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PM2.5 monitoring system based on ZigBee wireless sensor network

Lukai Lin, Xiangshun Li and Weiying Gu

School Automation, Wuhan University Technology, Wuhan 430070, China

Abstract. In the view of the haze problem, aiming at improving the deficiency of the traditional PM2.5 monitoring methods, such as the insufficient real-time monitoring, limited transmission distance, high cost and the difficulty to maintain, the atmosphere PM2.5 monitoring system based on ZigBee technology is designed. The system combines the advantages of ZigBee's low cost, low power consumption, high reliability and GPRS/Internet's capability of remote transmission of data. Furthermore, it adopts TI's Z-Stack protocol stack, and selects CC2530 chip and TI's MSP430 microcontroller as the core, which establishes the air pollution monitoring network that is helpful for the early prediction of major air pollution disasters.

1 Introduction

PM2.5 refers to particles that can be suspended in the air for a long time in the air with an aerodynamic equivalent diameter less than or equal to 2.5 microns. Due to the small particle size, large area, strong activity, easiness to carry toxic and harmful substances (such as heavy metals, microorganisms, etc.), PM2.5 has a great impact on human health and air environment [1]. In addition, the continued accumulation of PM2.5 concentration easily lead to a wide range of fog and haze weather. In China, the monitoring of PM2.5 is lagging behind, and only a few areas of the country have monitored PM2.5 before the national release of the latest ambient air quality standards. Due to the large variety of concentration of PM2.5 in residential areas, commercial areas and local production-intensive areas, it is not possible to rely on the data obtained from the city monitoring stations to determine the precise PM2.5 concentration in small areas. PM2.5 monitoring system used in the regions smaller than the urban areas usually uses wired network connections, which is expensive and difficult to maintain for large production bases.

As a wireless communication standard of low power consumption and low rate, ZigBee is a research hotspot in the field of wireless communication in recent years. It is widely used in the fields of intelligent meter reading, medical monitoring and environmental monitoring [2]. Therefore, the wireless sensor network based on ZigBee is applied in PM2.5 monitoring to improve the shortcomings of traditional monitoring methods, such as the insufficient real-time monitoring and limited transmission distance, and the effective establishment of air pollution monitoring network is of great significance for the early prediction of major air pollution disasters. The structure of this paper is as follows: (2) Overall system design: the overall scheme of the system and its implementation principle are summarized. (3) System hardware design: details of the system's hardware composition and hardware connection. (4) System software design: introductions of the software algorithms to make the system run efficiently and reliably. (5) Verification of experimental results: realize the system using the above hardware and software with great efficiency. (6) Conclusion: the corresponding conclusions are obtained according to the experimental data of the system.

2 System design

There are three specific forms of ZigBee wireless communication network, which are star network topology, tree network topology and network topology [3]. The design uses a tree network topology, whose size is larger than the simplest star network, suitable for large area of PM2.5 monitoring. And its resources required are less than the network topology to achieve a specific and simple environmental monitoring. The terminal node is responsible for collecting the data and transmitting the data to the upper layer of the routing node, the routing node will pass the data to the upper coordinator after summarizing the data. After that, the coordinator analyses and sends the data to the monitoring centre through the gateway. Thus, a PM2.5 remote monitoring system based on ZigBee and GPRS is built. The system diagram is shown in Fig.1.

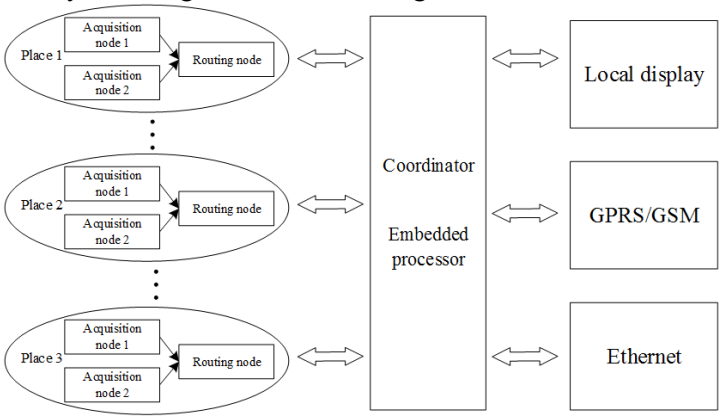

Fig.1 System diagram

3 Hardware components

3.1 Wireless transceiver module

As shown in Fig.2, the design of the terminal acquisition node is mainly composed of CC2530 module based on Texas Instrument and RF power amplifier module CC2591. The CC2530 is a true system-on-a-chip solution for 2.4GHz IEEE 802.15.4, Zigbee and RF4CE applications. It combines the leading RF transceiver with excellent performance and industry-enhanced 8051CPU, enabling to build a strong network at a very low total cost of material [4]. CC2591 is a low-cost high-performance RF front end for 2.4GHz band, which integrates power amplifiers, low noise amplifiers, balanced converters and RF matching networks, etc. With the use of CC2530, its data transmission range can be extended to 600 meters.

