A Fire Monitoring System In ZigBee Wireless Network

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***Abstract*—In the work, a kind of low power, multi-parameter composite fire detection node is designed, which can detect temperature, smoke concentration and CO gas concentration. And combining with the WSN (wireless sensor network), a real-time wireless fire monitoring system is established. This system is applied in fire detection of special circumstance represented by the ancient buildings. The hardware and software implementation is based on 2.4GHz wireless communication chip CC2430. ZigBee protocol is adopted in the system to form reliable wireless communication. The result of experiment shows that the sensor nodes can connect each other and form net automatically and the system works effectively and stably in wireless fire detection.**

Keywords- fire detection, WSN, CC2430, Zigbee

I. INTRODUCTION

Fire detection is to determine whether the fire occurred by detecting the signal of the fire characteristic parameters [1]. Traditional fire monitoring system needs arrangement of wires in the region. The installation procedure is tedious and also makes damage to the environment. With the continuous development of WSN, the advantages of wireless network are increasingly evident. Therefore, combining fire detection technology with WSN to realize wireless fire detection is a current and important direction of fire detection research.

ZigBee technology is a short-range, low power, low-speed, low-cost wireless communication technology, mainly for wireless sensor network, automatic control and remote control areas. It is generally considered as an optimal wireless communication protocol, because it fully meet the requirement of WSN application and owns such property as higher reliability, self-organization network, self-cure capacity and large network volume[2].

II. ARCHITECTURE OF FIRE MONITORING SYSTEM

In the fire monitoring system many low-cost and low-power micro-sensor nodes are deployed in the monitoring region to detect the fire parameters of the region. To form a ZigBee network, there needs three kinds of nodes: detection node, router and coordinator. The sensor nodes are configured as detection nodes in the ZigBee network to achieve a real-time data collection of fire parameter signals which include CO gas concentration, smoke concentration and temperature. The coordinator is responsible for PAN (personal area network) formation and collecting data from all detection nodes. Routers are responsible for data storage and delivery, router discovery, the connection with the devices, routing table maintenance, data forwarding, and the network link maintenance. The coordinator as a base station is connected to the computer through the RS232 interface. This system applies the ZigBee clutter-tree net topology and uses CSMA/CA principle, so the transmission module has strong points of better information hiding, anti-interference, self-healing and big coverage. Special background software of the fire monitoring is running in the computer to receive the upload information of the coordinator for processing and displaying, thus achieving a rapid state reflection of monitoring region. The fire monitoring system diagram is shown in Fig.1.

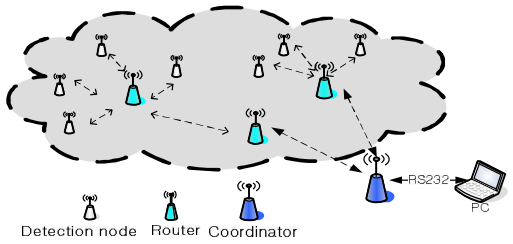

Figure 1. diagram of fire monitoring system with WSN

Fire monitoring system based on wireless sensor network, as shown in "Fig.1",deploys a great deal of detection nodes sensing parameter in the monitoring region, with a base station as a cluster node connected to the computer. Detection nodes not only can configure a network automatically with a multi-hop routing, but also have the ability to perceive temperature and humidity and smoke concentrations. The base station is responsible for collecting data from all detection nodes to the computer to process and display.

III. HARDWARE DESIGN

A. Structure of the fire detection node

ZigBee Wireless detection node is composed of the data acquisition unit, data processing unit, data transmission unit and battery-powered unit. Data acquisition unit is primarily through sensors to detect CO gas concentration, temperature and smoke concentration of the region. Data processing unit controls the node to process the detection data. Data transmission unit completes the interaction with the router and

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coordinator. Power supply unit is responsible for the energy of the node. The structure of the detection node is shown in Fig.2.

