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Design and Implementation of Formaldehyde Concentration Detector Based on STC12C5A

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This paper aims to develop a detection system that can accurately measure indoor formaldehyde emissions. For this purpose, the existing formaldehyde detection methods were reviewed in details, and the gas sensor method was selected for our research. Then, a formaldehyde concentration detection system was set up based on the STC12C5A, including a micro-controller unit (MCU) module, a sensor module, a liquid-crystal display (LCD) module and an alarm module. Through comprehensive tests on three different sites, it is proved that the system can capture the exact formaldehyde concentration indoor and display the results on the LCD; an alarm could be released when the concentration exceeds the preset threshold. Overall, the system is stable, reliable and easy to operate in various indoor environments.

1. Introduction

With the improvement of living conditions, more and more attentions have been paid to home environment. However, the home environment is severely affected by the formaldehyde emissions from building materials, decoration materials and furniture (Weng et al., 2008). As a colorless gas with a pungent odour, formaldehyde is easily dissolved in water and ethanol (Liu et al., 2016). Those exposed to formaldehyde may suffer from eyes and nose irritation, and even cancer if the exposure is long enough and the formaldehyde is highly concentrated (Tang et al., 2009). The carcinogenic effect of formaldehyde was confirmed by the World Health Organization in October 2017 (Claucherty and Sakaue, 2018).

In view of the serious health hazards, it is imperative to develop a detector that can detect formaldehyde in a fast and accurate manner. The existing formaldehyde detection methods fall into two categories, namely, photometric method and gas sensor detection method (Jeon and Park, 2018). The former can be further divided into phenol reagent spectrophotometry, phenyl hydrazine hydrochloride colorimetric method and chromo tropic acid colorimetric method (Hopkins et al., 2003). The photometric method can effectively measure the accurate mass concentration of formaldehyde according to its chemical properties. However, this method requires professionals to complete chemical reactions, involves complex operations and consumes a long test period. By contrast, the gas sensor detection method does not need to prepare any chemical material, and features simple measurement, small instrument size, strong portability, high precision and recyclability. As a result, this method has attracted much attention from the industry and the academia.

2 Principles of Related Detection Methods

2.1 Photometric method

The photometric detection method follows the Beer-Lambert law in optics. The law relates the attenuation of light to the properties of the material through which the light is travelling: the absorbance of a material sample is directly proportional to its thickness (path length) and the concentrations of the attenuating species in the material sample (Tucker and Sellers, 1986). The mathematical expression of the law is as follows.

Where I_O is the incident light intensity, I is the transmitted light intensity, A is the absorbance, k is the absorption coefficient of the absorbing medium; c is the concentration (Kasper et al., 2018) of the absorbing medium, l is the thickness of liquid layer. According to the difference of the measured solution, photometric

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method can be further divided into a phenol reagent colorimetric method, a phenylhydrazine hydrochloride colorimetric method, and a chromotropic acid colorimetric method. The chemical reaction between formaldehyde and phenol reagent produces a blue-green reactant; the mixed solution of formaldehyde and phenylhydrazine hydrochloride and potassium ferricyanide produce an orange-red reaction; the reaction of formaldehyde and chromotropic acid produces a purple reactant, depending on the color of the reactants. Compared with the standard color, concentration of formaldehyde can be judged.

$$\lg \frac{I_0}{I} = kcl = A \tag{1}$$

2.2 Gas sensor method

The gas sensor method relies on the sensor to detect the target gas. The principle is to convert the mass concentration of a certain gas in the air into electric signals, and judge the gas distribution in the environment according to the level of the signals. The formaldehyde sensor is a fuel cell type electrochemical sensor. Formaldehyde and oxygen undergo oxidation-reduction reactions on the electrode, and discharge charges to form a current. The generated current is proportional to the concentration of formaldehyde and follows Faraday's law. Faraday's law is shown in formula 2. m is the mass of formaldehyde, and k_e is electrochemical equivalent. Q isquantity of electric charge, I is the current. As shown in formula 3，The level of formaldehyde concentration can be determined by testing the magnitude of the current (Zhao et al., 2016). Formaldehyde gas sensor ZE08-CH2O is used in this paper. It has the advantages of low power consumption, high precision, high sensitivity, wide linear range, strong anti-interference ability, excellent repeatability and stability, which is widely used for the detection of formaldehyde gas concentration in civil and environmental protection.

