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Application of ZigBee wireless sensor network in gas monitoring system[1]

Jun Hu[2]

Abstract. The coal mines in our country are in great demand, and mining technology level is relatively backward compared with other developed countries. The monitoring system has the disadvantages of complicated wiring and high cost. In order to overcome the shortcomings of China's current coal and gas system, the application of ZigBee wireless sensor network technology in coal mine gas monitoring system was put forward. The hardware and software of wireless sensor network node and the overall scheme were designed, and the performance of the system was tested in this paper. The results show that the monitoring system can carry out a comprehensive real-time intelligent monitoring to gas accidents, which reduces the probability of gas accidents effectively and has certain practical significance.

Key words. ZigBee, wireless sensor, gas monitoring, application.

1. Introduction

Coal industry has always been the focus of China's industrial development. It is not only related to China's economic development and social progress, but also the key industry for the revitalization of the nation. Base on this, the status of coal industry in the development of China's industry can be seen. However, the coal industry in our country now has such disadvantages as low overall productivity, serious natural disasters, complicated mining conditions, low safety and frequent accidents. In addition, there are many small coal mines which are privately exploited in our country, and the security awareness is poor. Therefore, the coal mine industry is the key industry in our country's safety accidents. According to the survey of China's Security Supervision Bureau, China's coal mine accidents caused by death toll reached 5670 people in 2001 and the number of deaths caused by coal mines in China reached 6995 people in 2002. 7023 people died due to coal mine accidents in

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[2]College of Software, Hunan Vocational College of Science and Technology, Changsha, Hunan, 410118, China

2004. Thus, the safety awareness of China's coal industry has not increased year by year, but accidents happen frequently year by year. The study shows that gas explosion has the highest proportion and is the most dangerous among all accidents in these coal mine accidents. Therefore, gas monitoring is a very important work, and it is the guarantee of safety production in coal mining industry.

Based on the demand of coal mine industry safety guarantee, the hardware and software of the overall scheme of gas monitoring and wireless sensor network node were designed aiming at the coal mine gas monitoring system by using the Zigbee wireless sensor network technology based on the basic theory in this paper. In the second section, the concept of infinite sensor network was introduced, and the current development of the world wide sensor network was summarized briefly. In the third section, Zigbee technology was used to design the hardware and software of the wireless sensor network node. CC 2430 was used as the sensor node, and a whole gas monitoring system was designed. The data of the preliminary application of the system were summarized and analyzed in the fourth section. Finally, the research process and results were summarized in the fifth section.

2. State of the art

Through consulting relevant research documents, it can be seen that China began to apply gas monitoring technology in coal mine industry from the beginning of eightieth century [1]. The developed countries, such as the United States and Britain, have established the gas monitoring system with long time. Gas monitoring system is to monitor all kinds of harmful gas and working environment mainly, such as the concentration of oxygen and carbon dioxide gas, the temperature and humidity under the mine, and the highly dangerous methane gas and so on [2]. Once there is insecurity, people can find it in time. At first, our country imported related equipment and instruments from abroad, and later developed the K 14 monitoring system through the integration of the actual situation and characteristics of our country [3]. With the development of science and technology and the arrival of electronic era, the traditional gas monitoring system was replaced by K 195 and other high-tech, computer or electronic technology systems gradually [4]. The national government has also set up relevant laws and regulations to regulate the development of coal mine industry. It is stipulated that the gas monitoring system must be equipped regardless of the size of the mineral enterprise [5]. With the continuous development of China's coal mining industry, more and more small enterprises appear in the line of sight. Competition among enterprises is fierce, and it also promotes the development speed and quality level of China's coal industry. Gas monitoring system has also changed from traditional single microcomputer monitoring system to networked monitoring system or networked monitoring system [6]. However, the monitoring of safety is still in the international backward level.

