

# Design and Implementation of Smart Home System Based on ZigBee Technology

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## Abstract

*The system of smart home can provide a kind of easier, ordered and effective life style to human, and must be the development tendency for future inhabitancy mode. Therefore, a smart home system solution is proposed in this paper. Firstly, this paper analyzes the characteristics of ZigBee technology, device types, network topologies and ZigBee protocol specification. Secondly, a design scheme of smart home system based on ZigBee technology is put forward and discussed. Then, the hardware design of ZigBee nodes based on CC2530 chip is given in detail. And, embedded programming software in each ZigBee node and user management platform software are implemented respectively using IAR and Microsoft Visual C++ 6.0. Finally, system test results show that the smart home system implemented above can be served as practical application reliably.*

**Keywords:** smart home; ZigBee; CC2530; user management platform

## 1. Introduction

With the rapid development of technology and the improvement of living standards, the demand of people for home environment is also rising. As a result, the technology of smart home turns out, and develops quickly as the network progresses. Smart home is a combination of modern computer technology, control technology and information technology. The development of smart home technology has undergone wired and wireless stages [1]. Due to the cable restriction and poor scalability of wired network, wireless technology will be an inevitable trend for home network. ZigBee is a recently developed wireless communication technology in short range, which has many features, such as short-range, low-power, low-rate and low-cost. ZigBee technology can provide users with a mobile, flexible networking and is very suitable for home control [2, 3]. In order to take the advantages of the characteristics of ZigBee technology and applications in the controlling network, we put forward a smart home system based on ZigBee technology in this paper.

The smart home system based on ZigBee technology in this paper does not need wiring and can be installed directly in the home. The system can realize home monitoring and terminal nodes controlling by user management platform. What's more, in this smart home system, each sensor terminal node can collect environment data in home, such as brightness, temperature, humidity, security state, and each controlling terminal node can be connected with some home devices, such as light, air condition, electric curtain, alarm, etc.

The remainder of this paper is organized as follows. Section 2 introduces ZigBee technology in detail. The structure design of smart home system is studied in Section 3. Section 4 and Section 5 present hardware design and software design of the smart home

system respectively. Finally, experimental results on the proposed design are presented in Section 6, and conclusions are presented in Section 7.

## 2. ZigBee Technology

The ZigBee standard is developed by the ZigBee alliance, which is a standard of two-way wireless communication technology for low rate wireless personal area network (LR-WPAN).

### 2.1. Advantages of ZigBee Technology

In smart home system, the current commonly used three kinds of short-range wireless communication technologies are: ZigBee, Bluetooth and Wi-Fi. These three kinds of short range wireless communication technology are compared in Table 1, in which the number of network nodes, the power consumption, the transmission rate, the transmission distance, frequency, device activation time and other technical indicators have been considered.

**Table 1. Comparison of ZigBee, Bluetooth and Wi-Fi technologies**

Technical indicators	ZigBee	Bluetooth	Wi-Fi
Number of network nodes	65536	7	32
Power consumption	Low	Medium	High
Transmission rate/bps	250M	1M	1M
Transmission distance/m	10~75	10	100
Frequency/GHz	2.4	2.4	2.4
Device activation time/s	0.125	3	3

As one of wireless representative protocols with the characteristics of low rate, short range, low power, ZigBee protocol has many advantages when compared to other wireless transmission protocols [4].

1) Low power consumption: Its transmission power is low, and it uses the sleep mode, which leads to low power consumption.

2) Low cost: The price of ZigBee modules is low and the royalty of ZigBee protocol is free.

3) Low rate: ZigBee works on three unlicensed ISM bands (industrial, scientific and medical). According to the different frequency bands where it is, ZigBee respectively supplies 250kbps (2.4GHz), 40kbps (915MHz) and 20kbps (868MHz).

4) Short range: Transmission range of ZigBee is generally between 10 and 100 meters.

