Novel plug-configure-play ZigBee-based smart home system

CHEN Yan-ming(陈彦明)[1], DIAO Bo-yu(刁博宇)[2], ZHAO Qing-jie(赵清杰)[1,✉], XU Yong-jun(徐勇军)[2]

(1. Beijing Key Laboratory of Intelligent Information Technology, School of Computer Science, Beijing Institute of Technology, Beijing 100081, China;
2. Institute of Computing Technology Chinese Academy of Sciences, Beijing 100190, China)

Abstract: The key purpose of a smart home system is to provide people with a better indoor life experience using the technology of Internet of Things. However, there are some limitations which make the current smart home system impractical, such as high cost, complex installation, poor flexibility and maintainability. In this paper, a novel plug-configure-play ZigBee-based smart home system is proposed to provide repeatable use and improve flexibility and maintainability with the reductions of cost and complexity, which can be customized and reconfigured without redevelopment. In this system, new sensors can be flexibly added through different interfaces on the ZigBee nodes and the sensor network layer is transparent to the users. Therefore, by using our method, users can customize and use the smart home system simply by configuring the sensors information via software on the application layer.

Key words: Internet of Things; smart home; plug-configure-play

CLC number: TP 393.2 **Document code:** A **Article ID:** 1004-0579(2016)02-0264-07

Smart home is one of the most emerging and important application domains in the Internet of Things. The typical architecture of a smart home system consists of three layers: sensor network layer, smart gateway layer and application layer. The sensor network layer enables "things" to be identified by a variety of sensors. These sensors communicate with each other through ZigBee, WiFi, Ethernet, Bus, 3G/4G, RFID or others in the gateway layer. The sensor data can be utilized by users in the application layer. The three layers together form an application scenario of the smart home.

But there are many factors that limit the development of the smart home system. Studies show that high cost, inflexibility and poor manageability are three main factors to prevent the smart home systems from wide application[1-2]. Thus reducing cost is an important factor to be considered when a smart home system needs to be developed. On one hand, reducing development cost is an effective method to reduce the whole cost of the system. However, despite some existing research, current developments mainly focused on providing personalized services for users in the application layer[3-6], they hardly mention how to reduce the development cost. On the other hand, it is also a key issue to integrate non-intelligent fitments from an ordinary home to a smart home system while at the same time reducing the hardware cost. If this problem can be solved, the traditional families would enjoy the

Received 2014-11-24
Supported by the National Natural Science Foundation of China (61175096, 61303245, 61173132); Specialized Fund for Joint Building Program of Beijing Municipal Education Commission
✉ Author for correspondence, professor, Ph. D.
E-mail: zhaoqj@bit.edu.cn
DOI: 10.15918/j.jbit1004-0579.201625.0215

convenience of smart home products and do not need to replace the non-intelligent fitments with intelligent ones, which will greatly reduce the hardware cost and expand the application market of the smart home system.

In order to reduce hardware and software development cost in smart home system, in this article, we present a plug-configure-play system to reduce development cost in both application layer and sensor networks layer of the smart home. "Plug-configure-play" is a variation of the term of "Plug and Play". It includes two aspects. Firstly, sensors can flexibly plug into interfaces of ZigBee nodes, system installers or users just need to configure the sensor information without sensor driver redevelopment, then sensors can work normally and the whole smart home system will work. Secondly, a smart gateway which is not designed for specific kinds of sensor networks or applications can be implemented. It provides different interfaces such as Ethernet, 3G/4G/WiFi or universal asynchronous receiver/transmitter (UART) Bus, etc. It can reduce the complexity and overall cost of the system, and realize the user-friendly development by using different interfaces for different applications.

The remainder of this paper is organized as follows. In Section 1, the related work is briefly discussed. In Section 2, architecture of the smart home is presented. In Section 3, some example systems using low-cost plug-configure-play ZigBee-based smart home system are shown, and the last section presents conclusions and future works.

