Design and Implementation of Wireless Sensor Monitoring System for Temperature and Humidity based on ZigBee

Xinxin Wang, Jianlin Zhao, Chaofan Zhang, Huogen Lu

***Abstract*—**The design is a set of WSN (Wireless Sensor Network) software and hardware system which can monitor the temperature and humidity of the environment in real time on the basis of studying the structural characteristics of WSN and the principle of ZigBee technology, combined with TI CC2530 chip and the ZigBee protocol stack Z-Stack. The system is composed of collection nodes, ZigBee coordinator and upper computer. Acquisition nodes and coordinator are as lower computer using IAR as the software integrated development environment. Using C# language to develop the monitoring software of the upper computer. The acquisition node is responsible for the collection order of the upper computer, which realizes the periodic collection of temperature and humidity and transmits the data to the coordinator through the ZigBee network. The coordinator is responsible for the establishment and maintenance of the ZigBee network, the receiving of the node information, and transmission of the upper computer commands to the acquisition node timely. The GUI interface is designed to realize the processing, storage, visualization and display of the node status. The coordinator and the upper computer use serial port communication using the Stop-Wait Automatic Repeat Request (ARQ) to ensure the reliable communication. The system has been tested, the function runs normally, the performance is stable, and the system meets the design requirements.

***Keywords*—**wireless sensor network, ZigBee, ARQ, serial port, C#

I. Introduction

Wireless sensor network (WSN) expands the ability to obtain information. It links the objective physical information with the transmission network and provides the most direct, effective and the most authentic information to the people. WSN has been fully recognized and applied in national defense security and national economy. In environmental temperature and humidity monitoring, WSN provides a convenient means of technology. Arrange a large number of sensor nodes including temperature, humidity, light, pressure, infrared, visible light and other kinds of sensors in a not easy to direct human monitoring of natural environment [1].The system transmits the data to the distant base station by the self-organizing wireless network then via the Internet, satellite transmission to the server and the end users access the information. ZigBee technology is a Low Rate Wireless Person Area Network (WPAN). It is suitable for low data transmission, low transmission rate, short distance, multi distribution occasions, can provide mobility, flexible networking mode for users [2, 3].

The monitoring system is divided into upper computer system which is the monitoring software runs on the PC and lower computer system composed of the acquisition node and the ZigBee coordinator. After the lower computer is powered on, the ZigBee network is set up, and the upper computer sends out the collection order. Set the serial port related parameters and the acquisition cycle then issue the acquisition order for the upper computer. Coordinator receives the collection order and sends it to the collecting node that parses the received information and starts the acquisition cycle according to the requirements. The acquisition result and the node's own network state are transmitted to the coordinator through the ZigBee network, which is transmitted by the network to the upper computer. The network communication quality is also sent to the upper computer before forwarding. Receive the data frame and carry on the analytic processing, the upper computer displays the information through the GUI interface chart, simultaneously the data import to the EXCEL document for users to view [4, 5].

II. System Hardware Design

This ZigBee network is wireless mesh type of temperature and humidity sensor network composed of collecting node, coordinator and terminal PC as shown in Fig.1. Because the router node can collect data, it can also route the data to other nodes, in order to save resources, data acquisition node is all set to router. Therefore only two types of devices are used in the actual network, namely the coordinator and the router. Coordinator is responsible for the establishment and management of the entire network, control monitored area, send the sensor data to the upper computer for analysis and processing through the serial port. Router is mainly responsible for data forwarding, can be realized multi hop thus expanding scope of network coverage, monitor the environment information and send the collected data to the control center. The whole system is composed of 1 ZigBee coordinator and 3 acquisition nodes [6, 7].

