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Design and Implementation of Remote/Short-range Smart Home Monitoring System Based on ZigBee and STM32

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Abstract: As the continuous development of Internet of Things (IOT), life intelligent gradually. Therefore, home devices of remote/short-range monitoring become the inevitable trend of development. Based on this background, the smart home monitoring system is presented based on the STM32 and ZigBee technology. The system uses a low-power-cost STM32 processor as the main controller and porting of μC/OS-II and μC/GUI on the system is achieved. The system uses a resistive touch screen as the human-computer interaction interface, combined with the ZigBee technology to achieve a short-range monitoring of home devices. The system transplanted and modified the procedures of UIP network protocol. The master controller is connected to the Ethernet and erected a WEB server, achieved the remote monitoring of home devices. And finally give the implementation details of the prototype system and functional testing.

Keywords: Ethernet, remote/short-range monitoring, smart home monitoring system, STM32, touch screen, ZigBee

INTRODUCTION

The Internet of Things is the third wave of the information technology following Internet and mobile network (Atzori *et al*., 2010). Smart home is based on Internet of Things technology. Using of advanced computer technology, embedded systems and network communication technology, smart home devices of remote/short-range monitoring is achieved.

In recent years, Dedicated Short Range Communication Technology is rapid development in smart home system. ZigBee technology with low consumption, low cost, can be networking with routing function, big network capacity, support unlimited expansion characteristics, has become the first choice for the build of intelligent home network (Yang and Wang, 2006). Relative to the others wireless communication standard, ZigBee protocol has lower processor performance requirements, thereby reducing the cost of product development. After a systematic consideration, in the short-distance wireless communication, the system use ZigBee technology to achieve short-range monitoring of home devices.

In this system, we have adopted the STM32 processor instead of the traditional 8-bit or 16-bit MCU. STM32 processor is based on the ARM Cortex-M3 core, specifically for embedded application development and launch of 32-bit Flash microcontrollers. Its price is close to the traditional 8-bit microcontroller and much lower than ARM9 32-bit processor. Meanwhile, STM32 has characteristics of low consumption, high integration and ease of development (STM32F103VE Datasheet, 2012), is the first choice of the smart home microcontroller.

Currently, the remote control of smart home gateway technology is mainly divided into access Ethernet technology and GPRS technology. Access Ethernet technology combines low-cost, high availability, flexibility and other advantages, is the first choice of home devices remote monitoring. So the system adopts the method of access Ethernet, Smart home devices of remote/short-range monitoring is achieved.

THE OVERALL NETWORK STRUCTURE FOR SMART HOME MONITORING SYSTEM

The overall network structure for the typical smart home monitoring system is shown in Fig. 1. It mainly divided into two parts, ZigBee short-range wireless sensor networks and embedded STM32 access Ethernet.

ZigBee short-range wireless sensor networks: ZigBee short-range wireless sensor networks solve gateway and home devices terminal point-to-point wireless connection, so that the touch-screen terminal cans intelligent monitoring each home device node. ZigBee sensor network protocol uses a star topology; each network node is assigned a unique network address by a coordinator (PAN). The protocol also provides a relatively complete set of routing algorithm (Shouwei and Canyang, 2009), so coordinator can assign fastest to the best path of the node. Achieve communicate between coordinator and home devices.