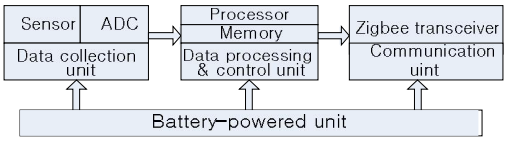

Figure 2. structure of the detection node

B. *Wireless Transceiver and processing Module*

In this system, we use CC2430 as the core of the wireless transceiver and processing module. The CC2430, a SOC (system on a chip) loading the ZigBee technique, is a kind of ZigBee wireless single chip microcomputer. CC2430 has a transceiver core, a high-performance 8051 controller, 128KB Flash , 8KB RAM, ADC, 16-bit timer and two 8-bit timer, AES128 synergistic processing device, watchdog timer, the sleep mode timer of 32 kHz crystal oscillator , power-on reset circuit, power failure detection circuit, and 21 programmable I / O pins[3]. Its peripheral circuits include crystal oscillator clock circuit, RF input/output matching circuit and micro-controller interface circuit. High-gain vertical antenna with proprietary 2.4G SMA interface is used in the module.

Since the chip has extremely powerful function, it needs only a few external components to work and the design can be simplified greatly. The chip's characteristics of ultra-short time when in sleep mode and switch to active mode is in particular suitable for the applications of low power consumption. Considering its high integration and low power consumption, we design the fire detection node applying CC2430 as processing unit and wireless communication unit. This can not only decrease the investment in hardware to a large extent, but also meet the requirement of the project.

C. *Fire Parameters Detection Module*

The early fire is in the smoldering stage, there would be a lot of smoke particles and harmful gases such as CO gas in the combustion and the temperature will rise. Based on these parameters, we design a fire detection module including three parts: smoke detection unit, CO gas detection unit, temperature detection unit. These three parts together achieve the detection of smoke concentration, CO gas concentration and temperature. The fire parameters detection module is shown in Fig.3.

1) Photoelectric-type smoke detection circuit is achieved through a pair of infrared transmitter and receiver diodes with a optical detection chamber. When the fire taking place, there are smoke particles entering the optical detection chamber then the infrared light scattering by smoke particles reach the photodiode, resulting in current signal [1]. The base electrode (the Pulse pin in Fig.3) of the transistor in the transmitter is connected to I/O pin of CC2430,which output a pulse to control infrared emission diode on and off. The generated signals are adjusted through the preamp circuit and the after-class amplifier circuit to amplify. At last the signals are sent to the AD converter in CC2430 and the Pulse pin goes low to close the infrared emitting diode in order to save power.

2) The low power digital temperature sensor TMP102 is used in the system to detect the temprature in real time. The TMP102 is a two-wire, serial output temperature sensor available in a tiny SOT563 package.Requiring no external components,the TMP102 is capable of reading temperatures with a resolution of 0.0625 ° C. The device is specified for operation over a temperature range of – 40 ° C to +125 ° C [4]. The TMP102 is ideal for the temperature measurement in this fire mornitoring system because of its low power and its digital temperature output . The TMP102 is connected to the I/O pins of CC2430 through IIC bus.

3) In this system the RAE_4CO-500 is used as CO sensor. The RAE_4CO-500 sensor is a three-electrode electrochemical sensor produced by RAE company in the United States, which has a monitoring range of 0-500ppm, a resolution of 1ppm and a very good linearity.The 4CO-500 Sensor detect CO gas and output a weak current signal. When the gas concentration changes, the current output by the gas sensor also will be proportional to the change.The current signal is convert to voltage signal by the I/V conversion circuit, and after amplifying the analog voltage signal is converted to digital signals by the AD converter built-in CC2430.After the relevant data processing the signal is sent out by the RF module.

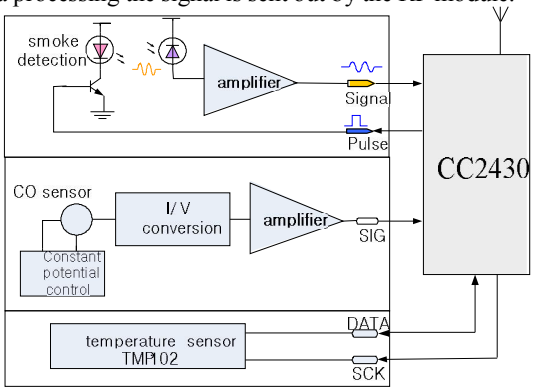

Figure 3. Fire Parameters Detection Module

IV. SOFTWARE DESIGN

A. *Software Development Platform*

Embedded Workbench of IAR is often used to design the system communication programming. It is an excellent software integrated development platform of ZigBee, and it is an integration of tools, such as embedded C/C++ optimizing compiler, assembler, debugger, and so on [5]. At present, it is the most complete and easiest professional development tools for embedded applications in the world.

