

國立交通大學

電控工程研究所

碩士論文

設計與實作適用於傳統紅外線家電之低功率

無線智慧型控制器

Design and Implementation of Low-Power Wireless Intelligent

Controller for Legacy IR Appliances



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中華民國一百年九月

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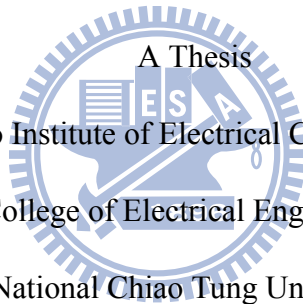
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碩士論文



A Thesis

Submitted to Institute of Electrical Control Engineering

College of Electrical Engineering

National Chiao Tung University

in partial Fulfill of the Requirements

for the Degree of

Master

in

Institute of Electrical Control Engineering

September, 2011

Hsinchu, Taiwan, Republic of China

中華民國一〇一年九月

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摘 要

智慧型住宅(Smart Home)技術與寬頻網路的日漸普及，帶動了智慧型網路家電產品的發展。但是目前大多數人都仍然還在使用那些非網路的傳統家電設備(Legacy Home Appliances)。其中有幾個關鍵的原因如產品價格、網路的互通性以及使用者習慣的問題，使得智慧型網路家電設備一直沒有辦法被廣泛使用。因此，配合家庭網路系統來控制傳統家電設備的概念因應而生。許多專家學者也開始針對傳統家電設備提出了各種不同的控制方法和流程。然而，這些針對傳統家電設備所提出的控制方法卻缺乏系統化、全面性的控制程序。因此，在這篇論文之中，我們引入網路分層的概念，提出了一套控制傳統家電設備的三層網路架構。在架構的最上層，我們設計一個介面供使用者控制和管理傳統家電。而中間是屬於網路傳輸層，主要是使用一些通訊技術來接收和傳送資料。而最底層則定義實體的傳輸媒介處理控制訊號的學習及轉換。我們的控制對象鎖定為能接收紅外線訊號的傳統家電。隨後，我們以無線電模組(TI CC2500)及紅外線收發模組(IR Transceiver Module)做為系統中主要的資料傳輸介面，並實際佈置一個簡單的住家場景，透過我們所提出的架構來管理與控制傳統家電設備。

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Abstract

With the popularity of smart home and broadband networking technologies, more and more networked modern home appliances are researched, developed and promoted. But, the expensive cost and bad interoperability make modern intelligent devices a bad replacement for non-networked legacy home appliances. Hence, many diverse control methods and intelligent control flows are proposed to control legacy home appliances using the existing home networks. However, these methods are lack of a systematic control procedures, including device registration, communication and signal conversion. In this research, we propose an architecture for controlling legacy home appliances by using 3-layer network model. The model consists of upper (users), middle (networking) and lower (devices) layers. The upper layer designs interfaces for users to register and control legacy home appliances. In the middle layer, two or more networking technologies are hybrid to send and receive control commands from users. Then, methods to learning and converting signals are defined in the lower layers. In our system, only infra-rad (IR)-based legacy home appliances are installed in a home environment. After learning the IR signals of legacy appliance, users can control these devices via the user interfaces provided in the upper layer. Then, we adopt RF modules (TI CC2500) and IR transceiver modules to forward commands between the users and the legacy home appliances.

誌謝

本論文能順利完成要感謝很多人的幫助，首先感謝指導教授黃育綸博士在這碩士兩年多的時間裡，給予相當自由的研究空間，並認真和耐心地教導我，培養我正確的研究方法，尤其是在任何事情的完整性、邏輯性等，讓我受益匪淺。

另外，還要感謝實驗室的同儕不僅在課業方面，也使我在這段兩年的研究生生活中逐漸成長茁壯。博班的學長姐蔡欣宜學姐以及陳柏廷學長，非常感謝兩位學長姐在論文、口試以及計畫方面的幫助。另外感謝甄元斌學長、黃啟彥學長、吳嘉祺學長、王雅萱學姐、吳思穎學姐、彭博群學長等；同屆的好友黃奕奇、許鴻生以及黃晉澤；還有學弟妹們包括賴鈺婷、葉書宏、李勇叡、陳玟煊等人。另外要特別感謝和我一同從電工進入電控所同學黃錦銘，在我的研究方面給予我很多的幫助。實驗室的研究生生活因為有了你們，變得更加多采多姿。

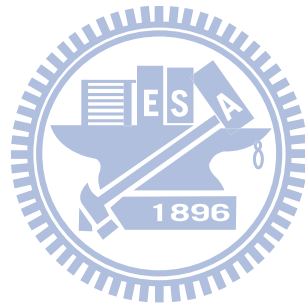
最後，感謝我的家人們這些年來在背後默默的支持及鼓勵。感謝父母總是在做決定時給予我絕對的自由，讓我的求學生涯一路順遂，並期許自己在將來能更加精進。

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Chapter 1

Introduction

A Smart home is also named as an intelligent home, home automation, electronic home (E-home), digital family, network home or intelligent building [1] [2] [3] [4]. Smart home, based on home automation, is implemented via simulating human needs. Exploiting advanced computing technologies, network communication and routing techniques, home appliances are systematically connected together. Comparing with traditional home environment, passive and stationary machines become automatic devices with intelligence providing all-purpose message exchanging functionality.

The goal of a smart home is to provide better life quality through a multimodal intelligent control system embedded in a home environment. Applications and services that a smart home provides are extensive, including home appliance automation, health care (home care) [5], home security [6], remote-controlled management and maintenance on home appliances, home energy management system [7]. However, this thesis focuses on home appliance automation. This chapter introduces the definition and elements of a smart home. We also discuss the new technologies and challenges for a smart home communication network.