3. Methodology

At present, the gas monitoring system in our country has the following problems compared with the foreign countries, as shown in Table 1. And ZigBee technology characteristics and gas monitoring system problems can be fused together. Specific features of ZigBee are shown in Table 2. Therefore, targeted research is conducted on existing issues in this article. Sensor nodes, management nodes and sink nodes are three major components of a sensor [7]. The nodes of the general sensor are located in the monitored area randomly, and all nodes are connected to form a huge network system. Sensor nodes can communicate the monitored signals to each other, and aggregate in the pooled nodes, and then transmit to the management node via satellite and Internet processing. People can manage and set up the entire sensor network according to the signal of the management node. At the same time, it can also monitor the release of the monitoring task and obtain the statistical results [8]. The general structure of the sensor network is shown in Fig. 1. Sensor nodes usually exist in the form of embedded systems [9]. Each node has a path to the node terminal, and it can also propagate the signal to other nodes. Each node has the function of processing data and storage, so the core of the sensor network is even the terminal monitoring node [10].

Table 1. Existing problems of gas monitoring system in China compared with those in other countries

Serial number	Problems existing in gas monitoring system in China
1	The wired network has complex wiring, high labor intensity and high maintenance cost of communication lines. Therefore, its scalability and flexibility are inadequate for industrial buses. The communication line is easy to destroy, and it is easy to waste the resources because of the increase of cost.
2	The network structure is relatively fixed, and it is not suitable for the dynamic change of tunneling.
3	The monitoring point is relatively fixed, and the detection blind area is prone to occur.
4	The processing level of primary instrument (sensitive component) in safety instrument is much lower than that of foreign advanced level, which makes the accuracy and reliability of detecting gas data insufficient.

It is well known that wireless sensor nodes are very important for the whole monitoring network. A general wireless sensor node consists of the following sections: SCM and wireless communication module, energy supply module, sensor module and processor module [11]. The detailed structure is shown in Fig. 2. The most important component of the infinite sensor nodes is the microcontroller and wireless communication module. The biggest difference between the chip and CC2420 is the integration of Zigbee, 8KB and RF front-end SARM and large capacity storage space on the basis of CC2420, and the advanced performance of 8051MCU enhanced

industry standard is joined. The chip has an analog digital converter, CO processor, time and sleep mode timer, and has the core MJC4/3.0L original carrier catalytic gas concentration monitoring circuit and a temperature and humidity sensor.

Table 2. Technical features of ZigBee

Serial number	Features of Zigbee Technology
1	Excellent wireless reception sensitivity and powerful immunity
2	Only 0.9 microns of flow is consumed in sleep mode, and external interrupts or RTC can wake up the system. In standby mode, the flow loss is less than 0.6 a, and external interrupts can wake up the system.
3	Wider voltage range (2.0∼3.6 V)
4	Hardware support for CSMA/CA functionality
5	Digital RSSI/LQI support and powerful DMA capabilities
6	ADC integrated with 14 bit analog to digital converter
7	There are 2 powerful USART protocols that support several groups of protocols, 1 MAC timers that conform to the IEEE 802.15.4 specification, 1 regular 16 bit timers and two 8 bit timers.
8	Powerful and flexible tools for development.

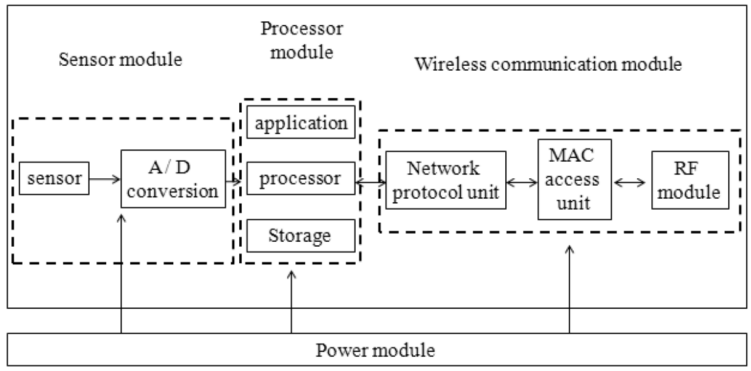

Fig. 1. Structure of wireless sensor

The CC2420 chip has a working band of 2.400–2.4835 GHz. The current consumption is low and the receiving sensitivity is –99 dBm. The CC2420 chip adopts the IEEE 802.15.4 standard direct sequence spread spectrum (DSSS) mode. The speed is 2 MChip/s, and the output power is controlled by the programming program. The internal has VCO, LNA, PA, and current rectifier. The power supply voltage is 2.1–3.6 V, and the anti-interference channel capability is stronger. And the MAC layer application of IEEE802.15.4 can support the generation of automatic