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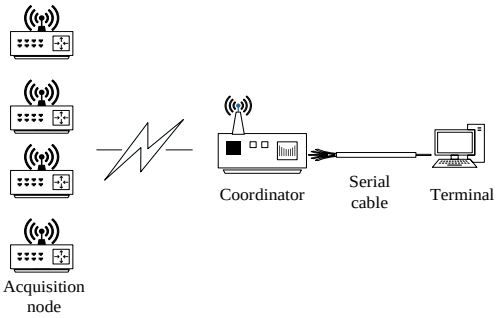

Fig. 1 system structure diagram

A. Coordinator Function Module

Coordinator and collection node module mainly include CC2530 data processing module, power module, serial module, LCD module, keyboard module and LED parts, as shown in Fig.2. CC2530 is mainly responsible for the control of the node's processing operations, task management. The power supply module provides 3.3V voltage to the node through the voltage conversion module. Serial port module provides the interface between the upper computer and the node, converts the USB protocol to the serial port protocol. LCD is mainly used to display the status of nodes. LED is used to indicate the connection of the network. If the actual application needs to increase the transmission distance, increase the RF amplifier module [8].

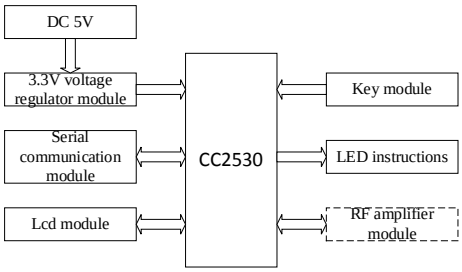

Fig. 2 hardware block diagram of coordinator

B. Acquisition node function module

The acquisition node is mainly composed of CC2530, data processing module, sensor acquisition module, power supply and LED, as shown in Fig.3. Among them, the sensor acquisition module is mainly responsible for the data collection and conversion. The LED part is to indicate whether the nodes join or exit the network. The acquisition node is generally used for battery power supply because it is not limited by the environment.

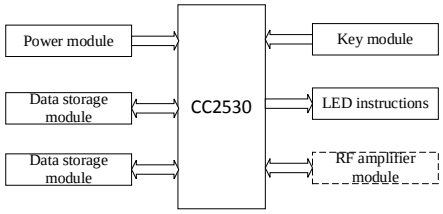

Fig.3 hardware block diagram

C. Sensor Module Design

The temperature and humidity monitoring system in the monitoring system is realized by the temperature and humidity sensor chip DHT11. DHT11 has the function of temperature data and humidity data acquisition, the acquisition results in digital signal feedback to the controller, the accuracy of humidity + 5%RH, temperature ±2℃, measuring range of 20-90%RH, temperature 0~50℃.The data exchange between the sensor and the controller is carried out in the form of serial, and the result is sent by bit by bit after the analog digital conversion. It consists of a resistive humidity sensor and a NTC temperature measuring element. The external interface is provided with a simple interface, only need to provide power supply interface, data interface and grounding. The data interface is connected with the universal IO port of the CC2530 chip through the pull up resistor. The communication protocol between DHT11 and MCU is a single bus, a communication event 4ms or so, the data is divided into small parts and integer parts. One time communication time is about 4ms, the data is divided into the fractional part and the integer part. A complete data transmission is 40 bits, high first out, as shown in table 1.

Table1 DHT11 data format

data format	8bits Humidity integer	8bits humidity decimal	8bits Temperature integer	8bits Temperature decimal	8bits Check code

The communication between DHT11 and CC2530 uses a single bus protocol. Each communication is initiated by CC2530 and DHT11 responses. The connection circuit of DHT11 and CC2530 is shown in Fig.4.

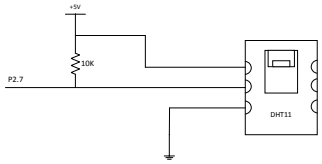

Fig. 4 DHT11 connection circuit

D. Power Design

The ZigBee base plate is powered by an external 5V power supply which is connected with the power supply interface through a power adapter and converted from a power supply conversion module on the bottom board to a 3.3V voltage to supply power for the whole circuit board. Circuit schematic diagram is shown in Fig.5. POWER is a power socket, output voltage is 5V. PowerSW is for the switch. 5V voltage will be converted to 3.3V voltage for the entire circuit board power supply by the voltage conversion circuit after the fuse and filter circuit. Voltage conversion circuit using 3.3V AMS117 voltage conversion chip, which C4 is input bypass capacitor, C5 is output bypass capacitor, use of tantalum capacitors [9].