5) Short time delay: Delay of communication and delay of activation from hibernation are both short. The typical search equipment delay is 30ms; hibernation activation delay is 15ms; activity equipment channel access delay is 15ms.

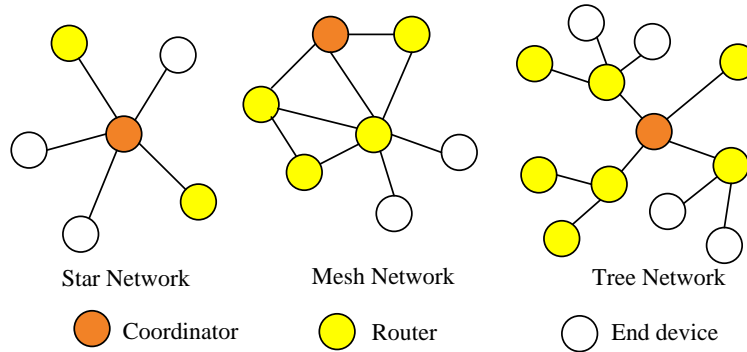
6) Large network capacity: Each ZigBee network can accommodate more than 65,536 internal device nodes.

7) High reliability: The collision avoidance strategy is adopted, and the time slot is reserved for the communication services, which needs fixed broadband.

### 2.2. Topologies and Device Type of ZigBee Network

There are different topologies of ZigBee network. Its main three kind topologies include star network, mesh network and tree network [5]. Star network is appropriate for small scale, low complexity and easy connection system. Taking into account the network cost and reliability, the star network is the best choice for the smart home system in this paper.

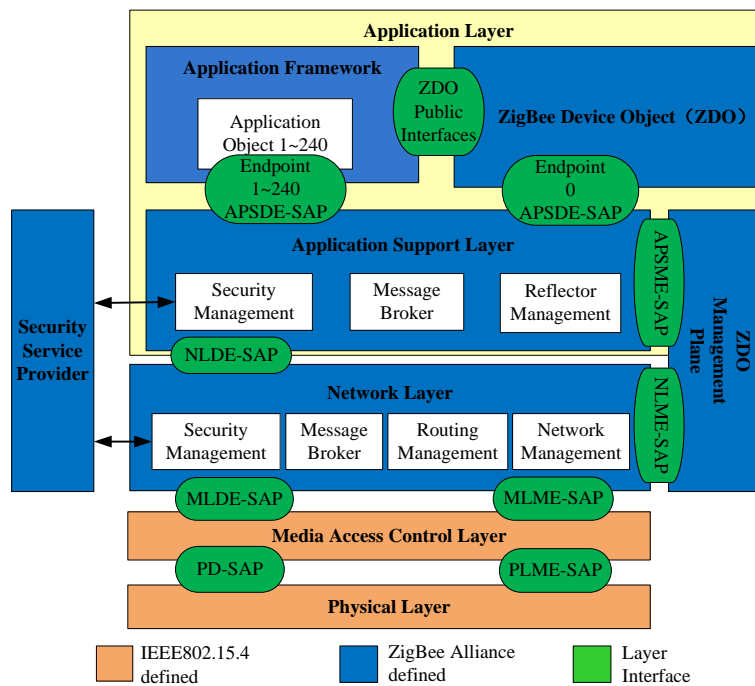
Sorted by the status in network, ZigBee devices can be classified into three types: coordinator, router and end device. According to the function, the devices can be divided into two types: full function device and reduced function device [6]. The former can be used as a router or coordinator, which is responsible for gathering data from sensor terminal nodes and communicating with the controlling terminal nodes in home. The latter can only be terminal node in smart home to collect environment data or to be controlled, and not be expanded. Figure 1 shows three kinds of ZigBee network topologies.



**Figure 1. ZigBee Network Topologies**

### 2.3. Architecture of ZigBee Protocol

ZigBee protocol has been divided into two parts. IEEE802.15.4 defines physical layer (PHY) and media access control layer (MAC) technical specifications; ZigBee Alliance defines network layer (NWK), application support layer (APS) and the application layer (APL) technical specifications. Figure 2 shows the architecture of ZigBee protocol stack [7].