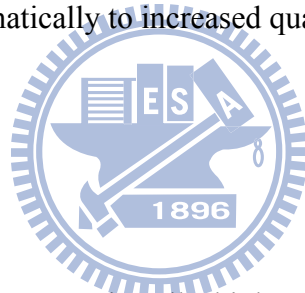
1.1 Definitions and Elements

In Department of Trade and Industry (DTI) Smart Home Project, a smart home is defined as "a dwelling incorporating a communications network that connects the key electrical appli-

ances and services, and allows them to be remotely controlled, monitored or accessed." In the definition, "remotely" means both inside and outside the dwelling [8].

Mainly, a smart home consists of three major elements, including an internal network, a intelligent control system and a home automation system [2]. The internal network the basis of a smart home is a home networking system. Such a network, either wire or wireless, is in charge of communication of home appliances, and it can be power-line, bus-line or radio frequency. The intelligent control means the gateway, routing rule or protocol to manage the home network systems. The main purposes is to bridging different technologies within the home and providing access from the home to external services or from external systems to home. The home automation means those appliances within the houses are linked to the services and systems outside the home automatically to increased quality of life.

1.2 Challenges



Building up a house smart means to install a high tech communications network in a house, which allows various systems and appliances communicate with each other. Comparing to the OSI model [9], the smart home communications network technologies can be classified into three layers, which is also called smart home model, show as Figure 1.1.

In a smart home model, the low layer represents physical communication technologies, such as Ethernet, RF, Infra Red (IR) and Bluetooth. The middle layer is responsible for packet processing and routing. The upper layer is devised for applications. User-end to device-end communication interfaces are realized at this layer.

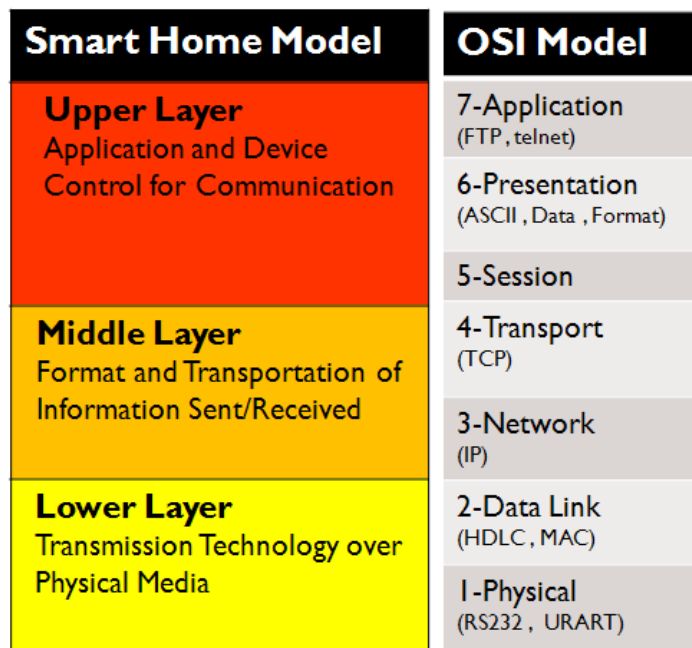


Figure 1.1: OSI model vs Smart Home Model

1.2.1 Technologies for Communications Network

Lots of industrial standards designed for smart homes have been proposed. Some common technologies of communications network are developed by several familiar alliances, such as Digital Living Network Alliance (DLNA), ZigBee Alliance, UPnP Forum and Echonet.

These alliances include consumer electronics, mobile, PC corporations etc. They develop their own communication standards depending on their proprietary technologies and applications. For example, standards made by DLNA(Digital Living Network Alliance) [10] focuses on multimedia entertainments. ZigBee Alliance [11] applies low-cost, low-power wireless technologies (IEEE802.15.4) to home automations. UPnP(Universal Plug and Play) Forum [12] aims at making devices linked seamlessly and simplifies implementation of home networking systems.

1.2.2 Challenges

Accompanying with developments of the emerging communication technologies, designs of modern home appliances are gradually linked to home networking systems. These home appliances are usually called networked appliances. In generally, networked appliances are equipped with smart embedded devices, including a network interface, a processor and a storage device. The purpose is making networked appliances capable of executing application programs and services in home networking systems. Due to downsizing, prices reduction and energy-saving of embedded devices, all appliances networkized can be imagined in the future.

However, transition to networked appliances is an incremental and slow process. Most people still use non-networked legacy home appliances now. Several determinant factors make networked appliances not widely deployed. First of all, because networked home appliances are equipped with embedded devices, prices of these appliances are even higher than the legacy counterparts. Many manufacturers also consider their market value. If the market value is not appealing enough, the product will not be deployed. Hence, commercially available products are very rare.

Another determinant factor is the interoperability problem, the integration of networked appliances are limited especially in the multi-vendor environment. The key factor that a user keeps using original appliances is the user's habits. Changing from legacy home appliances era to networked appliances era is not easy. Thus, many researchers start conducting researches and inventions on automatic control for legacy home appliances.

1.3 Existing Solutions

Recently, quite a few researches are conducted on control and management of legacy appliances. For example, in 2006, M. Nakamura et al. designed a web based remote control [13]. They focus on designs at application layer. The overall architecture takes software as basis, so application programming interfaces (APIs) are defined for different platforms. The software modules design based on the API can be inter-operated in the manner of web services.. However, we consider that data transfer at physical layer is incomplete. Another researches focus on control and management at middle and lower layers. For instance, in 2007, W. K. Park et al. designed a ZigBee based universal remote control [14], which replaces infra-red remote controller with ZigBee. In 2010, a utility model patent about using wireless virtual IP to make infra-red devices available in a wireless network system has been proposed [15]. The purpose of their design is to control infra-red home appliances over a wireless network. We consider that these researches and inventions on control and management of legacy home appliances are not intact systems.