B. *Zigbee technology*

ZigBee can work at the 2.4GHz ISM band without the need for registration. It defines 16 channels and the transmission rate is 20 ~ 250kb / s, the transmission distance is 10 ~75m. The architecture of ZigBee technology is usually to quantify and simplify the various standards by layers. Each layer is

responsible for the completion of the mandate and providing services to the upper[6]. The architecture is primarily formed by the PHY (physical) layer, MAC (media access control) layer, NWK (network) layer and APL (application) layer. The PHY layer and the MAC layer adopt IEEE802.15.4 protocol.

The task of PHY layer is to start and shut down the wireless transceiver, to detect link layer's quality, to select the channel, to clear channel assessment, as well as sent and received the packets through physical media. The specific role of the MAC layer is the beacon management, channel access, slot management, and a confirmation frame, a request to connect and disconnect, and for the application of appropriate security mechanisms. ZigBee technology uses CSMA/CA channel access method, so it can effectively avoid communication conflicts. Network layer protocol is developed by the ZigBee Alliance. The application layer can be developed according to the needs of users.

C. Software flow

The detection nodes in ZigBee wireless sensor network are deployed in the detection area for collecting and transmitting information, collaborating to complete the assigned task. Program running on each node can be exactly the same, but the ID is unique. In order to increase the capacity of ZigBee wireless sensor network and to resolve an important issue of energy supply in sensor network, the detection nodes in this network apply the operation of timing wake-up. This model can greatly save the power consumption of sensor nodes, reduce the probability of information collision and extend the life of the network. The software flow chart of the end device is shown in Fig.4.

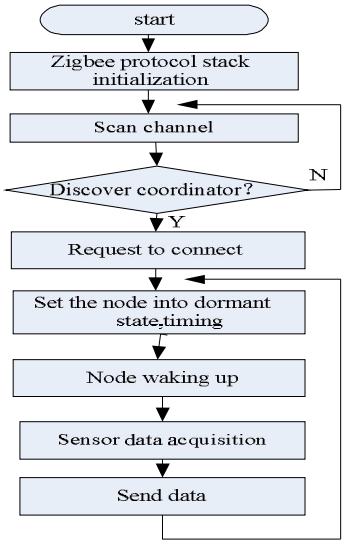

Figure 4. Software flow chart of the detection node

Coordinator establishes a ZigBee PAN, selects the ZigBee PAN identifier, and set its short address to 0. Coordinator then sends a beacon to its neighboring devices and accepts the link request of other devices. The end device when establishing a connection with the coordinator is assigned a unique 16-bit network address, which the device will use in the network communication. According to the beacon received from coordinator, router configures and sends its own beacon, allowing other nodes to establish a connection with it. The software flow chart of coordinator is shown in Fig.5.

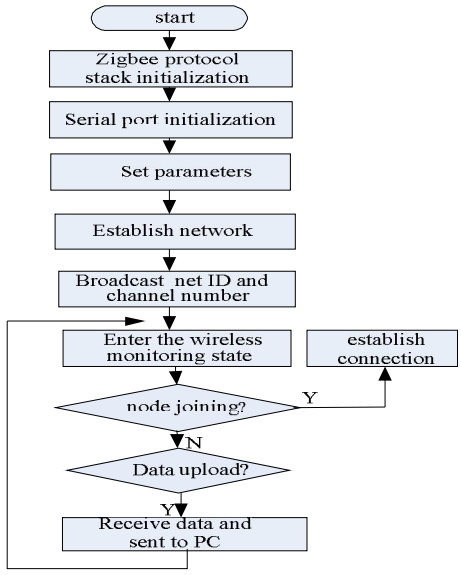

Figure 5. Software flow chart of the coordinator

We use Visual C++ to design the background software running on the computer which connects to the coordinator via the serial port to obtain data. By processing and analysis, the temperature, smoke concentration, CO concentration and the node's routing information are displayed to facilitate the experimental observation. The software also put the fire feature parameters of multiple nodes in fusion, using the neural network algorithm to determine the occurrence of fire and to further reduce the possibility of false positives. When the fire is confirmed, the alarm is given.

V. EXPERIMENTAL DATA AND ANALYSIS

Experiments show that the software and hardware design of fire monitoring system based on CC2430 development platform and ZigBee protocol is successful. The results show that the detection nodes can form network automatically in an effective communication distance, a single node failure does not affect data transmission of the entire network.