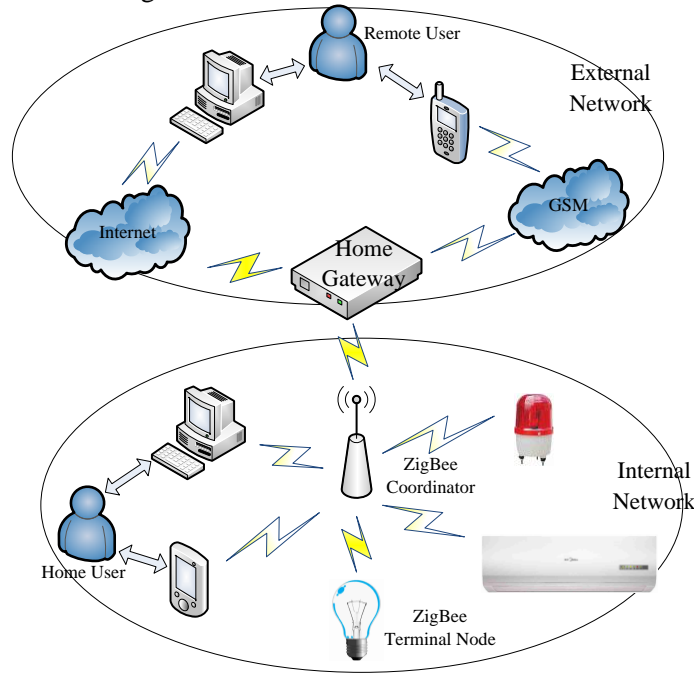


**Figure 2. Architecture of ZigBee Protocol Stack**

ZigBee protocol uses the idea of layering. Different layer is responsible for different function, and data can only flow between adjacent layers. The adjacent layers in the ZigBee protocol stack can realize interaction through a suit of service entities, which provide service functions. The interface of the service entities and adjacent layers is called service access point (SAP). Service access point is responsible for the exchange of service primitives, which realize service functions.

### 3. Design of Smart Home System

In the view of network, smart home system is usually divided into three parts: external network, home gateway and internal network. Internal network is established by ZigBee nodes, which assist user management platform in getting state of appliances and convey the commands from the user management platform to appliances via ZigBee network. And the users outdoor or in remote areas need to achieve the family network monitoring and management through an external network, using a computer, web or mobile phone, which enables the application surface of the system to be broaden. Home gateway plays the role of a manager for the internal network, which can control the nodes in home. For the external network, home gateway works as a protocol converter [8]. The overall framework of smart home system is showed in Figure 3.



**Figure 3. The Overall Framework of Smart Home System**

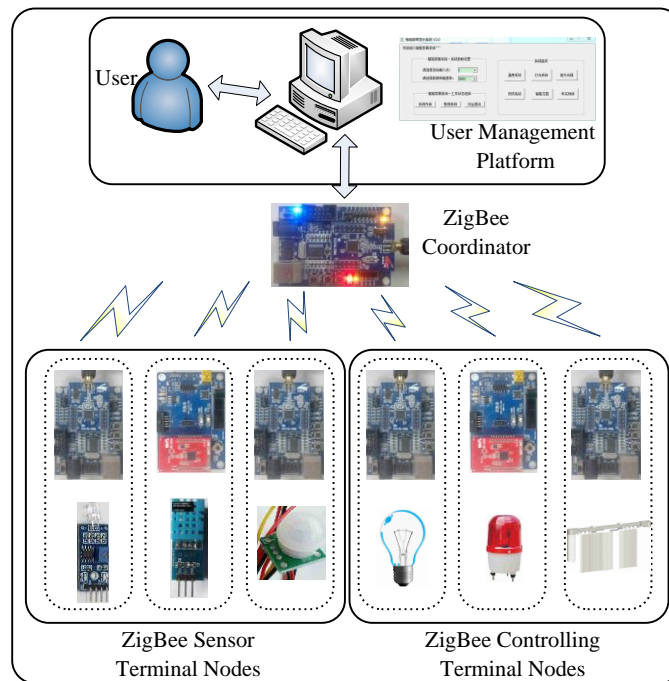
The smart home system designed in this paper uses the star network topology and focuses on the internal network, which mainly includes the user management platform, ZigBee coordinator and ZigBee terminal nodes, as showed in Figure 4.