1.4 Motivation


In a dwelling environment, most legacy home appliances are controlled and managed via corresponding remote controllers. Transmissions of most of these remote controllers are based on infra-Red (IR) signals. Therefore, we define legacy home appliances as home appliances which receive IR signals and do not have network interfaces.

In this thesis, we introduce layers notion to proposed architecture based on a three-layer smart home model (Figure 1.1) and propose corresponding control and management mechanisms in different layers. These mechanisms are integrated into an intact system. We consider

that designing a intelligent control system for home appliance. Compared to the previously mentioning model, such a model might be limited on legacy home appliances.

In our design, home gateway are installed at the upper layer to support user interfaces. At middle layer, wireless personal area network (WPAN) is used to support infra-red communication, helping long distance transmission and obstacle bypassing to control legacy home appliances. In the field of short-range wireless communication, especially the wireless remote control. Therefore, the lower layer we designed is equipped with infra-red transceiver modules, providing communication interfaces between our system and legacy home appliances. We ultimately realize the proposed architecture with the implementation of a wireless network module and a infra-red transceiver module, eZ-Red.

1.5 Synopsis



The remainder of this paper is organized as follows. Chapter 2 introduces the Infra-Red signal specification. Related works, which designed to solve legacy home appliances control problem, are described in chapter 3. Chapter 4 presents the proposed model and chapter 5 discusses our implementation in detail. Finally, conclusion summarizes our research in chapter 6.

Chapter 2

Infra-Red Control

Principles, characteristics and applications of infra-red are illustrated in this chapter first. Then, operation of infra-red remote control comes after. Finally, the way we use infra-red remote control signal is explained at the end of this chapter.

2.1 Infra-Red

Infra-Red (IR) is one of electromagnetic waves used in wireless communication technologies. Its wavelength is between 0.76 μm to 1 mm . This wavelength is out of visible spectrum, so IR belongs to invisible light. There are many IR applications and can be classified into two categories, un-modulated IR signal and modulated IR signal [16]. Un-modulated IR signals are common used for temperature sensing. Modulated IR signals are normally used in wireless remote control and data transmission of home appliances or digital products. Our research focuses on modulated IR signals.

Modulated IR signals of home appliances are mainly used with wireless remote control. A remote controller is the typical example. Wireless remote control includes a transmitter and a receiver. Operating components are IR light-emitting diodes (IR led) and IR sensors. In next section, operating principles of transmitters and receivers in remote control are illustrated in detail.

2.2 IR Remote Control

An IR remote control uses modulated IR signals. Transmitters and receivers operation as described as follows. First, transmitter-end emits infrared-ray emitted via IR led, and uses harmonic waves produced by oscillators as carrier waves to emit particular waves. In general, the frequency of the carrier waves is about 38 to 40kHz. This procedure is called IR modulation and shown in Figure 2.1.

At the receive-side, a receiver uses an IR sensor to receive emitted infrared-ray and evaluate luminance of emitted infrared-ray to produce corresponding electric currents. Other post-processing like magnifying signals by operational amplifiers is carried out by gather information from IR signals.

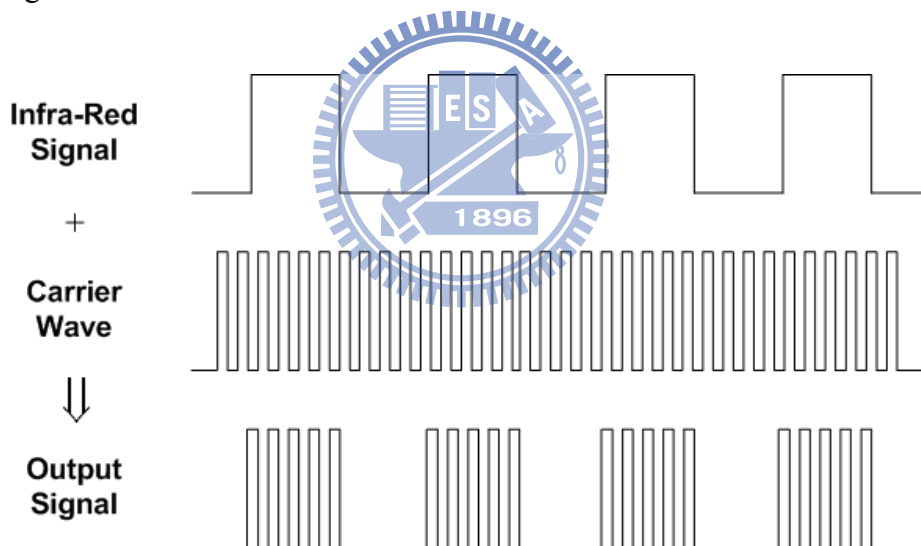


Figure 2.1: Infra-Red Signal Modulated

Normal domestic remote control devices require multiple control commands, so coding on an IR signal is necessary. When coding, coding chips are used to produce digital waves and superimpose these digital waves on carrier waves. Then, IR led emits these combined waves. Coding chips produced by different manufacturers have different IR control protocols. For example, Philips RC-5 protocol, NEC protocols and so on [17] [18].

A typical frame structure of IR remote control signal is shown in Figure 2.2. In general, IR

