac{3}{4} S_1 \\ S_3 = \dfrac{1}{4} S_1 \end{cases} \tag{1}$$

Assumed that the confined space length, high, wide is L, H, W, as a result, the volume of space is

$$V = L \times W \times H = 6 \times 5 \times 2m^3 = 60m^3 \tag{2}$$

Provided the suction blower evenly blow onto the pharmacy bed wheel. If wind velocity is v, the probability of air through the pharmaceutical bed is p1, the average air purifier efficiency of the absorbent is p2, and the velocity of backflow air is v2. So the volume of the gas to be purified is

$$V_{\text{pur}} = p1 \times p2 \times S_2 \times v \tag{3}$$

Backflow air volume is

$$V_{\text{bf}} = v2 \times p1 \times S_3 \tag{4}$$

Equations (1) and (3) give the gas purification efficiency P is

$$P = \frac{V_{\text{pur}}}{v \times S_2} = p1 \times p2 \tag{5}$$

This shows that the purifier efficiency of this device depend on the resistance of pharmacy bed and the purifier efficiency of absorbent. The absorption efficiency of activated carbon is between 85% and 95% [7]. Take purifier efficiency of absorbent is 90%, p1 is 87%, so the air purification efficiency P is about 78%.

If the concentration of the gas in the closed space reaches the explosion limit 5% to 16% [8], then the harmful gas volume is 0.05V to 0.16V. Take the maximum value of 0.16V. We suppose all of these harmful gas converted into clean air, then we have the following formula.

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$$\begin{cases} V_{pur} = 16\% \times V \\ V_{pur} = p1 \times p2 \times S_2 \times v \\ S_2 = \frac{3}{4} S_1 \end{cases} \tag{6}$$

$$S_1 = \frac{4}{3} \times \frac{0.16 \times V}{p1 \times p2 \times v} \tag{7}$$

The min wind speed v in this system is 5 meter per second, bearing radius R0 is 30 millimeter. Formula (6) and (7) indicates the radius of rotor core R is 1.02 meter. In the actual situation, the concentration of gas is generally not reached the upper limit of explosion and the wind speed can change between 5 and 10 meter per second. So we can take the rotor radius R between 0.5 meter and 1.0 meter.

5. Oxygen Regeneration Device Design

Usual supply of oxygen and their advantages or disadvantages are as follows: Outside oxygen supply is simple but not reliable; The product of chemical reaction process oxygen and electrolytic process oxygen is not easy to storage, in addition, the process of the reaction is not easy to control; High pressure oxygen bottle supply oxygen is relatively safe and reliable, this method is easy to monitor the oxygen concentration and the remaining amount of oxygen. Therefore, this design uses high pressure oxygen bottles supply oxygen.

In mine environment, according to the specified number of people to select appropriate number of high pressure oxygen bottle. These bottles compose oxygen bottles gas station. Each oxygen bottles of oxygen through the branch conduits pooled to a main conduit which solenoid valve, pressure monitoring apparatus, pressure-relief device on it. The indicator of mine life-saving equipment in oxygen supply is 0.5 liter per person in 1 minute [9]. The number of oxygen bottle can be computed by formula (8).

$$\mathrm{N} = \frac{0.5 \times \mathrm{M} \times \mathrm{T} + \mathrm{V}_1}{\mathrm{V}_2} \tag{8}$$

N is the number of oxygen bottles, M is the refugee number, T is the time of maintenance, V_1 is the remaining amount of oxygen in the bottle under insufficient pressure, V_2 is the amount of oxygen that can be stored in the oxygen bottle.

Based on the standards of high-pressure oxygen bottle, the capacity has several specifications like 15L, 40L, 60L and 70L. Theoretically oxygen cylinder internal pressure is 16MPa, but actually it can only be reached 13MPa. In the process of release oxygen, a small portion of the oxygen remaining, the pressure is generally 1MPa. Therefore, the effective pressure of the bottle is 12MPa.

Choose 60L oxygen bottle supply oxygen, refugee number is 12. So a bottle of oxygen release amount of 7200L oxygen (60*120L). 12 refugees in 96 hours need 34560L oxygen (12*0.5*60*96L).So the number of oxygen bottles N is 31560/7200 about 5. Take into account the environment space is not absolutely airtight, thus N take 6. The structure of oxygen regeneration device is shown in Figure 4.