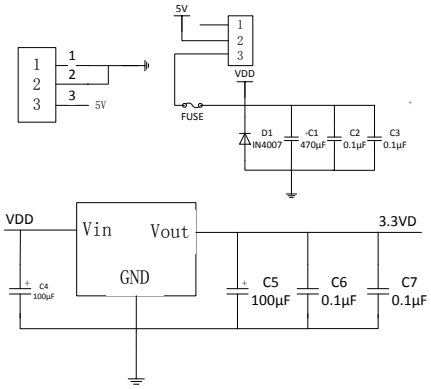

Fig.5 floor power supply

E. LED and Key Design

There are 3 LED lights on the base plate which are respectively connected with the P1.0, P1.1 and P1.4 interface of CC2530. They can be set according to the program to show the different states of ZigBee. Joystick direction keys with only one I/O port achieve a multi directional button function in the way of simulating input, then obtain the port input voltage through the ADC sampling to determine the location of the button. The circuit connection is shown in Fig.6.

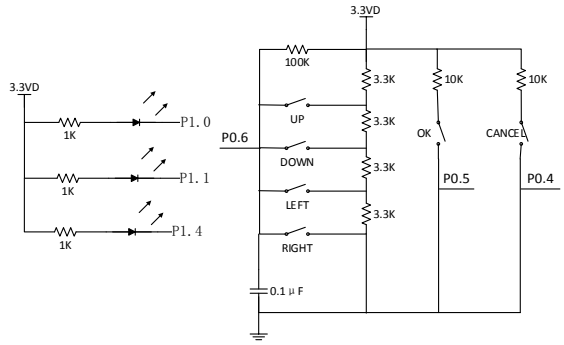

Fig.6 LED and key circuit

F. J-TAG Interface

J-TAG interface is for chip code burning and online debugging simulation. Interrupt program execution temporarily by setting the breakpoint, view the running state of the program, the values of variables and registers in real time, and provide a great convenience for the development of the program. Schematic diagram is shown in Fig.7. Due to P2.1 and P2.2 for CC2530 is the debugging interface, the effective connection of the J-TAG interface is only four lines: ground, power lines, P2.1 and P2.2. J-TAG interface pin 1is to ground wire, pin 7 is to the power supply, pin 3 and pin 4 are respectively to DD and DC, and the rest of the pin is left vacant.

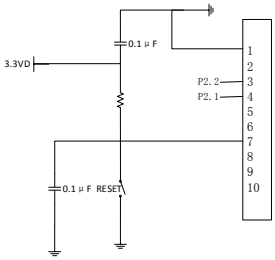

Fig. 7 J-TAG interface

III. Application Development Based On Z-Stack

A. Transport Protocol

Z-Stack is an open source ZigBee protocol stack developed by TI which needs to be matched with TI's hardware platform for ZigBee application development. The transmission protocol includes wireless communication between the ZigBee network and the serial communication between the ZigBee coordinator and the upper computer system. In order to ensure the reliable and error free transmission of the two part, a mechanism is needed to ensure the reliable data transmission [10, 11].

As the data transmission of the monitoring system is not large and the rate of the transmission is not high, comprehensive consideration of selecting stop wait for automatic retransmission protocol (ARQ). The ARQ protocol requires two types of information to be transmitted over the link: data packets and response packets. Cluster is an identifier for the distinction of information in ZigBee network internal communication (Cluster ID), includes input and output cluster. They are connected to different types of data that flow from the device and into the device. Make the appropriate treatment of different data types through the identification of Cluster ID. Data from the sender uses CLUSTER_DATA as identification and data from the receiver uses CLUSTER_RSP as identification, as shown in Fig.8. The data structure of cluster identification is shown in table 2. Serial number is used to identify the number of the data sent, serial number automatically increases when the data is sent successfully [12, 13].