frame format, simultaneous insertion and detection, 16bit, CRC collation, inspection, monitoring for power supplies and full MAC layer security protection. With 4 bus SPI interface, development tools are fairly complete, including the development of documents and presentations, the size of 7×7 mm, and QLP-48 packaging. Although all aspects of CC2420 performance have been able to meet the general monitoring system, CC2430 chip has many more powerful features. Various aspects of performance of CC2430 have been improved greatly on the basis of CC2420. Details are shown in Table 3. The power supply of this system is a low voltage RE113-3 regulator chip, which can provide stable voltage of 3 V continuously. The principle of an infinite sensor node is shown in Fig. 3.

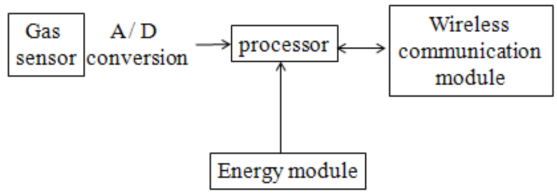

Fig. 2. Structure of wireless sensor node

Table 3. Features of CC 2430 chips

Characteristic	performance parameter
Data rate	868 MHz, 20 kbit/s, 915 MHz, 40 kbit/s, 4 GHz, 250 kbit/s
Communication range	up to about 150 m in the open environment, and within 100 meters generally,
Communication delay	About 15 ms
Channel number	868/915 MHz 11, 24 GHz 16
Band	868/915 MHz and 2.4 GHz
Addressing mode	64 bit IEEEE address, 8 bitnet work address
Channel access	CSMA-CA and Time slot CSMA-CA
Temperature	–40∼85 ° C

The key information of this system comes from the user's special keyboard mainly. The input program in section 1 consists of 8 bytes. When a key is pressed, the first byte represents the corresponding value of the keyboard. When two keys are pressed, the first byte and second byte represent the corresponding values of the keyboard. Based on the same principle, when 8 keys are pressed, all bytes represent the corresponding values of the keyboard. However, when the key pressed is less than 8, the bytes that are not represented will be displayed in the form of "00H". The status of the keyboard is scanned regularly and the scanning information is sent to the fast detection module. When CH375 completes the task of receiving the information, the application is interrupted to the microcontroller. The single chip

microcomputer takes the corresponding value as the judgment and the operation processing after the judgment mark.

