Application of ZigBee-WSN Technology for Indoor Environmental Parameter Monitoring System

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Abstract— **The four factors that affect comfort of human living are environmental temperature, humidity, light intensity and CO2 concentration in the air. Therefore, in order to intelligently control and improve living environment in real-time monitoring method, a kind of indoor environmental parameter monitoring system is proposed in this paper, which based on ZigBee Wireless Sensor Network. Firstly, we choose the CC2530F256 microprocessor as the main control chip. Secondly, we select the DS18B20 as temperature sensor, the HM1500LF as humidity sensor, the Cds photosensitive resistance LXD3526 as photoelectric sensor and the MG811 as CO2 gas sensor. And then, all the environmental parameters collected from smart home are uploaded to upper PC monitor which belongs to monitoring center for display.**

After determining device selection, we complete system hardware design by use of Designer Altium 6.9, according to design philosophy of function modularization. This system hardware design mainly consists of three parts, including end device node, router node and coordinator node. Then, this system software design is completed in integrated development environment of Embedded Workbench for IAR 8051 V8.10 by using structured programming ideas. And the main function of this program is to complete collection, display, transmission, alarm and communication tasks of indoor environmental parameters. Afterwards, a test platform is set up, which can carry on testing of all functional modules and overall performance for indoor environmental parameter monitoring system. The test results show that this system can complete predetermined functions with high reliability and practical value, which also providing a reference example of design and development for similar products.

Index Terms—**ZigBee; Wireless Sensor Network; indoor environmental parameter monitoring system**

I. INTRODUCTION

Internet of Things (IoT) is yet another technological advancement which is considered as important and revolutionary as invention of personal computers and Internet. Smart home is one of the most popular and trendy IoT applications. Home automation integrated with various sub-systems (such as intelligent building, communication networks, environment monitoring, entertainment video, smart household appliances and lighting) is just what smart home does. It helps people get more comfort, security, better health and intelligent living or working environment in the house [1] [2]. Environmental monitoring includes the collection and transmission of data from various appliances and is a key part that ensures normal operation of the smart home system. However, a question whether we can effectively achieve real-time monitoring of indoor environmental parameters has arisen as a prominent issue and needs to be resolved.

With the rapid development of sensor technology, wireless communication technology and micro electrical-mechanical system technology, it is possible to establish a wireless sensor network which composed of intelligent micro sensor interconnection. Besides, the ZigBee technology, as a new wireless communication technology, has such characteristics of low power consumption, low cost and strong self-organization, so that it is completely suitable for data transmission in wireless sensor networks [3] [4]. At the same time, for one thing, under comprehensive utilization of computer technology, communication technology and measurement and control technology, the main purpose of the indoor environmental parameter monitoring system is to realize collection, recording and display for all kinds of physical parameters, and to change these analog signals into digital quantity. For another, the main purpose of the indoor environmental parameter monitoring system is to give processed data and results back to the user or the control center [5] [6].

As a result, this paper introduces a kind of indoor environmental parameter monitoring system that based on ZigBee Wireless Sensor Network. So as to realize wireless data acquisition, real-time monitoring and transport control of indoor environmental parameters for smart home by using ZigBee network technology, which ultimately having a great practical significance for improving people's living environment and offering technical support for practical and distributed wireless environmental parameter monitoring system that built in other specific occasions or complicated conditions.

II. ZIGBEE TECHNOLOGY OVERVIEW

A. *Brief introduction of CC2530F256*

The ZigBee technology has a low cost, low power consumption, small size, large network capacity, and strong security features, and it is very conducive to the construction of a wireless sensor network. This distributed wireless

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temperature monitoring system uses the CC2530F256 microprocessor as its core chip, which is meeting the current ZigBee technology standards for TI company in recent years. Meanwhile, it belongs to a CMOS SOC chip, embedded with high performance and low power consumption of enhanced 8051 microcontroller core, and integrated the 14 bit analog-to-digital conversion module and RF wireless transceiver (using 2.4 GHz) that conformed to the IEEE 802.15.4 standards. Therefore, the CC2530F256 microprocessor has excellent wireless receiver sensitivity and strong anti-disturbance ability [7].

B. Brief introduction of ZigBee protocol

Although the ZigBee protocol is based on lEEE 802.15.4 technical specifications, but the IEEE 802.15.4 technical specifications only deal with lower MAC layer and physical layer protocol, and the ZigBee alliance standardizes network layer protocol and API. Furthermore, the ZigBee alliance has also developed a security layer to ensure that this portable device does not accidentally leak its identity, which making long-distance transmission will not be obtained by other nodes in network [8] [9] [10]. And then, the ZigBee protocol has divided the network nodes into three kinds of equipment types, such as coordinator node, router node and end device node, so that its typical functions are shown in TABLE Ⅰ.