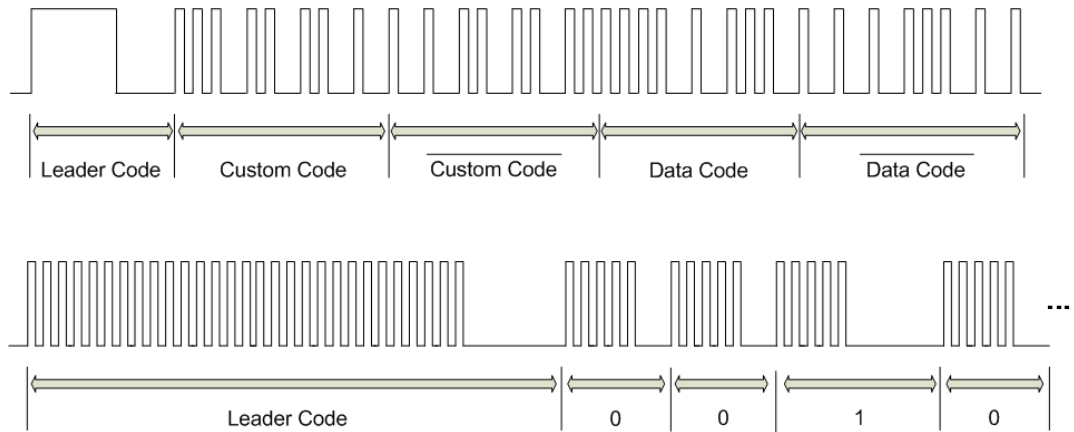
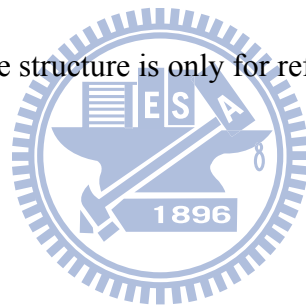


Figure 2.2: Typical frame structure for IR control signal

remote control signals are composed of leader code, custom code and data. Leader code indicates the start point of an IR signal. Custom code is used to represent manufacturer code. Data represents the pressed button on remote controller. These codes are defined by each manufacture alone. In other words, this frame structure is only for reference.



2.3 Summary


An IR remote control uses infrared-ray as its transmission media. IR has many merits like high noise-resistance, reliable message transmission, low-cost and low-power. Accompanied with these merits, IR is widely used in remote control of home appliances. However, developed by various different manufactures, the format of IR remote control signal is difficult to be adopted into a smart home system. Besides, IR is limited by its light property. It cannot penetrate most of obstacles. Its track should be straight. These limitations put impact on the development of integrating legacy home appliances into a smart home. In next chapter, several researches on legacy home appliances control are stated in company with different pros and cons.

Chapter 3

Related Work

In this chapter, three related research related to home appliance control are discussed. The controlled subject is locked on the range of legacy home appliances. Web first take control and management methods on home appliances in the beginning [13]. Then, the design scheme of ZigBee based remote control is introduced [14]. Last one is a utility models patent, which merges infra-red control into wireless network [15].

3.1 Web-based Remote Control



In 2006, Nakamura et al. presented a framework to adapt the legacy home appliances with an IR remote control to an emerging home network system. Nakamura used the concept of service-oriented architecture (SOA) [13] [19] to improve programmable interoperability among multi-vendor legacy home appliances.

First, a traditional legacy home appliance control method, using PCs or handheld devices such as handy phones is adopted. Figure 3.1 shows an example using traditional method to control a legacy TV. A user selects and executes a control command through the user interface (UI). Then, the proprietary application sends the corresponding infra-red signal to the legacy TV through driver and the interface of the infra-red remote controller (denoted by IrRC). The limitation of this method is that, the appliance and the application are tightly coupled. The same controller cannot be used directly for other appliances. Therefore, Nakamura et al. exploited SOA

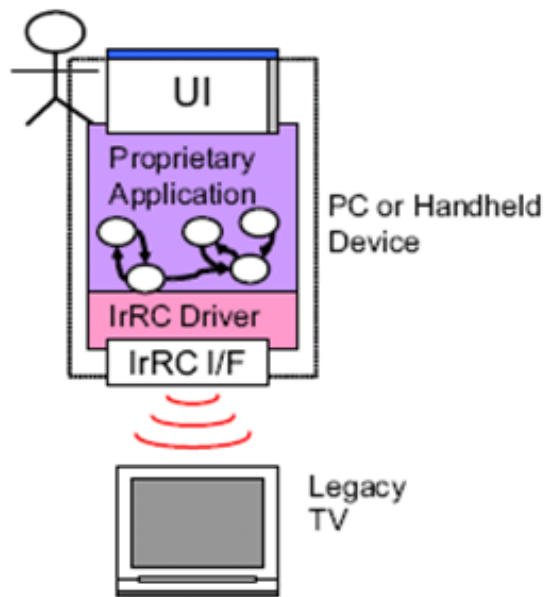


Figure 3.1: A soft-controller for a legacy TV [13]

concept to implement multi-vendor appliances control in a home networking environment [20]. SOA is a system architecture that facilitates flexible integration of a distributed heterogeneous system. That is, all programs and contents are wrapped in services, and a standard interface is implemented to encapsulate inconsistencies.

As shown in Figure 3.2, Nakamura develop a set of Ir-APIs that assist a mini PC to send infra-red signals to the legacy appliances. Then they aggregate the multiple Ir-API within self-contained service components, which achieve a logical feature independent of the appliance specific operations. For every service, components implemented at the service layer are strictly typed by a XML-based language, called web services description language (WSDL). Finally, the service components are exported to the home network system as a Web-API with web services. Thus, the legacy appliances can be used as distributed components in the network system. By combining these components, the user can assemble various integrated services. Furthermore, they also implemented the actual home network system with multi-vendor legacy appliances to verify their proposed framework.