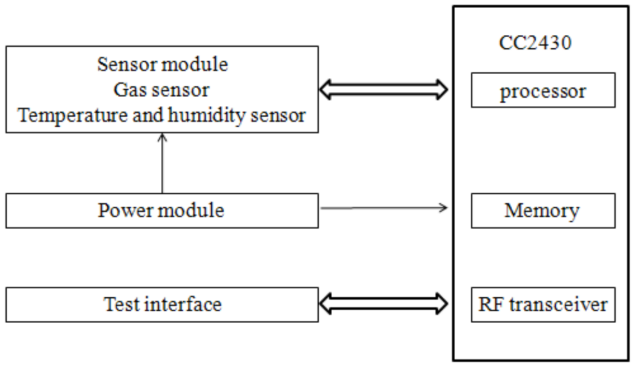

Fig. 3. Principle of infinite sensor nodes

4. Results analysis and discussion

The infinite sensor node structure adopted in this paper not only saves the cost, but also solves the problem of the connection between single chip computer and wireless communication module. The software used is the C51RF-3-CC 2430-PK wireless single-chip microcomputer development system of Chengdu Antenna Dragon Company. The process of designing a wireless sensor network node by using ZigBee technology is as follows: firstly, ZigBee C51RF-3 was used as the development platform to build the platform for wireless sensor nodes. The platform consisted of two ZigBee based host computers and two wireless extended performance boards. The wireless expansion board was used to connect the antennas to complete the function of sending and receiving information. The host and wireless extensions board were connected via the RS-232 interface. Secondly, the driver software for each function was developed. The development environment for IAR7.2C51 was installed after the establishment of the wireless sensor network platform. And then through the software design, the application development was completed according to the need, and the function of each module was realized. Thirdly, the simulation test of the system was carried out. The online emulator system was connected to the host via the USB interface. At the same time, the 10 wire simulation cable is used to connect the system to the wireless MCU target board of CC2430 chip. The wireless network node system was simulated and tested online. The overall system flow is shown in Fig. 4.

Generally, when the gas concentration is more than 1 % in the mine, the gas monitoring system will give an alarm prompt. The prescribed gas monitoring system shall not exceed 0.05 % of the prescribed error range. Different concentrations of methane gas were prepared in the laboratory and stored in closed cylinders. Then, the probe of wireless sensor was extended into the bottle, and the on-line simulation

test of the system was carried out. The results show that the gas concentration of the gas in the cylinder is determined by the alarm concentration of the gas under the mine.

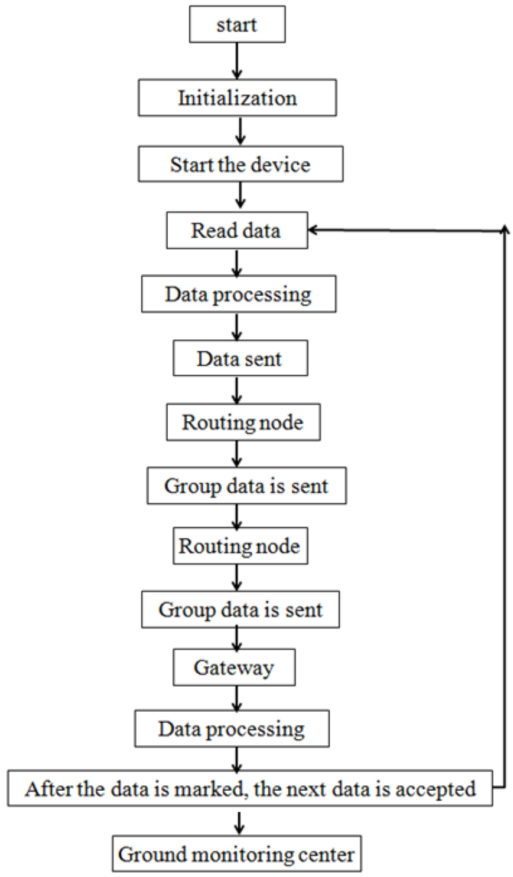

Fig. 4. System construction diagram

Some source files and software functions in the coordinator used in the system are shown in Table 4.

The protocol stack is responsible for assisting the coordinator to build the network mainly in routing nodes. The functions of sending information and data are realized by connecting the RFD nodes. Some source files and software functions used in the system are shown in Table 5.

Mote View visual monitoring software was used in the design of real-time monitoring system in this paper. The software got all the data passed by all the nodes from the Postre SQL database successfully, and achieved real-time monitoring. As long as the manager can observe all the data of the Mote View in the display screen or the situation diagram and the topological graph of the node, the environment information of all the nodes can be mastered for the first time. The software can

also be set to mobile mode, which means that when there is an alarm message, it will be sent to the manager's mobile phone in the form of SMS or e-mail. The security hidden danger can be discovered in the first time and the prompt measures are made.

