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Design and Implementation of WSN Detection System for Harmful Gas Based on Odour Recognition

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In view of the safety problem with the harmful gas leakage in chemical environment, this paper developsone wireless sensor network (WSN)detection system for harmful gas based on odour recognition. In this system, the sensor array is used to make odour recognition of the four harmful gases such as Cl_2, CO, NO_2 and SO_2 in the chemical environment; then, the data is transmitted through the ZigBee technology-built WSN to the central sink node for data analysis. Thus, the effective recognition and detection of harmful gases in the chemical environment can be achieved so as to avoid potential safety hazards.

1. Introduction

The leakage of harmful gases such as Cl_2, CO, NO_2 and SO_2, etc. in the chemical environment leak can seriously threaten the safety of the on-site staffs (Al-Maskari et al., 2018). When the concentration of harmful gases reaches a certain limit, it is easy to evolve into a major safety accident such as fire, explosion, human poisoning and casualties (Dung et al., 2018). To avoid such safety accidents, it is essential to develop a timely and effective harmful gas detection system. The harmful gas detection system can accurately detect the leakage of harmful gases through odour recognition, and provide gas leakage alarm information in time, so as to offer reliable technical support for the rational development of emergency measures in the chemical production process (Mondal et al., 2016, Khan et al., 2016). This system can also detect theharmful gases in areas where safety thresholds are exceeded and alerts the staffs who can quickly locate leaks and take necessary emergency measures to avoid large-scale production accidents (Hotel et al., 2017, Wu et al., 2018).

Therefore, this paper develops one WSN detection system for harmful gas based on odour recognition. This system uses odour recognition technology to detect toxic gases in the chemical environment, and transmits the detection data to the control centre through the WSN. Thus, the staffs can determine the leakage of harmful gases according to the relevant data, and then take urgent measures to ensure production safety.

2. Overall design and odour recognition method

2.1 Overall design

The entire system is mainly divided into two parts: the harmful gas odour recognition devices and the sink centre. The harmful gas odour recognition device sare equipped with the stepping motor, which can be moved to a designated position in chemical environment; the multi-sensor module performs odour recognition and collects gas concentration on harmful gases such as Cl_2, CO, NO_2, SO_2 in a chemical environment; the camera module is used to record the surrounding environmental conditions; the processor Stm32f105 chip integrates this information, and then transmits data through the Zigbee module. The wireless sensor network (WSN) is formed between the Zigbee modules in all odour recognition devicesand finally the data is sent to the sink centre through the network. The sink centre is composed of the Zigbee module and host computer, which plays a role of data analysis and aggregation; it receives the data sent by each odour recognition device in WSN and makes simulation to conduct odour recognition analysis on the harmful gas, and then the data transmitted from the camera is used to obtain the on-site status/state/condition. The overall block diagram of the system is shown in Figure 1.

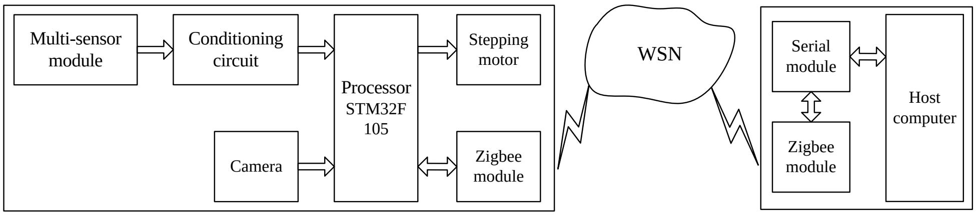

Figure 1: Overall diagram of the system

2.2 Odour recognition method of harmful gas

The odour recognition sensors of four harmful gases selected in this paper are independently developed by the laboratory. They are shown in Figure 2. The working principle is that under certain temperature conditions, the changes of the gas concentration to be measured leads to the change of the resistance value in the sensitive resistor, and the back-end circuit realizes the detection of the gas concentration by processing the resistance signal. All these four odour recognition sensors use the same side-heating sintering tube, and through this sintering tube, the nickel-chromium heating wire works as the heating electrode of the sensor; their difference lies in the sensitive material applied on the side-heating sintering tube and the sintering temperature during the manufacturing process. The four sensors-doped sensitive materials are based on SnO_2. The first sensor mainly measuring the Cl_2 gas is additionally provided with Pt and Nb, sintered at a temperature of 500-600°C to achieve the highest sensitivity to Cl_2 gas; the second sensor mainly for CO gas is supplemented with Nb and Ti, sintered at a temperature of 500-600°C to achieve the highest sensitivity to CO gas; the third sensor for mainly measuring NO_2 gas is added with Pt, sintered at 600-700°C temperature environment to achieve the highest sensitivity to NO_2 gas; the fourth sensor for SO_2 gas is with Pt and Nb, and sintered at a temperature of 600-700°C to achieve the highest sensitivity to SO_2 gas.