1 Related work

In recent years, there has been a lot of research related to smart home systems and applications. Wu et al.[7] proposed a service-oriented architecture (SOA) for smart home environments, based on Open Services Gateway Initiative (OSGi) and mobile-agent (MA) technology. Their main contribution is to propose a software solution based on service-oriented architecture. Considering the limited characteristics of sensors, Byun et al.[8] designed and implemented a ZigBee-based intelligent self-adjusting sensor for home energy management service. But they mainly concern energy consumption of the system. Han et al.[9] introduced smart home interfaces and device definitions to the smart home systems, in order to allow the interoperability among different ZigBee devices produced by various manufacturers of electrical equipment, meters, and smart energy enabling products. Their main work is to design a practice system for demand response and load management "Smart Energy" applications needed in a smart energy based residential or light commercial environment. Rashidi et al.[10] introduced an adaptive smart home system that utilizes machine learning techniques to discover patterns in resident's daily activities and to generate automation strategies that mimic these patterns. The biggest highlight of their work is using machine learning methods to design smart home.

Compared with the existing related research, this paper focuses on designing and implementing a plug-configure-play ZigBee-based smart home system. This paper not only puts forward a smart gateway which can be configured according to different applications, but also presents a framework in which users can customize their own smart home system according to individual demands. Meanwhile this article does not specify in the protocol standard, so the software implementation can be chosen according to different applications. Of course, you can use the OSGi technology as mentioned in Ref. [7]. Because the smart home systems have a characteristic of individual differences, the hardware and software needs may be different for different applications. But our system can satisfy a variety of applications, and greatly reduce development cycles and the cost of smart home in aspect of the software and hardware development.

2 Architecture of smart home

In this section, a novel plug-configure-play ZigBee-based smart home architecture is presented. In detail, Fig. 1 shows an overview of the system. The sensor networks layer includes ZigBee nodes, various household sensors and actuators. The system adopts a true system-on-chip (SoC) solution CC2530 chip for IEEE 802.15.4/ZigBee chip [11] as a ZigBee control node and uses the ZigBee protocol to connect sensor nodes to the smart gateway. ZigBee nodes can form different network topologies according to the realistic home environment. The smart gateway layer includes a smart gateway node which was first proposed by G. Shang et al [12]. The smart gateway node is composed of a database, the hardware and a service-oriented middleware. The database stores the sensors' types, sensor data and association rules, which is a necessary component for the ability of plug-configure-play. The middleware manages sensor network nodes and provides a simple interface for the application layer. The application layer consists of a web application and a smart phone application. Users can subscribe to different services according to their need. For example, they can subscribe to an alarm event produced by the smoke detector. They can get the real-time information about the house such as the temperature, the humidity and the energy consumption. They can also control the household appliances such as lamps, TV and air-conditioner. Multiple modes are provided for users to achieve intelligent management with just a simple click.

2.1 Sensor networks layer

This layer consists of a number of nodes which contain a variety of sensors. It contains kinds of sensor nodes, such asthe smoke detector, the environmental sensor etc. But in order to shield the variety of different hardware in the low layer, this paper uses a hardware abstraction layer which provides a unified interface to the top layer. It can simplify the design of the application layer.