TABLE Ⅰ Equipment types and typical functions.

Equipment types	Typical functions
Coordinator node	Only one in network; Used to build network, distribute network address, and set up save-binding table.
Router node	Optional; Allow multiple nodes to join in network; Used to extend the physical scope of network and complete monitoring and control function.
End device node	Complete monitoring or control function.

The ZigBee protocol is realized by ZigBee protocol stack. And the ZigBee protocol stack as a complete protocol specification, its organization of wireless sensor network, join and exit of node, routing algorithm, network topology and each layer of services are defined in detail. Thus, it is convenient to quickly establish wireless sensor network, which eliminating the need for a large number of network workload [11].

This IEPMS adopts the ZigBee protocol stack (ZStack-CC2530-2.3.0-1.4.0) that developed by TI company, and also is one of the most widely used ZigBee protocol stack at present. As a software platform for system design, it is convenient to establish a wireless sensor network that belongs to distributed wireless temperature monitoring system, so as to provide users with a powerful and complete solution for ZigBee technology.

III. OVERALL DESIGN OF SYSTEM

According to the characteristics of actual monitoring area for smart home, this indoor environmental parameter monitoring system uses multi-point collection and distributed system, so that the indoor environmental parameter data can be monitored from different locations, which helping us to get more monitoring information. And this system mainly includes four parts, such as end device node, router node, coordinator node and upper PC monitor. Only in this way, we can complete data acquisition and transmission, ZigBee network establishment, network management and maintenance functions for indoor environmental parameters. The overall design structure block diagram of this system is shown in Fig. 1.

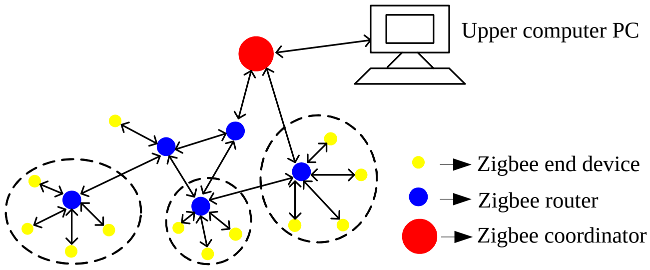

Fig. 1. Overall Design Structure Block Diagram of This System.

From Fig.1, we can see that the end device node are distributed in monitoring area for real-time monitoring of indoor environmental parameters, and the location of end device node also can be adjusted according to actual needs in effective communication range of the router node. And the router node with routing function, can be used to relay and expand ZigBee network scale. Above all, the coordinator node is the transmission and control core for this system, and it can make communication with other router node or end device node through wireless way, which achieving indoor environmental parameters information that obtained by router node or end device node. Then, the coordinator node transmits these data to upper PC monitor for data display and management.

IV. HARDWARE DESIGN OF SYSTEM

A. Hardware design of end device node

End device node is the most frontier of data acquisition for indoor environmental parameters.

It is based on CC2530F256 microprocessor of ZigBee chip as the core, composed with the temperature sensor module, humidity sensor module, photoelectric sensor module and CO_2 gas sensor module. And the hardware design structure block diagram of end device node is shown in Fig. 2.

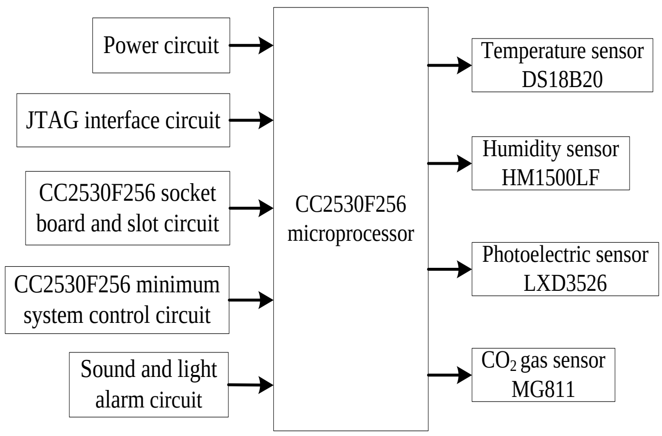

Fig. 2. Hardware Design Structure Block Diagram of End Device Node.

CC2530F256 Main Control Module. Among this indoor environmental parameter monitoring system, such as four parts of the power circuit, JTAG interface circuit, CC2530F256 socket board and slot circuit and CC2530F256 minimum system control circuit can be referred to as CC2530F256 main control module. And the hardware design circuit of CC2530F256 main control module is shown in Fig. 3.