By referring to national standard GB 4715-2005 which defines technical requirements and test methods for point type smoke fire detectors, six detection nodes, respectively node 1 to node 6, are arranged along three meters loop in the standard fire laboratory and the standard cotton rope fire is used in this test. Besides we install standard an optical densitometer of smoke to detect the smoke data for reference. The data of node 1 and 3 with reference data of optical dosimeter are shown in Fig.6. The change trend is similar, while the response time to smoke of node 1, 3 is less than the wired optical densitometer. The result of experiment shows the detection nodes we designed have a high sensitivity.

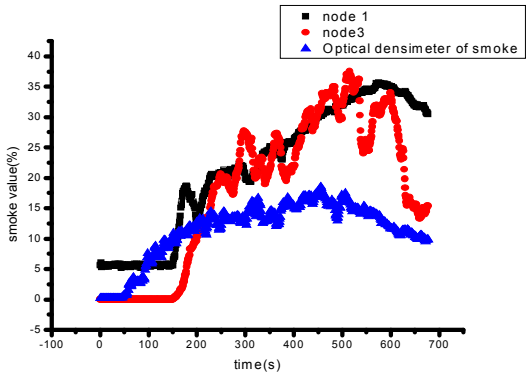

Figure 6. Result of photoelectric smoke sensor detecton

Fig.7 shows the change of temperature in a short time at the beginning of fire. The result shows that the temperature change is slow because of the smoldering stage in the fire beginning. Since the nodes are different in the distance from the fire, the temperatures detected by the nodes are also different, but the upward trends are consistent.

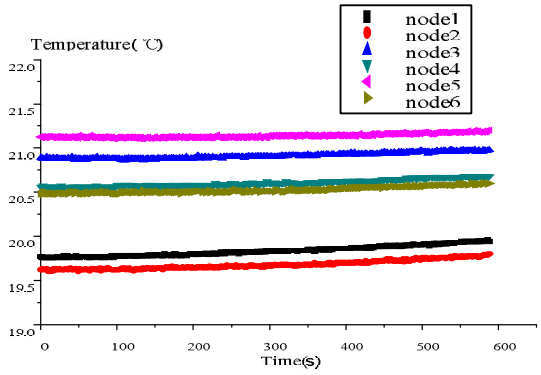

Figure 7. Result of temperature detection

Multiple detectors are used to detect a given concentration of CO standard gas at the same time in the experiment, and from data collected we make repetition analysis and calibration for each detector. Also we arrange each detector to detect at different concentration of standard CO gas through the detection data we analyze the linearity. The standard concentration of CO is respectively 99ppm, 203ppm, 303ppm, 50.3ppm, 397ppm, 502ppm. The detectors have very short response time and detect the standard value of the corresponding concentration. The data keep stability when the concentration is not change. The detector has a good linearity, and its sensitivity reached to 1ppm. Fig.8 draws the experiment result of four detectors under 303ppm concentration of CO gas. The experimental results showed a good linearity, a high sensitivity of the detectors. Therefore these detectors can detect the change of the concentration of CO gas sensitively early in the fire.

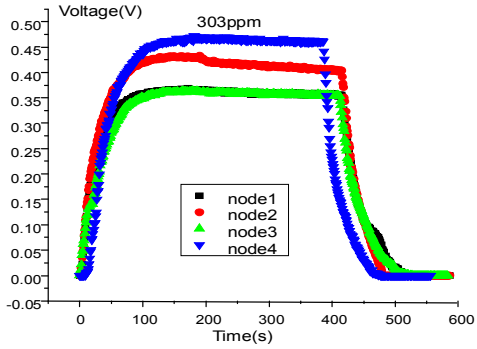

Figure 8. CO gas detection result

VI. CONCLUSION

It is a new research topic of fire safety that applying ZigBee wireless sensor network for fire detection which is an effective means for early detection and timely suppression of fires. The achievement of miniaturization, networking, and ultra-low power system design in ZigBee wireless sensor network is effective mean to solve the dangerous gas leakage monitoring and an early warning of fire. This system applies multiple detection nodes to work together and multi-parameter to identify the fire accurately. Using CO concentration as a fire parameter can help the fire detection quickly and also compensate the detection of some fires without smoke such as alcohol fire .Low-power chips are selected and low-power hardware circuits are designed in the system. In the aspect of fire safety and monitoring for special places which are not suitable for the layout of wired fire alarm system, this kind of system has its unique advantages and has a broad application prospects and great significance.

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