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Design and Implementation of a WSN-based Monitoring System for Hazardous Gas in Chemical Production

Chaoqing Mao

Chongqing College of Electronic Engineering, Chongqing 401331, China
cq_mao@foxmail.com

Hazard gases generated during chemical production process pose great risks to personal and property safety, and only rapid monitoring of hazardous gas can ensure the safety of the production process. In this paper, we design and implement a wireless sensor monitoring system for hazardous gas concentration based on wireless sensor networks. In a wireless sensor network, small, low-energy, low-cost wireless sensor nodes detect the concentration of a hazardous gas in the monitored area and transmits the monitoring information to the wireless sensor network in a self-organized manner and connects to the network through the interface to achieve real-time monitoring and detection of hazardous gas concentration data and provide guarantee for chemical production safety.

1. Introduction

Hazardous gas leaks are common in the chemical production process; however, hazardous gases pose significant threats to human and the surrounding environment (Moldenhauer et al., 2012; Campo et al., 2016; Cariou et al., 2016; Fabiano et al., 2016; Dusso et al., 2016; Rad and Rashtchian, 2016; Fakandu et al., 2016). According to relevant requirements provided in the national standard GB50493, appropriate gas monitoring devices should be installed for combustible and toxic gas production and such devices not only need to give audible and visual alarms, but also have to send the hazard signal to a remote monitoring station (Zhou, 2015) to achieve monitoring on the gases produced from chemical reactions in the chemical production and ensure work safety (Johansson et al., 2003; Al-Mohannadi et al., 2016; Liemberger et al., 2016; Skrinsky et al., 2016; Krasnokutskiy et al., 2016; Zhu and Lai, 2016; Li et al., 2016).
Wireless sensor network is a product that combines contemporary electronic technology, sensor technology, wireless communication technology, embedded system and distributed computing system (De Angelis A, et. al, 2015). It is a wireless network system consisting of many small, low-cost and low-energy sensor nodes distributed within the monitored area that gradually gets close to the destination through multi-hop routing. It sends various information of the perceived object in the network area to the observer by perceiving, acquiring and transmitting it (Li et al., 2015). The low cost, high stability, and high adaptability of wireless sensors (Arapatsakos et al., 2015) are very suitable for hazardous gas monitoring in chemical production processes.
In this paper, in light of the toxic gas leaks in chemical production plant areas, we conduct dynamic monitoring on hazardous gases like methane and formaldehyde, select appropriate sensor chips and gas sensors, and complete the wireless sensor network in the self-organized form based on the wireless sensor zigbee protocol, and then achieve the information exchange between the wireless sensor network and PC through appropriate portals and design and implement a hazardous gas monitoring system.

2. Wireless sensor technology and its application

2.1 Zigbee-based wireless sensor technology

Zigbee network is divided into four layers, namely physical layer (PHL), media access control layer (MAC), network layer (NWK) and application layer (APL). The lowest two layers of ZigBee - PHL and MAC use IEEE802.15.4, and ZigBee alliance is responsible for developing NWK and APL (Patwari et al., 2005). Each layer of the protocol provides services to its upper layer, including data and management services. The

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application support sub-layer, device object and vendor-defined application object constitute the application layer, which is clearly shown in the protocol stack structure (Kulik et al., 2002). The detailed protocol stack structure is shown in Figure 1.