Due to the smart home system based on ZigBee technology is supported by computer technology, sensor network technology and control technology, so the design of smart home can be divided into three blocks [9].

1) Smart home user management platform: Smart home user management platform is achieved on PC, which realizes the home network management and controlling through the simple man-machine interface.

2) Smart home sensor network: The sensor network is based on the ZigBee protocol stack. Users can control wireless nodes distributed indoor. The sensor network is primarily composed by the ZigBee coordinator, ZigBee sensor terminal nodes and ZigBee controlling terminal nodes.

3) Smart home control technology: CC2530 is the core chip of each node in this system. The control technology mainly contains the process of data collecting by ZigBee sensor terminal nodes and the management of the controlling terminal nodes by the coordinator.



**Figure 4. The Design Structure of Smart Home System**

#### **4. Hardware Design of the System**

Hardware design of the system focuses mainly on ZigBee nodes, which include coordinator, sensor terminal nodes and controlling terminal nodes. As the sensor terminal nodes are mainly responsible for information collection, while controlling terminal nodes are mainly used to output commands. The hardware design is basically the same for each terminal node. According to different functions, sensor terminal nodes carry difference sensors for environmental monitoring such as light sensitive sensor, infrared sensor, temperature and humidity sensor, while controlling terminal nodes connect with difference appliances such as light, air condition, electric curtain and alarm.

The design for ZigBee nodes in this paper uses CC2530 chip made by Texas Instruments, which is a true system-on-chip solution specifically tailored for IEEE 802.15.4 and ZigBee applications. CC2530 combines the excellent performance of CC2520 RF transceiver with an industry-standard enhanced 8051 MCU, 32/64/128KB flash memory, 8KB RAM and many other powerful features [10]. Because of being integrated with CC2530 chip, ZigBee nodes

can be used for coordinator or terminal nodes, which increase the flexibility of the system. Figure 5 shows CC2530 chip application circuit.

#### 4.1. Hardware Design of Coordinator

Data collected by sensor terminal nodes will be brought together and sent to user management platform on PC via serial port by coordinator. Users can also send commands to the controlling terminal nodes through coordinator by user management platform. Figure 6 shows the hardware structure of coordinator.