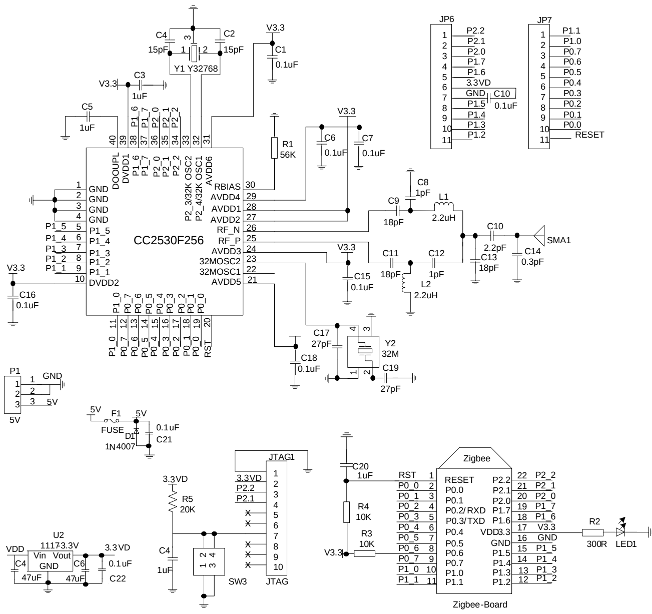

Fig. 3. Hardware Design Circuit of CC2530F256 Main Control Module.

Temperature Sensor Module. The indoor environmental parameter monitoring system uses single-bus intelligent and digital temperature sensor DS18B20 to accomplish collection of temperature information. It is a sensor that launched by United States DALLAS corporation. Its power supply voltage range is 3V to 5.5V, and its temperature measurement range is -55℃ to +125℃ [12]. As a new type of intelligent and digital temperature sensor, the DS18B20 could directly output digital quantity, with the help of internal integrated temperature sensor module, A/D conversion module and single data output control module. That's making it easy to connect single-chip or other microprocessors with simple interface circuit and easy expansion. Accordingly, the DS18B20 could be widely used in long distance, multi-node and distributed temperature detection field [13] [14]. The hardware design circuit of temperature sensor module is shown in Fig. 4.

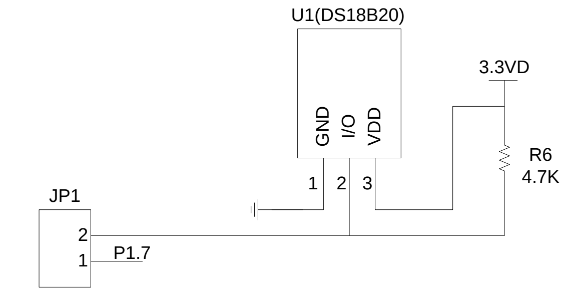

Fig. 4. Hardware Design Circuit of Temperature Sensor Module.

Fig. 4 also shows that the DS18B20 can be connected to general I/O port P1.7 of cc2530f256 microprocessor only by a single bus connection mode. Because the temperature sensor DS18B20 has unique product serial number, therefore, it can also be easy to accomplish the task of distributed multi-point temperature monitoring based on single point temperature monitoring task.

Humidity Sensor Module. The indoor environmental parameter monitoring system uses HM1500LF as its humidity sensor. It belongs to a kind of linear voltage output and integrated humidity sensor, which is a production of French Humirel company. By using 5V power supply with constant pressure, the HM1500LF can output a proportional relationship between voltage level signal and relative humidity. Moreover, the HM1500LF has many outstanding characteristics, such as built in amplifying circuit, fast response speed, good repeatability and strong anti-interference ability and so on [15]. The hardware design circuit of humidity sensor module is shown in Fig. 5.

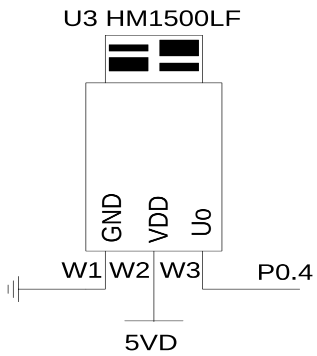

Fig. 5. Hardware Design Circuit of Humidity Sensor Module.

Photoelectric Sensor Module. The indoor environmental parameter monitoring system employs CdS photoresistor LXD3526 as its photoelectric sensor. Its bright resistance (when the sun is in direct sunlight) is only 8KΩ to 20KΩ, and its dark resistance (when there is no visible light) can be up to 0.5 MΩ. When photoresistor LXD3526 is connected with 51 KΩ resistor R7 in series way, then the 3.3V would be decomposed into two parts voltage. So, the voltage value obtained by both ends of photoresistor LXD3526 can be used to represent light intensity [16]. The hardware design circuit of photoelectric sensor module is shown in Fig. 6.