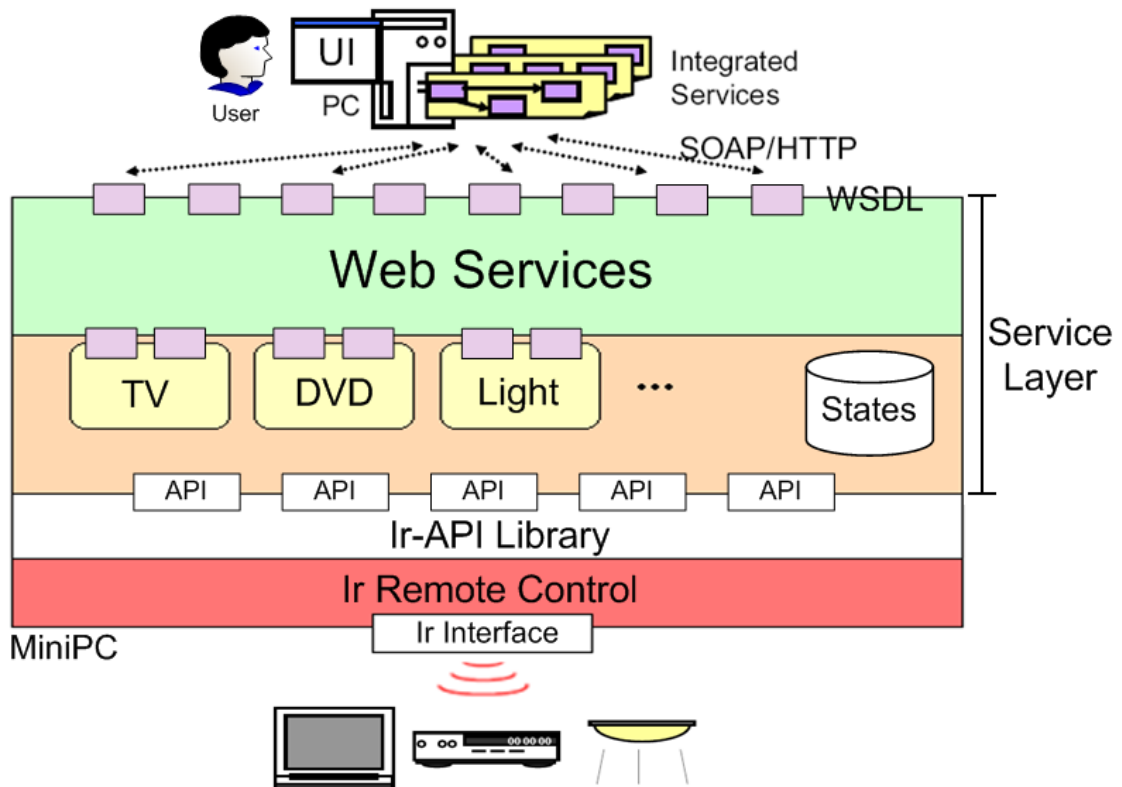


Figure 3.2: Proposed architecture for adapting legacy appliances using web services

Base on the SOA technology, web services provide services through standard web protocols to ensure that applications running on different platforms can be interoperated [19]. With this characteristic, the framework proposed by Nakamura et al. extensively reduces interoperability problem at the upper layer. Also, the framework is applicable to wide range of types and vendors of the appliances. However, the limitation of Nakamura's framework is the reliability of the lower layer (the physical channel between an IR remote control interface and the appliance). We consider the insufficiency comes from device combining the system and infra-red remote controller. Once the amount of appliances becomes much more, constructor should spend more cost on purchasing more mini PCs, as shown in Figure 3.2, ensuring accurate control. Another shortcoming is that, their user interfaces are not user-friendly. The author's web APIs are written in XML format, encapsulated using SOAP and transmitted by HTTP. If self-implementation is needed, users should understand XML format first. Also, the ability of programming is part of

requirements. These requirements are tough for normal users.

3.2 ZigBee based Remote Control

In 2007, Wan-Ki Park et al. proposed a novel ZigBee based universal remote control system to control and manage multiple IR-based legacy appliances. The scheme is based on IEEE802.15.4, especially ZigBee protocol [14].

There is two types of main components used in this scheme. One is a universal remote control using Zigbee based wireless network technology, called Z-URC (ZigBee based Universal Remote Control). All control commands used to control the multiple legacy home appliances are generated by this single Z-URC unit. Z-URC operates as a ZigBee coordinator in the scheme. Another component is the conversion module, called Z2IR (ZigBee to Infra-Red), converting IR and ZigBee signals. A Z2IR used to convert a control message transferred through the ZigBee wireless network into IR typed signal. The module is attached on each target appliance. Z2IR modules operate as a ZigBee devices in this scheme. The overall system configuration for Park's scheme is shown in Figure 3.3. The ZigBee WPAN (wireless personal area network) shown in the figure is the communication network between a Z-URC and Z2IR modules. It is based on IEEE 802.15.4 ZigBee wireless networking technology.

The list of appliances to be controlled by a Z-URC is dynamically reconfigured. It depends on the location of a user holding the Z-URC unit. Each Z2IR module can be configured with a product identifier and a vendor identifier for his target appliances. Z-URC uses these two identifiers, sent by Z2IR modules within the signal range, to reconstruct the list of appliances. In this manner, the system can control and manage multiple IR-based home appliances more efficiently and the limitations on unidirectional transmission of IR signals is also eliminated. Using