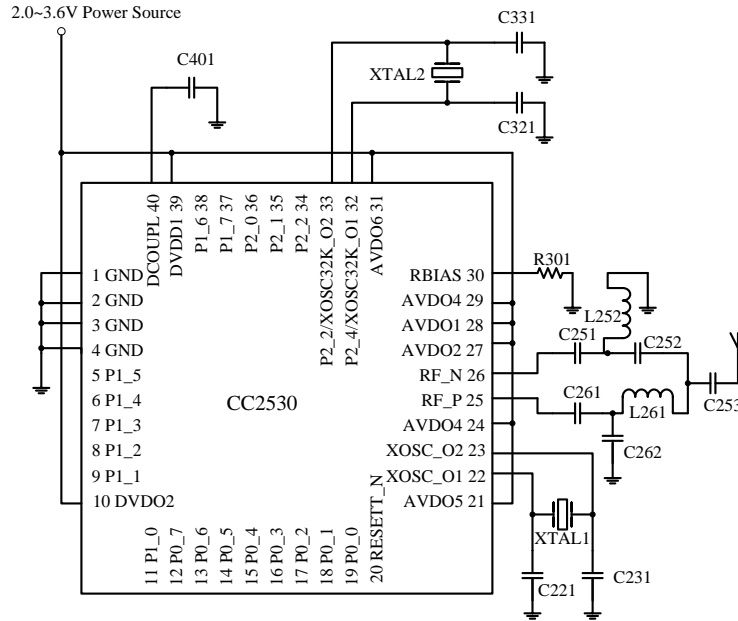


Figure 5. CC2530 Chip Application Circuit

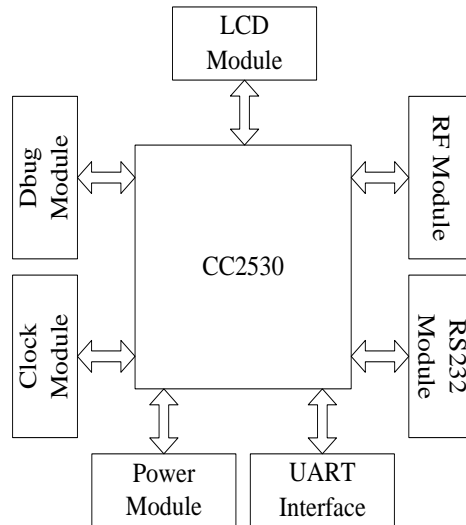


Figure 6. Hardware Structure of Coordinator

#### 4.2. Hardware Design of Sensor Terminal Nodes

The hardware design is basically the same for each sensor terminal node. The main difference is the different type of external sensor connected with sensor terminal node [11]. For example, terminal node can connect with the light intensity sensor BH1750FVI. BH1750FVI uses two-wire serial bus interface and has digital type output. Taking advantage of its high resolution, we can detect a large range of light intensity change. Its serial bus interface supports I2C BUS interface. It has a photodiode, operational amplifier and 16-bit ADC. What's more, the clock signal is provided by internal oscillator. Figure 7 shows the circuit diagram of BH1750FVI. Figure 8 shows the circuit structure diagram of BH1750FVI and CC2530.

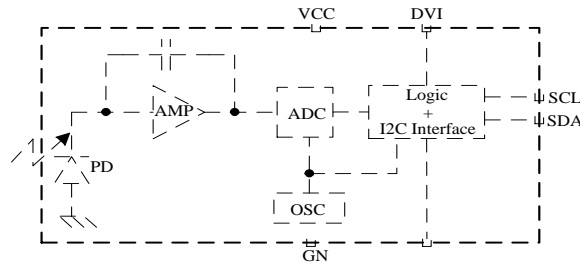


Figure 7. Circuit Diagram of BH1750FVI

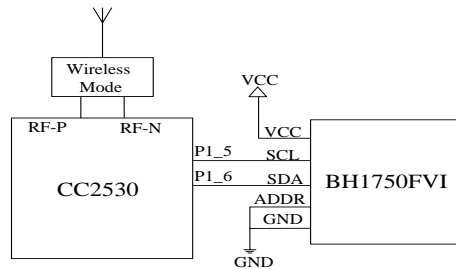


Figure 8. Circuit Structure Diagram of BH1750FVI and CC2530

#### 4.3. Hardware Design of Controlling Terminal Nodes

The hardware design is also basically the same for each controlling sensor terminal node [12]. The main difference is the different type of controlled device connected with controlling terminal node. For example, terminal node can connect with the light. And the switch control of light is actually the drive control of electric relay. Figure 9 shows the circuit design of light controlling terminal.