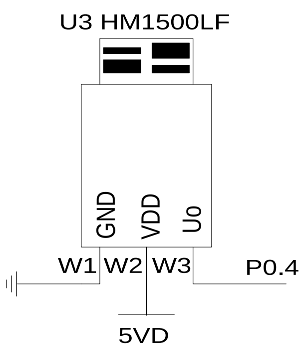

Fig. 6. Hardware Design Circuit of Photoelectric Sensor Module.

CO_2 Gas Sensor Module. The indoor environmental parameter monitoring system adopts MG811 as its CO_2 gas sensor. When CO_2 concentration in the air is higher, the output voltage of MG811 is lower. And when CO_2 concentration in the air is lower, the output voltage of MG811 is higher. Due to CO_2 concentration in the air is generally 300ppm to 1500ppm, corresponding with MG811 output voltage for 325mV to 300mV. Therefore, the MG811 output voltage will be amplified through CA3140 for 3 times, which entering into CC2530F256 microprocessor for sampling. The hardware design circuit of CO_2 gas sensor module is shown in Fig. 7.

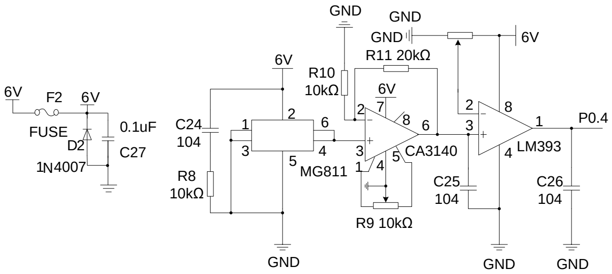

Fig. 7. Hardware Design Circuit of CO_2 Gas Sensor Module.

Fig. 7 also shows that the supply voltage of MG811 is 6V, which can be supplied by 220V to 6V power adapter.

Sound and Light Alarm Module. The indoor environmental parameter monitoring system selects a piezoelectric passive buzzer as its sound and light alarm module. When the temperature, humidity, light intensity and CO_2 concentration are less than preset upper limit value or greater than preset lower limit value, we can control CC2530F256 microprocessor pin P2_0 to output high level by programming, so that the buzzer does not work. On the contrary, when the temperature, humidity, light intensity and CO_2 concentration are greater than preset upper limit value or less than preset lower limit value, we can control CC2530F256 microprocessor pin P2_0 to output low level by programming, and then drive buzzer to achieve automatic sound alarm function for indoor environmental parameter information. Besides, in order to accurately identify sound alarm that corresponding to different types of indoor environment parameters, this indoor environmental parameter monitoring system also uses LED as a flashlight alarm module. And it is a solid state semiconductor device which can directly convert electrical energy into light energy. The hardware design circuit of sound and light alarm module is shown in Fig. 8.

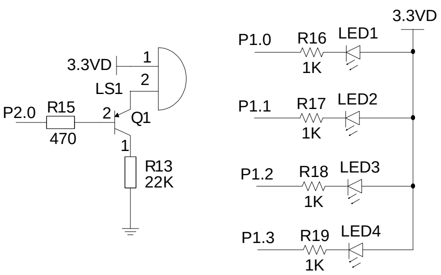

Fig. 8. Hardware Design Circuit of Sound and Light Alarm Module.

B. Hardware design of router node

The router node allows the end device node to join the network, routing the data and assisting the end device node with wireless communication. That means the router node controls the ZigBee network. The actual indoor environmental parameter monitoring process may be affected by many factors, and may end up shortening the distance of the data message sent by the end device node. Consequently, an appropriate increase in the number of router nodes can create a "jump" transmission for data collected by end device nodes. At this point, the router node would establish a message forwarding the channel between the coordinator node and the end device node, expanding the monitoring scope for the ZigBee network [17] [18]. However, because all the monitoring data from the end device node are uploaded by the router node, the data processing workload is relatively large and the energy consumption is correspondingly higher. The hardware design structure block diagram of the router node is shown in Fig. 9.

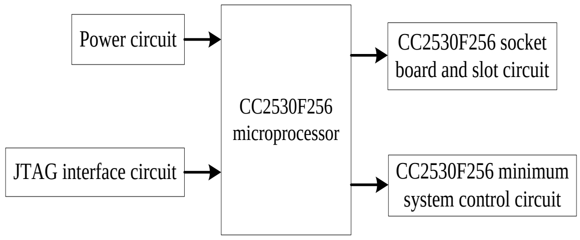

Fig. 9. Hardware Design Structure Block Diagram of Router Node.

