Design of Toxic Environment Monitoring System for Industrial Sites Based on Wireless Sensor Networks

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Abstract. In view of the actual demand of toxic gas monitoring in the production, storage and use field environment of chemical enterprises, considering the large amount of monitoring data and the difficulty of real-time transmission of information, a toxic gas environment monitoring system is designed. The system based on low-power microcontroller chip CC2530 by using wireless sensor intelligent information processing and data communication technology, which evaluates and improves the ambient air conditions and provides theoretical basis and technical support. The sensor node collects the concentration data of CO, formaldehyde, ozone, SO₂ and other toxic gases in real time, processes them and sends them to the receiving end. According to the stored data, the receiver monitors the air quality of the industrial production and storage environment in real time, and effectively solves the problems of complex wiring and maintenance difficulties of traditional cable sensors to reduce the risk of accidents or early warning and reduce the hazards of accidents. The test results show that the system has stable performance, can effectively detect industrial toxic environmental parameters, and can be widely used in various fields, especially in unattended or inaccessible environment for monitoring tasks.

Keywords. Toxic environment; industrial sites; wireless sensor networks; design.

1. Introduction
Toxic gases in industrial production have caused great harm to people’s lives. Qualitative and quantitative detection of toxic and harmful gases and timely understanding of the information of toxic and harmful gases in the environment can provide very important data and basis for environmental monitoring of industrial environment and people’s living environment [1-3]. For the gas monitoring in the large environment, it is necessary to form a monitoring network by monitoring points, so that the toxic gas detection and monitoring can be multifunctional, intelligent and networked [4-6]. In recent years, the emerging wireless sensor network has been applied in environmental monitoring, engineering safety, agricultural greenhouse, livestock and poultry breeding and other fields [7-10]. Although some scholars have applied wireless sensor network and wireless communication technology to agricultural or working environment monitoring [11, 12], they usually have the disadvantages of high cost, high power consumption and poor precision, so they can not be widely applied.

The system described in this paper is mainly composed of low-power wireless sensor network nodes through ZigBee ad hoc network, which can realize continuous and long-term online monitoring and early warning of toxic gas concentration in the air in the production, storage, and use sites of
chemical enterprises. The main monitoring items of the system include CO, formaldehyde, ozone, SO2, etc. Finally, the test experiment of communication distance and system monitoring function test of the monitoring system are realized.

2. Overall Structure Design of Environmental Monitoring System in Industrial Field

System requirements analysis: the main functions of the monitoring system include data acquisition, transmission, and processing. The system is sent to the gateway node by wireless transmission to solve the problems of complex site environment and wiring difficulties. It can observe the environmental parameters of industrial site at any time, facilitate the analysis of the site situation, and carry out real-time data display, storage, and historical data query, to find out the cause after the accident. The system is composed of monitoring terminal, gateway node and monitoring center. The structure diagram is shown in figure 1.

3. Selection and Design of Hardware Platform for Monitoring System

3.1. Design Scheme of Wireless Sensor Node

The selection of wireless communication node mainly considers the node power consumption, node communication distance and the processor with corresponding functions, as well as the low-cost design and networking of nodes. The node is composed of sensor, signal conditioning and digital to analog conversion module, embedded microprocessor system, wireless data transmission and receiving module and node power supply module. The wireless communication chip uses CC2530, which is introduced by TI Company and embedded with ZigBee protocol stack.

3.2. Gateway Node Design

The gateway node is connected with the sensor network and the central monitoring computer respectively. Its main functions include two aspects. On the one hand, it can receive the data from the sensor network and carry out correction and fusion processing, and send it to the central monitoring computer. On the other hand, it can receive the commands sent by the central monitoring computer, process the instructions sent by the monitoring center, and issue the monitoring tasks. The gateway node still adopts CC2530 design, which can unify the transmission protocol and ensure the reliability of transmission.

4. Design of Monitoring System Software Platform

4.1. Software Flow Design of Sensor Node

The sensor-monitoring node is mainly responsible for collecting sensor data and transmitting these data to the central node through wireless network. At the same time, it receives commands from the central control platform and performs operations such as closing the monitoring node and collecting what kind of sensor data according to the data.
4.2. **Software Flow Design of Gateway Node**

The main function of the gateway node is to receive the data from each sensor node, process and fuse the data, and send it to the monitoring center computer, to receive the command from the monitoring center to determine the working state of the node. The program flow chart is shown in figure 2.

