Dust concentration detection system based on wireless sensor network

Zhang Quanzhu[1]*, Zhao Zimei[2], Qian Huifa[3], Ge Yanxiang[4]

Institute of Information and Control Technology, North China Institute of Science and Technology, No. 806, Dongyanjiao College Street, Sanhe City, 101601, China.

*Corresponding author: E-mail: 931606464@qq.com

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Abstract

In order to solve the problem of continuous large-scale detection of dust detection system in mines, a dust detection system based on wireless sensor network is designed. The system is composed of data acquisition node, ZigBee coordinator and ARM9 processor S3C2440. The data acquisition node includes temperature and humidity sensor DTU21D, laser dust detector and ZigBee node. CC2530 as the second generation of on-chip system that integrates RF and controller, is applied to ZigBee nodes and coordinators. The ZigBee protocol stack is used in software, and various functions of application layer are implemented on the basis of ZStack general module. This paper introduces the wireless data acquisition node based on ZigBee protocol, and gives the hardware design block diagram and software flow chart of data acquisition node, coordinator and data processing module. The experimental data prove that the communication reliability of the system is high, and it can realize the wireless, real-time, accurate and large-scale detection of dust concentration in the mine.

Keywords: Wireless sensor network, ZigBee, ARM, dust concentration, temperature and humidity sensor DTU21D.

Introduction

Dust is closely related to human work and life. In coal mines, even if the mine has a ventilation system. The coal mining machine will generate a large amount of dust when the coal is pulverized due to the harder coal. Among them, invisible particulate dust is a serious threat to the safety of workers. The dust concentration in the mine is excessive. The workers are in a harsh environment for a long time. These particles enter their eyes and lungs, causing their retina, lung function and even blindness. Suffering from serious diseases such as pneumoconiosis and lung cancer. It can be seen that the particulate dust affects the equipment in the mine, and these particles enter the air exhaust system of the air conditioning system and other equipment. Which seriously affects their service life. What is more serious is that when the excessive concentration of dust encounters a gaseous medium such as oxygen.it is very easy to cause a dust explosion. As can be seen from the above. The study of dust concentration detection systems has a positive impact on human health and production practices.

The system uses analog-digital technology. All-digital intelligence and wireless sensor network technology to achieve high-precision and large-scale measurement of dust concentration. The temperature and humidity sensor is used to correct the dust concentration to a certain extent, and the intelligent serial display screen displays data information sharing to form a high-precision dust measurement control system. Which realizes intelligent and high-precision measurement of coal mine dust. Dust concentration over-limit alarm. Automatic storage of measured dust concentration data and past data recall to avoid data loss during coal mine dust data analysis, and to achieve intelligent, low power consumption to improve the high-precision performance of the entire system [**1**].

System hardware design

The mine dust concentration detection system designed this time is shown in **Fig. 1**. It is a dust concentration detection device of a wireless sensor network composed of several data acquisition nodes. Each data acquisition node includes a temperature and humidity sensor. A laser dust detector and a ZigBee node. The data acquisition node communicates with the ZigBee coordinator through a ZigBee-based communication protocol, and the ZigBee coordinator and the ARM9 processor communicate via a serial protocol. The ARM processor performs digital-to-analog conversion on the collected signals, further completes the analysis and processing of the data, displays and stores the processed data, and performs sounds when the measured values are not within the set concentration threshold or the device fails. Light alarm, this information can be transmitted to the PC display through the ZigBee protocol.

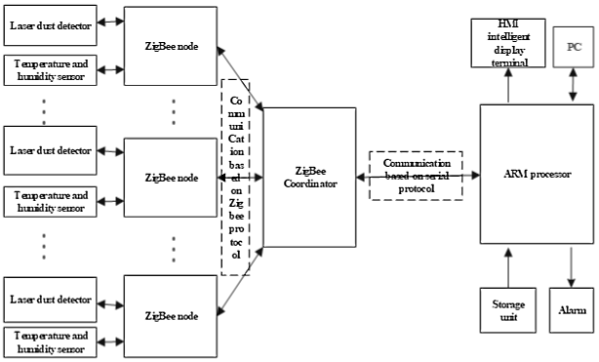

Fig. 1. Block diagram of dust detection system in wireless sensor network.