Fig. 9 also shows that the router node and end device node bear resemblance in hardware structure design, though the latter additionally has four kinds of sensor modules and a sound and light alarm module. In short, the router node hardware design is basically consistent with that of the end device node, and the specific circuit design is shown in Fig. 3.

C. Hardware design of coordinator node

The coordinator node has two main purposes: to use the wireless communication module to control the data acquisition occurring at the end device node, and to use the serial data bus to transfer these collected records to the upper PC monitor of the monitoring system. Fig. 10 depicts the hardware design structure block of the coordinator node.

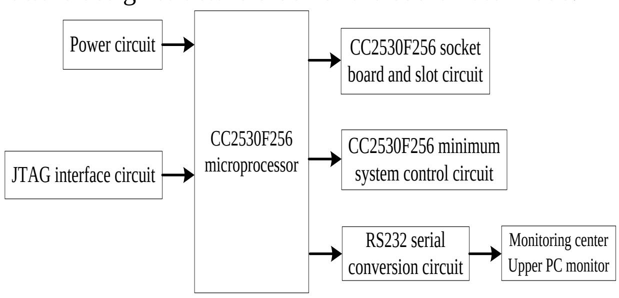

Fig. 10. Hardware Design Structure Block Diagram of Coordinator Node.

From Fig. 10, we can see that the coordinator node and end device node have the same essential hardware structure design, though the latter additionally has four kinds of sensor modules and a sound and light alarm module, while the former has a RS232 serial conversion circuit for serial data communication. In short, the coordinator node hardware design is basically consistent with that of the end device node, and the specific circuit design is shown in Fig. 3.

However, the hardware design circuit of RS232 serial conversion module is shown in Fig. 11.

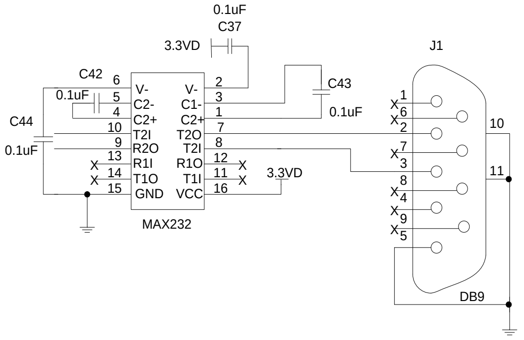

Fig. 11. Hardware Design Circuit of RS232 Serial Conversion Module.

V. Software Design of System

The development environment of this system software design is IAR Embedded Workbench for V8.10 8051, and the communication protocol uses ZigBee 2007 protocol stack. After using IAR software to open the project file MyfirstApp.eww in protocol stack, the network architecture of entire protocol stack is shown in Fig. 12.

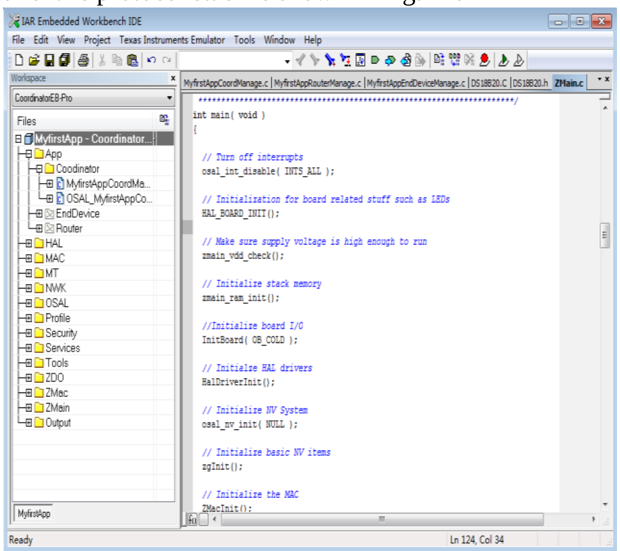

Fig. 12. Network Architecture of TI Z-Stack 2007.

A. Software design of end device node

Before the end device node can be activated, it requires specific information through the built-in erasable, programmable, read-only memory (EPROM). It is also necessary to call the Write_Configuration ( ) function for configuring device properties to DEV_END_DEVICE and configuring the device's startup mode to initiate automatically when the power turns on [19] [20]. In addition, the My_Task_Process_Event ( ) function can be configured in the end device node's application layer. The software design flow of the end device node is shown in Fig. 13.