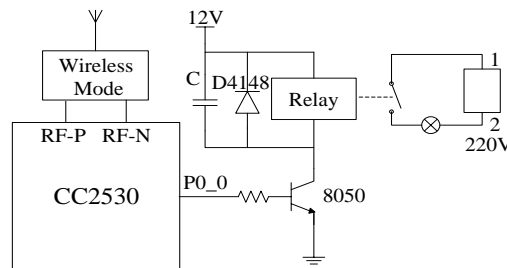


Figure 9. Circuit Design of Light Controlling Terminal

## 5. Software Design of the System

Software design of the system is mainly divided into two parts: software design of ZigBee nodes and user management platform. Software design of ZigBee nodes is based on the ZigBee protocol stack which chooses IAR Embedded Workbench as the software platform. It includes the software design of coordinator, sensor terminal nodes and controlling terminal nodes. Software design of user management platform is based on VC++ platform and includes serial communication program and man-machine interface design.

### 5.1. Software Design of Coordinator

ZigBee coordinator is the core of wireless sensor network, which is responsible for network establishment, address assignment, information management and data transmission, etc. In addition, it communicates with the PC through RS232 serial port [13]. The workflow of ZigBee coordinator is showed in Figure 10.

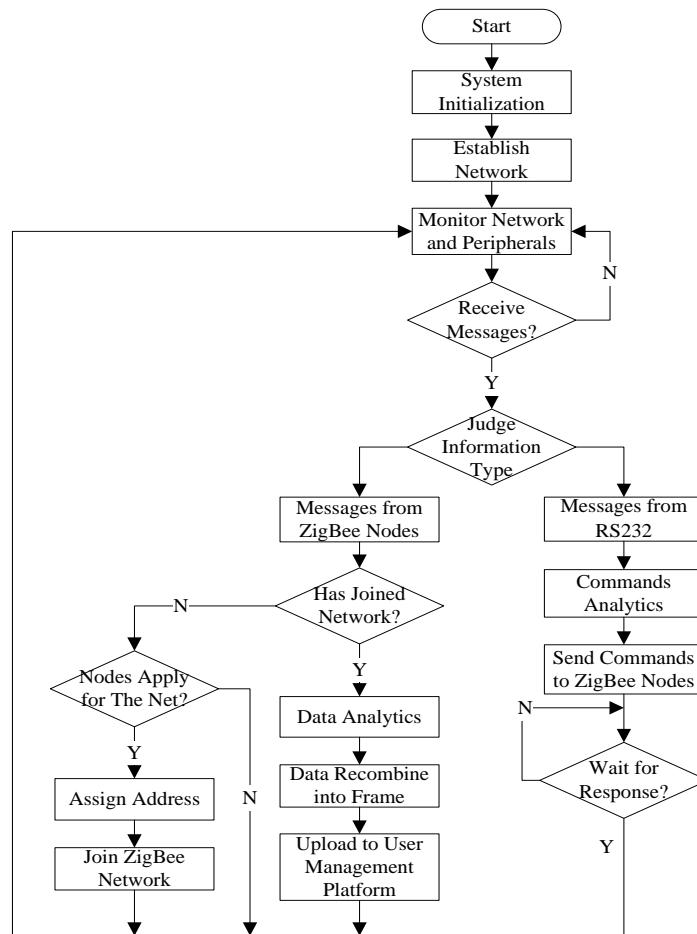


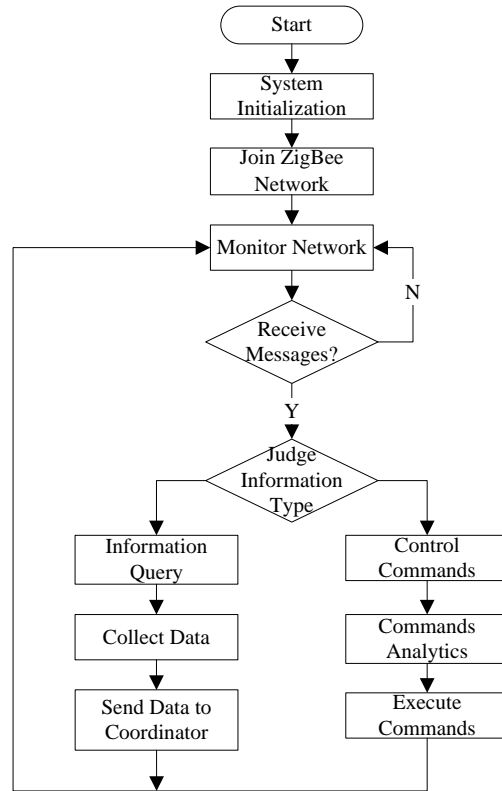
Figure 10. Workflow of ZigBee Coordinator