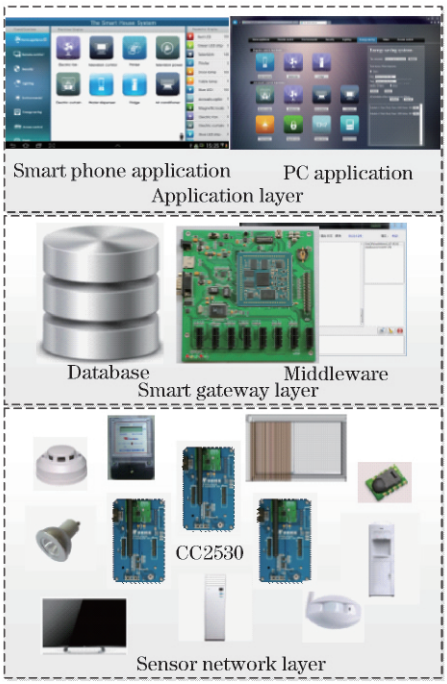

Fig. 1 Architecture of the smart home system

2.1.1 Virtual nodes

For smart home applications, a node may control a plurality of types of sensor at the same time, forexample a node controls multiple lamps. This will not only reduce the amount of hardware which is beneficial to control the overall arrangement of smart home, can also reduce the overall hardware cost. In addition, in order to better distinguish the different lamps and show the different nodes position in the upper position, this paper uses a concept of virtual node [13]: a physical node maybe have many virtual addresses to map different virtual nodes. Sensors may be arranged on different virtual nodes. As it is known, ZigBee compliant chip has a 64-bit IEEE address for its physical address. This paper uses a changed 8 bytes physical address where the highest byte physical address is replaced by a virtual ID, and other seven bytes remain unchanged. As shown in Fig. 2, this article uses 5 different IEEE addresses to represent different virtual nodes. For example, the address of the temperature virtual node is the address of 0x01124b0001a9a0ef in Fig. 2. Addres-

ses for the other virtual nodes, only the first byte is different. Obviously by using the virtual node technology the cost of the smart home system can be reduced.

2.1.2 Pin configuration protocol

The basic sensors interface types are including general purpose IO (GPIO) interface, UART interface, Serial Peripheral Interface (SPI) interface, Inter-Integrated Circuit (I2C) interface, etc. This paper uses virtual nodes to represent different sensor nodes. When adding a new physical node, user needs to register a virtual node and configure the sensor type, the sensor connection port pin information, the sensor virtual address and other information.

When sensors are plugged on a node, the sensor information of the node is configured as shown in Fig. 2. The information includes node address, node name, and GPIO pins used by sensors.

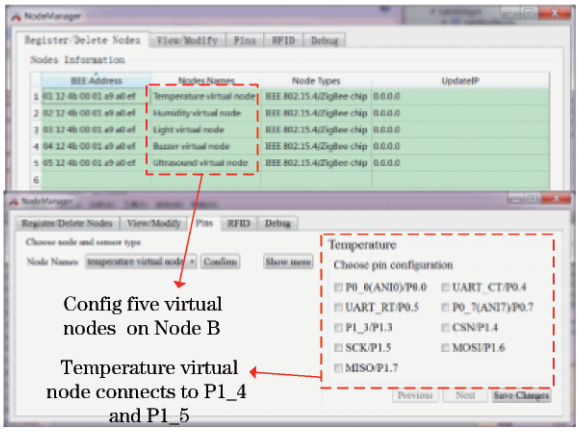

Fig. 2 Configuration of the sensor information

After being configured, normally the sensors can work. Nodes will collect sensor data and transmit data to the gateway, and then the demo software shows sensor data in graphic user interfaces. For example, the four sensors including temperature, humidity, light intensity, and ultrasound ranging are mounted on Node B. After being configured as shown in Fig. 2, four sensors on Node B can work. The data from four sensors will be collected and shown in the demo system.

2.2 Smart gateway layer

This paper uses a smart gateway which we had proposed [12]. It is a novel configurable smart gateway which has three important advantages. First, the gateway has a pluggable architecture. It can choose different inserted modules according to the different application requirements and communication protocols. Secondly, it has unified external software and hardware interfaces which are fit for flexible development. Finally, it has a flexible protocol to translate different sensor data into a uniform data format which simplifies the development of applications. Based on those characteristics mentioned above, the proposed system can reduce development cycle of new systems, thereby reduce the cost of systems, and also has better flexibility and scalability than similar systems.