The system does not use the dust sensor alone, but the temperature and humidity sensor is added because the temperature and humidity affect the diameter of the dust particles in the measured range, and the dust concentration measured by the laser dust detector based on the light scattering principle used in the system. There are obvious effects, so it is necessary to correct the influence of temperature and humidity on the algorithm level.

Design of acquisition module and transmission module

The acquisition module and the transmission module of the system mainly complete the collection and transmission of data. The acquisition module is composed of a laser dust concentration sensor. A DTU21D temperature and humidity sensor and a ZigBee node, and the ZigBee node is a bridge for communication between the sensor and the coordinator. The ZigBee protocol defines three network topologies: star, number, and mesh. The system uses a star type. The data collection node and the ZigBee coordinator form a star network to achieve dust concentration and ambient temperature and humidity transmission.

Design of data acquisition node

The above star network includes one coordinator node and multiple ZigBee nodes. The processor in the ZigBee node is CC2530, which is responsible for collecting temperature, humidity and dust data, and uploading the data to the coordinator. The ZigBee nodes are distributed in the detection area. Multiple locations, and the data collected by each sensor is wirelessly transmitted to the coordinator node. The acquisition module consists of a laser dust detector, a temperature and humidity sensor, a ZigBee node, an antenna, a power supply module, a debugging module, and an LED indicator. Since the ZigBee nodes are placed in different areas and the power consumption is low, the LED indicator is used. It is used to indicate the working status of the ZigBee node. When the red light is on, it indicates that the node is successfully established or joined to the network. When the yellow light is on, it indicates that the data transmission is successful. The function of the antenna is to increase the coverage of the wireless signal in the environment. **Fig. 2** shows the hardware connection diagram of the data collection node.

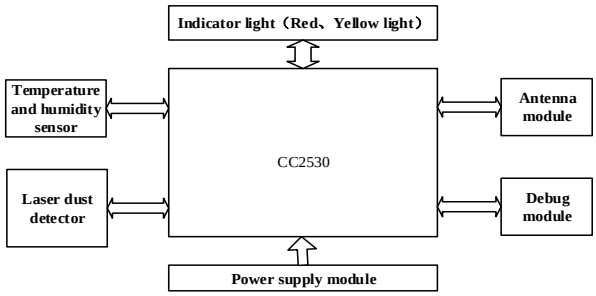

Fig. 2. Hardware connection diagram of data acquisition node.

Coordinator design

As the core of the wireless transmission and transmission system, the ZigBee Coordinator is a bridge connecting the data acquisition module and the data processing module. The establishment and maintenance of the entire wireless sensor network is the responsibility of the coordinator to complete the reception and transmission of data [**2**]. The ZigBee node is responsible for receiving the signals collected by the temperature and humidity sensors and the dust sensors, and then transmitting them to the coordinator in a wireless manner. At this point, the coordinator is uploaded to the ARM processor and communicates through the serial protocol [**3**]. The components of the ZigBee Coordinator are identical to the data collection nodes. The CC2530 uses the Z-Stack2007 protocol stack to implement the ZigBee wireless network. The main module communication architecture is shown in **Fig. 3**.

Since the coordinator is responsible for receiving and uploading data, the power consumption is relatively high. Therefore, the coordinator uses two power supply modes to supply power. The battery and the DC power supply are used in combination. Usually, the DC power supply is used, and when there is a power failure or the like, the power can be used. Use the battery to keep the system running properly and prevent the coordinator from terminating data collection due to power failure.

