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Design of CO Concentration Detector Based on Infrared Absorption Method

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Carbon monoxide is a kind of poisonous, flammable and explosive gas, which has great harm to people's life and property. Detection of carbon monoxide concentration is an effective measure to prevent fire. Therefore, the design of an accurate, reliable and timely warning of carbon monoxide detector can largely avoid the occurrence of accidents. In view of the problems caused by CO, we design and realize a CO concentration detection system based on infrared absorption method. By detecting the concentration of CO, we can better judge the harm degree of CO, and do a good job of prevention as soon as possible. Firstly, this paper introduces the principle of infrared absorption measurement of CO. Then, according to the characteristics of CO, the system hardware circuit and software program are designed. Finally, the linear fitting of the CO concentration and the reference intensity of the CO gas to the measured intensity ratio is carried out by means of experimental data. The experimental results show that the CO concentration values are in good linear relationship with the values of the intensity ratio, indicating that the calibration method is feasible. The design has the advantages of low cost, small size and low power consumption, and has good application value.

1. Introduction

CO is a colourless, odourless and poisonous gas. Its ability to combine with haemoglobin is far more than oxygen, which makes haemoglobin lose oxygen carrying capacity and function, resulting in tissue hypoxia, and even cause suffocation death (Li et al., 2007). If the concentration of CO in air is more than 0.005%, it will cause poisoning. If the concentration is 12.5%, it will cause explosion when exposed to flame (Zhang, 2010). Gas poisoning and gas explosion occurred frequently due to excessive indoor CO concentration in life. Therefore, real-time and effective measurement of CO concentration is of great significance to our production and life.

There are five methods commonly used to measure the concentration of CO, which are electrical detection, carrier catalysis, electrochemistry, light interference and infrared detection (Zhong et al., 2006). Infrared absorption method is also called infrared spectrum absorption method. Compared with other methods, infrared spectrum absorption method has the advantages of good selectivity, high sensitivity, fast response, strong stability and strong anti-interference performance. Therefore, people have done a lot of research on infrared technology (Li et al., 2009; Song et al., 2013; Kasyutich et al., 2008).

Due to the needs of industrial monitoring and environmental monitoring, the development of carbon monoxide sensing system has attracted more and more attention (Wang, 1998). A new type of CO gas concentration detector is developed to monitor CO gas concentration in real time and accurately. This has important significance for ensuring safety production and improving people's quality of life (Chen et al., 2006; Svanberg, 1996).

2. The principle of infrared absorption method for CO detection

At present, there are many methods to detect CO gas concentration at home and abroad, among which the main methods are electrochemical method, light interference method, solid state ionization method and infrared absorption method. The infrared absorption method is mainly based on the gas absorption spectrum

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theory and Longbow Bill's law to detect the gas species and concentration. In general, the infrared absorption method has the advantages of wide range of gas measurement, high accuracy, high sensitivity, fast response, long life, simple structure and less affected by the surrounding environment. Therefore, infrared absorption method is used as the detection of carbon monoxide concentration in this paper.

2.1 Theoretical analysis of CO gas absorption spectroscopy

The absorption spectra of gas molecules should follow the photon energy theory, as shown in the following formula

$$\varepsilon = hv \quad (1)$$

In the formula, ε is the photon energy, h is the Planck constant, and v is the light frequency.
Different gases have different molecular structures, and the molecular structure of the different determines that different gases can only absorb the corresponding wavelength of the photon, which is the selective absorption of gas spectrum. Therefore, if a segment of the spectrum is absorbed, the existence of a gas is indicated. Then we can know the concentration of gas by studying the absorption spectrum of this band.
The main purpose of this paper is to detect the concentration of CO gas, and select the CO spectral absorption peak mainly from two aspects. On the one hand, the absorption peak energy is large, so it is easy to detect. On the other hand, it does not overlap the absorption peaks of other gases as far as possible. In Figure 1, the infrared absorption spectra of CO from 1um~9um wavelength are described, and the infrared absorption of CO in 4.5um~5.0um band is obvious.

