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The Design and Implementation of Smart Monitoring System for Large-Scale Railway Maintenance Equipment Cab Based on ZigBee Wireless Sensor Network

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Abstract: In recent years, organizations use IEEE 802.15.4 and ZigBee technology to deliver solution in variety areas including home environment monitoring. ZigBee technology has advantages on low-cost, low power consumption and self-forming. With the rapid expansion of the Internet, there is the requirement for remote monitoring large-scale railway maintenance equipment cab. This paper discusses the disadvantages of the existing smart monitoring system, and proposes a solution. A ZigBee wireless sensor network smart monitoring system and Wi-Fi network is integrated through a home gateway to increase the system flexibility. At the same time the home gateway cooperated with a pre-processing system provide a flexible user interface, and the security and safety of the smart monitoring system. To testify the efficiency of the proposed system, the temperature and humidity sensors and light sensors have developed and evaluated in the smart monitoring system. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Smart monitoring System, ZigBee wireless sensor network, Wi-Fi, Home gateway, Pre-processing system.

1. Introduction

It is usual for large-scale railway maintenance equipment working in the temperature of minus 40 °C in the north of China, or the temperature of zero 50 °C in the south of China. But it is an unbearable suffering for the drivers in the cab. To deal with these problems, many house hold appliances such as air conditioners and heating equipment have been settled in the cab. In recent years, network enabled household appliances have proceeded at an unprecedented rate. At the same time, the wastage of the smart household appliances is getting more and more serious. Focus on this point, there is the potential for the monitoring of such network enabled household appliances to give a suitable energy efficiency operation. The forward researches on smart monitoring technology have done great contribution.

1.1. Existing Smart Monitoring Technology

The research into field of smart monitoring has done significantly. In recent years, a java based smart monitoring system has continued to receive much attention in the field of smart monitoring. A ZigBee based smart home environment monitoring design [1], proposed a solution to use Wireless Sensor Network (WSN). This proposed design use four devices: a personal computer (PC), a Coordinator, the network router devices and the end sensor devices. The main communication among the coordinator, the network router devices and end sensor devices are ZigBee using IEEE 802.15.4 protocol. And the coordinator connects the PC by USB. This proposed design using ZigBee technology has committed the possibility to use WSN as the wireless communication medium of the smart monitoring system. However, this proposed design only realized the basic home environment monitoring function, and did not provide a remote access to the system.

The introduction provides a brief review of the existing academic research in the field of smart monitoring. And this research lies predominantly in the academic arena, with little available publically industrial research. The steps of smart monitoring system into commercial system have been limited, and where available consumer uptake has been slow.

To focus on the remote access to the smart monitoring system, another design of smart home based on WSN, has installed in some of the recently built residence communities in China [2]. This design offers home gateways which connect the local area network to the Internet. In this proposed design, users can remote access the smart home system to check the real time home environment parameters. Moreover the home gateways based Web service gather all the home environment data and store the data in the central database. However, this proposed design has largely neglected the privacy which the service providers can get access into each home database. For some users, this open architecture raised privacy problem, which may be much greater than the advantages offered by granting third party access.

These researches have done a greater job on contribution to the development of a home gateway. However, this home gateway has focused on the provision of remote connectivity and has largely neglected investigating the integration of existing local wireless network.

1.2. Analysis of the Existing Systems

There are three main categories which limit the adoption of the smart monitoring system by consumers.

1) Expensive and Complex: these existing systems generally using a PC for the network management and the remote access point. By this way, it adds the extra complexity, and it also increases the fiscal expense.

2) Inflexible user interface: these existing systems have offered many kinds of solutions for users to monitor the smart monitoring devices. However, these existing systems limited the users using a single method. Some of these existing systems provided more than one interface to the users always causes the uncomfortable and confusion.

3) Ignoring the security of the system: these existing systems have largely neglected the safety and the security of the monitoring system. That may cause the potential privacy problems.

1.3. Features of the Proposed System

In this paper presents a flexible, stand alone, low-cost and energy efficiency ZigBee based remote smart monitoring system. This architecture is designed to reduce the system complexity and provide varying access to the system with good security. This proposed system allows users at home to use any Wi-Fi enabled devices which support Java, and the devices can access the Internet to monitoring the home. A home gateway can work on the facilitate interoperability between heterogeneous network and support any devices accessing in a consistent interface.

In this proposed system, there is a pre-processing system to check all communication before these commands are worked on the devices. And this proposed pre-processing system can guarantee the security of the whole system, through checking the messages by the authorized users [4, 5].

In this paper, section 2 discusses the system architecture and a review of the technology used in this design. Section 3, Section 4 and Section 5 show the implements of the proposed system as ZigBee network hardware design, ZigBee network software design and pre-processing system design. And Section 6 describes the system evaluation and the Section 6 provides a conclusion.

2. System Architecture

The system architecture is shown as Fig. 1; the whole system provides flexible interfaces for different users to access the system.

The whole monitoring system using two kinds of networks, ZigBee based on IEEE802.15.4 is for low data rate monitoring sensor network, and Wi-Fi is for high data rate multi applications usage.

The home gateway is for connecting these two heterogeneous ZigBee and Wi-Fi networks, and implements the functions of monitoring the home environment.

The pre-processing system with users and devices database can implement a real time security for the smart monitoring system.

As shown in Fig. 1, there are two kinds of users in the system; the remote users can get access into the system by the Internet as the users are not at home and the local users can get access into the system by using the local area Wi-Fi network to monitor the home environment. When the users access the system, they have to identify themselves through the gateway and the pre-processing system, only the authorized users whose username have already been resisted in the user and devices database [7, 15]. And the ZigBee part is implemented the smart monitoring function. The temperature sensors, the light sensors and the humidity sensors are arranged all over the house to monitor the home environment.