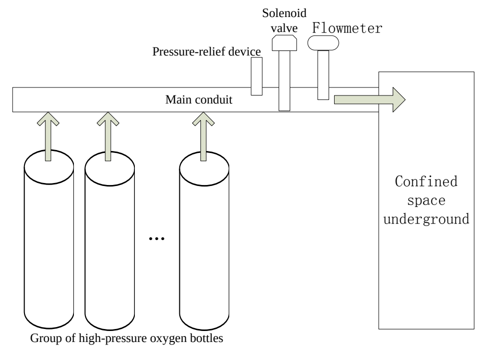

Figure 4. Structure of oxygen regeneration

6. Multi-sensor Information Fusion Algorithm Design

As mine environment is complex, many environmental factors like temperature, humidity, noxious gas concentration need to be monitored. In addtion, wind speed, stepper motor speed, solenoid valve opening and closing also need to be monitored. To ensure the reliability of the system, group sensors are used to monitor the same location which makes the handled data better to reflect the actual situation. The method of data processing is information fusion.

The processing of information in multi-sensor information fusion technology has following four steps [10]: information acquisition, information preprocessing, extract information features and related calculations. Information fusion method can basically be summarized as two categories [11], random class and artificial intelligence class. Random class includes weighted average method, Kalman filter method, Bayesian estimation, etc. Artificial intelligence class includes neural networks, genetic algorithms and fuzzy reasoning. For this system, an improved weighted average algorithm was adopted.

Provided there are n sensors in the sensor group, x is a nonzero positive integer, n satisfy the following relationship

$$n = 5 \times x \tag{9}$$

N data can be measured by this group of sensors, respectively, a_1~ a_n. Bubble sort orderly sequence is b_1~b_n. Remove the first and last x number of data in the orderly sequence. After that, seek the arithmetic mean value. From formula (10) mean value $\overline{X}$ can be get.

$$\overline{X} = \frac{1}{n-2x}\sum_{i=x+1}^{n-x} b_i \tag{10}$$

Total variance is

$$\sigma^2 = E\left[(\mathrm{b_i} - \overline{X})^2\right] = E\left[\sum_{i=\mathrm{x}+1}^{n\text{-x}} (\overline{X} - \mathrm{b_i})^2\right] \tag{11}$$

A set of temperature values which measured by a group of temperature sensors in the experiment is shown in Table 1.

Table 1. A set of temperature values

Sensor no.	1	2	3	4	5
Value	26.7℃	27.4℃	29.0℃	20.6℃	27.3℃

The bubble sort orderly sequence of these values is 20.6, 26.7, 27.3, 27.4 and 29.0. Remove the first and last 1 data can get sequence 26.7, 27.3, 27.4. Calculating the estimated value by the formula (10) we can get $\overline{X}$.

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$$\overline{X} = \frac{1}{5-2}\sum_{i=2}^{4} \mathrm{b_i} = 27.1℃$$

Total variance is

$$\sigma^2 = E\left[\sum_{i=x+1}^{n\text{-}x} (\overline{X} - \mathrm{b_i})^2\right] = \sum_{i=2}^{4} (\overline{X} - \mathrm{b_i})^2 = 0.29$$

General weighted average of the algorithm is 26.2, the total variance is 1.684. By contrast, we can see the improved algorithm not only reduce the amount of calculation but also make the result is closer to the actual.

7. Host Computer User Software Design and Implementation

Demand analysis revealed that the host computer software is required to achieve the following functions: upload data stored in a database; choose observation points; drawn curve based on data; add or delete observation points; add or delete observation items; choose observation time.

We developed this user software by Java language, which supported by SQL Server 2000 database. The observation point uploaded data like temperature, humidity and gas concentration values are stored in the database. To observe the relevant data and draw curve, user can click the select button to choose a different observation point. Add or delete items button is used to add or remove the item in existing observation items. Add or delete observation point button is used when increase or decrease observation point. For observe the abnormal value and time in recent time, set display abnormal button. In order to achieve the goal of automatic alarm, user can set the abnormal range of parameter values by set limit button.

The interface of user software is shown in Figure 5.