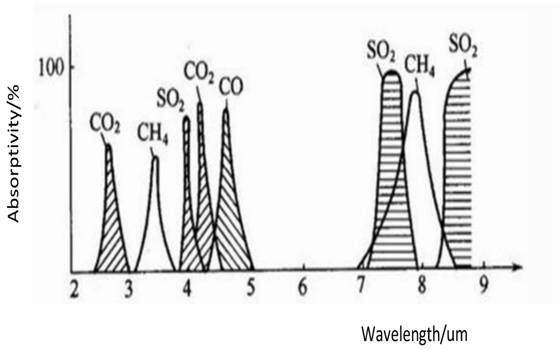

Figure 1. Absorption spectra of several gases

2.2 Longbow Bill's law

According to the theory of gas absorption spectrum, when a beam of light to be measured after a certain concentration gas, if the gas absorption spectrum and spectral overlap some light, part of the gas absorption spectrum of photon coincidence line, and the relationship between absorption obeys Longbow Bill's law. Longbow Bill's law is shown as follows.

$$I = I_0 \exp(-KCL) \quad (2)$$

Among them, I :The outgoing light intensity of a specific wavelength light passing through a gas;

I_0:Intensity of light before incident light;

C : Gas concentration. The unit can be either g/L or mol/L;

L : Optical path. The unit is cm;

K : Absorption coefficient of gas. It is related to the characteristics of gas molecules, temperature, pressure and incident wavelength.
According to formula (2), the expression of gas concentration can be obtained as follows

$$C = \frac{\ln(I_0 / I)}{KL} \quad (3)$$

It can be seen from the formula (3) that the gas concentration is related to the incident light intensity, the outgoing light intensity, the gas absorption coefficient and the optical path length. For a gas to be measured and an environment determined system, both K and L are constant, so the gas concentration is only related to the logarithm of the incident light intensity and the outgoing light intensity.

3.System design

In the design of this paper, the CO gas concentration detection controller is a system which realizes the collection, display, control, alarm and other functions of the CO gas concentration in the living environment through the microcontroller programming. The specific control process is as follows. First of all, the gas sensors react with the CO gas in the environment to produce a linearly varying weak current signal. Then, after filtering and amplifying, the signal is converted to a voltage signal to the microcontroller. Finally, the mass concentration of the gas measured is displayed directly on the LCD screen through the A/D conversion and model operation. The instrument can set two level alarms, when the gas mass concentration reaches the pre-set alarm value, it will send different frequency of sound and light alarm signal according to the different alarm level.

STM32 is a 32 bit flash microcontroller. It has the characteristics of strong encryption, strong anti-interference, ultra-low power consumption and programmability in the system. STM32 single chip microcomputer has built-in A/D conversion function, the chip is equipped with EEPROM, so that the mass concentration settings can be easily written and read out. In this paper, STM32 microcontroller is selected to simplify hardware circuit and software programming. The overall design of the system block diagram is shown in Figure 2.

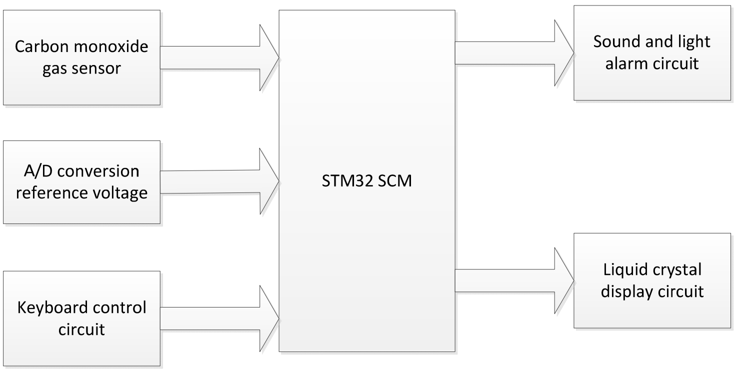

Figure 2.The block diagram of CO detection system.

3.1 Hardware circuit design

3.1.1 Design of power supply module

The power supply has great influence on the operation performance of the system. Our requirements for power supply are stable, reliable, small ripple, and can provide stable voltage and enough current. The power supply circuit is composed of three terminal voltage regulators LM7805. Multilevel capacitor filter is used to output constant 5V voltage. The power module circuit is shown in Figure 3.