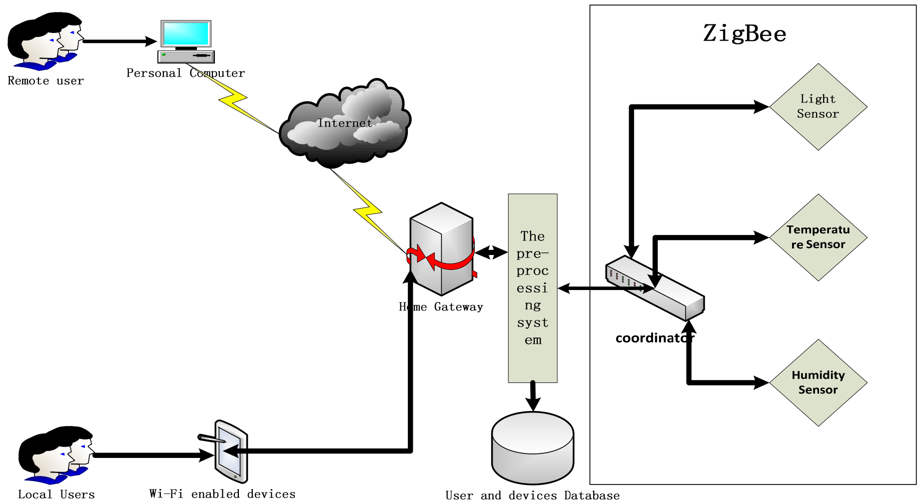

Fig. 1. System architecture.

1) Home Gateway.

As shown in Fig. 1, the home gateway is the central device of the system, it transverses the communications between different networks and provides the interoperability. There are two main functions of the home gateway. The first is the interoperability, the home gateway provides the connection among Internet, Wi-Fi, and ZigBee network, which makes the communication flexible between users and ZigBee wireless sensor network. The second is the standardized user interface based on Web Serves, the home gateway provides the standardized user interface for both remote users and local users, and the user interface is more flexible for users to get access into the system and quiet convenience to understand the information which is gathered and analyzed the data of the home environment [6, 13]. Through the standardized user interface the commands that used in the system can be standardized when different users get access into the system can operate the system to get real time monitoring data using the same commands and without having to remember the standardized commands. That provides more flexible and interoperability between the users and the smart monitoring system.

2) The pre-processing system.

As shown in Fig. 1, the pre-processing system is responsible for the security and safety of the smart monitoring system. The pre-processing system is cooperated with the home gate way. It connects the users and devices database to identify the users, who access the system, and check the commands sending to the devices for availability. For this purpose, all the users who want to get access into the system will firstly identify themselves by username and password examination [8, 9]. Moreover, the users send commands by using standardized user interface; the pre-processing system will check these commands for availability. As the end devices are powered by battery, maybe one time an end devices is not available in the system, the pre-processing system will send the user a message to inform the users to change the battery or replace the end devices when it is out of use. And the pre-processing system will guarantee the whole system will not be died in an unreachable dead cycle.

3) The Wi-Fi technology.

In the proposed system, the Wi-Fi technology is used to provide the flexible access to the system. The Wi-Fi technology is based on IEEE 802.11g protocol, and it operates in the unlicensed 2.4 GHz band and provides a high data rate in 150 M at maximum. The Wi-Fi technology can provide the multimedia application and flexible user interface. And it also provides more convenience access to the system by using Wi-Fi enabled devices such as Ipad, smart phones, this is more useful for the local users.

4) The ZigBee wireless sensor network.

As shown in Fig. 1, the ZigBee part is a ZigBee wireless sensor network. ZigBee is a low energy cost, low date rate wireless communication technology based on IEEE 802.15.4 protocol operating on unlicensed 2.4 GHz band. In this propose system, the ZigBee wireless sensor network is working on the PAN network coordinator network topology, which means all the communication in the ZigBee wireless sensor network are through the coordinator to the end devices. The ZigBee technology can provide 250kbps data rate in theoretically and that meets the requirement of the 40 kBps of the system. There is another advantage of ZigBee technology. It is the low fiscal expense of the devices based on ZigBee. That tackles the expansive problem of the system with the existing smart monitoring system as discussed earlier.

3. The Implement of ZigBee Devices Hardware Design

The hardware design of ZigBee devices is mainly divided into four parts: the power unit, the sensor unit, the wireless communication unit and the processing unit. The power unit function is providing power to the ZigBee devices. The sensor unit is used to gather all the home environment information, then translate the analog signals to digital signals, and send the digital signals to the processing unit at last. The wireless communication unit is responsible for the ZigBee wireless communication among ZigBee end devices and the ZigBee wireless communication between the coordinator with each ZigBee end devices. At last, the processing unit is the core part of this ZigBee Wireless sensor network. The processing unit is providing the functions as data processing, energy efficiency management, task management, and a variety of communication protocols.

3.1. The Processing Unit

In this proposed design, the ZigBee devices use STM32F103 serial chips produced by STMicroelectronics. This chip is based on high performance ARM Cortex-M3 32 IP core using RISC. The working frequency of STM32F103 serial chips can reach 72MHz at Maximum. STM32F103 serial chips provide 4 driving units and 4 supporting units. The driving units are D-bus, S-bus, general DMA1, and general DMA2; the supporting units are inner SRAM, inner Flash memory, FSMC and AHB2APBx.