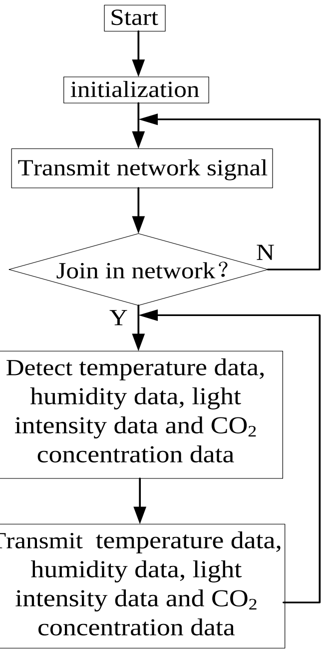

Fig. 13. Software Design Flow of End Device Node.

Fig. 13 also demonstrates that when the end device node's power turns on, this node will initialize, starting up all units in the hardware. After initialization, this node will search the network signals to trigger the AF_DataRequest ( ) function that joins the node to a network. Once the router and coordinator nodes send a valid response, the end device node will call several functions—DS18B20_GetTem ( ), HM1500LF_GetHumi ( ), LXD3526_GetLight ( ), and MG811_GetCO2 ( ) to read temperature data, humidity data, light intensity data, and CO_2 concentration data, respectively.

The end device node's software design is predicated on the query method. First, we divide this system into modules according to system functions. Second, we compile relevant subroutines according to the functions of these modules. Last, we implement subroutines for system self-checking, indoor environment parameter monitoring, and serial communication with the main program.

System Self-checking Subroutine. The function of this system self-checking subroutine is to complete function test for the four types of sensors, so as to test whether the four types of sensors are working properly or not, and to collect the data in system working environment with selecting an appropriate data weight.

After power on, this system firstly call system self-test function of system_check ( ) to carry out self inspection. Prior to self inspection, the program will go through a delay of about 500 μ s to prevent this system from reading error caused by instability when starting. And afterwards of self inspection, the program will start A/D converter of the four types of sensors in turn and read the corresponding sensor data.

As can be seen in Fig. 4, Fig. 5, Fig. 6 and Fig. 7, if the temperature sensor or humidity sensor or photoelectric sensor appears malfunction, even it is pulled out. The input voltage of the A/D converter for CC2530F256 microprocessor will be set as 3.3 V, and its corresponding conversion result is 8192. Then this data will be used as a criterion for judging whether these sensors are working correctly or not. While if the CO_2 gas sensor fails or it is pulled out, the input voltage of the A/D converter for CC2530F256 microprocessor will be set as 0 V, and its corresponding conversion result also is 0. In the same way, this data will be used as a criterion for judging whether CO_2 gas sensor is working correctly or not. However, in the process of self inspection, if abnormal ways of these sensors are found, the error messages will be displayed in a timely manner. At the same time, it is necessary to hang-up the system to avoid causing damages during continue running on the system.

After four types of sensor can be confirmed to work properly by system self-checking subroutine, then the "SYSTEM IS NORMAL" information will be displayed in LCD12864 screen. And, the system self-checking subroutine could carry out weight allocation for sensor data according to the weight distribution table. Finally, the system enters into a normal operation state. The flow chart of system software design for self-checking subroutine is shown in Fig. 14.

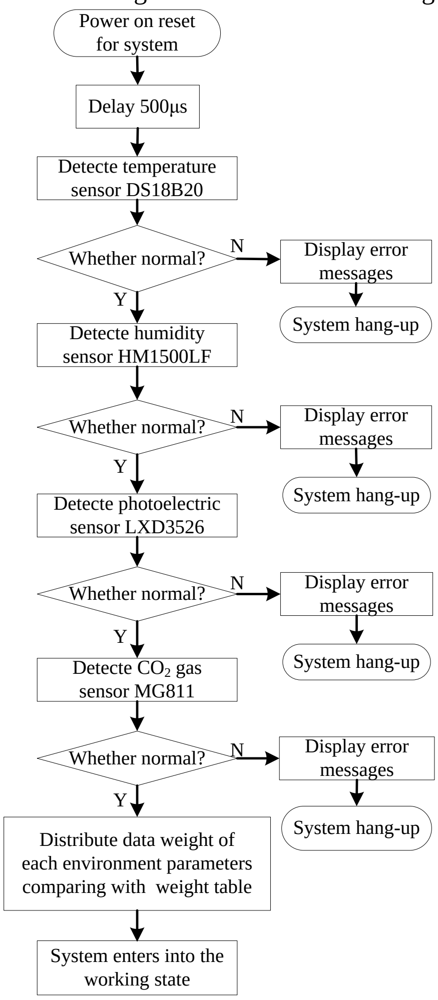

Fig. 14. The Flow Chart of System Software Design for System Self-checking Subroutine.