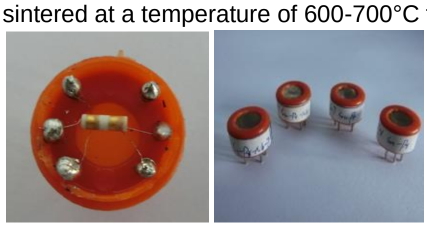

Figure 2: Four gas sensors

3. Software and hardware design

3.1 Main hardware circuit design

(1) Sensor conditioning circuit design of odour recognition

In terms of harmful gas recognition division, the four harmful gas odour recognition sensors of the system are all resistive devices. In order to convert the resistance signal into the voltage signal for easy acquisition, the signal conditioning circuit was designed in this paper; Figure 3 shows its circuit principle, where,U_a is the reference voltage of the output, R_x is the resistance of the analog sensor, U_0 is the output voltage after conditioning, and the resistance signals of the other three sensors adopt the same conditioning principle.

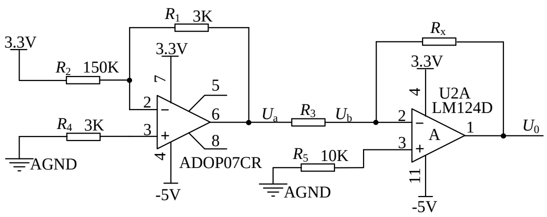

Figure 3: Schematic diagram of sensor conditioning circuit

Among them, U_a is the reference voltage -0.1V, and R_3 is the known resistance. Then, by the two inverting amplifier circuits. the relationship between the input resistance signal and the output voltage is established as:

$$U_0 = \frac{1}{10R_3} R_x \quad (1)$$

where, the change of U_0 can reflect the change of R_x resistance value, and the concentration of the gas introduced at this time can be known by information calibration of the harmful gas.

(2)Communication module circuit design

Zigbee module adopts SZ05-ADV series of Shunzhou Technology; the wireless communication distance can support up to 2000 meters, while the 2.4G DSSS spread spectrum technology makes the equipment's anti-interference ability strong enough to support multiple flexible networking modes. The transmitting end TXD and the receiving end RXD of the SZ05 can be directly connected to the Stm32f105; the level switch is made through the serial port chip to make communication with host computer. Figure 4 shows the circuit diagram of Zigbee module.

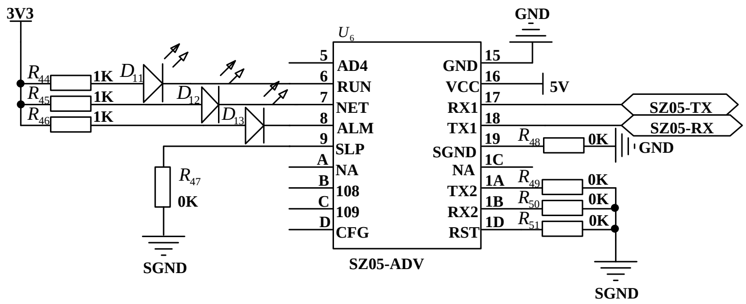

Figure 4: Communication module circuit diagram

3.2 Main software design

(1) Odour recognition software design

Figure 5 shows the odour recognition subroutine of the harmful gas odour recognition device. For the four critical gases of Cl_2, CO, NO_2 and SO_2, the data conversion is made by the A/D module inside the processor, and the obtained voltage values are averaged to achieve the final data of each gas.