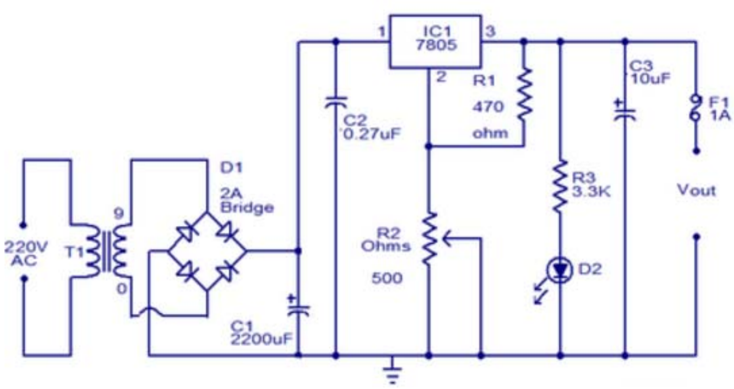

Figure 3. Power module design.

3.1.2 Design of CO gas detection unit

The gas sensor is a device that detects the specific components in the gas and converts it into electrical signals. According to the strength of these signals, the gas sensor can detect, monitor and alarm. The sensor is an important part of the control system to obtain the characteristics of the controlled object, and its characteristics directly affect the accuracy of the control system. This design chooses MQ-7 series sensor as CO detector. Figure 4 is the equivalent circuit of MQ-7 series sensors.

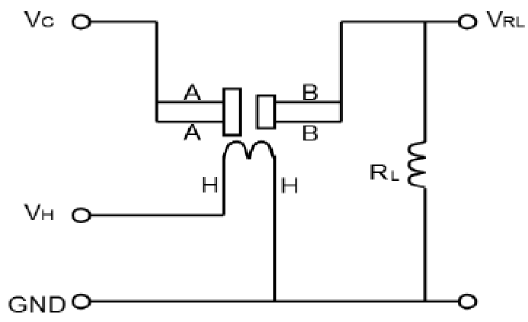

Figure 4.Equivalent circuit of MQ-7 series sensors.

3.1.3 Alarm unit design

The alarm circuit is composed of light emitting diode and buzzer. The output value of the gas sensor is compared with the setting alarm threshold (the given value) by software programming. When the gas sensor detects the gas concentration beyond the alarm setting value, the sound and light alarm will be sent out simultaneously. The alarm circuit is shown in Figure 5.

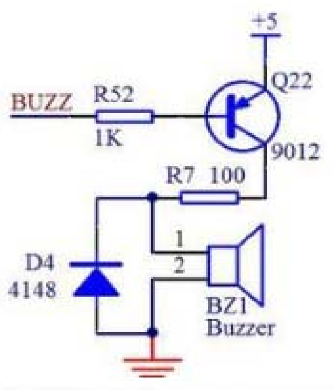

Figure 5. Alarm circuit.

3.1.4 Display module design

The display module is the core module of the external system, containing MCU. This module mainly completes the function of MCU communication with the internal module. LCD12864 provides the display function of CO concentration, and the key can realize the input control operation of LCD12864.LCD has the advantages of low cost, flexible configuration, low working voltage, low energy consumption, small size, large amount of display information and no radiation.

3.2 Software programming

The software program is written in C language, and the whole software design mainly includes the main program and several subprogram modules. These subroutine modules are A/D conversion, display module, sound and light alarm and control subroutine module. The overall flow chart of the system is shown in Figure 6. The system reads the electrical signal output from the gas sensor to the A/D converter, and the A/D converter outputs the binary code to the microcontroller for processing. STM32 MCU uses first order linear fitting algorithm to calculate the concentration of CO gas, and then sends it to the LCD display. At the same time, the detected CO gas concentration is compared with the pre-set concentration threshold (alarm setting value) to determine whether the sound and light alarm is needed.