Indoor Environmental Parameter Monitoring Subroutine. The main function of indoor environmental parameter monitoring subroutine is to achieve sensor data reception, data analysis processing and judgment and carrying out sound and light alarm. If this system is operating normally, then this system will start to enter the loop to detect monitor state of the data returned by each sensor. After returning information by each traverse of these sensors, we carry out data analysis and determine whether these sensors occur abnormal situation or not, according to the weight algorithm design. When abnormal condition happened, the corresponding message prompt and sound and light alarm prompt will be started. And the flow chart of system software design for indoor environmental parameter monitoring subroutine is shown in Fig. 15.

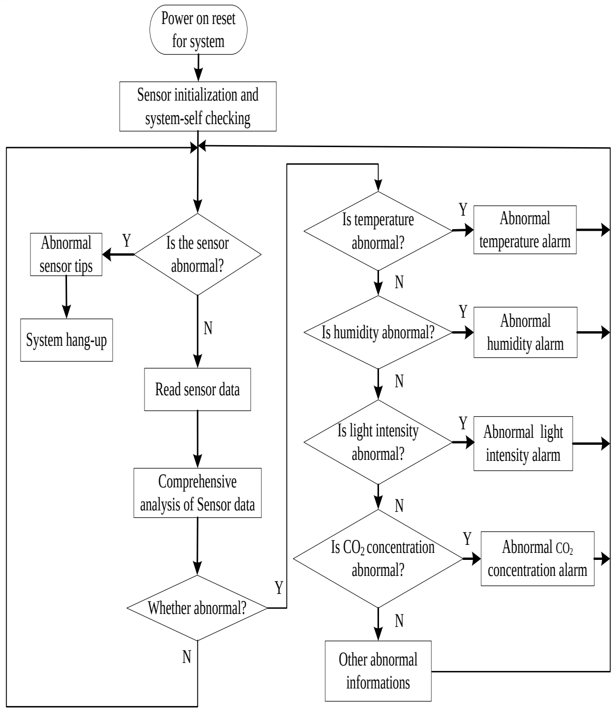

Fig. 15. The Flow Chart of System Software Design for Indoor Environmental Parameter Monitoring Subroutine.

B. Software design of router node

Before the router node can be activated, it requires specific information through the built-in EPROM. It is also necessary to the call Write_Configuration ( ) function for configuring device properties to DEV_ROUTER and configuring the device startup mode to initiate automatically when the power turns on. In addition, the My_Task_Process_Event ( ) function can be configured in the router node's application layer. The software design flow of the router node is shown in Fig. 16.

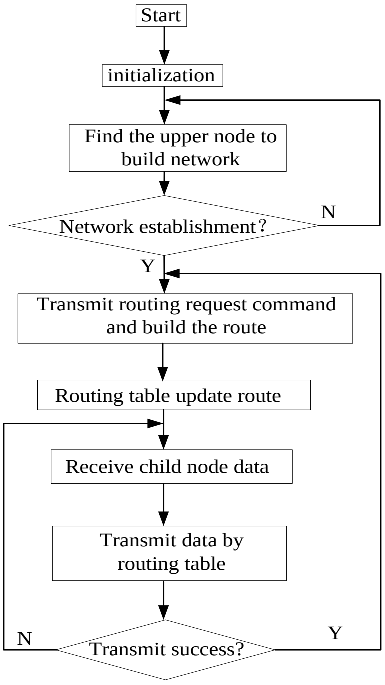

Fig. 16. Software Design Flow of Router Node.

Fig. 16 also demonstrates that when the router node's power turns on, this node will initialize, starting up all units in the hardware. After initialization, this node will activate the AF_DiscoveryRequest ( ) process to search for a connection with a coordinator node. Once successful, the AF_JoinRequest ( ) process sends network signals to the coordinator node for application. Once the response has been validated and configured for the 16-bit address, this node will enter a real-time monitoring state and periodically request signals from all ports. The ZigBee network will treat any newly-detected end device nodes as new nodes, using the Cluster_Tree algorithm to update the route. The router node can then begin to transmit temperature data, humidity data, light intensity data, and CO_2 concentration data from all end device nodes.

C. Software design of coordinator node

Before the coordinator node can be activated, it requires specific information through the built-in EPROM. It is also necessary to call the Write_Configuration ( ) function for configuring device properties to DEV_ZB_COORD and configuring the device startup mode to initiate automatically start when the power turns on. In addition, the My_Task_Process_Event ( ) function can be configured in the coordinator node's application layer. The software design flow of the coordinator node is shown in Fig. 17.