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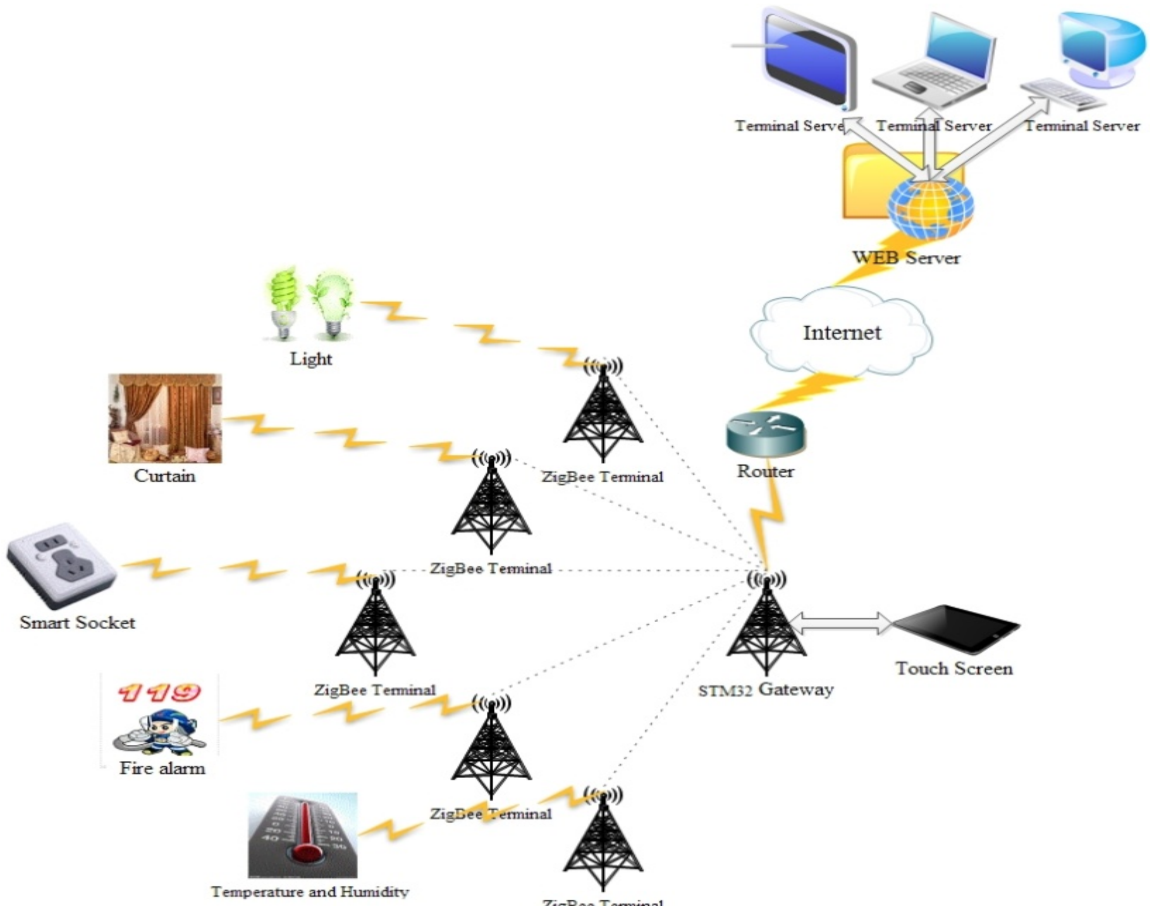

Fig. 1: The network structure for smart home monitoring system

Embedded STM32 access ethernet: Embedded STM32 Access Ethernet, solve gateway access to the Internet network link, so that the PC terminal can be remote intelligent monitoring of each home device node. Embedded STM32 using the Ethernet interface, which set to the server, using of Ethernet Carrier Sense Multiple Access (CSMA/CD) mechanism to send and receive data on the network. System transplant the open source embedded operating system μC/OS-II (Ucos_II+2.52 Source Chinese Annotation Material, 2012) based on STM32 gateway, using the open source embedded network protocol UIP (Uip (Micro Ip), 2012). Achieve communicate between STM32 gateway and the Internet.

Note that, achieve communicate between ZigBee coordinator and STM32 gateway mainly through the serial port. Data transfer between the two is not a simple, but mutual and can be controlled. In the transfer process, in order to make the data transmission more secure and reliable, we need to add the corresponding identifier in the data. Sometimes, because the two communication systems have different supply voltage, we need to uplift the low voltage to normal communication. In this system, ZigBee coordinator and STM32 gateway system both supply 3.3 V powers, so the serial data can be sent and received directly.

SMART HOME MONITORING SYSTEM HARDWARE DESIGN

The hardware design of the system structure and component selections are as follows: CPU choose ST Inc production the STM32F103VET6 processor based on ARM Cortex-M3 kernel. ZigBee chip choose TI Inc production the CC2530F128. 10M NIC choose Microchip Technology Inc production the ENC28J60. Regulated power supply module chooses the AMS1117-3.3 chip which output voltage is 3.3 V. The hardware structure and the hardware platform are shown in Fig. 2 and 3.