STM32F103 serial chips have great advantage on energy efficiency, which can work on three modes: Sleep mode, Standby mode, and Stop mode [3].

1) Sleep mode: In Sleep mode, only the CPU is stopped. All peripherals continue to operate and can wake up the CPU when an interrupt/event occurs [3].

2) Standby mode: The Standby mode allows achieving the lowest power consumption. The internal voltage regulator is switched off so that the entire 1.8 V domain is powered off. After entering Standby mode, SRAM and registers content are lost except for registers in the Backup domain and Standby circuitry. The device exits Standby mode when an external reset (NRST pin), an IWDG reset, a rising edge on the WKUP pin, or an RTC alarm occurs [3].

3) Stop mode: Stop mode allows achieving the lowest power consumption while retaining the content of SRAM and registers. All clocks in the 1.8 V domains are stopped. The device can be woken up from Stop mode by the PVD output, the RTC alarm or the USB wakeup [3].

STM32F103 serial chips provide three kinds of Pinout, LQFP100 Pinout, LQFP64 Pinout, and LQPF48 Pinout.

Based on the performance of coordinator and end devices, in the proposed system, the coordinator uses LQFP64 Pinout chips; the end devices use LQFP48 Pinout chips [3].

As shown in Fig. 2, 4 0.1 uF capacitors in parallel connection work as filter capacitor.

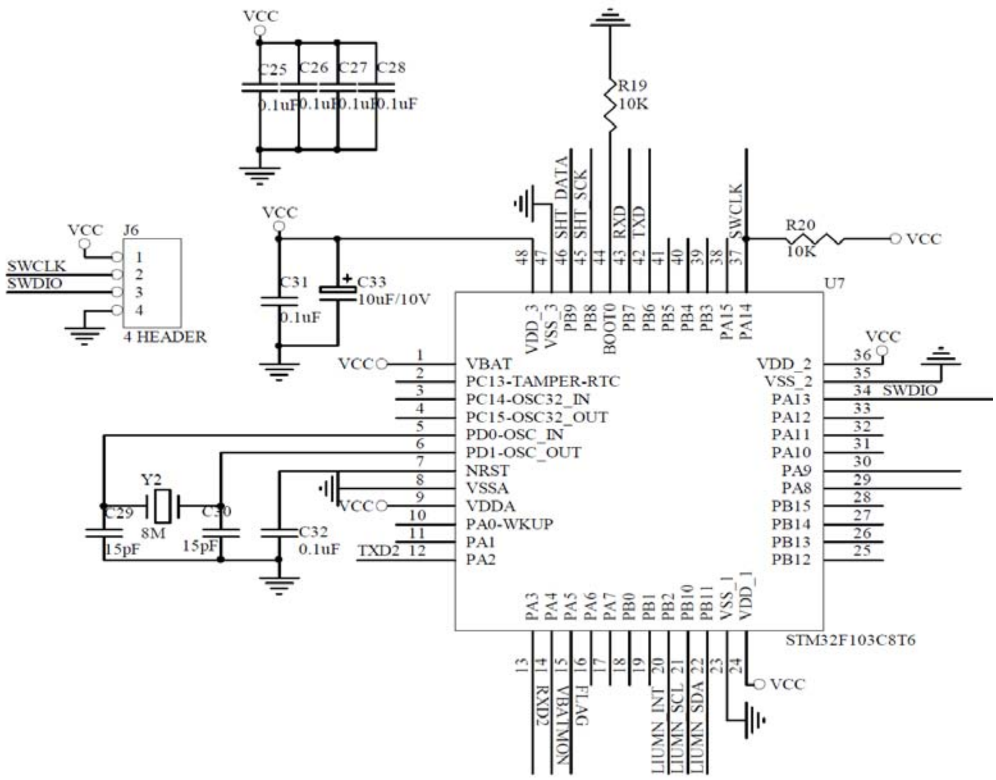

Fig. 2. The PCB of LQFP48 Pinout.

Pin 20, 21 and 22 are used respectively as the interrupt output, SCL and SDA of the light sensor; Pin 42 and 43 connect respectively to the send pin and receive pin of Serial Port 1; Pin 14 and 12 connect respectively to the send pin and receive pin of Serial Port 2; Pin 45 and 46 are used respectively as SCL and SDA of the temperature and humidity sensor.

As shown in Fig. 3, the design of LED lights will show the coordinator working statue intuitively. The Serial port 2 connects to the ZigBee module, and controls the ZigBee module by using AT commands.