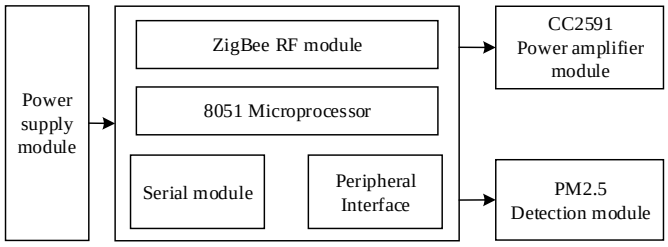

Fig.2 Terminal node structure

3.2 Data acquisition module

A sensor (also called detector) is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument [5]. A PM2.5 sensor is used to measure the concentration of atmospheric particles with light scattering method. The method is based on the Mie (MIE) law, which is used to measure the mass concentration of particulate through measuring scattered light signal emitted by the particles in the air. According to the Mie theory, under fixed

observation angle and observation distance, the intensity of the scattered light is linearly related to the concentration of the particles when the wavelength and intensity of the incident light and the composition of the particles are fixed. Therefore, as long as illuminate it with monochromatic light and then detect the scattered light intensity of a fixed angle and distance, the particle concentration can be calculated. This design uses the laser diode as the light source, with red light as the incident light. Sampling air enters the region of laser beam through air duct. When the particles in the air enter the laser beam region, the laser is scattered, and the photoelectric detector receives the scattered light intensity signal reflected by the concave mirror. The photoelectric signal is converted to the corresponding electrical signal by the photoelectric effect of the photo detector. After the signal is processed by the circuit, the concentration of PM2.5 is obtained [6].

3.3 Communication module

In order to transmit the data detected by the sensor network, the scheme adopted in this paper is (1) serial communication: the coordinator connect with the PC machine through the serial port and transfers data in the local distance directly, which not only can view the data but also facilitate the system debugging. (2) GPRS module communication: SIM900A module can realize GPRS/GSM remote communication, which has long communication distance and high reliability. (3) Through the Ethernet Real-time data uploaded to the data monitoring centre, PM2.5 data is analysed more intuitive and scientific and their trend can be forecasted, which played a positive role in the prevention of air pollution disaster. Here mainly introduces the GPRS communication. This design uses the SIM900A module produced by SIMCom. The chip uses a power saving technology designed to minimize power consumption in SLEEP mode to only 1.0mA, which is suitable for most of the low power requirements. Chip embedded TCP/IP protocol, the SIM900A uses the standard AT command to write to achieve the TCP connection with the central server, so that the data collected by ZigBee network transfer out [7]. The module has the advantages of compact structure, easy production and processing, and is based on the ARM926EJS architecture, can be widely used in wireless sensor networks, vehicle tracking, intelligent meter reading and other fields.

3.4 Coordinator

Coordinator is the core module of the whole wireless sensor network. The main function is to process data, store data and control flow. On the one hand, it processes and calculates the data and sends it to the radio frequency module. On the other hand, it should deal with the data information received by the radio frequency module and control the operation of other modules of the hardware platform [8].

MSP430 microcontroller is a TI's 16 bit ultra-low power mixed signal processor. The chip uses the current popular instruction set, the use of advanced architecture greatly enhance its data processing and computing capabilities. Also, its power consumption is extremely low: in active mode, the operating circuit is only 280uA, in the closed state requires 0.1uA current. In addition, MSP430 microcontroller also has a rich peripheral interface, which is suitable for the large data transmission and high real-time requirements of the PM2.5 inspection system. Coordinator node hardware composition as shown in Fig.3.

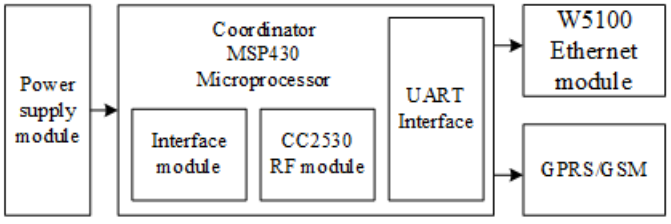

Fig.3 Coordinator node structure

4 System Software Design

The system software implements the ZigBee protocol and completes the networking based on the hardware nodes. At the same time, it realizes the real-time monitoring of PM2.5 on the basis of the

network. The main tasks are as follows: the terminal nodes achieve the data collection and AD conversion, then carry out the calculation of the concentration of atmospheric particulates and packet transmission; the coordinator builds and maintains the entire network and achieves the data transmission.

4.1Introduction to the ZigBee protocol

The wireless sensor network nodes need to have corresponding wireless network protocols to complete the mutual data exchanges (including the MAC layer, the routing, the network layer, the application layer, etc.). The traditional wireless protocols are difficult to meet the requirements of the wireless sensors such as low cost, low power consumption and high reliability. In this case, the ZigBee agreement came into being. ZigBee technology is a low data rate, low power consumption, low cost; wireless networking protocol targeted towards automation and remote control applications [9]. The ZigBee defines a series of communication protocols needed by the wireless communication with a low transmission rate within a short distance. It enables a large number of sensors to communicate with each other while maintaining minimal energy consumption and high communication efficiency. This design, as the core software platform for the 802.15.4 / ZigBee technology, is based on the Z-Stack protocol stack of TI Corporate. Users can finish the corresponding application designs and develop the wireless sensor networks with corresponding functions by carrying out a series of initialization operations according to the IEEE 802.15.4 standard and completing the configuration and high-level calls of the polling operating system [10].