The micro-controller module: The first Micro-controller module is made up of the STM32F103VET6 and its peripheral circuit, mainly used for the gateway, which is the core of the system. The operating frequency of this type microprocessor is 72 MHz, with 512 K bytes of Flash and 64 K bytes of SRAM and a wealth of GPIO and a rich communication interface (USTAR, I2C, SPI, CAN, USB) in it (Sun *et al*., 2010).

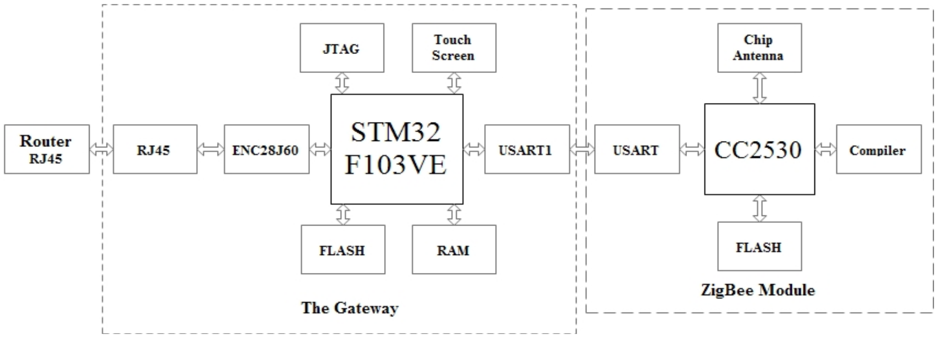

Fig. 2: The hardware structure

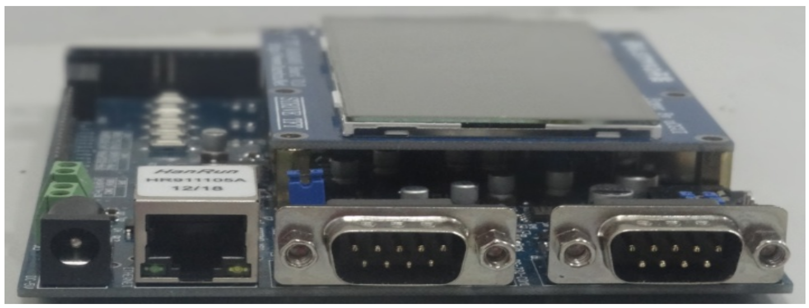

Fig. 3: The hardware platform

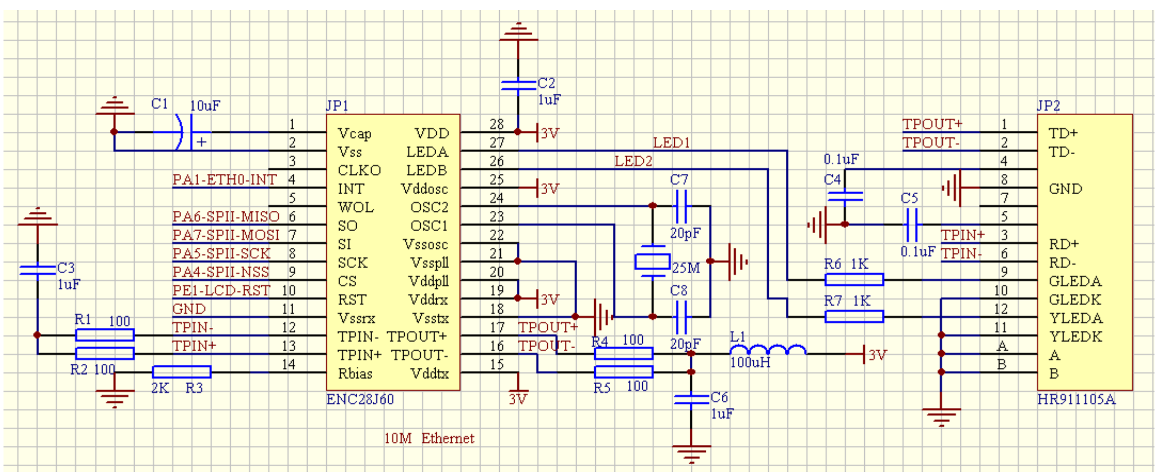

Fig. 4: The ethernet controller connected circuit

The second Micro-controller module is made up of the CC2530 and its peripheral circuit, mainly used for short-range wireless communication, which is the core of the system. CC2530 has a 2.4-GHz IEEE802.15.4 compliant RF transceiver, with 128K bytes of Flash and 8K bytes of SRAM. It is the first choice for the build of intelligent home network (BaiduBaike, 2012).