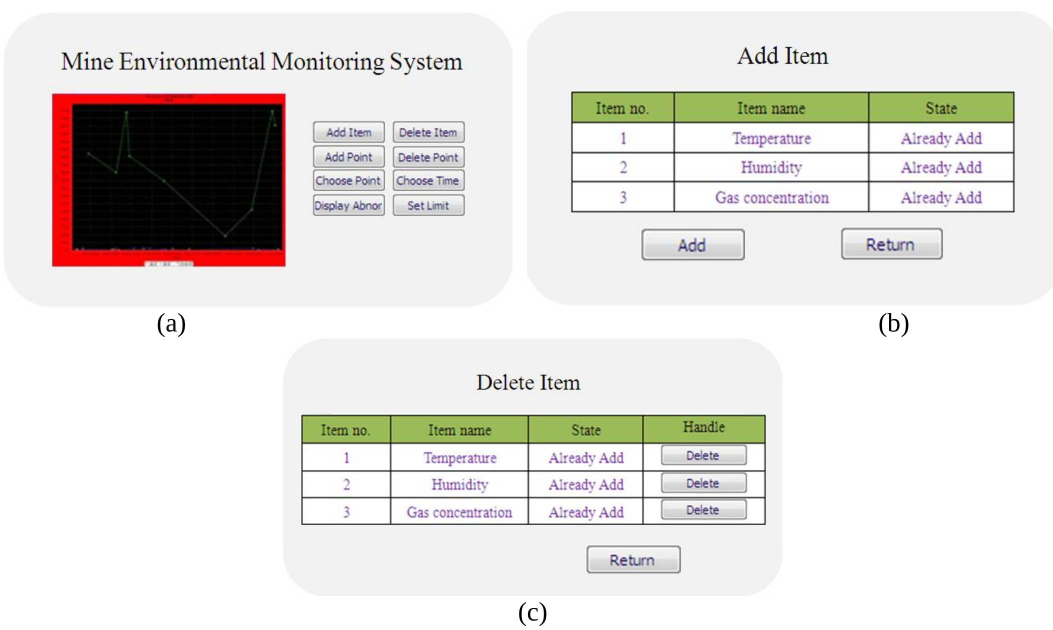
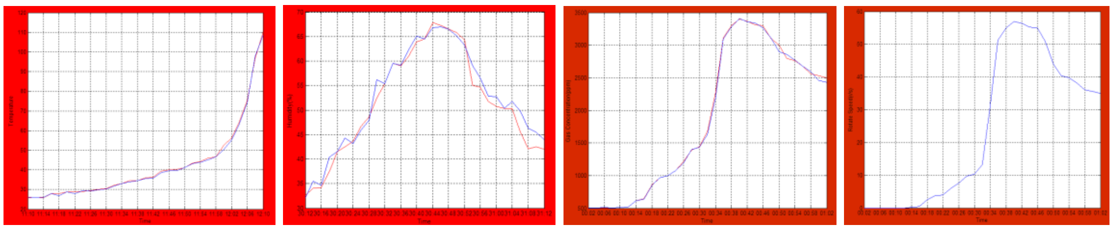


Figure 5. (a) The interface of draw curve; (b) The interface of add item; (c) The interface of delete item

8. System Test

An experiment in the lab environment is carried to test the above designed system. After assembling and connecting above system, we place the hardware in a confined space. We use every 5 sensors as a sensor kit. Considering the influence between the sensors, the space of each sensor is not less than 10 cm. We use 3 stepper motors to execute commands. The curve of temperature, humidity and gas concentration in a period of time are shown in Figure 6.



(a) (b) (c) (d)

Figure 6. (a) Temperature curve; (b) Humidity curve; (c) Gas concentration curve; (d) The speed of stepper motor

In above pictures, the red line represents the processed data and the blue line represents one of 5 sensors' data. As we can see from (a) to (c) picture, the processed data is more stable and the fluctuation of raw data is large. Please pay special attention to the blue line in (a) picture. The fluctuation is large but the blue line is stable and small. This means the multi-sensor information fusion algorithm playing a good role in this system. Figure 6(d) shows the speed of stepper motor. This speed is proportion to the speed of blower. Through comparing Figure 6(c) and (d), we can give a conclusion that when the gas concentration rise, the processing capacity of filter device enhance. All of the above results indicate this system achieves the desired purpose.

9. Conclusions

The hardware and software of a mine environmental monitoring system is presented. The hardware system is composed of MCU control system and mine environmental equipment. AT89S52 microprocessor is selected to build the MCU control system. It not only reduces costs, but also makes full use of the chip resources. The user software is developed by JAVA language, so the system has a better portability. Besides realizing data storage, displaying, rendering graphics and monitoring abnormal data, this software can forecast the dangerous information according to the abnormal data. Harmful gas adsorption equipment and oxygen regeneration device is designed. Thus, these devices can receive and execute instructions issued by MCU control system. For the purpose of improving the reliability of this system, an improved algorithm is proposed. The use of this algorithm is reducing the amount of calculation, and it makes the result more accurate. Finally, the joint system test shows this system achieve the desired objectives.

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