As shown in Fig. 3, the smart gateway provides eight unified user interfaces. In practical applications, different user cards have be designed in the form of standard Bus interface (miniPCIe). This design makes the connection and replacement with the user cards easily. And there are many communication interfaces between gateway and the user cards, such as SPI interface, UART interface, Ethernet, USB, audio/video interface and I2C interface. Users can configure the smart gateway with different user cards according to different application requirements.

2.3 Application layer

Application layer consists of multiple application platforms including home PCs, smart mobile phones, etc. In the home PC, control center software is constructed under Browser/Server (B/S) structure. Anywhere, as long as you have a browser that does not require any configuration, you just need to login it, then you can access the control center and get information about the real-time situation in the house. All these operations are implemented based on a security password. Software is mainly based on .NET framework which

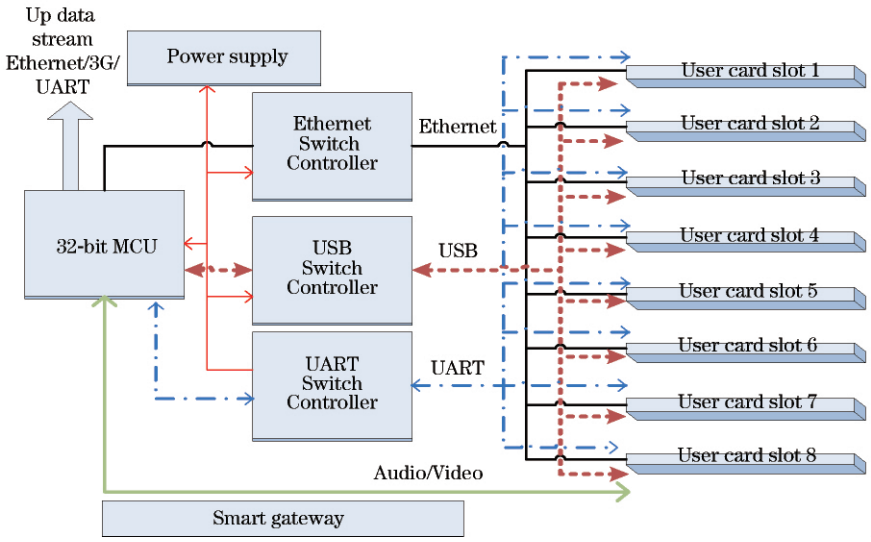

Fig. 3 Hardware structure of smart gateway

can provide a much more rich display effect. This paper also develops a mobile control center software system on android smart phones. Anything you handle on the home PC, you can handle it on an android smart phone. You may carry a smart phone with you at any time. A smart phone is a convenient interface to access the smart home.

Most of smart home systems mainly focus on sensing and adjusting certain kinds of environment arguments such as the temperature or the humidity. The main goal of it is to provide a comfortable home environment for users, but this smart home model seems to be unable to meet the needs of all people. Security and indoor behavior recordings are two important applications which need to be added to the smart home system. All these problems will be solved in this paper.

Issues related to security in the house, people primarily think of theft-proof and fireproof. In the proposed smart home system, a sensor subscription system is designed and implemented. Once the sensor is triggered, the control software will send a warning by short message service (SMS) to your smart phone. In this way, you can subscribe via the magnetometer sensor to monitor the illegal opening of windows and doors, or you can also subscribe via the smoke alarm to monitor gas leakage etc. Once the system is in the abnormal situation, you will get the warning at the first time from your smart mobile phone, and everything is in your hands.

Our proposed system has a set of behavior recording mechanisms to record indoor behaviors related to the smart home. Through a variety of sensors, RFID radio frequency controllers, and efficient fusion algorithms, you can record a variety of behaviors in the room. For example, when the user goes out or comes home, the length of time the user spends in each room, power consumption records and forecasts, etc. The data are stored offline in the software of control center, and you don't need to worry about privacy problems. Recording these indoor activities can help you understand what you do at home. It is essential to form a vital and healthy living habit.