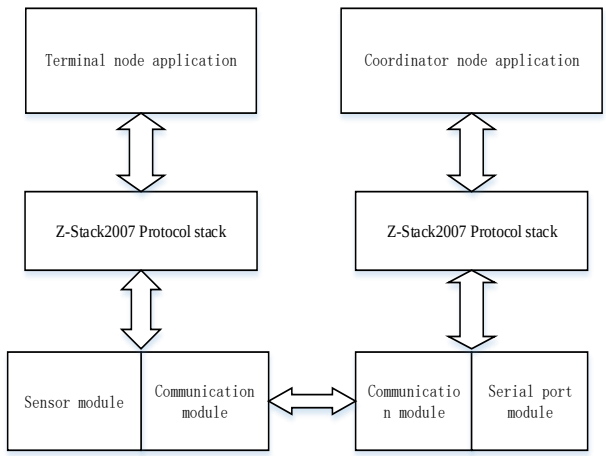

Fig. 3. CC2530 module communication architecture.

Data processing module design

Processor introduction

The S3C2440A is an embedded ARM9 core-based microprocessor that uses an ARM9 architecture, 0.13μm CMOS standard macrocell and memory cell, [**4**] 289-FBGA package, and operates at 300MHz/1.2V, 400MHz/ 1.3V, memory addressing space up to 1GB. As the core of the detection system, its CPU core uses ARM's 16/32-bit ARM920T RISC. The ARM920T implements MMU (Memory Management Unit), AMBA BUS and Harvard cache architecture. This structure has independent 16KB instructions. Cache and 16KB data cache, each consisting of rows of 8 words long. By providing a complete set of general-purpose system peripherals, the S3C2440A reduces the cost of the overall system without the need for additional configuration components.

The S3C2440A processor has a wealth of internal resources: independent dedicated DMA LCD controller, 8-channel 10bit ADC, 4-channel DMA (Direct Memory Access), 4-channel PWM, 3-channel UARTs, 2-channel SPIs, 2-channel USB host controller, 1 Channel internal counter and USB slave controller, IIC bus interface, IIS bus interface, AC97 interface, SD and MMC interface, Camera interface, etc. [**5**] The processor has the advantages of low power consumption, low cost, rich interface (up to 130 general-purpose IO ports) [**6**], can receive data from the coordinator for a long time, systematically analyze and process the dust concentration data, and problems occur. The relevant personnel can be notified in time.

Data processing module hardware connection diagram

Fig. 4 is a hardware connection diagram of the data processing module. The control center of the system is an ARM processor module, which can realize functions: send acquisition commands; analyze and store data uploaded by the coordinator; and instruct the LCD to display data.

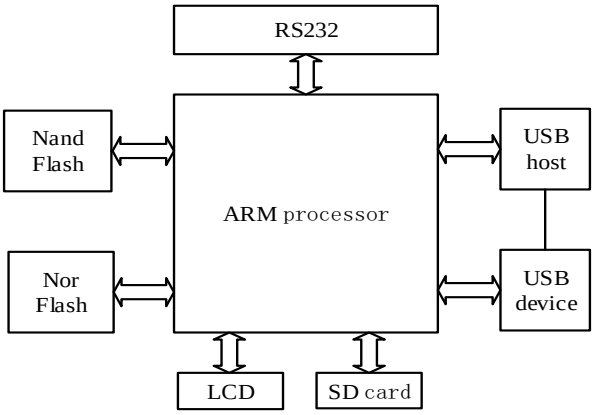

Fig. 4. Hardware connection diagram of data processing module.

According to the requirements of the dust concentration detector for related functions, this module mainly analyzes the collected data and makes corresponding processing according to the analysis result. The data transmission between the coordinator and the ARM module is not wireless transmission, but through the serial port, the data is displayed through the LCD. At compile time, the host communicates with the host through the RS232 interface; during the migration of the operating system, the USB HOST selects the corresponding file through the HyperTerminal, the USB DEVICE is used to communicate with the Coordinator; and the LCD interface is used to display the dust collected by the node. And the temperature and humidity information, through the touch screen, you can select the acquisition node on the detection graphic interface, view the historical data, etc.; the historical data collected by the backup is completed by the SD card.