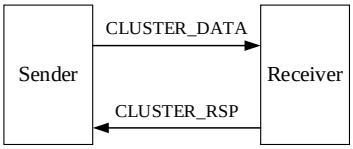

Fig. 8 transmission form

Table 2 cluster data structure

CLSUSTER ID	Data Format		
CLSUSTER_DATA	sequence number	length	data
CLSUSTER_RSP	state		sequence number

Assume that the acquisition node (denoted as A) sends data to the coordinator (denoted as B). B cannot receive data and send a response packet because of the interference caused by the loss of data packets in the process of transmission. A sets a retransmission timer after sending and waits for the response packet from B. A does not receive at the end of the time and repeats the same data. First check whether the serial number of the data package is repeated with the number of the last packet in the record after B receives the data. The status is identified as OTA_DUP_MSG if repeat and discard this duplicate data packet. If B is processing the last data packet, then the state is set to OTA_ BUSY_MSG. If the write is successful, the state is set to OTA_SUCCESS_MSG. The state and data packet sequence number stored in the response bag is returned to the data sender A. According to the state of the received response

packet to determine whether the success of this send and whether it is required to resend data. When A receives OTA_SUCCESS_MSG or OTA_DUP_MSG, it is determined that the packet has been sent successfully. When A receives BUSY_MSG_OTA, retransmit the data packet. Flow charts are as shown in Fig.9, Fig.10. B sends out the data to the upper computer in in a similar ARQ protocol after the successful receipt. The difference between two transmissions is the different identifier but communication process of the two sides is the same.