$$m = k_e \times Q = k_e \times I \times t \tag{2}$$

$$\rho = \frac{m}{V} = \frac{k_e \times I \times t}{V} \tag{3}$$

3 System Design

Formaldehyde detector consists of such five parts as the micro-controller unit (MCU) module, the sensor module, the keyboard module, the alarm module and the liquid-crystal display (LCD) module (Figure 1). The MCU module, the core of the system, is responsible for detecting, processing and displaying the formaldehyde concentration. Before the detection, the alarm value of formaldehyde concentration should be configured in the MCU module via buttons. Then, the concentration will be measured by the sensor module. The detected result will be outputted on the LCD module. The buzzer of the alarm module will give off an alarm once the detected concentration exceeds the preset limit.

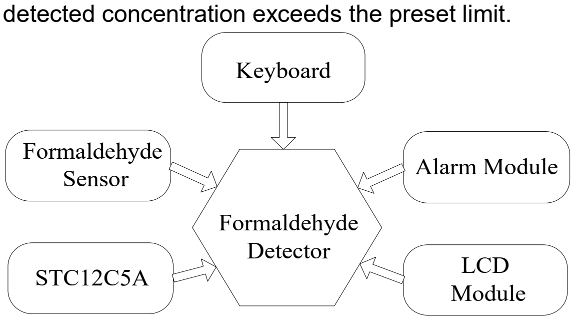

Figure 1: System design

3.1 MCU module

The MCU module uses the STC12C5A (Hongjing Technology, China) as the core chip. The chip is a single-clock MCU compatible with traditional 51 cores. In normal conditions, the MCU module operates at the voltage between 3.3V and 5V and a speed 10 times that of MCU 8051. Integrating EEPROM, RAM and serial port, the rich hardware resources of the chip include 2 pulse-width modulator (PWM), 8 high-speed 10-bit A/D conversion, 4 interrupt timers and 36 general-purpose I/Os.

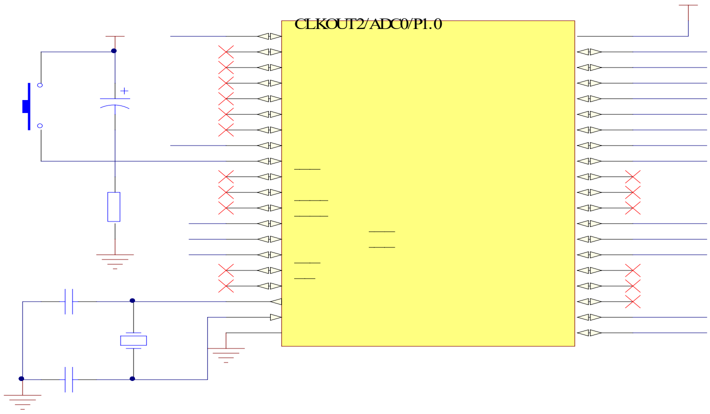

Figure 2: Circuit diagram of the minimum system

The main part of the MCU module is an STC12C5A minimum system, which consists of a power supply circuit, a reset circuit and a crystal oscillator circuit. The power supply circuit adopts a 5V USB power source; the reset circuit uses a 10K resistor and a 10uF capacitor; the crystal oscillator circuit relies on a 11.0592M crystal oscillator and a 30pF capacitor, aiming to provide a reference frequency for the other circuits. The circuit diagram of the minimum system is shown in Figure 2.