4.2 Terminal node programming

The terminal node is mainly responsible for the data collection in the wireless sensor network. It sends the network access request to the coordinator after the completion of power-on initialization. The sensor node will send the connection request to the coordinator after receiving the network access request from the terminal nodes. If the request response is correct, then users can access to the network successfully. When the network is successfully connected, the coordinator will assign a unique ID and associate the MAC address of the sensor node with the ID to register. Otherwise, it fails [11]. The flow chart of the sensor node is shown in Fig. 4. After the network is successfully connected, the sensor node will collect the soil moisture every other hour and send the data packet. It will enter the sleep mode during the spare time. Only when the interrupts, the timer and the wireless transceiver module are powered on can the low power consumption be realized.

4.3 Coordinator node programming

As the centre of the entire sensor network, the coordinator node is primarily responsible for the remote wireless data transmitting of the network. After the power-on initialization of the coordinator node, it will build a network first and then enter the network monitoring state. After receiving the network access request from the sensor node, it will assign the address to the child node and send the network confirmation information to establish the connection [12]. In the sensor network, the Z-Stack behaves in the form of an operating system. The coordinator continuously inquires whether events occur or not. Once the data packet is received from the child node, the corresponding AT command will be sent to the SIM900A through the serial port to realize the remote transmission of data through the GPRS. The coordinator work flow chart is shown in Fig. 5.

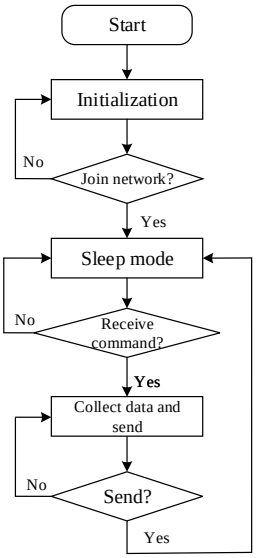

Fig.4 The flow chart of the sensor node

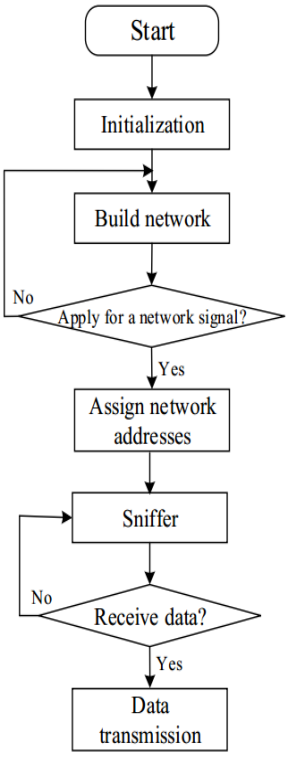

Fig.5 The coordinator work flow chart

5 Verification of experimental results

In order to verify the actual effect of the system, three different regions were selected to carry out the PM2.5 monitoring experiment, and each experimental site was placed with five different sensor nodes for data collection. After analyzing the five sets of data, a time varying curve is obtained, as shown in Fig.6. The experimental results show that the concentration of PM2.5 in the vicinity of the plant is the highest, and the residential area is the lowest. In addition, it shows the trend of high at night and low in the daytime, which is in line with the actual situation.

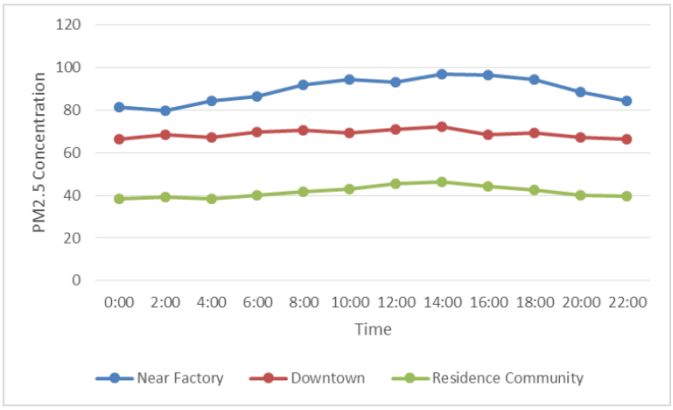

Fig.6 Experimental results

6 Conclusion

The paper builds a wireless sensor network through reliable hardware structures and software designs with ZigBee as the core. It uploads the PM2.5 monitoring data through the GPRS/Ethernet to realize the remote real-time monitoring. The system features a large number of typical WSN nodes and a great quantity of data collection. It also combines the advantages of the GPRS/Ethernet which has a wide coverage and can transfer mass data over a long distance. According to the experimental data, it can accurately monitor the content of PM2.5 in the environment and realize real-time upload effectively. In addition, by changing the network topology, it can be used in different regions. With strong applicability and high stability of the system, it plays a positive role in the prevention of major disasters caused by the air pollution.

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