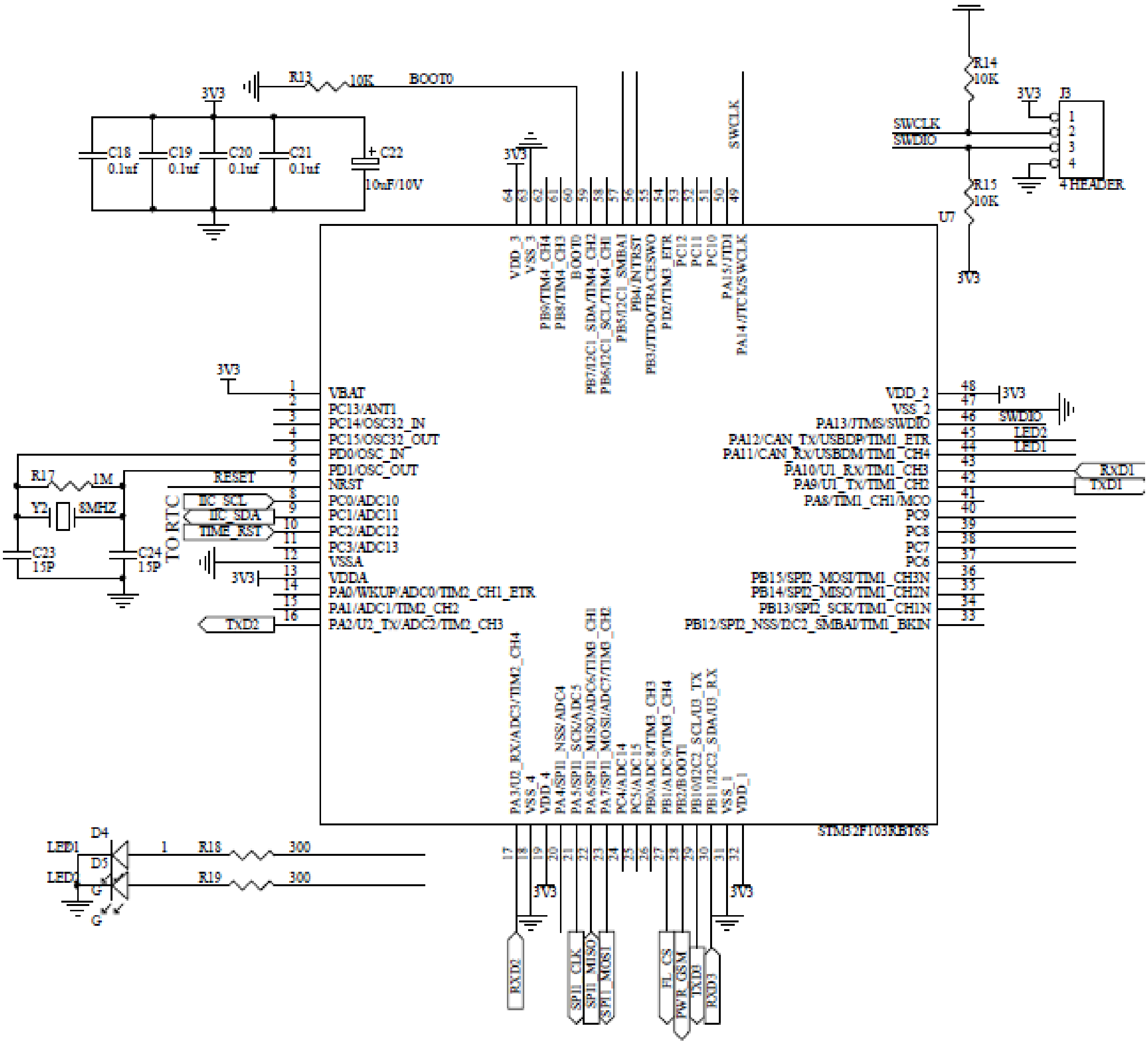

Fig. 3. The PCB of LQFP64 Pinout.

3.2. Sensor Unit

In the proposed system, the sensor unit is designed to collect the home environment information. The sensor unit translates the analog signals to the digital signals, and transports the digital signals to the processing unit. The basic requirement if the smart monitoring system is gathering the temperature, humidity, and light parameters in real time, on this purpose, the sensors have to work on three conditions:

1) The sensor operation temperature is -20~60°C;

2) The sensor operation humidity is 5 %~95 %, non-condensed;

3) The sensor security level is at least IP65.

3.2.1. SHT10 Temperature and Humidity Sensor

In the proposed system, the end devices use SHT10 temperature and humidity chips produced by Sensirion based on CMOSens ® technology. As shown in Fig. 4, the SHT10 chip pin VCC and GND are parallel connection to a 0.1 uF capacitor as decoupling filter. The SHT10 chip Pin 2 and Pin3 are respectively used as SHT_SCK and SHT_DATA, which connect to the STM32F103 serial chips Pin 45 and 46 as discussed earlier. STM32F103 serial chips use low-level to drive the serial port to avoid signal conflict. The two 10 k resistors are used as pull-up resistors for the SHT_SCK and SHT_DATA.

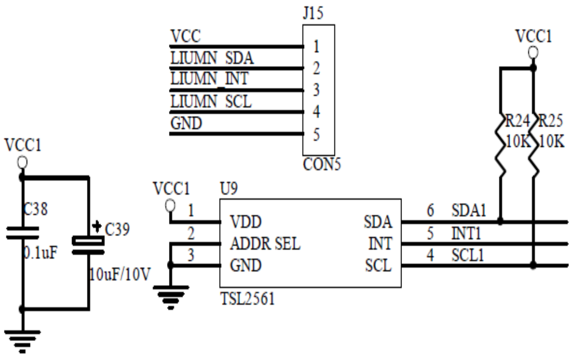

Fig. 4. The PCB of SHT10 temperature and humidity sensor.

3.2.2. TSL2561 Light Sensor

In the proposed system, the end devices use TSL2561 light sensor chips produced by TAOS. This chip is power consumption, highly translation rate, good quality, and easy installation. It connects to processer by I2C bus. As shown in Fig. 5, the two GPIO pins PB10 Pin and PB11 Pin of the STM32F103 connect to SCL1 and SDA1 of the TSL2561. To avoid signal conflict, we use the same way as said earlier, two 10 k resistors are working as pull-up resistors.

3.3. Wireless Communication Unit

In the proposed system, the ZigBee devices use REX3D ZigBee chips produced by Zhejiang Rexense Technology. The REX3D chip size is only 32.20*20.50*10.50 mm, which can be put in a very small device.