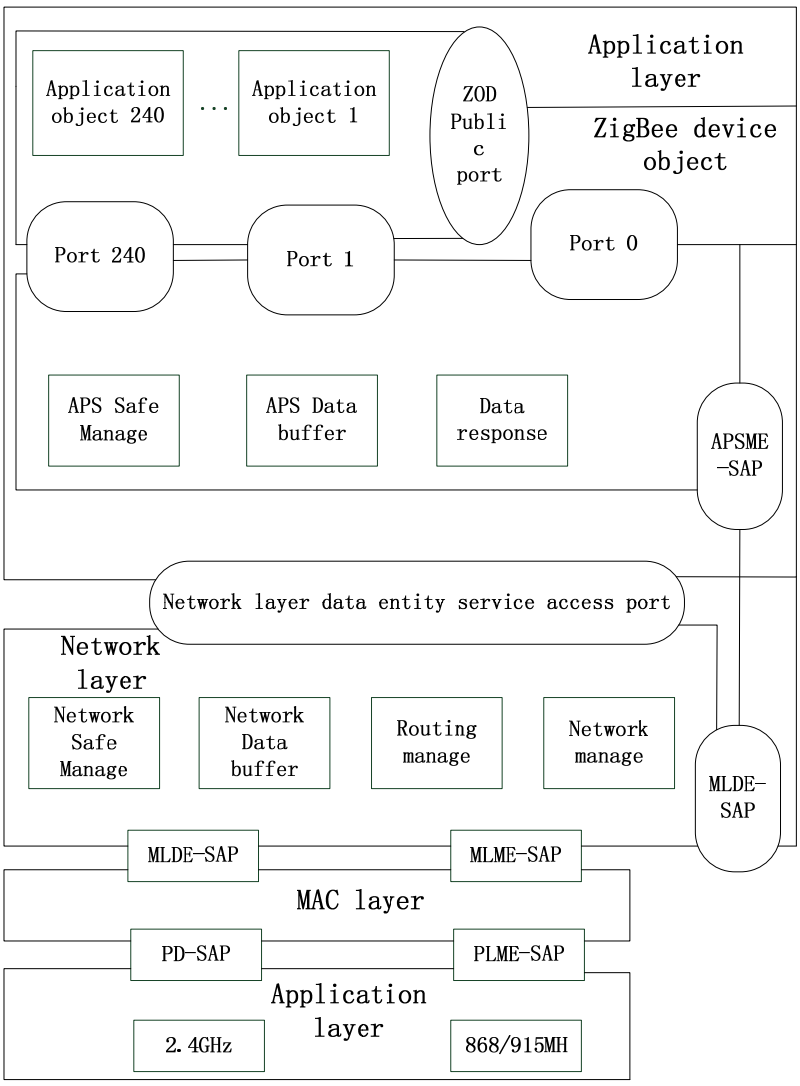

Figure 1: ZigBee protocol stack structure

The physical layer consists of sensor hardware and interfaces; the MAC layer mainly achieves data sharing to make communication more efficient and accurate; in the network layer, various levels of nodes and routers work together to achieve information forwarding and transmission; the application layer provides the connection to the Internet.

2.2 Interconnection between the wireless sensor network and the Internet

2.2.1 Existing issues

a. WSN data acquisition is carried out in real time, so there is a data synchronization problem between WSN and Internet TCP/IP.
b. The accuracy of data transmission between WSN and the Internet still needs to be improved.
c. The flexibility of data communication still needs to be improved.

2.2.2 Major solutions to internetwork communication

Currently, major solutions to the connection between WSN and the Internet include: 1. agent system, which uses an agent as the intermediary program between the client and the server; 2. TCP/IP is directly used as

the communication protocol for WSN; the TCP/IP portal is deployed on the physical layer. 3. delay-tolerant network (DTN), which is running on TCP/IP protocol, presented through the application layer (Patwari et al., 2003).
For the agent system and the solution where TCP/IP is directly used as the communication protocol, there are a lot of problems in communication security and costs. Therefore, in this paper, we mainly use DTN to achieve the interconnection between WSN and the Internet. Figure 2 shows the DTN system structure diagram.

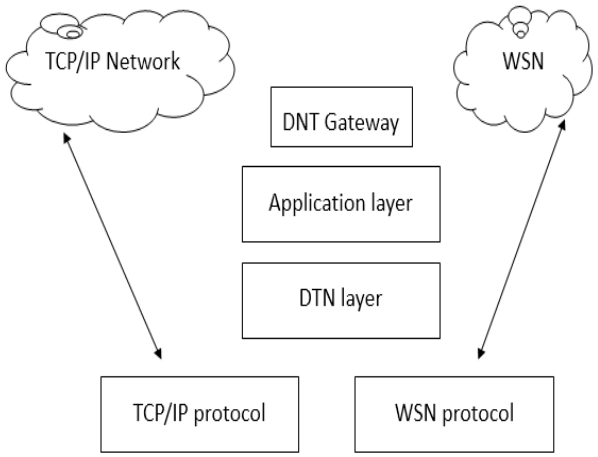

Figure 2: DTN system structure diagram

DTN adopts the storage and forwarding mechanism to transmit data level by level to the lower-level nodes. This system mechanism is not clearly formulated, and dynamic selection is based on the different communication characteristics of each region and the different protocols used. The gateway is responsible for forwarding packets between regions. Due to this reason, the system sets up multiple gateways in each region to forward packets, transmitting the packets sent from other regions over the Internet to the local region control center (Gungor and Hancke, 2009).