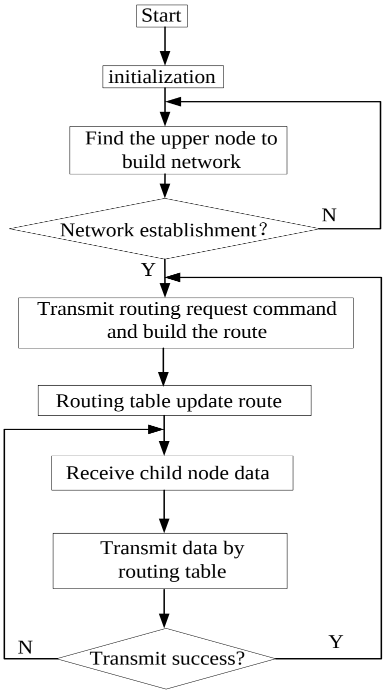

Fig. 17. Software Design Flow of Coordinator Node.

Fig. 17 also demonstrates that when the coordination node's power turns on, this node will initialize, starting up all units in the hardware. After initialization, this node will call the ENTRY_EVENT ( ) function and activate the ZigBee wireless communication protocol to create a new network with the default channel preset by the Zigbee network. This node will then enter a real-time monitoring state and periodically request signals from all ports. If this network detects a request from new end device or router nodes, it will treat each as a new node and configure it with a 16-bit address. Once the network construction is successful, the coordinator node can call the StartConfirm ( ) function to detect the network state and determine the success of the network structure. The temperature data, humidity data, light intensity data, and CO_2 concentration data from the new node can now be transmitted to the monitoring center's upper PC monitor through the serial data bus.

At this point, we have completed all the design work required for this indoor environmental parameter monitoring system.

VI. SYSTEM TEST

In order to test the performance of this indoor environmental parameter monitoring system, we establish an actual circuit according to system hardware and software design. The actual ZigBee network is composed of 4 terminal nodes, 2 router nodes and 1 coordinator node. And then, we complete the four kinds of parameter acquisition for indoor temperature, humidity, light intensity and CO_2 concentration under simulated smart home. Among them, the indoor temperature standard value of simulated smart home is 12 degrees Celsius, the indoor humidity standard value is 25 %RH, the indoor light intensity standard value is 1300 LX and the indoor CO_2 concentration standard value is 450 ppm.

Through the upper VB software interface to realize serial data communication between coordinator node and upper PC monitor, and then the system test results are shown in Fig. 18.

In which, the temperature data (Temp) unit is ℃, humidity data (humi) unit is %RH, light intensity data (light) unit is LX and CO_2 concentration data (CO_2) unit is ppm.

Fig. 18. (a) System Test Results of First Indoor Environmental Type.

Fig. 18. (b) System Test Results of Second Indoor Environmental Type.

From Fig. 18, we can see that this indoor environmental parameter monitoring system has a high measuring accuracy, which obtained with satisfactory results. In addition, when the monitoring temperature data is lower than -15℃or higher than 40℃, humidity data is lower than 20 %RH or higher than 80 %RH, light intensity data is lower than1000 LX or higher than 1800 LX and CO_2 concentration data is higher than 1000 ppm, this system would continue buzzer alarm for 2 seconds and the Beep button color will change into red, which conveniently helping user to take appropriate measures in a timely manner in according to practical application.

VII. Conclusion

As a kind of intelligent equipment in collection and transmission of environmental data, this indoor environmental parameter monitoring system plays a very important role in smart home. Therefore, combining two advantages of digital communication and network function for modern smart home system, this paper introduces a complete set of wireless networking solution for indoor environmental parameter monitoring system based on ZigBee Wireless Sensor Network.

Meanwhile, combining ZigBee wireless communication technology and modern sensor technology, this scheme can ensure accuracy of data transmission. So, this system has changing existing data transmission way, and solving a few difficult problems of wire transmission in some specific application occasions, which making the data transmission more convenient.

At the same time, the four types of sensor modules used in this design scheme not only simplify the hardware design, but also improve the measurement accuracy, so that the whole system can be easy to operate and maintain. After field debugging various basic functions of indoor environment parameter monitoring system for smart home, the testing results show that this system has giving full play to the flexibility of ZigBee wireless sensor network in the indoor environmental parameter monitoring process. Moreover, the testing results also show that this system could achieve the predetermined functional requirements with high reliability and practical value. So as to complete wireless data acquisition and transmission of indoor environment parameters for smart home in real time by using ZigBee network technology, which ultimately establishing a solid practice foundation for automatic monitoring of the indoor environmental parameters.

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