The communication range is 300 m in version, it works in two modes: Sleep mode which uses only 0.4 uA, and Normal mode which uses only 29 mA. This chip provides a variety of ports, such as 24 GPIO which 4 of them are interruption ports, 6 channels of A/D, one USART, one TWI (Inter-Integrated Circuit), one SPI, and USART Bootloader with AT commands. The REX3D supports FCC, IC and CE communication protocols for variety usage in different working environment.

As shown in Fig. 6, there are 28 Pins of REX3D chips. Pin1 and Pin2 are VCC, Pin17, 18, 27, and 28 are GND, Pin 15 is nRESET. Pin13 and Pin16 are respectively working as RXD and TXD. Pin19 and Pin22 are cooperated as simulation and debugging.

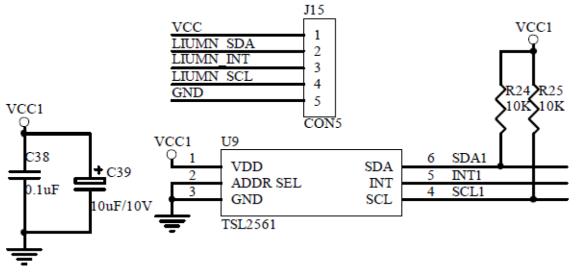

Fig. 5. The PCB of TSL2561 light sensor.

3.4. Power Unit

STM32F103 serial chips need accuracy power supply as the STM32F103 has three working modes. In proposed system, the power unit uses high accuracy voltage regulator NCV8051. The accuracy of the voltage output is ±2 %. NCV8051 also supports $\overline{REST}$ output for the processer logical control. As shown in Fig. 7, Pin1 is Vin; and Pin2 is voltage monitoring pin; Pin3 is Output ENABLE; Pin4 is Reset DELAY; Pin 5 is GND; Pin6 is $\overline{REST}$; Pin 7 is FLAG output; Pin8 is Vout.

4. The Implement of ZigBee Devices Software Design

In the proposed design, the implement of ZigBee devices software design mainly includes two parts: the coordinator device program module, and the end devices program module. And each program module is made by variety modules.

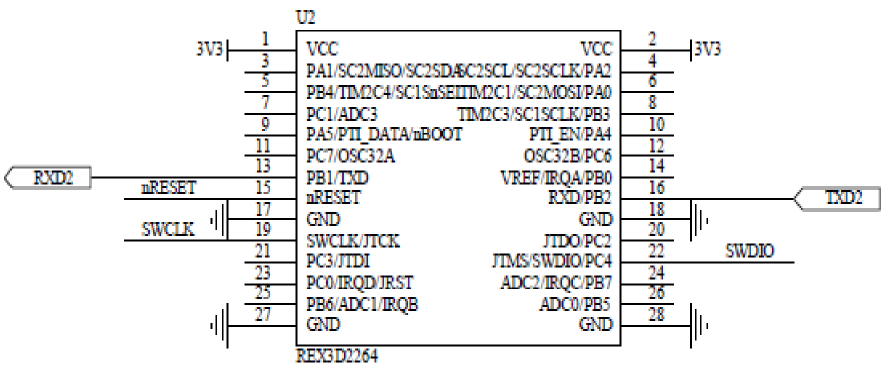

Fig. 6. The PCB of REX3D chip.

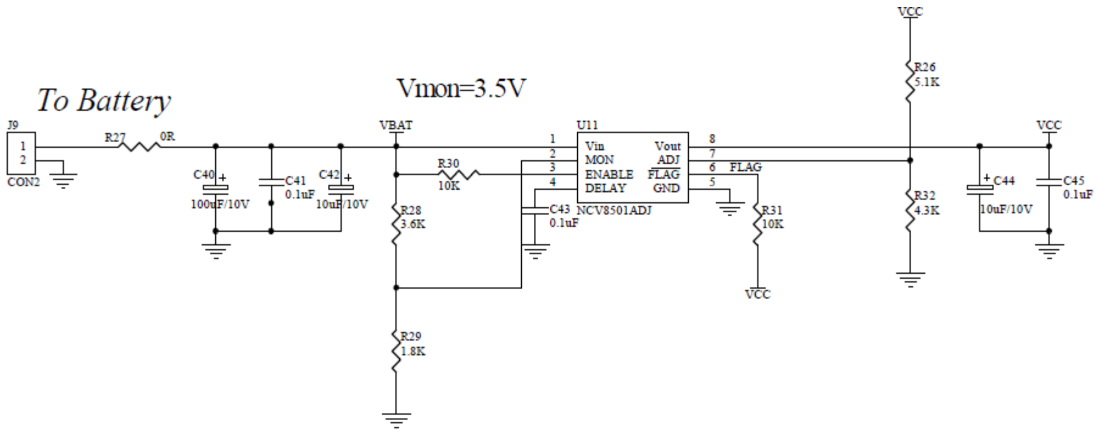

Fig. 7. The PCB of NCV8051 voltage regulator chip.

4.1. The Implement of ZigBee End Devices Software Design

The ZigBee end devices program module includes system initialization module, real-time clock module, temperature and humidity sensor module, light sensor module, delay processing module, serial communication module, and ZigBee module, as shown in Fig. 8.

1) System initialization module: it initializes the I/O ports and interrupt vector table of STM32F103 microprocessor, and sets the microprocessor clock multiplier factor;

2) Real-time clock module: it initializes the RTC, and checks the RTC operation status. Another function of this module is setting a wake alarm to call up the microprocessor;

3) Temperature and humidity sensor module: it processes and analyses the information which is collected by SHT10;

4) Light sensor module: it processes and analyses the information which is collected by TSL2561;

5) Delay processing module: this module meets the requirement of the accuracy of delay processing and configures the all the registers connected to the delay processing;

6) Serial communication module: it realizes the communication between the coordinator and the end device, and sends the data or AT commands to the ZigBee module by serial port;

7) ZigBee module: in this module, AT commands realize the functions of ZigBee wireless communication and switching the working modes of ZigBee chip.