Table 4. Coordinator source and software functions

Application layer program	Master coordinated control application (coord.c) , SPI master control interface (MSPI.c) , RS-232 terminal program (Console.c) , Zigbee application layer program (zAPL.c) , Zigbee application support sublayer (zAPS.c) , Zigbee device object (ZDO.c) , Proximity tables and binding tables are set up (NeighborTable.c) , Dynamic storage manager for indirect transport buffers (SRALLOC.c) etc.
Network layer program	Zigbee network layer program (zNWK.c)
MAC layer program	IEEE802.15.4MAC layer program (zMAC.c)
PHY layer program	CC2430 specific PHY program (zPHYCC2430.C)

Table 5. Source code and software function of routing node

Application layer program	Routing application (ROUTER.c), SPI master interface (MSPI.c), RS-232 terminal program (Console.c), Zigbee (zAPL.c), application layer Zigbee application support sublayer (zAPS.c), Zigbee (ZDO.c), the device object near the table and set up the binding table (NeighborTable.c), dynamic indirect transmission buffer storage manager (SRALLOC.c) etc.
Network layer program	Zigbee network layer program (zNWK.c)
MAC layer program	IEEE802.15.4MAC layer program (zMAC.c)
PHY layer program	The specific PHY program for CC 2430 (zPHYCC2430.C)

The monitoring results of the gas monitoring system established in this paper are shown in Table 4. Gas content of 0 cylinder monitoring results were in full accordance with reality in the three minute test, and the monitoring result was 0. That is to say, the error was 0. For the gas content of 0.79 cylinder test results, the monitoring result was 0.77, and the actual error size was 0.01 %, which accorded with the corresponding standard of gas monitoring concentration. For the gas content of 1.19 cylinder test results, the monitoring result was 1.16 and the actual error size was 0.02 %, which also conformed to the gas monitoring concentration corresponding standard. For the gas content of 1.69 cylinder test results, the monitoring result was 1.65, and the actual error size was 0.03%, which also conformed to the gas monitoring concentration corresponding standard. For the gas content of 1.49 cylinder test results, the monitoring result was 1.55, and the actual error size was 0.03 %, which accorded with the corresponding standard of gas monitoring concentration. For the gas content of 1.09 cylinder test results, the monitoring result was

1.08, and the actual error size was 0.01 %, which was in line with gas monitoring concentration of the corresponding standards. The error of gas concentration and actual gas concentration detected by wireless sensor based on ZigBee was less than 0.05 %. The average error of all experiments was only 0.019 %. According to gas monitoring standard and error range under coal mine, the wireless sensor network system based on ZigBee conforms to the standard of corresponding gas monitoring index fully.

Table 6. Monitoring results of gas monitoring system established in this paper

Gas concentration (%)	Test time (min)	Determination result (%)	Error (%)
0	3	0	0
0.79	3	0.77	0.01
1.19	3	1.16	0.02
1.69	3	1.65	0.03
1.49	3	1.55	0.03
1.09	3	1.08	0.01

5. Conclusion

In order to establish a more perfect gas monitoring system and reduce the occurrence rate of mine accidents, the node hardware of the gas monitoring system based on the ZigBee wireless sensor network of single chip microcomputer MSP430F149 and radio frequency chip CC2430 was designed. The sensor module based on the ZigBee protocol was designed to complete the information acquisition and collection in the monitoring area and control the whole system. A 2.4 GHz IEEE 802.15.4/ZigBee standard was used to establish a wireless sensor gas monitoring system for monitoring the gas concentration in the target environment. The system was used for simulation and test in this paper. The conclusions were drawn as follows: the wireless sensor network node ZigBee designed by MCU MSP430F149 and RF chip CC2430 designed in this paper can accomplish the functions of information collection, aggregation and sending. The application of Mote View software also can realize the real-time monitoring of the monitoring environment and the prompt of real-time alarm successfully. However, the environment under the mine is very complex, and the simulation of the cylinder is different from each other. So it is necessary to further optimize and adjust the system for the underground mine. There is no doubt that ZigBee based wireless sensor network monitoring system will become more and more mature, and its application will be expanded in the near future.

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