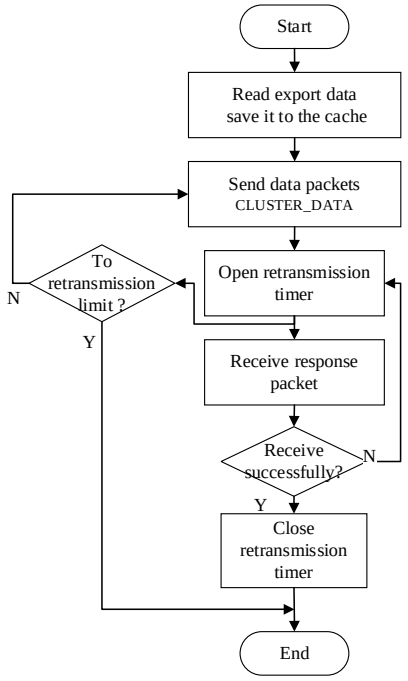

Fig. 9 sending data flow

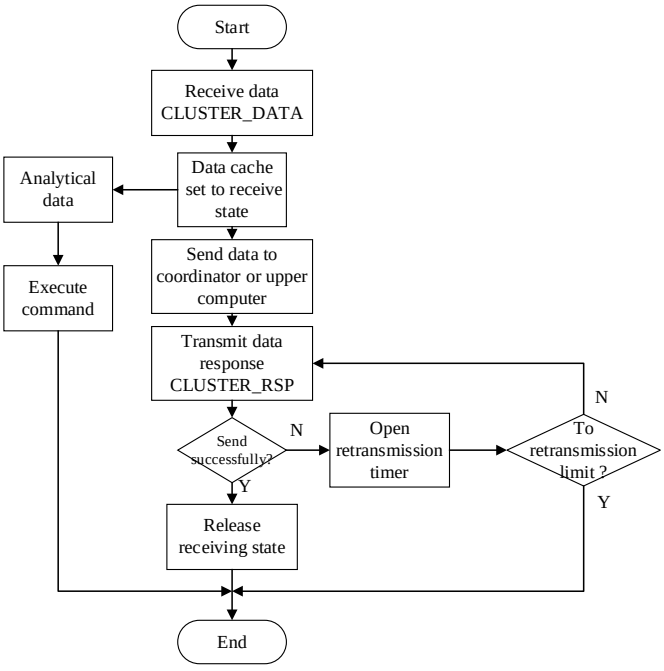

Fig.10 receiving data flow

B. Data Frame Format

In order to facilitate analysis and processing of data, define the data structure in CLSUSTER_DATA and the data structure that the upper computer sent to the data acquisition node. As shown in Table 3. Node ID is set by the user which is used to distinguish the different acquisition node. The network address is obtained from the function NLME_GetShortAddr (). RSSI indicates the received signal strength related to the distance between the transmitter and the receiver. LQI indicates the energy and quality of the received data frame related to the probability of receiving the data frame correctly. The command format of the upper computer sent to the collection node is shown in Table 4. Command sent by the user is used to start or stop collecting. 0XFF is to start the collection, 0X55 is to stop collecting.

Table 3 data structure of data acquisition node

Content	Node ID	Data length Len	Temperature integer Temp_H	Temperature decimal Temp_L	Humidity integer Hum_H
Number of bytes	1	1	1	1	1

Content	Humidity decimal Hun_L	Network address Addr	RSSI	LQI
Number of bytes	1	2	1	1

Table 4 PC command structure

Content	Command CMD	Length Len	Data DATA
Number of bytes	1	1	1

IV. Design of Upper Computer

A. Function Module Design

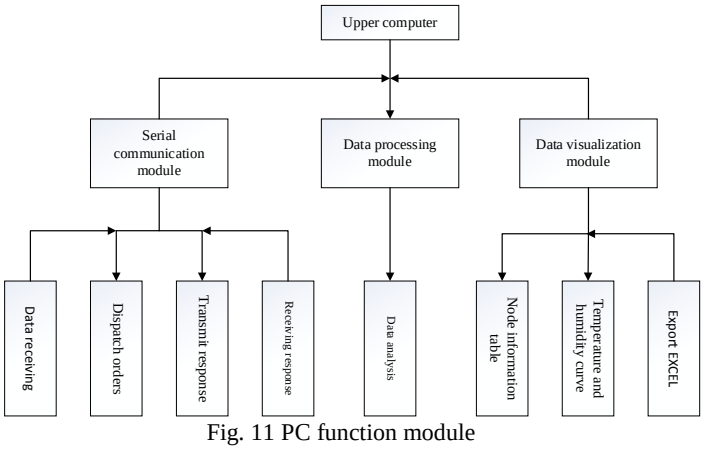

Fig. 11 PC function module

The function of the monitoring system in the upper computer is sending commands, receiving the acquisition data from the lower machine, processing data and realizing visualization, data storage. The host computer includes three main modules

according to the above application requirements, that is, serial communication module, data processing module, data visualization module, as shown in Fig.11.

Serial communication module is responsible for the implementation of PC and ZigBee to achieve two-way communication, communication protocol follows ARQ. The workflow is initialization of the serial port, to open the serial port, to save the receiver buffer data. The function of data processing module is to analyze data and extract the corresponding data. The data visualization module will resolve the data stored in the node information table and the temperature and humidity. If need to export data, save the data to the EXCEL file [14, 15].

B. PC Software Design

The upper computer is the WinForm forms application which uses C# language to create the Studio Visual integrated development environment. It is the visual interface between the upper computer and the user. Members visible in the form of the control includes button controls, text controls, form controls. The hidden members are called components including the timer, Serial Port. PC uses Serial Port components of Studio Serial platform for serial communication. According to the universal serial transmission protocol, combine with system requirements on data communication rate, select the typical parameters of the serial communication: baud rate 115200, 8 data bits; 1 stop bit, no parity bit, no flow control [16]. When the serial data achieves the threshold set, the callback function of the serial port will be triggered to read and process data. Need to pay special attention to the serial callback function in the serial data read before the thread to sleep for a period of time to ensure that the data are all received after reading. According to the length of the data set to set the length of time to sleep to ensure that it is completed before the second reception. The probably range can be estimated by the baud rate and the reception of the data length, as shown in Fig.12 [17].