The ethernet module: Ethernet module uses the independent Ethernet controller ENC28J60 with SPI bus interface. It integrates the IEEE 802.3 Ethernet Media Access Control, 10Base-T Physical Layer and 8K bytes of SRAM (ENC28J60 Datasheet, 2012), is the core of the Ethernet communication hardware. The Ethernet controller connected circuit is shown in Fig. 4.

Human-computer interaction module: The Human-Computer Interaction module mainly consists of the HannStar LCD touch screen. HannStar Display model HSD043I9W1-A is a color active matrix Thin Film Transistor (TFT) Liquid Crystal Display (LCD) that uses amorphous silicon TFT as a switching device. This model is composed of a TFT LCD panel, a driving circuit and a back light system. This TFT LCD has a 4.3 (16:9) inch diagonally measured active display area with WQVGA (480 horizontal by 272 vertical pixel) resolution (HannStar 4.3 inch HSD043I9W1-A

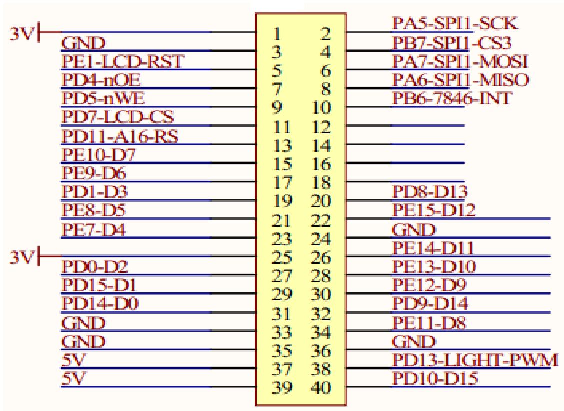

Fig. 5: The touch screen interface circuit

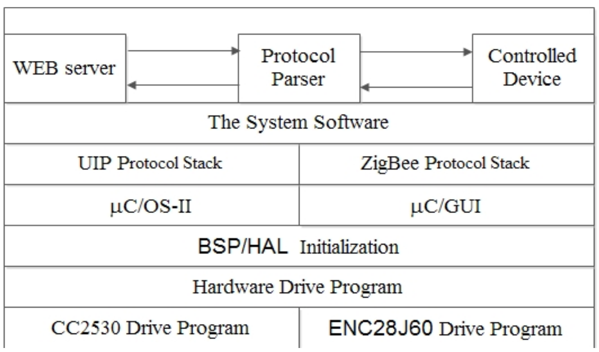

Fig. 6: The system software structure

Datasheet, 2012). The touch screen interface circuit is shown in Fig. 5.

SMART HOME MONITORING SYSTEM SOFTWARE DESIGN

The system software is the core part of the embedded systems. Software is based on hardware platform to achieve the drive and control of each module. The software design of the smart home monitoring system is mainly composed of the following four parts: The open source embedded operating system μC/OS-II (Ucos_II+2.52 Source Chinese Annotation Material, 2012), initially developed by Jean J. Labrosse. The open source embedded GUI interface μC/GUI (UCGUI Professional Website, 2012). The short-range wireless network protocols ZigBee (ZigBee Alliance Home, 2012), initially developed by ZigBee Alliance. The open source embedded network protocol UIP (Uip (Micro Ip), 2012), initially developed by Adam Dunkels. The system software structure is shown in Fig. 6.