System software design

Fig. 5 shows the software structure of the system. It can be seen from the figure that the data wireless transmission and wireless networking of the system is based on the ZigBee protocol stack to realize data transmission, and the data uploading and development platform is through a serial port protocol. Therefore, the software design of the system mainly includes the collection point-to-data measurement, wireless networking, data analysis processing and data uploading.

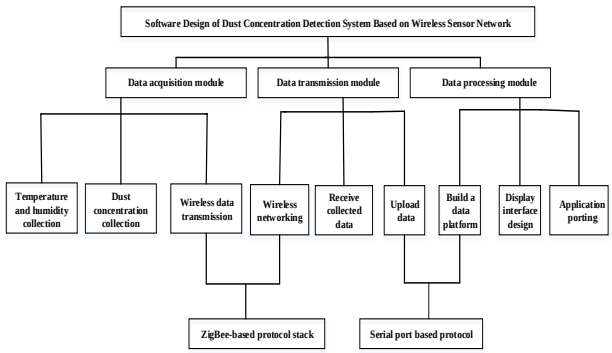

Fig. 5. Software structure diagram of dust concentration detection system.

Software design of system data acquisition module

Fig. 6 shows the flow chart of the data acquisition software. The acquisition module should first be initialized, and then the collection point sends the incoming network information. After receiving the ZigBee coordinator, the instruction is given and the node is admitted to the network. If the node is successfully connected to the network, the indicator blinks; the light does not flash, indicating that the network fails [**7**]. You need to re-apply for network access. If the coordinator has something to be processed after the network is successfully accessed, the event will be processed first, and the timing will not start until the event is processed. After the time expires, the coordinator starts sending signals to the node, and the dust and temperature at the node. The sensor will start working. For the dust concentration and ambient temperature and humidity

measurement, the measured data will be transmitted wirelessly using the ZigBee protocol stack and sent to the coordinator. If the data is sent successfully, continue to collect. If it fails, re-apply to the network and repeat the above steps.

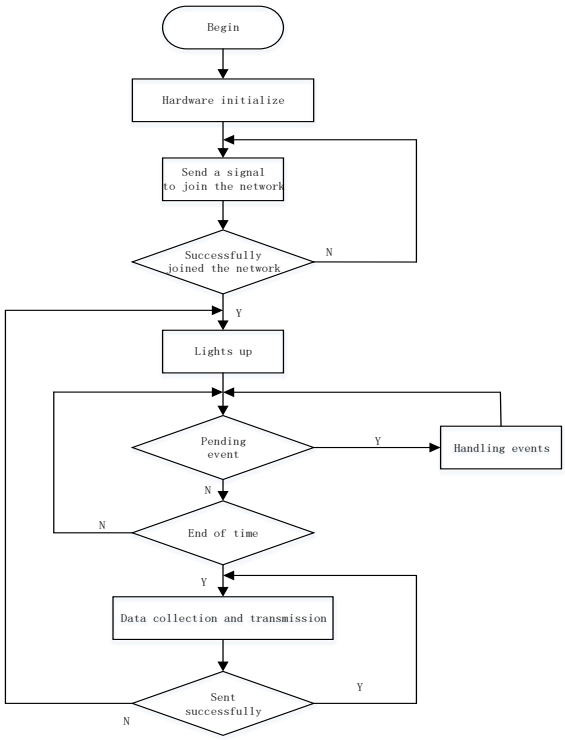

Fig. 6. Software process of data acquisition module.

ZigBee networking design

Fig. 7 shows the ZigBee networking process. The coordinator will receive the information of each node in the wireless sensor network, and then further share the data with the host computer through the RS232 interface, and the host computer can further share the data on the network.