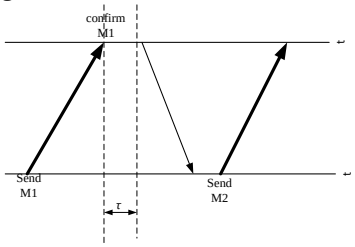

Fig. 12 thread sleep time

Node information uses the ListView control to display, the data required by the serial processing module provided, the data include ID, network address, RSSI, LQI, network status, etc. By adding the timer control can update data periodically. Temperature and humidity curves use the chart control display. The data processing module stores the node data in the corresponding queue through into the team and the team to operate dynamic updates to the data. According to the setting of collection period, set the appropriate time to update the curve chart.

C. Data Save

In order to facilitate the data storage and post processing, collect the collected data to EXCEL file. There are two ways: by calling the native Office software, open the EXCEL process in the background achieve storage, using NOPI components to store EXCEL data in the form of a data stream. Because the second method does not need to install the Office software, read and write speed, small computer performance requirements, this design uses the NOPI component to save the EXCEL file [18].

V. System Debugging

Connect the coordinator with PC through the USB cable. After completing acquisition node antenna and sensor installation, when the start command is issued with the aid of the serial port, the coordinator will send the data to the upper computer. Command sends in the form of Hexadecimal, 0x01 is for the data packet identifier, 0x00 is for the send serial number, 0x02 represents the length of the command, 0xFF is on behalf of start, 0x01 identifies the collection period of 5 seconds for the index. Coordinator sends the response immediately after receiving the order and sends commands to the collection node to start 0x02 representing the response identifier, 0x00 for the serial number, follow up 0x00 on behalf of the coordinator to receive successfully [19]. The acquisition node receives the command to start the collection at once and sends the result to the collection. Power the acquisition node and the coordinator, firstly reset the acquisition node and then reset the coordinator. Set COM port and open the serial port. Set the sampling period and whether the EXCEL file is stored in the collection to start collection. After receiving the data, the overall effect is as shown in Fig.13, Fig.14. The system meets the design requirements through testing, and the operation condition is good, the condition is stable [20].

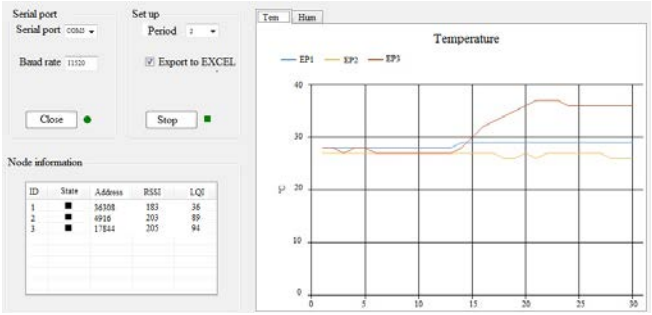

Fig. 13 temperature curve

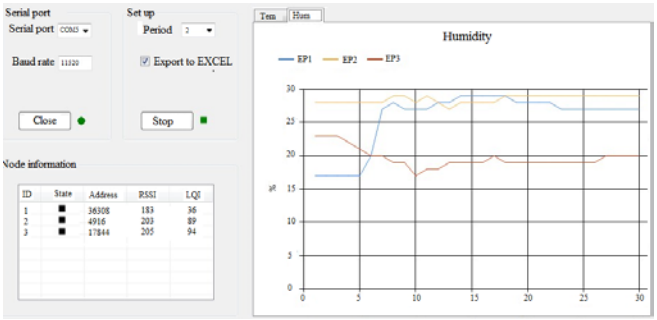

Fig. 14 humidity curve

VI. Conclusion

With the rapid development of wireless sensor networks, many technologies including ZigBee will have more and more influence in many fields. The design of wireless sensor networks for the introduction, focusing on the specific implementation of ZigBee technology closely related to wireless sensor networks, including ZigBee principle, system structure, each layer protocol and the network establishment process and so on. A set of temperature and humidity acquisition system for environmental information is developed. The system includes the combination of lower computer and upper computer, software and hardware based on TI CC2530 chip and ZigBee protocol stack Z-Stack. It realizes the distributed, low power, real-time and on-line detection of the environment.

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