![Figure 2. Program flow chart of the gateway node.](image)

4.3. **Software Design of Network Router**

The main function of network router is to help gateway node find terminal monitoring point to join the network, forward sensor data and control instructions. The flow chart of network router program is shown in figure 3.

![Figure 3. Flow chart of network routing program interface.](image)
4.4. Design of Operation Interface of Monitoring Center Management Software

Through the monitoring software, the concentration data of toxic gases can be observed in real time, and the database and report forms can be formed. According to the monitoring data, charts and curves can be used to display or print out. The management software is mainly composed of menu operation, database operation and communication. Design the function structure of the system management software as shown in figure 4.

![Block diagram of main operation interface.](image)

5. Test and Analysis of Monitoring System

5.1. Sensor Selection

The requirements of the system for sensors are on-line detection, good anti-interference, fast response, small size, low cost and so on. This design chooses the electrochemical sensor made in Switzerland. The specific sensors and related parameters are shown in table 1.

| Sensor | Model       | Measuring range | Precision | Remarks                     |
|--------|-------------|-----------------|-----------|-----------------------------|
| CO     | CO/CF-1000  | 0-1000ppm       | 0.5ppm    | Maximum load 2000 ppm, response time <40s |
|        |             |                 |           |                             |
| Formaldehyde | CH2O/C-10 | 0-10ppm         | 0.05ppm   | Maximum load 50 ppm, response time <50s  |
| Ozone  | O3/C-5      | 0-5ppm          | 0.05ppm   | Maximum load 50 ppm, response time <60s |
| SO2    | SO2/C-100   | 0-100 ppm       | 0.5ppm    | Maximum load 500 ppm, response time <25s |

5.2. Analysis of System Test Results

The nodes of monitoring equipment are put into the sealed gas chamber to observe the response of sensor nodes to realize the monitoring of air parameters in the air chamber. The main object of the system monitoring is the concentration of toxic gas in the air, so the test experiment only monitors the concentration of toxic gas in the gas chamber. In order to calibrate the measurement accuracy of the system, it is necessary to compare the system with the toxic gas measurement equipment on the market. Fad-400 series CH2O monitor of Shenzhen Fuanda Company is selected as the comparison instrument. The device has been calibrated before delivery, and the resolution is 0.05ppm, which has a certain value for comparison.

In the actual test, considering the convenience of observing the test effect, we adopt the method of only installing formaldehyde sensor in the node to collect the formaldehyde concentration data and upload it to the monitoring center computer to observe the data transmission and verify the monitoring
effect of the system. A certain concentration of formaldehyde gas is introduced into the sealed gas chamber, and the wireless monitoring network of toxic gas and fad-400 series CH2O monitor of Shenzhen Fuanda company are put into the gas chamber. Through the monitoring center control platform to send instructions to control the data collection and sending and receiving data of each node, and display the data on the computer. The statistics of sensor node monitoring data in the seal gas chamber are shown in table 2. The formaldehyde concentration curve is shown in figure 5.

Table 2. Statistics of formaldehyde concentration monitoring data in sealed gas chamber.

| Formaldehyde concentration in sealed gas chamber (Unit) | Monitoring time (s) |
|--------------------------------------------------------|---------------------|
|                                                        | 10 20 30 40 50 60 70 80 100 |
| Monitoring system display data (mg/m³)                 | 0.25 0.35 0.60 0.85 1.70 2.65 2.95 3.60 5.10 |
| Field monitor data (mg/m³)                             | 0.20 0.30 0.50 0.80 1.60 2.60 2.90 3.50 5.00 |

![Figure 5. The formaldehyde concentration curve.](image)

The results show that there are some errors in the system, which are caused by many reasons, mainly from three aspects: detector error, a/d conversion error and system response time lag error. The trend of observation data shows that the gas concentration trend of the monitoring system is basically consistent with that of fad-400 series CH2O monitor, which proves the accuracy and reliability of the system monitoring.

6. Conclusions

In this paper, the monitoring system developed for petrochemical enterprises can monitor the concentration of harmful gases and environmental temperature and humidity in real time. The system has the advantages of low cost, real-time online, and good industrial application value. For the phenomenon of data loss, the software method is improved to increase the data acquisition frequency, extend the data transmission cycle, and reduce the data packet loss rate. The experimental results show that the system has good applicability, especially for data acquisition, transmission, and monitoring of environmental parameters.

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