Real-time multi-tasking embedded operating system μC/OS-II: System transplant the open source embedded operating system μC/OS-II. Firstly, the system implementing the μC/OS-II of initialization function OSInit() and hardware platform of

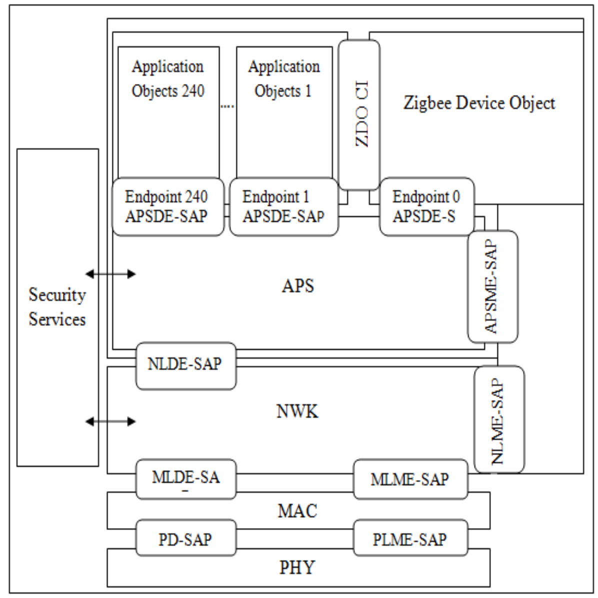

Fig. 7: ZigBee protocol stack structure

initialization function BSP-Init(). Then, build main task through OSTaskCreate() function and start the μC/OS-II kernel through OSStart() function. In addition to the two tasks generated automatically, the system has also built the other five tasks (By two function to execute App-TaskCreate() and OSTaskCreateExt()). The five tasks are: Human-Computer Interaction task, touch-driven task, serial port 1 receiving and sending task, network processing task and seconds update task.

The embedded GUI interface μC/GUI: In Human-Computer Interaction task, system mainly uses the LIB library functions in μC/GUI (UCGUI Professional Website, 2012), to achieve the design of touch screen interactive interface. The study mainly does a brief introduction to the main function using in design. Firstly, the system uses WM_SetCreateFlags() function, creates a window of the interface. Secondly, the use of GUI_SetColor() function and GUI_SetBkColor() function, to set the foreground and background colors. Thirdly, the use of BUTTON_Create() function, to set button of the interface. And then, the use of GUI_DrawBitmapExp() function and GUI_ DispStringAt() function, to display images and text on the interface. Finally, the use of GUI_Clear() function, to clear the window of the interface.

The wireless network protocols ZigBee: ZigBee protocol uses the IEEE 802.15.4 defines the Physical layer (PHY) and the Media Access layer (MAC). And on this basis to define the architecture of the Network layer (NWK) and Application Layer (APL) (Shouwei and Canyang, 2009). ZigBee protocol stack structure is shown in Fig. 7.

Table 1: The hierarchical model of the system

Application layer	HTTP
Transport layer	TCP
Network layer	ICMP, IP
Link layer	ARP

The embedded network protocol UIP: In network processing task, system mainly transplant the open source embedded network protocol UIP, to send and receive the control information and status information on the Ethernet. UIP protocol stack is divided into four layers. The hierarchical model of the system is shown in Table 1.

ARP protocol, mainly to get the destination host's MAC address before the destination host sends frames. The destination host's MAC address is based on its IP address. Protocol uses uip_arp_arpin() and uip-arp-out() function to construct the ARP request and reply, to achieve the mapping between IP address and Ethernet address.

IP protocol, mainly transmit data to the upper-layer protocols and transmit packets to the data link layer to encapsulate into the frames. The IP packet header data mainly store parameters into the structures tcpip_hdr. Details are as follows:

```
struct tcpip_hdr
{
u8_t vhl, // IP version number and the length of the
             header
tos;      // Type of Service
```