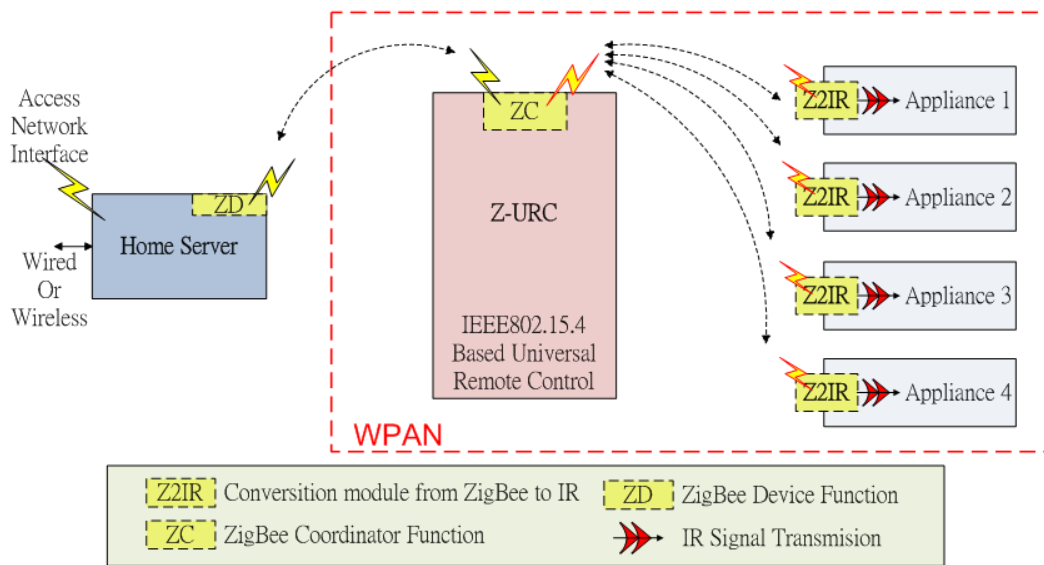


Figure 3.3: System configuration for Park's scheme

ZigBee WPAN networks, information transmitted between appliances becomes bi-directional.

As Figure 3.3 shows, Park's set a home server. The functionality of the server is linking Z-URC to internet in order to gather control profiles and provide services. However, the actual connection mechanism between a Z-URC and a home server is un-mentioned. We consider that the upper layer is not complete enough. Besides, every home appliance is equipped with a Z2IR module, which makes cost high. An ideal smart home control system should not add any extra hardware to control legacy home appliances. Otherwise, the original control system is useless.

3.3 Infra-Red Control in Wireless Network

In 2010, a new utility patent equips an infra-red control device with wireless virtual IP has been proposed by R.S. Tang. (R.O.C patent: M 373076) [15]. The main function of this utility patent is exploiting network communication on infra-red remote control devices controlling home appliances.

Figure 3.4 is the system architecture of an infra-red remote control system. This system

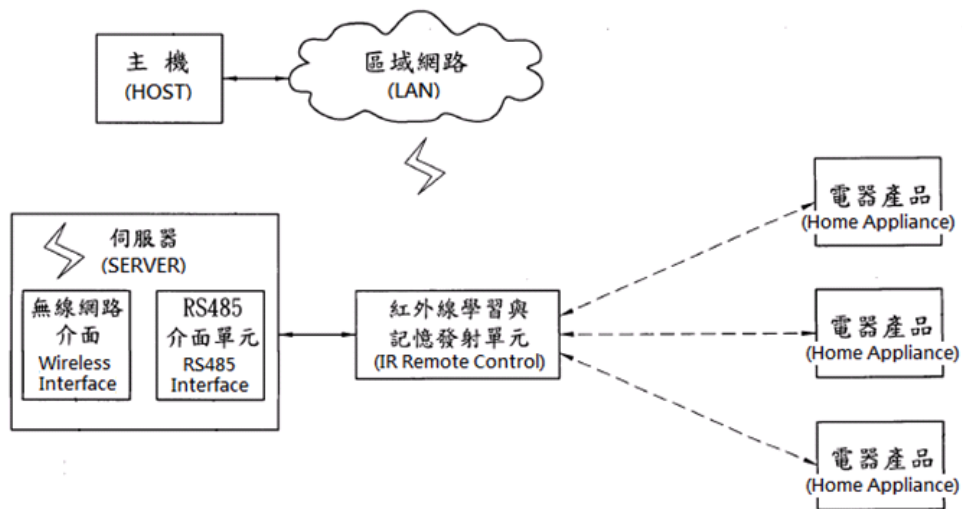


Figure 3.4: Architecture of IR control in wireless network [15]

consists of three units, including the host, the server and IR remote control device. The host is linked using LAN (local area network) and controls at least one home appliance. The host can be a PC or a mobile phone.

The server has a wireless network and RS485 interfaces. This wireless network interface is used to connect the previously mentioned LAN. The network protocol can be Bluetooth, microwave or infra-red. The RS485 interface connects the IR remote control device. The server can transmit an IR signal via this IR remote control device, controlling home appliances. Therefore, a user links the LAN using a device called the host to connect to the server, and then he/she can manage home appliances via this server. The server receives user's commands, transfers to IR signals and transmits them to assigned home appliances via RS485 connected to the IR remote control device.

Tang's depicts detailed content and techniques using several examples in Figure 3.5. In Figure 3.5(a) and Figure 3.5(b), the system can be implemented with IP Router or wireless AP, which provides a virtual IP or fixed IP for the server connecting to the internet. Therefore, users can link to the server via the internet, remotely controlling home appliances. In Figure 3.5

(c), when the IR signal between IR remote control devices and home appliances are blocked, an infra-red transfer unit can be added to enhance transmission distance and solve the signal-blocked problem. In addition, a video camera unit, like a surveillance camera, can be added into the system. Users at the outside or in the different room realize that operations of home appliances are correct.

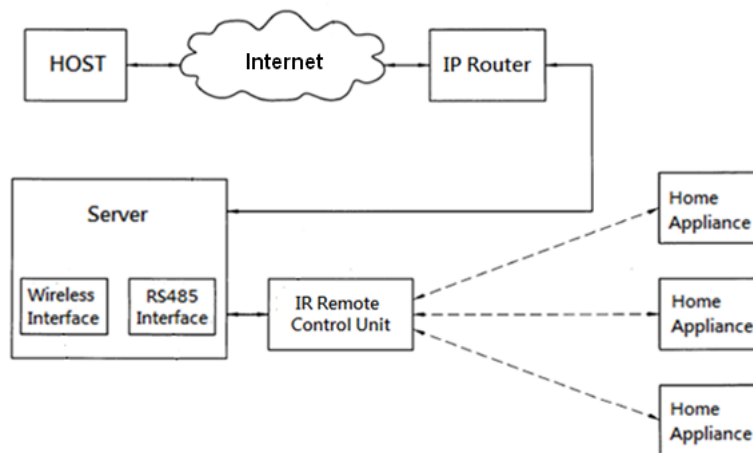
The primary characteristic of this new utility patent is that, the server links to the internet via a selectable virtual IP. Remotely control home appliances from outside can be achieved using any linked PC. Also, using virtual IPs can avoid network attack by hackers, who elevate security. From system aspect, this patent has complete designs from upper layer to lower layer. However, the author only provide system architecture scheme and does not attach actual design and implementation contents.