3 System demonstration

The proposed system has been applied to many practical projects. According to the implementation, it is clear to see that the proposed system is not only easy to install and configure, but also has a lower implementation cost than others system. A brief presentation of the system implementation is listed as follows. The system is composed of eight sub-systems which are consisting of the home appliance system, the remote control system, the environmental system, the security system, the lighting system, the energy-saving

system, the video system, and access control systems, respectively. Different sub-systems have different subordinate functions. Fig. 4 shows the interface of the energy-saving function. Meanwhile, the system has two control modes: the regular mode and the automatic control mode. By inputting the time and date in time and data box, you can set the appropriate regular schedule. Regular schedule information of all devices can be seen on the right setting box, you can choose and click the "Delete" button to remove the regular schedules which you want to delete. Automatic control mode allows the devices to run automatically. For example, when the light is greater than the set value, the automatic curtain controller will automatically shut the curtains, or when the light is less than the set value, it will automatically open the curtains. In the smart home system, following devices can carry out automatic control operation including curtains, fans, air conditioners, television switches, door lights, magnetic locks, etc. More examples, fans can be linked with a smoke detector; air conditioners can be linked with temperature and humidity sensors; door lights can be linked with pyro-electric infrared sensors; magnetic locks can be linked with RFID readers.

Fig. 4 Energy-saving function

In order to support the point that the proposed smart home system can reduce development cost, this paper lists the number of sensor nodes used in three different actual projects. Fig. 5 shows the number of sensor nodes without using virtual nodes technology (NSNWV) and the number of sensor nodes using virtual nodes technology (NSNUV) used in three projects. As shown in Fig. 5, it can be seen that the proposed smart home system can decrease hardware cost. Meanwhile it can reduce software development cost. For example, project I used 2 months for software development. Because of the use of a configurable architecture, project II and III only need to modify parts of the system. They shorten the development cycle for the two weeks and one week respectively. From the implementation of these projects, it clearly shows that the proposed smart home system can greatly reduce the cost of hardware and software. So it can effectively reduce the consumers´ cost.

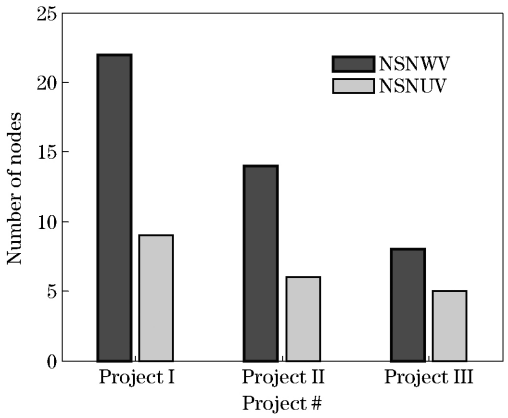

Fig. 5 Comparison NSNWV vs NSNUV

Based on the illustrations above, we can conclude that the proposed system has many advantages such as reducing the hardware cost, easy-to-secondary development and so on. Moreover, our proposed system can greatly satisfy the different needs from different users.

4 Conclusions and future works

As is well known, smart home is an emerging important application domain in the field of wireless sensor network. But many factors limit its development such as high cost, complex installation and deployment, low flexibility and maintainability. This paper presents a novel plug-configure-play ZigBee-based smart home system with

goals of reducing cost, deployment complexity and repeatable development, improving flexibility and maintainability. In this paper, there are several innovations in smart home applications:

①This paper proposes a plug-configure-play smart gateway. The gateway can do a simple hardware configuration according to different application needs, without re-designing the new hardware;

②In the smart home system, the paper proposes the concept of virtual nodes. Using virtual nodes it can reduce the number of actual nodes, further reduce the hardware cost and system energy;

③The proposed system software can support the subscription feature which can provide intelligent processing according to the different needs of different users.

In the future work, security policy and fault-tolerant strategy should be added in the proposed smart home system, to make it more stable and reliable.

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(Edited by Wang Yuxia)