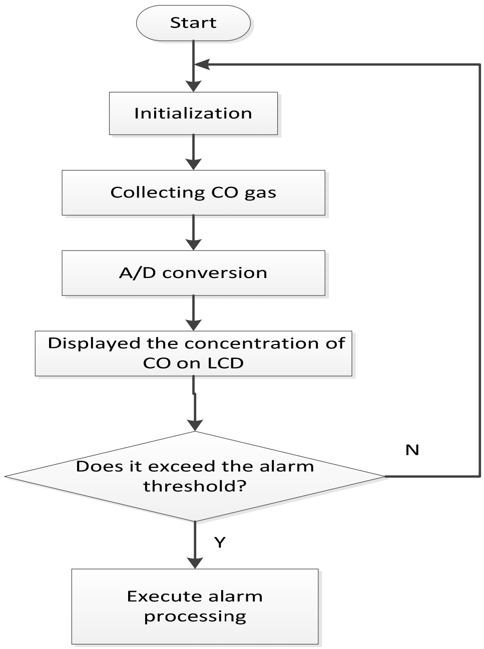

Figure 6.Flow chart of STM32 single chip control program.

4. Experiment and result analysis

The values of reference voltage and measurement voltage are read and the average value is displayed on the LCD panel. The concentration of CO in the experiment was 0PPM, 1000PPM, 2000PPM, 3000PPM, 4000PPM, 5000PPM, 6000PPM, 7000PPM, 8000PPM, 9000PPM and 10000PPM respectively. The corresponding AD average values and the reference AD mean values are obtained, and the results are shown in Table 1. ・

Table 1.Experimental data on the output voltage.

CO concentration/ppm	Measurement of AD mean	Reference AD mean	The logarithm of the quotient
0PPM	57226	49029	-0.155
1000PPM	56463	46184	-0.201
2000PPM	55108	45736	-0.186
3000PPM	52029	46105	-0.121
4000PPM	51237	45986	-0.108
5000PPM	50132	46012	-0.086
6000PPM	49198	45278	-0.083
7000PPM	47871	47049	-0.017
8000PPM	45073	46963	0.041
9000PPM	42652	45823	0.072
10000PPM	39464	46067	0.155

The voltage measurement range of this system is 0~2.5V, and the corresponding value is 0~65535.The logarithm for the ratio of reference light intensity to measured light intensity is $\ln \frac{D_{ref}}{D_{mea}}$. The linear fitting of $\ln \frac{D_{ref}}{D_{mea}}$ and CO concentration points is carried out, and the fitting curve is shown in Figure 7.

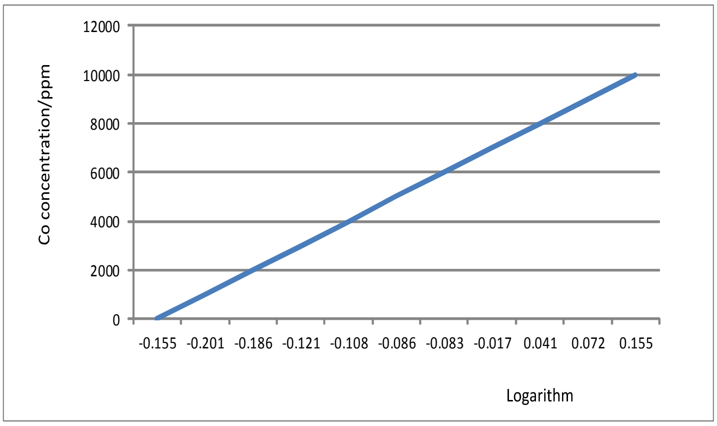

Figure 7. Fitting curve of CO concentration and absorption luminosity.

It can be seen from Figure 7 that there is a good first order linear relationship between the CO concentration value and the ratio of the intensity of the two light beams, indicating that the calibration method is feasible.

5. Conclusion

The CO concentration detector designed based on infrared absorption method has the advantages of low cost, small volume and high precision. The system realizes the real-time monitoring of CO concentration in the living environment. In this paper, MQ-7 series sensors are used as CO gas collection, and the hardware circuit and software program of CO concentration detection system are designed. The linear fitting between the CO concentration and the ratio of the reference intensity of CO gas to the measured intensity of CO gas is linear by experimental data. The experimental results show that the first order linear relationship between the CO concentration value and the light intensity ratio is good, which indicates that the calibration method is feasible.

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