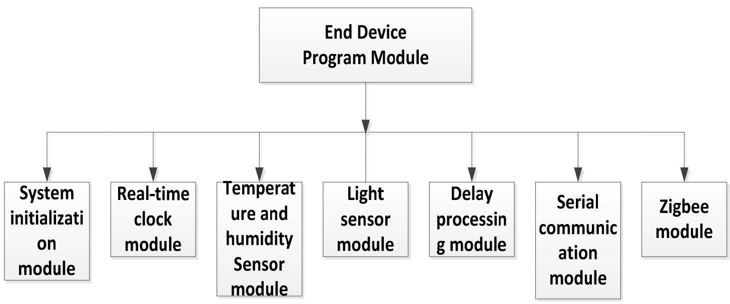

Fig. 8. The frame of end device program module.

As illustrated in Fig. 9, the end device main program flow chart is illustrated in Fig. 9.

1) Initialize the system;

2) Wake up ZigBee to the working status, and collect the home environment information through temperature and humidity sensors and Light sensors;

3) Page the data for wireless communication;

4) Send the pages to the ZigBee module by serial port, and then send these pages to the coordinator by ZigBee wireless communication;

5) Use AT commands to put the ZigBee module into Sleep mode;

6) Configure the registers of microprocessor to put it into Sleep mode.

There are two functions in the main program to realize the requirement. As shown below:

SensorNodeInit(); //System Init

SensorNodeHandleLoop(); //Main loop

SensorNodeInit() realizes the functions of system initialization, delay processing initialization, serial port 1 initialization, temperature and humidity sensors initialization, and RTC initialization. Then the main program goes into SensorNodeHandleLoop(), this function powers on light sensors and wakes up ZigBee, then puts the sensors to collect the home environment information and reset RTC, at last puts the microprocessor into Sleep mode.

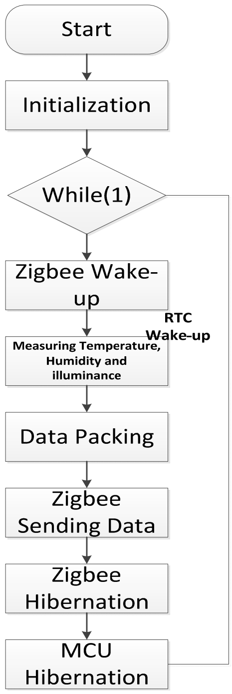

Fig. 9. The end device main program flow chart.

4.2. The Implement of ZigBee Coordinator Software Design

The coordinator software module has some same program modules with the end devices as they use the same microprocessor, as System initialization module, Real-time clock module, Delay processing module, Serial communication module, and ZigBee module. As the coordinator manages the ZigBee wireless network, the main program has two management functions: end devices register and get available data from the pages which are sent by end devices [10, 11].

When there is a new end devices enter the network, the new end device registries itself in the end device list, and configure the parameters to apply the parameters list. The flow chart is shown in Fig. 10.

When the coordinator receives the packages from end devices, the coordinator has to get the available information from these packages. Fig. 11 shows the main flow chart of this approach.

1) Enable interrupt of Serial port, and receive the packages into buffers;
2) Search the available package head(0X55, 0XAA) of a frame, if found, go on searching the available package tail(0X0D, 0X0A), else, keep searching the available package head;
3) If the available package tail is found, process this frame;
4) Verify the CRC of this frame, if available, store this frame in Matrix NodeMessage, else, delete this frame;
5) If the buffers are full, disable interrupt, and clear the buffers;
6) Return to step (1).

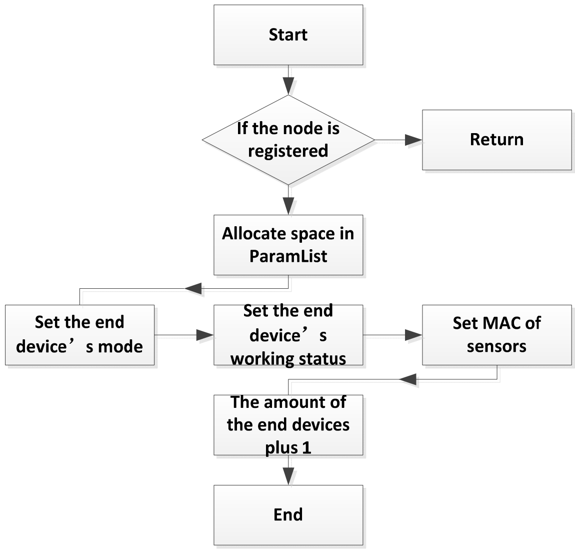

Fig. 10. The end device register flow chart.

5. The Implement of Pre-processing System

The pre-processing system is a software construct developed in JAVA; the pre-processing system is implemented in home gateway for the safety and security of the whole smart monitoring system. All the users’ accesses, communication, and instructions are checked before the operation and implementation in the real smart monitoring system. The program flow chart is shown in Fig. 12.