3.4 Summary

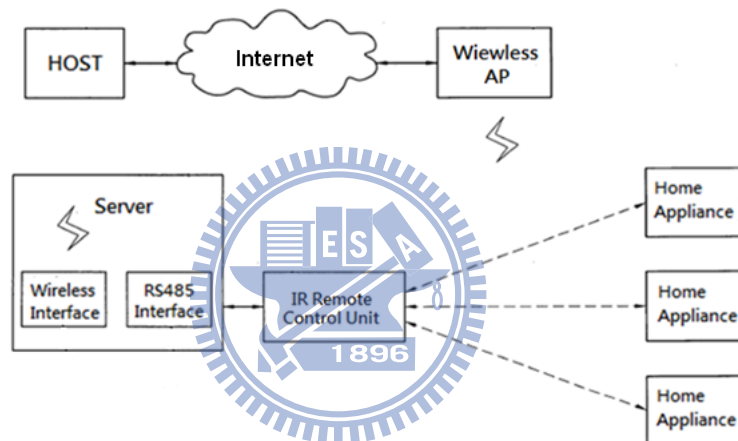


We introduce three related researches on controlling legacy home appliances in this chapter and discuss problems from the aspect of smart home three-layer model. Although the web based remote control focuses on web services of upper layer, we consider that their framework would be more complete if they considered designs of lower layer. The ZigBee based remote control method dexterously exploits wireless characteristics of ZigBee, but their designs on upper layer are not enough. On the other hand, Tang's patent fits three-layer smart home model most, it is a new utility patent only, not an actual implementation.

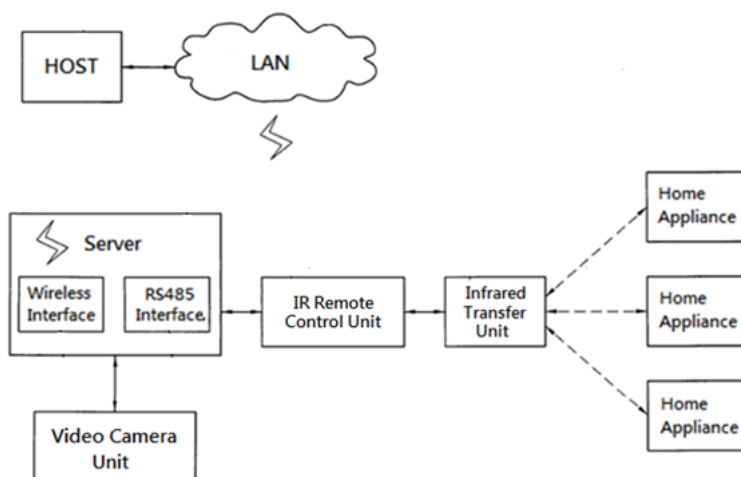
We consider the three-layer smart home model is needed. For this reason, we intend to design an architecture supports the three-layer smart home model in controlling and managing legacy home appliances. We detail our designs in the next chapter.



(a) With IP router



(b) With wireless AP



(c) With IR transfer unit and video camera unit

Figure 3.5: Example to depicts detailed content and techniques

Chapter 4

Proposed Architecture

This chapter discusses the proposed architecture to manipulate multiple legacy home appliances (IR appliances) in a smart home system. Our design is based on three-layer smart home model. Please refer to Figure 1.1. We design respective control mechanism in each layer and integrate them into an intact architecture, which makes control on home appliances more efficiently.