### 5.2. Software Design of Terminal Nodes

ZigBee terminal nodes include sensor terminal nodes and controlling terminal nodes. The main function of terminal nodes is to join the existing wireless sensor network and



communicate with the coordinator [14]. Sensor terminal nodes will gather real-time environment information from sensors and upload them to the coordinator. While controlling terminal nodes will receive messages from the coordinator and execute relative commands to control different devices. The workflow of terminal nodes is showed in Figure 11.

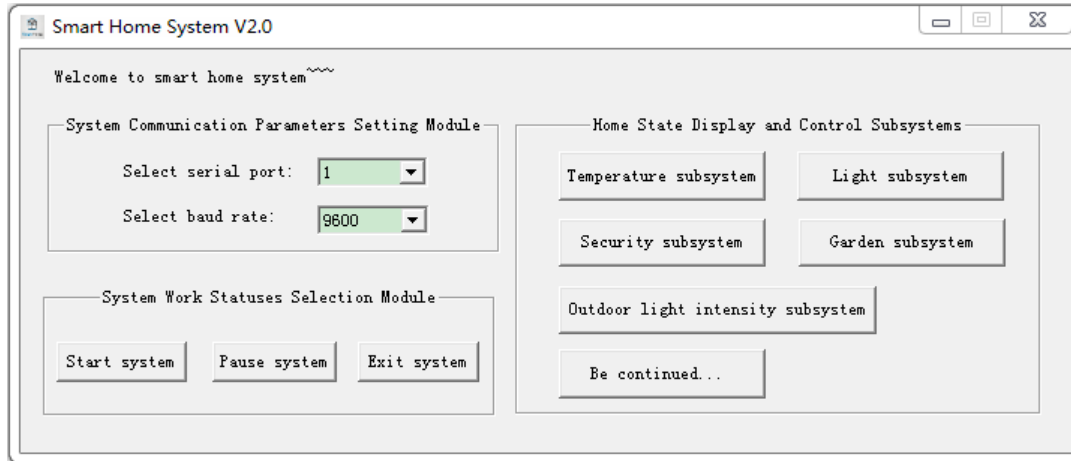


**Figure 11. Workflow of Terminal Nodes**

### 5.3. Software Design of User Management Platform

User management platform is mainly composed of the system communication parameters setting module, the system work statuses selection module and a series of home state display and control subsystems. Communication parameters setting module is mainly used to set serial port communication parameters of the PC and network coordinator, which includes the selection of serial port and baud rate. The system work parameters selection module can be controlled to start, pause or exit the user management platform. The home state display and control subsystems include temperature subsystem, light subsystem, outdoor light intensity subsystem and security subsystem, etc. In addition, the series of subsystems can display real-time state of indoor temperature, indoor light intensity, outdoor light intensity, indoor security respectively and control the open or close of light, air condition, electric curtain, alarm, etc.

The software design of user management platform is based on VC++ platform. Microsoft communication control is ActiveX control of serial communication programming under simplified Windows provided by Microsoft Company, and provides a simple method of receiving or sending data for serial port in the application program. On one hand, user management platform can send control commands to the coordinator through serial port. On the other hand, it can identify and extract relevant data from frames sent by serial port, and then display them on different subsystem. Figure 12 shows the user management platform.