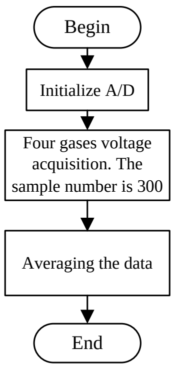

Figure 5: Flow chart of harmful gas data collection

(2) ZigBee software design

Zigbee software design is made in two aspects: identification device node and sink centre node. The identification device node forms a sensing network through Zigbee, and sends the collected harmful gas data to the sink central node. The sink central node receives the data of each device node and stores it in the upper computer, and finally identifies the harmful gas of various odours by the simulation result of upper computer. Figure 6 shows the Zigbee software flow of the device node, while Figure 7 depicts the Zigbee software flow of the central sink centre node.

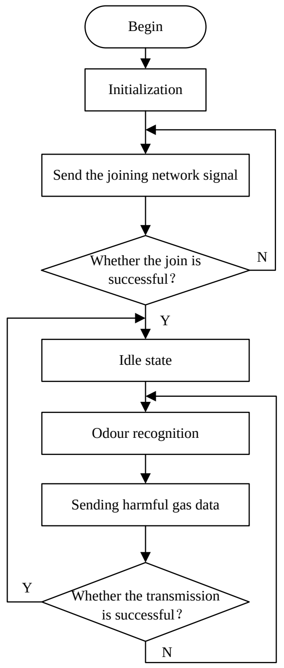

Figure 6: Zigbee software flow chart of device node

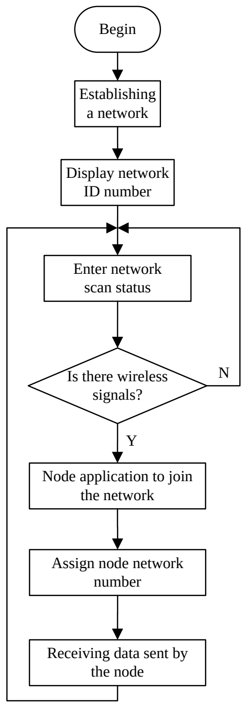

Figure 7: Zigbee software flow chart of sink centre node

4. Network system model

Figure 8 shows the wireless sensor network system model. The Zigbee wireless sensor network is built in a chemical environment using the star topology. The structure is simple in control, easy in fault diagnosis, convenient in service, and easy to add new nodes in the network. Thus. The data security and priority are easily controlled.

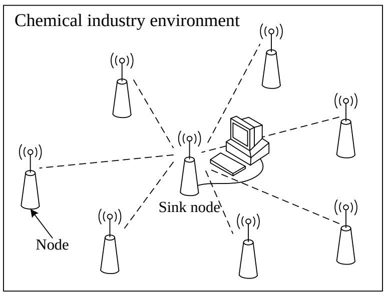

Figure 8: Network system model

5. Experiments and analysis

The harmful gas odour recognition device and experimental environment are shown in Figure 9. In the experimental process, the odour recognition ability of the detection system was verified. For the device in a simulated chemical environment, four experiments were performed, each with different gas. Five bottles, numbered 1 to 5, were placed in each experiment, and the gas concentrations in the bottles were different. When the harmful gas odour recognition device passes by the bottle filled with harmful gas, the gas can be identified and detected by the sensor, and then the data is sent to the sink centre for analysis and odour recognition through the Zigbee wireless sensor network.