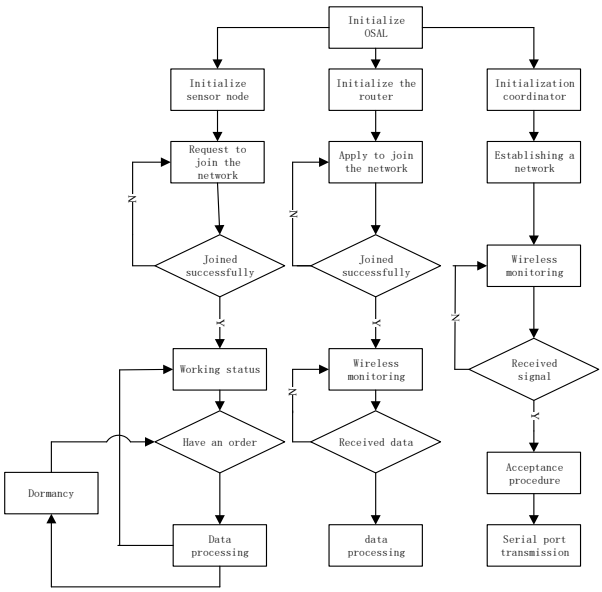

Fig. 7. ZigBee network flow chart.

Experimental data analysis

In order to further understand the communication reliability of the system nodes, relevant experiments were carried out, mainly analyzing the variation of the received signal strength and the number of packets with the increase of the spacing. In the experiment, the dedicated intensity detection module is responsible for receiving the measurement of the signal strength. When the packet rate is tested, the node is set to send the data 500 times. The experimental data is shown in **Table 1**. The experimental results show that with the increase of node spacing, the RSSI value and the packet receiving rate are gradually reduced, and the communication reliability is the best, the spacing is up to 10m [**8**]**.**

Table 1. ZigBee communication reliability experimental data sheet.

spacing (m)	1	5	10	15	20
RSSI(dB • m)	-64.99	-79.33	-83.55	-83.97	-85.04
Number of packets received	500	500	500	496	486

Table 2. Experimental data table of dust intelligent detection instrument (unit mg/m3).

Serial number	Roadway dust concentration (mg/m^3)			Working flour dust concentration (mg/m^3)		
	standard	Measurements	error	standard	Measurements	error
1	30	32	2	200	217	17
2	40	43.5	3.5	250	273	23
3	45	49.2	4.2	300	280	20
4	50	52	2	320	341	21
5	57	54	3	400	431	9
6	59	57	2	430	395	35
7	60	61	1	450	416	34
8	65	62	3	500	535	15
9	68	66	2	540	586	46
10	70	73	3	600	645	45

The experimental data in **Table 2** is measured by the system, and the data acquisition module is used to detect the dust concentration of the roadway and the working surface, respectively. The standard value of dust is obtained by a dust sampler. A total of 10 sets of data were tested, and 10 data collection points were placed in the roadway and the working surface respectively to collect the dust concentration and temperature and humidity values of the roadway and the working face, and the distances placed by each ZigBee node were 10 meters apart. Once the nodes are placed, they begin to power the instrument. In this experiment, the system can collect 100 data points in 3 minutes, collect nearly 20,000 data from 10 dust points, and then analyze and process the data. The results show that the collected data is more accurate. Scientific research is of high value.

Conclusion and outlook

It can be seen from the above that the system can realize large-scale, wireless, real-time, accurate and reliable detection of dust concentration, and the measurement

error is also controlled within a relatively small range, which can truly and accurately reflect the concentration of dust under the coal mine, which is consistent with the initial The standard of design.

Due to the existence of the ARM processor, the dispersity can be statistically classified according to the diameter of the coal dust particles, and the degree of dryness and hardness of the coal seam can be learned through the side of the system to further guide the relevant personnel to work. Further design can be made in system explosion protection and sensor electromagnetic compatibility.

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Author's contributions

Conceived the plan: Zhang Quanzhu, Zhao Zimei; Performed the expeirments: Zhao Zimei, Qian Huifa; Data analysis: Qian Huifa, Ge Yanxiang; Wrote the paper: Zhang Quanzhu, Zhao Zimei,. Authors have no competing financial interests.

Supporting information

Supporting informations are available from VBRI Press.

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