2.3 Hazardous gas detectors in chemical production processes

Hazardous gas detectors is essentially a device that converts a physical or chemical quantity into an electrical signal. They can be mainly divided into semiconductor sensors, insulator sensors and electrochemical sensors.
This paper mainly addresses the detection of hazardous gases in chemical production processes. In chemical production, a common hazardous gas is methane, which can be detected by semiconductors, light methane gas sensors and transmission method. We integrate gas detectors with wireless sensors to detect hazardous gas leaks in chemical production processes.

3. Design and implementation of the monitoring system

3.1 Hardware design of the monitoring system

3.1.1 CC2430 chips

CC2430 chip is used as the core chip in the wireless sensor network (Gagliano et al., 2015); MS114's are used as the methane sensors, which compose the field monitoring nodes of WSN.
A picture of the monitoring devices is shown in Figure 3.
A CC2430 chip includes 3 8-bit input/output ports, namely P0, P1 and PPT. Through the program status word (PSW), we will know the working status of CPU (Felemban et al., 2006). As shown in Table 1, where CY is the carry flag, OV is the overflow flag, AC is the auxiliary carry flag, RS is the register group selection, and P is the parity flag.

Table 1: 8-bit input/output ports

7	6	5	4	3	2	1	0
CY	AC	F0	RS		OV	F1	P

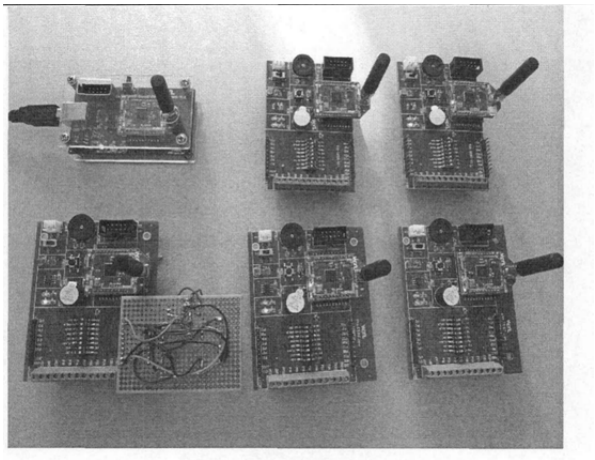

Figure 3: Monitoring equipment physical graph

3.1.2 MS1100 gas sensors

The leakage of hazardous gas in the chemical production process is generally small and therefore requires the sensors to be highly sensitive to low-density hazardous gas (Bosch, R. E et. al, 2004); at the same time, in the chemical production process, high concentration of hazardous gas may cause personal risks and huge property damages, and thus sensors need to be highly stable (Enz et al., 2004) to ensure the safety of the chemical production process. Therefore, sensors need to be highly sensitive and stable, able to detect the above gases and formaldehyde, benzene, and other organic matters in the air (Guo et al., 2011).
The MS1100 specifications are shown in Table 2. MS1100 has good performance in both sensitivity and stability tests.

Table 2: The MS1100 specifications

Product Name			MS1100
Sensing element type			Semiconductor
Electrical feature under standard test conditions	RH	Heater resistance	25.5Ω±0.2Ω
	VH	Heater Voltage	5.0V±2%
	PL	Road resistance	Variable
	PH	Power consumption	Less than 420m W
	VC	Circuit voltage	Less than 12.0V

We use CC2340 chip and MS1100 in combination of A/D converter and other accessories to complete the hardware design of the monitoring system.

3.2 Software design of the monitoring system

The software system of the monitoring system consists of: 1. terminal node program; 2 router node program; 3 gateway node program and host computer program. The sensor node programs are developed on the ZigBee-based wireless sensor network and the host program is completed on the chip and the host computer. The two parts of programs can not only achieve data acquisition and communication, but also control and monitor the entire system through the host computer.

3.3 Commissioning and operation of the system

We first set the hardware detection nodes in the chemical plant production area and write data receiving and sending programs at all levels of nodes in advance. When the signal strength is adjusted to greater than 100, the sensor network node is green, indicating that the signal communication is good. When the receiving sensitivity is -94dBm, the transmission power 1mW and the transmission frequency 2.4GHz, the monitoring system can achieve monitoring and alarm of hazardous gas in the chemical production area 130m away.

4. Conclusions

We deploy a number of wireless sensor gas detection nodes in the complex chemical production area, and establish a hazardous gas monitoring system based on WSN through the ZigBee mode. Based on hardware and software design, we realize the real-time detection of hazardous gases in the chemical production process. While ensuring detection accuracy and stability, this monitoring system can also adapt to a variety of chemical production scenarios and is very energy-efficient. The system achieves the detection of hazardous gases in chemical production processes, which ensures production safety.

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