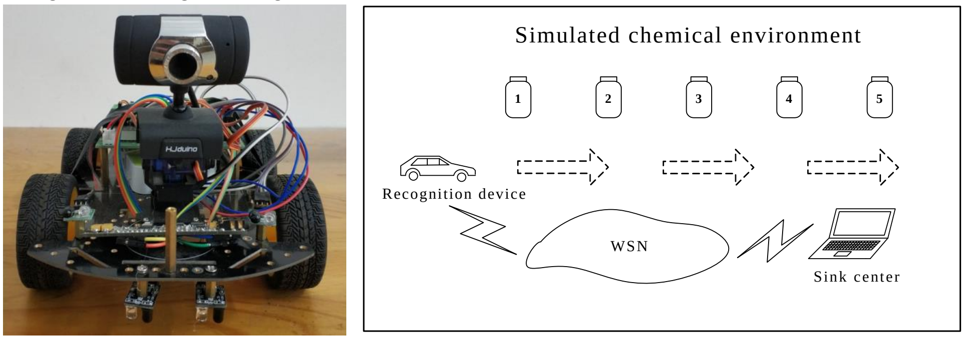

Figure 9: System physical map and test environment

When the odour recognition device of harmful gas passed the Cl_2 region with concentration of 40ppm, 20ppm, 10ppm, 5ppm and 2.5ppm respectively, it's found that the change rate of the No. 1 sensor was the highest at Cl_2 gas concentration, so the No. 1 sensor was selected as the identification front end of Cl_2. When the harmful gas odour recognition device passed the NO_2 region with concentration of 25ppm, 20ppm, 15ppm, 10ppm and 5ppm respectively, it's found that the change rate of the No. 3 sensor was the highest at NO_2 gas concentration, so the No. 3 sensor was selected as the identification front end of NO_2. According to the received datas of sensor No. 1 and No. 3, the curves for the change of Cl_2 and NO_2 concentration with the resistance value are fitted, as shown in Figure 10.

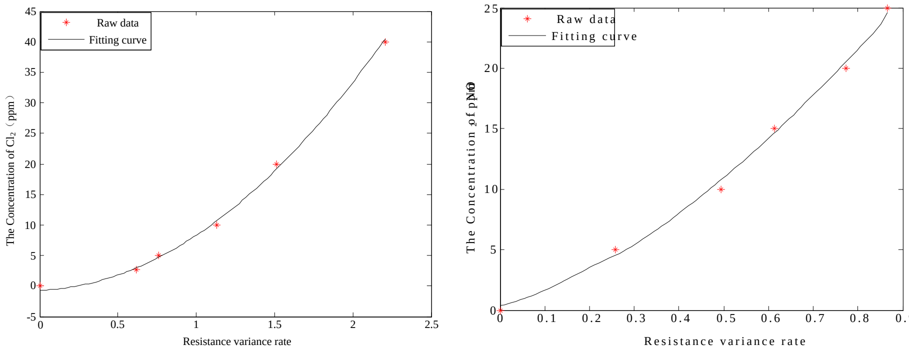

Figure 10: Fitting curves for the changes of Cl_2 and NO_2 concentration with change rate of resistance values

So, the sensitivity analysis of the No. 2 sensor for CO concentration and the No. 4 sensor for SO_2 concentration are obtained. The curves for the change of CO concentration and SO_2 concentration with the change rate of the resistance valueis are fitted, as shown in Figure 11.

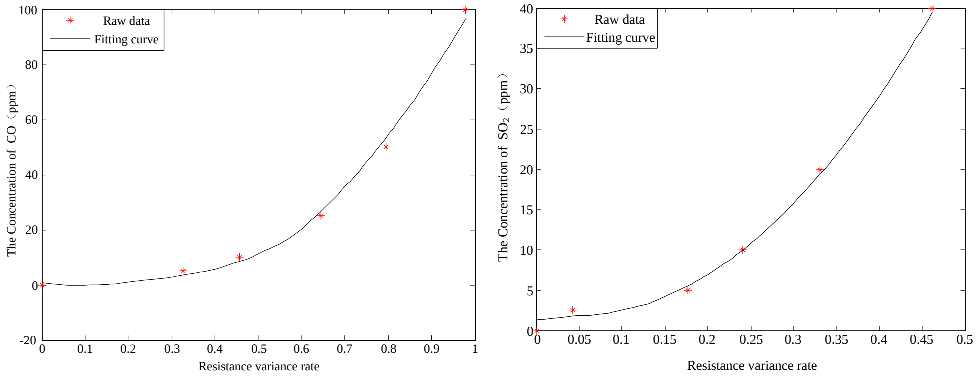

Figure 11: Fitting curves for the changes of CO and SO_2 concentration with change rate of resistance values

The experiments indicate that No. 1 sensor can be used for detecting Cl_2, No. 2 sensor for CO, No. 3 sensor for NO_2, and No. 4 sensor for SO_2. Meanwhile, according to the test results, this system can accurately identify harmful gas information, and effectively recognize the odours of the harmful gases in the chemical environment.

6. Conclusions

Combining with harmful gas odour recognition technology, Zigbee technology and wireless sensor network technology, this paper develops one WSN detection system for harmful gas based on odour recognition. It can make detection and data analysis for the common harmful gases such as Cl_2, CO, NO_2 and SO_2 in chemical environment, thus achieving the goal of safety pre-warning.

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