3.2 Sensor module

Being the core of the entire system, the sensor module converts formaldehyde concentration into electrical signals. Hence, the selection of sensor is particularly important. Considering volume, cost, accuracy, range and other factors, formaldehyde gas sensor ZE08-CH2O was adopted (Figure 3), which is a universal gas sensing module integrating electrochemical detection technology with fine circuit design. The range, resolution and working temperature of the sensor are 0~5ppm, 0.01ppm and 0~50°C, respectively. The sensor supports both the UART and the DAC output modes, and is well received for its small size, high resolution, low power consumption and strong anti-interference ability.

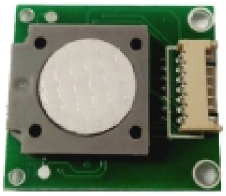

Figure 3: Formaldehyde sensor ZE08-CH2O

3.3 Keyboard module

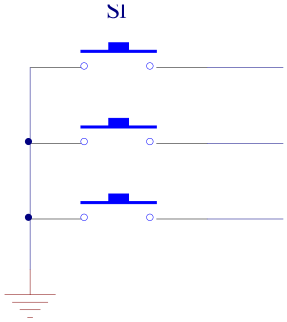

Figure 4: Schematic diagram of button circuits

The keyboard module, composed of three button circuits, is used to set the alarm value of formaldehyde concentration. According to the sketch map of button circuits (Figure 4), button S1, connected to external interrupt pin P3.3, determines whether to launch the alarm function, while the other two buttons S2 and S3 respectively tunes up and down the alarm value at the step of 0.01ppm. Under normal conditions, the external interrupt is triggered by button S1 when it is necessary to set the alarm threshold. At this time, the MCU reads the level of S2 and S3, thus completing the setting of the alarm value.

3.4 Alarm Module

When the formaldehyde concentration surpasses the preset value, the buzzer in the alarm module will give off an alarm to avoid excess formaldehyde from harming human body. The alarm module is realized by the buzzer circuit shown in Figure 5. Since the buzzer cannot be drove directly by the I/O port of the MCU, a transistor is needed to amplify the driving current so that the current is sufficiently strong for the normal operation of the buzzer. After the power is turned on, if the P1.1 pin of the MCU outputs a high level, the transistor will not be activated and the current cannot pass smoothly. In this case, no alarm will be released by the buzzer. Otherwise, the buzzer will give off an alarm. Transistor cannot be turned on and current cannot pass smoothly. At this time, buzzer does not vibrate and sound isn't generated. When MCU outputs a low level, circuit is turned on and alarm is generated.

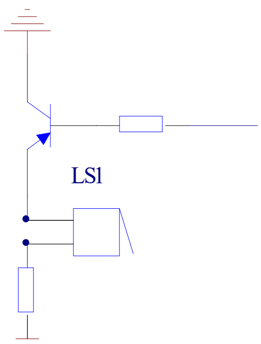

Figure 5: Circuit diagram of the buzzer

3.5 LCD module

The LCD module displays the detected formaldehyde concentration and the alarm value on an LCD1602 screen. According to the circuit diagram (Figure 6), the LCD1602 can display 16 characters in each of its two lines under the voltage of 4.5~5.5V and the current of 2.0mA. The LCD is connected to IIC port of MCU for data transmission; the P0 port of MCU is connected to DB0~DB7 of LCD; the P2.5, P2.6, and P2.7 pins are connected to RS, RW and EN of LCD, respectively, to control the corresponding working mode; the VL pin is connected to potentiometer for contrast adjustment. Before starting the LCD1602, the LCD must be initialized as follows: turn on power, enter the setting of the input function after 2ms, turn off the display and input clear screen command. After these steps, the input mode will be set and the data will be displayed on the LCD.