**Figure 12. User Management Platform**

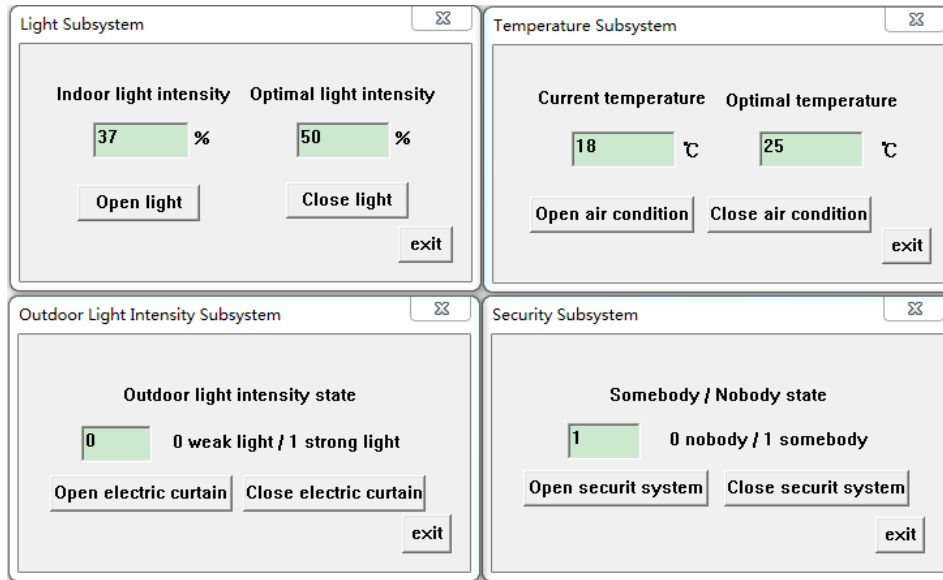
## 6. System Test

The reliable communication is very important between wireless sensors and coordinator in smart home system [15]. Due to many rooms in smart home system, data transmission may be obstructed by the barrier wall. So we test the communication between 5 wireless sensors and coordinator. Then we set the time cycle of wireless sensor data acquisition as 1min, the length of test as 10H (600min), and the power supply of the test as an AAA battery. The test results are showed in Table 2. As we can see, the success rate of communication between wireless sensors and coordinator is 100%, which verify the reliability of ZigBee protocol communication.

**Table 2. System Test of Transmission Performance**

Sensor number	Number of send	Number of correctly received	Success rate
1	600	600	100%
2	600	600	100%
3	600	600	100%
4	600	600	100%
5	600	600	100%

A comprehensive test has been done after the completion of system software and hardware design. Sensor terminal nodes collect indoor temperature, indoor light intensity, outdoor light intensity state, security state by 10s time cycle, and display them on user management platform in real-time. Figure 13 shows the real-time display of user management platform .As we can see from Figure 13, the indoor temperature is 18 degrees Celsius, indoor light intensity is 37, outdoor light is weak, and there is someone indoor. By the user management platform, we can control the open and close of light, air condition, electric curtain, alarm, etc. The test results show that the smart home system implemented by this paper can fulfill the task successfully.



**Figure 13. Real-time Display of User Management Platform**

## 7. Conclusions

The smart home system based on ZigBee technology is a new solution that used to meet the demand of high automation and intelligent home. In this paper, we introduce the advantages of ZigBee technology, architecture of ZigBee protocol, topologies and device type of ZigBee network. Then we put forward and discuss a design structure of smart home system. After that, the details of hardware and software design in smart home system are also given, which include the design of coordinator, terminal nodes and user management platform. Finally, the test shows that this system can provide a real-time and reliable management for the smart home. The system has a certain significance and application prospects in practical application. Because of the prominent advantages of low cost, low power and versatility, and as the further development of wireless network technology, ZigBee technology will become an inevitable trend in the development of smart home.

## Acknowledgements

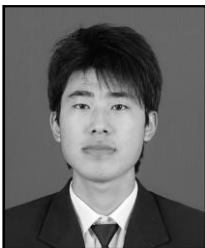
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