Before the users get access into the smart monitoring system, they must identify themselves by entering the Username and Password, in this matter, the pre-processing system protects the privacy and safety of this home. After that, the pre-processing system waits for the input. All the ZigBee devices including coordinator and end devices incorporate a dedicated AES Coprocessor. The communications on the smart monitoring system are encrypted. Once the messages payload are received by the preprocessing system will be encrypted [12, 17]. As the encrypted messages are established, the pre-processing system will check the messages safety implementation information. Then pre-processing system will extract the destination address from the messages, the address information will be checked in the devices database for its existence. If the device is available in the system, the pro-processing system will extract the commands from the messages; these commands will be checked for its legal operation. Only after the messages have been processed by the pre-processing system for the safety and security, these messages will be re-encrypted and forwarded to the real devices in the smart monitoring system.

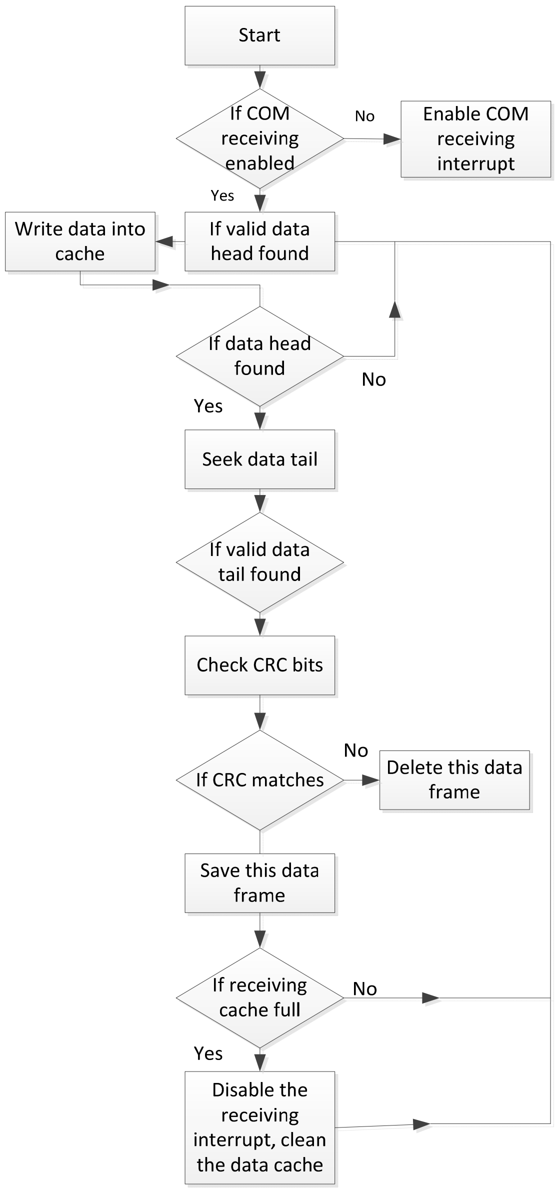

Fig. 11. The flow chart of coordinator processes the packages.

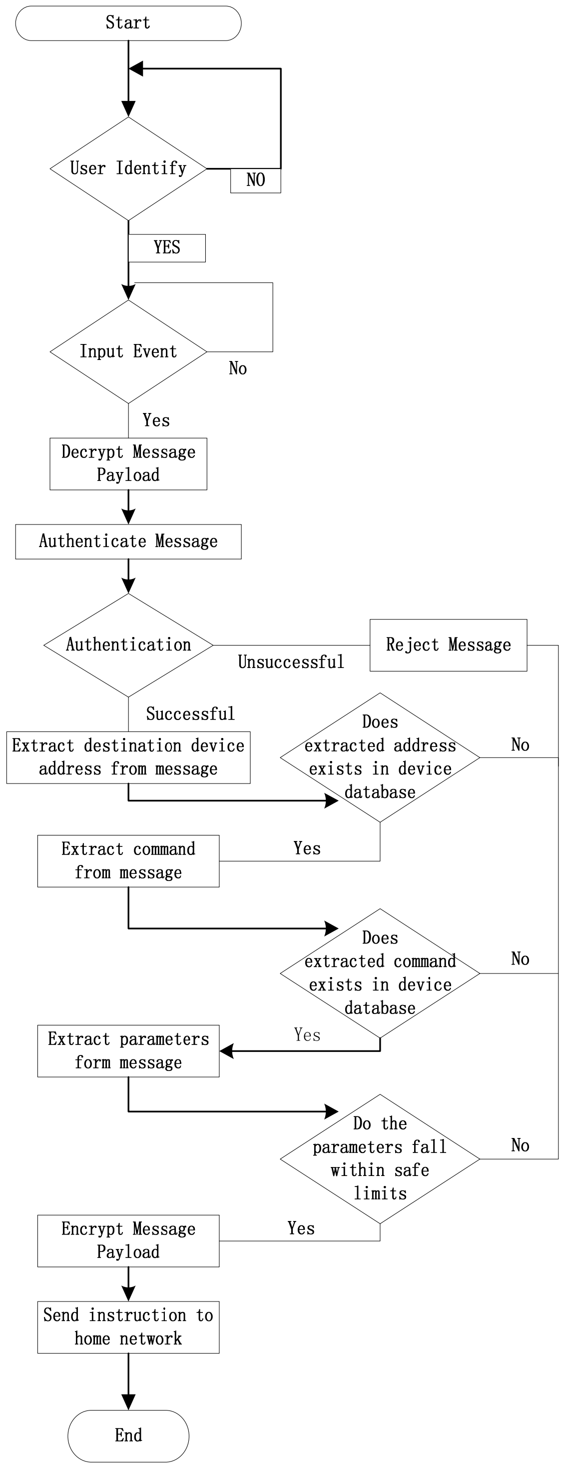

Fig. 12. The flow chart of the pre-processing system.