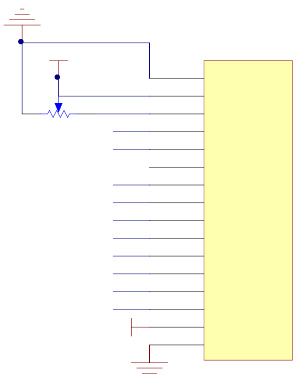

Figure 6: Circuit diagram of the LCD module

3.6 Software design

The system software was programmed in C-language through the procedures specified in Figure 7: First, all programs, including system clock and sensor, should be initialized; then, the sensor module should be called to measure formaldehyde concentration; after the measured data have been processed by STC12C5A, the processing results will be displayed on the LCD; if the results surpass the pre-set threshold, the MCU will call the alarm module.

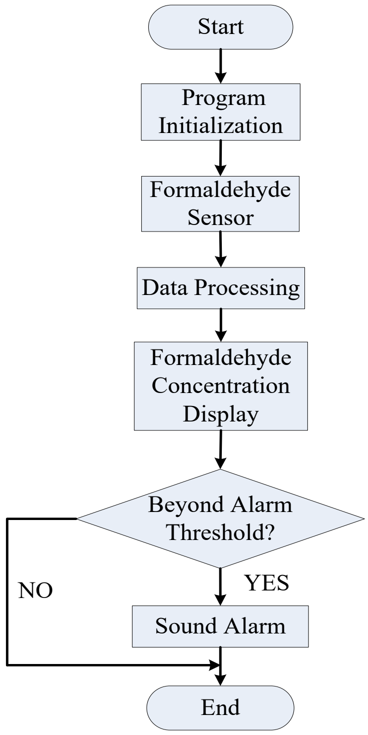

Figure 7: Software design procedure

4 System Test

The proposed formaldehyde concentration detection system was subjected to 12h airtight tests on a dorm constructed 5 years ago, a house renovated half a year ago, and a new closet. To minimize the external interference, the formaldehyde concentration was measured in a closed and non-ventilated state. The measured results were compared with those obtained by standard formaldehyde measuring instrument.
During the tests, the proposed systems were arranged in the dorm, the house and the closet. When the systems displayed the results, the data on the LCD were recorded. The above steps were implemented three times and the mean values of the three results were adopted for further analysis. Table 1 shows the formaldehyde concentrations of all three sites measured by our system and the standard instrument.

Table 1: Measured formaldehyde concentrations

Test the venue	Reference value	Actual result	Absolute error
Dorm room	0.0627 mg/m^3	0.0535 mg/m^3	0.0092 mg/m^3
Wardrobe	0.1126 mg/m^3	0.1058 mg/m^3	0.0068 mg/m^3
House	0.1635 mg/m^3	0.1456 mg/m^3	0.0179 mg/m^3

It can be seen from Table 1 that the proposed system effectively detected the indoor formaldehyde concentration. Compared to the standard instrument, the proposed system controlled the absolute error within 0.0179mg/m^3. Then, the measured results of our system were contrasted with the value specified in national standard (0.08 mg/m^3) (Table 2). It is clear that the formaldehyde concentrations in the newly renovated house and the new closet both surpassed the value specified in national standard and may endanger human health. Therefore, newly renovated houses and furniture are need to be ventilated for a period of time to reduce formaldehyde concentration to safe range.

Table 2: Comparison between the measured results and national standard

Test the venue	Measurement	National standard
Dorm room	0.0627 mg/m^3	0.08 mg/m^3
Wardrobe	0.1126 mg/m^3	0.08 mg/m^3
House	0.1635 mg/m^3	0.08 mg/m^3

5 Conclusions

This paper designs a formaldehyde concentration detection system based on STC12C5A. The system is featured by small volume, simple hardware, high accuracy and strong stability. Through comprehensive tests on three different sites, it is proved that the system can capture the exact formaldehyde concentration indoor and display the results on the LCD, an alarm could be released when the concentration exceeds the pre-set threshold. Overall, the system is stable, reliable and easy to operate in various indoor environments.

Acknowledgements

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