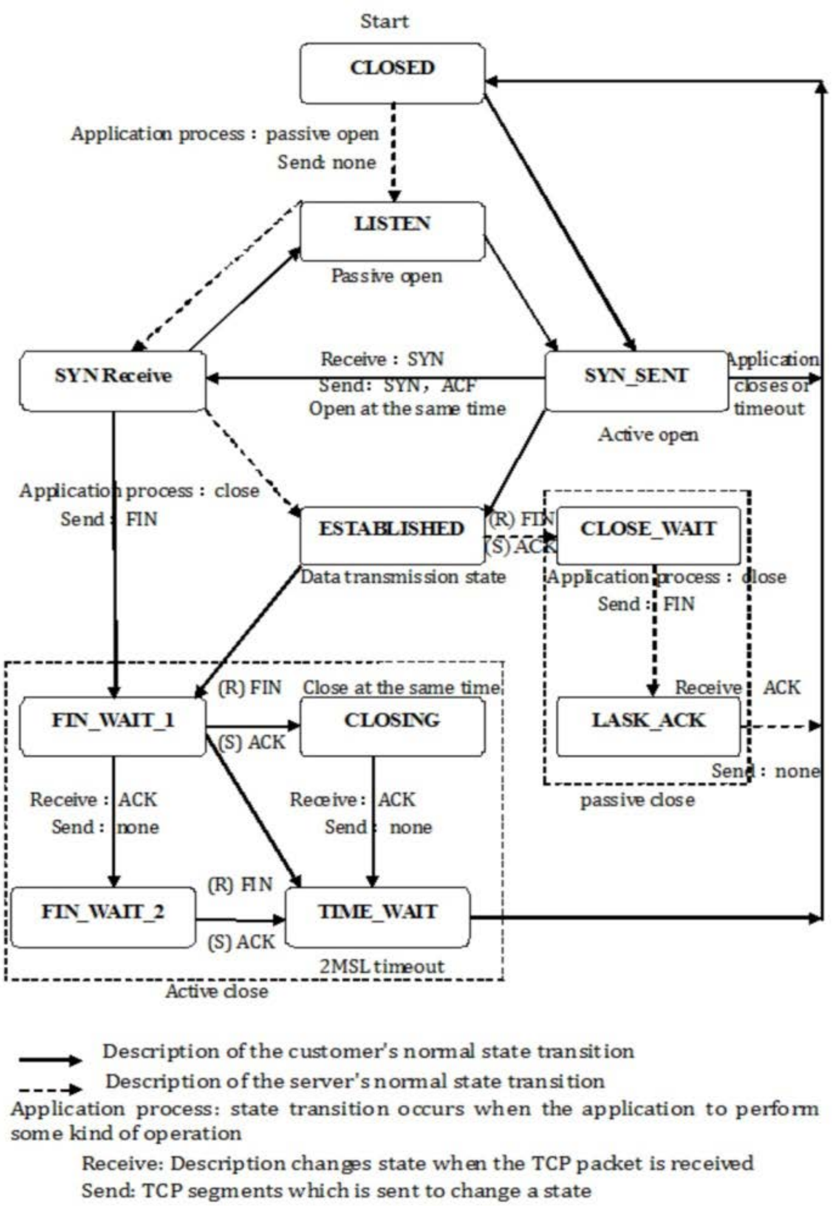

Fig. 8: The state transition of TCP

```
u16_t len,  // The total length of the IP datagram
ipid,       // IP datagram identifier
ipoffset;   // Segmented information
u8_t ttl,   // Time to Live
Proto;      // Protocol type
u16_t ipchksum;   // Checksum
u16_t srcipaddr (BaiduBaike, 2012), // IP address of the sender
destipaddr (BaiduBaike, 2012);      // IP address of the receiver
}
```

ICMP protocol, mainly used for passing control information between the host and the router, including reporting error, exchange limited control and status information and so on. The ICMP packet header data mainly store parameters into the structures icmpip_hdr. Details are as follows:

```
struct icmpip_hdr
{
u8_t type,           //   Message type
icode;               //   Message code
u16_t icmpchksum;    //   Checksum
u16_t id,            //   ICMP datagram identifier
seqno;               //   serial number
u8_t payload (Atzori et al., 2010); // Data start address
}
```

The TCP protocol (Xiren, 2009), mainly provides a connection-oriented service. When a new data packet is received, newdata() function is invoked to prepare data, but not transmit temporarily. When sending packets, invoke the senddata() function to send data. When sending packets successfully arrived, the acked() function is invoked to declare the client is ready for data communication. The state transition of TCP is shown in Fig. 8.