6. Evaluation

The implement of the smart monitoring system was evaluated in real home environment for both the quantity and the quality. The system was subjected to a 24*7 of strenuous operations at a high level usage. The focal points of the evaluation are end devices consumption, the ZigBee wireless network communication stability.

6.1. SMA Antenna Installation

To guarantee the communication stability and ZigBee signal intensity, in the proposed system, the ZigBee modules add the SMA antennas in the U.FL ports. SMA antenna gains 2dBi signal intensity. The SMA antenna connected line, SMA antenna, and combination of SMA antenna and ZigBee module are illustrated in Fig. 13, Fig. 14, and Fig. 15.

Fig. 13. The SMA antenna connected line.

Fig. 14. SMA antenna.

Fig. 15. The combination.

6.2. The End Devices Consumption Evaluation

To guarantee the flexibility of installation, the end devices are powered by butteries, as so the device consumption evaluation is testing the how long time a battery can support the end devices to work.

At the point the end device is sending the data, it has 31 mA current output; and at the point the end device is collecting the data through temperature and humidity sensor and light sensor, it has 800 uA current output in extra. So the end device at full operation, it has 32 mA current output. For the consumption of the whole end device, many peripheral circuit components had been removed from the ZigBee module, and the current output cut from 0.07 mA to 0.02 mA.

As the battery capacity is QamAh, the end device full operation current output is Iw mA, the end device full operation time is tw s, the end device in Sleep mode working current output is IsmA, and the end device in Sleep mode working time is tss, the battery whole working time is Tds, the calculation formula is the following:

$$T_d = \frac{Q_a \times 3600}{I_w \times t_w + I_s \times t_s} \times (t_w + t_s) \div 60 \div 60 \div 24 = \frac{Q_a \times (t_w + t_s)}{24(I_w \times t_w + I_s \times t_s)}, \quad (1)$$

Base on the formula 1, supposing the battery capacity is 1000 mA, the voltage is 3.3 V, Sleep mode time respectively is 1 s, 5 s, 10 s, 20 s, and 30 s, the whole working time is illustrated in Table 1.

Table 1. The whole working time form.

Testing Parameters	Sleep mode Time (unit: s)	Working Time (unit: D)
Qa=1000 mAh Iw=32 mA tw=0.145 s Is=0.05 mA	1	10.17
	5	43.83
	10	82.23
	20	143.89
	30	204.56

As shown in Table 1, the easiest way to increase the whole working time is putting the end device in long Sleep mode time. But in practical usage, the system used only 1 s and 5 s as the Sleep mode time, and used 2 alkaline batteries as power supply. As illustrated in Table 2, the whole working time in two Sleep mode time modes is shown. And the end device basically met the requirement of daily usage.

Table 2. The whole working time in practical usage.

Sleep mode Time	Beginning Time	Ending Time	Working Time	Calculation Time
1 s	2013-4-15 8:30	2013-4-24 9:16	9D and 1H	9D and 6H
5 s	2013-5-3 10:48	2013-5-13 17:52	37D and 7H	41D and 6H

6.3. ZigBee Wireless Network Communication Stability Evaluation

To test the ZigBee wireless network communication stability, we used 1 coordinator and 10 end devices in one house with 3 rooms. Each end device sent 36 bytes data every 2 minutes. For the test convenience, we marked the 10 end devices from Node1 to Node10. And the results are shown in Table 3.

Table 3. Frame loss rate.

Node NO.	Beginning Time	Ending Time	Actual Sending Frame	Expected Sending Frame	Frame Loss	Frame Loss Rate
Node1	2012-9-2 10:48	2012-9-6 11:51	2876	2881	5	0.17 %
Node 2	2012-9-2 10:49	2012-9-6 11:50	2878	2880	2	0.06 %
Node 3	2012-9-2 10:51	2012-9-6 11:53	2873	2881	8	0.27 %
Node 4	2012-9-2 10:52	2012-9-6 11:54	2874	2881	7	0.24 %
Node 5	2012-9-2 10:52	2012-9-6 11:54	2879	2881	2	0.06 %
Node 7	2012-9-2 10:53	2012-9-6 11:55	2872	2881	9	0.31 %
Node 8	2012-9-2 10:53	2012-9-6 11:54	2875	2880	5	0.18 %
Node 9	2012-9-2 10:55	2012-9-6 11:55	2872	2880	8	0.27 %
Node 10	2012-9-2 10:56	2012-9-6 11:59	2877	2881	4	0.13 %

As shown in Table 3, the end devices frame loss rate are under 0.3 %, because of the Wi-Fi wireless network interference and the walls in the house, as we analyzed. The ZigBee wireless network communication stability met the requirement.

7. Conclusions

This paper has taken a brief review of the existing smart monitoring system, and proposed three brief disadvantages of these systems; they are expensive and complex for consumers, inflexible user interface for consumers to use these systems, and ignoring the security of the system to protect the consumer's privacy. To face these disadvantages, this paper proposes architecture for smart monitoring system based on ZigBee wireless sensor network. Through using ZigBee technology, the smart monitoring lowers the expense of the system and complexity of installation. The home gateway incorporated with pro-processing system concept the system security and safety. The proposed home gateway provides interoperability between ZigBee network and Wi-Fi network and the Internet, this method provides flexibility user interface. Testaments have shown the stability of the proposed system, including the power consumption evaluation and ZigBee wireless network communication stability evaluation. Through the evaluation the co-existence and interoperability of Wi-Fi and ZigBee have been proved successfully. For the potential of this system to be used in consumer's home, a more nicely user interface constructed developed in JAVA should be implemented.

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