HTTP protocol, mainly uses for exchanging data between the browser and the Web server. The protocol is based on TCP/IP connection and the port is set to TCP 90. We use tcp_server_appcall() function and httpd-appcall() function to achieve the communication between the server and the browser. The system also uses HTML language, made a simple control web page. We convert web pages to an array and set up a server, to achieve remote control function.

SYSTEM TEST AND RESULT ANALYSIS

System test is divided into three parts. First, the touch screen of the terminal device test. Second, WEB server connected to the Ethernet test. Third, the WEB server uses ADSL broadband dial accessing to the Internet test.

First of all, the system controls the home device by a touch-screen terminal successfully and real-time monitoring the home device by the terminal. The interface display of the touch screen and real-time monitoring interface are shown in Fig. 9 and 10.

Fig. 9: Interface display of the touch screen

Fig. 10: Real-time monitoring interface

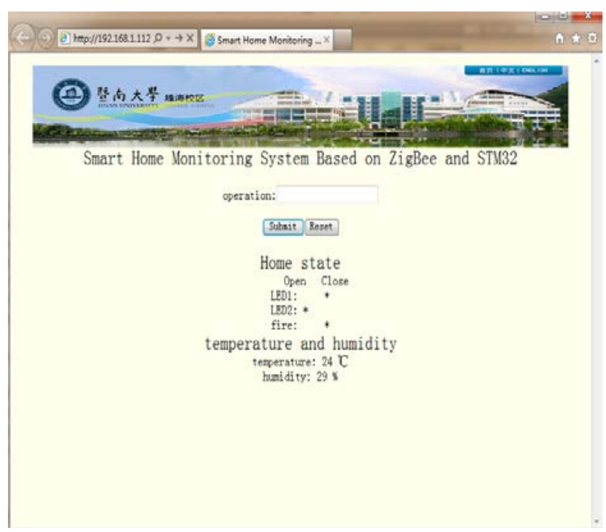

Fig. 11: The display of the control web page

Secondly, the computer runs the IE browser. Access address: 192.168.1.112:90. Successfully access the WEB server computer, enter the system control page and smart home devices of remote monitoring is achieved. The display of the control web page is shown in Fig. 11.

Finally, the system is also connected to the Internet, to achieve a true sense of the remote control. The system uses the TP-LINK router and telecommunications 2 M broadband account. In

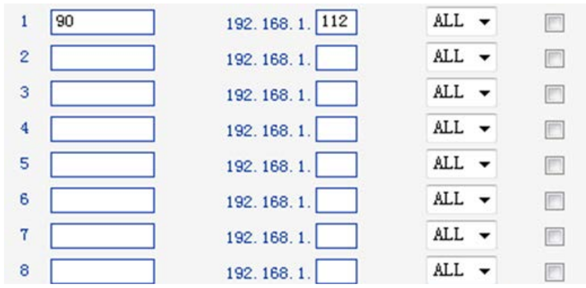

Fig. 12: The setting of the port mapping

Fig. 13: The setting of domain name server

addition, still need to use the router port forwarding functions and peanut shell service. To achieve the mapping between the IP address of the external network and IP address of the internal network, we need to set the port mapping of router. The setting of the port mapping is shown in Fig. 12.

Note that, as each ADSL dialing assigned public IP address is different, thus access server by the changing public IP is not reliable. To solve this problem, this study adopts TP-LINK router peanut shells Domain Name Server. First, we register a free domain name on the official website of the peanut shells, then mapping the public IP address to the domain of peanut shells (Use Peanut Shell from the Network Access, 2012). Therefore, when accessing the server, only need to access a fixed domain to log WEB control page. The setting of Domain Name Server is shown in Fig. 13.

CONCLUSION

The thesis has designed and implemented the Smart Home Monitoring System. Achieved the remote access of home devices to the Internet and the ZigBee short-range wireless sensor networks connect with terminal. The thesis also presented the structure of hardware based on the ZigBee protocol and UIP protocol under the embedded operating system μC/OS-II. The STM32 master controller is connected to the Ethernet and erected a WEB server, with configuring its port number and IP address. And using the peanut shells dynamic DNS service, the system achieved a true sense of the remote control. The system has advantages of low consumption, low-cost, easy of deploy. The thesis has a good reference value and guiding significance for the research and application of smart home system.

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