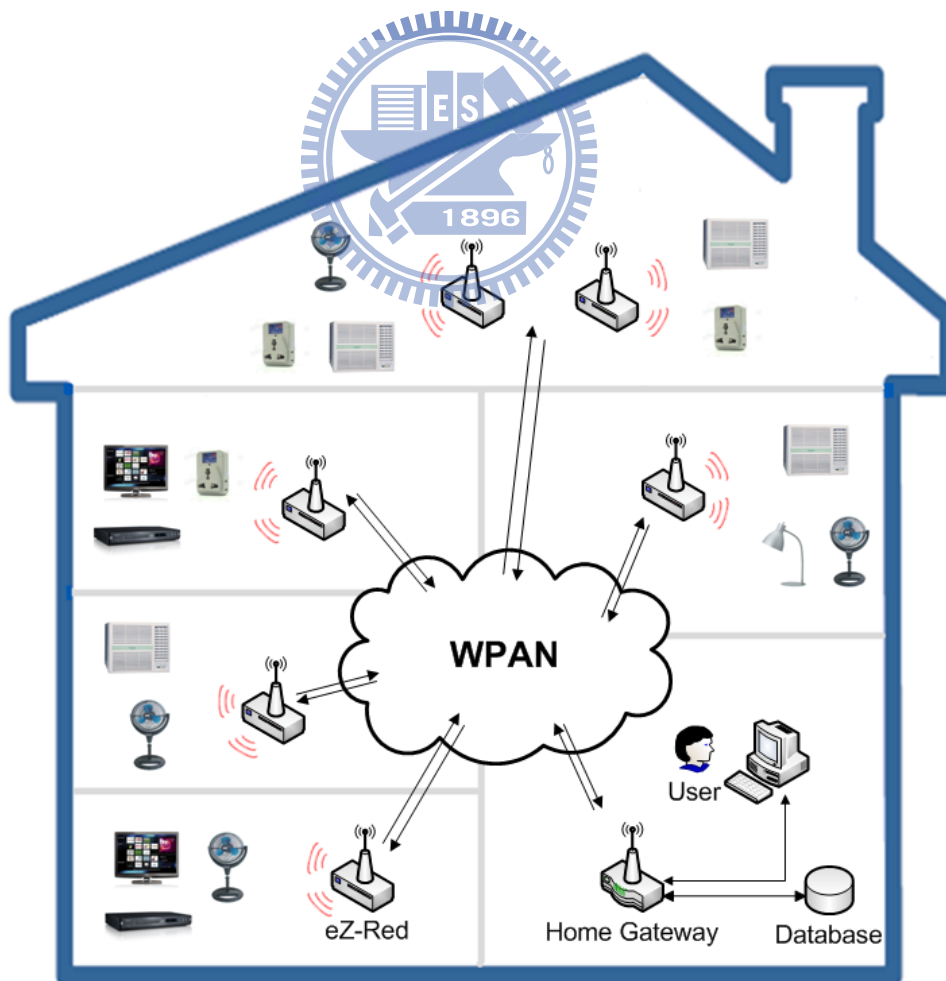


Figure 4.1: System overview of proposed architecture

Figure 4.1 is the system overview of the proposed architecture. Due to the control limitations on distances and orientations of IR controlled home appliances, we add a compact device with wireless network modules and IR transceiver modules, called eZ-Red. The reason we choose wireless network as transmission method is not only to remove IR control limitations, but also benefit from many merits wireless network possessed like low-cost, low-power and high reliability. Thus, wireless network is appropriate to be used in automatic control and many similar wireless technologies like ZigBee, SimpliciiTI can be chosen [21]. In addition, the eZ-Red we adopted is a one-to-many control device. Many home appliances can be controlled using an eZ-Red device.

In this chapter, we introduce system components first, and then import layer notion to illustrate the design of system flow. Next, we explain the registration procedure and system control flow. Finally, illustration puts on IR communication.

4.1 System Components

First, we present system in a simplified manner, and then introduce goal and features of every component in detail.

According to our design at least one user interface (UI) is needed to let user link to home gateway (HG). Also, at least one eZ-Red device should be connected to HG and communicate with HG via wireless network. Therefore, HG and eZ-Red require wireless network module. Next, IR signal is used in communication between eZ-Red devices and home appliances. Figure 4.2 shows the connection scheme among all components.

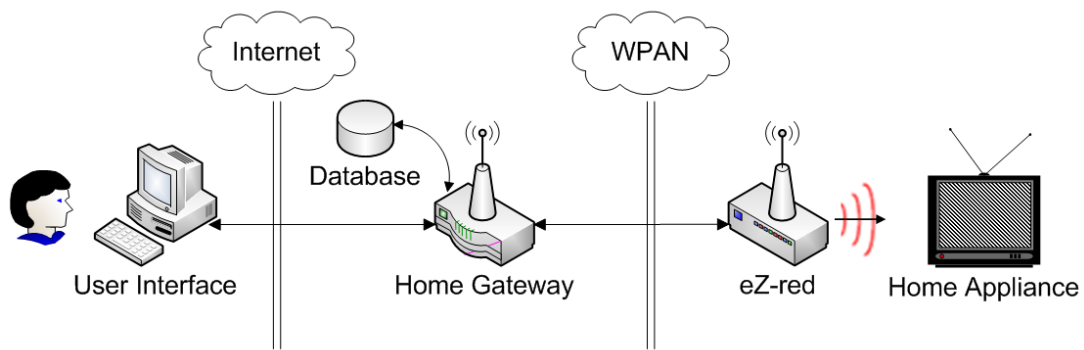


Figure 4.2: Connection scheme among all components

4.1.1 Home Gateway (HG)

The key component in whole system is HG. We design HG as central management unit (CMU), a bridge which connects the outer network, the Internet, and the inner network, wireless personal area network (WPAN). Thus, HG connects Ethernet, WPAN and the database (DB) for data recording. For the sake of functionality, CMU offers two primary functions, user interface and data processing.

User Interface (UI)

User interface (UI) builds connections between users and devices to let users communicate with the system. Thus, UI is the bridge for communication between users and the system.

Data Processing

Data processing stands for control message processing. Here, control message includes control code, appliance identifier (ID) of home appliances and address of eZ-Red device.

Previous mentioned functions are for efficient management on entire system. However, information produced by these functions becomes huge when appliances amount is increasing.

Thus, we design a database (DB) to access related information. Figure 4.3 is the schematic of CMU. Arrows indicate communication relationships between components.

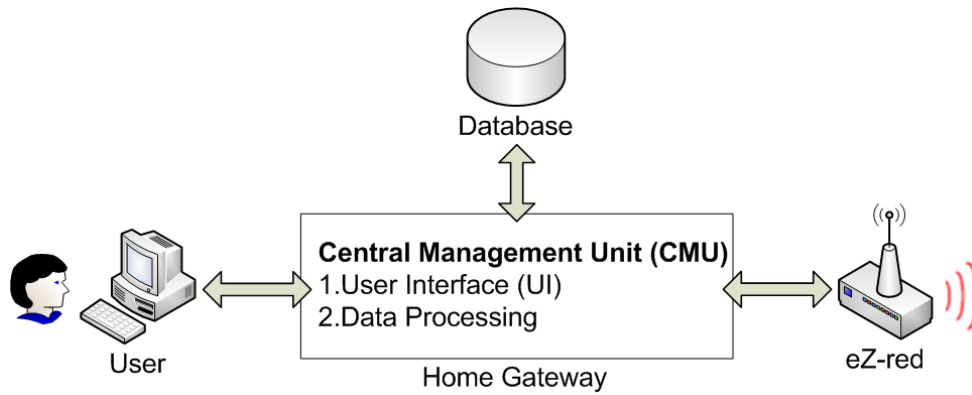


Figure 4.3: Schematic of Central Management Unit (CMU)

4.1.2 eZ-Red Devices

In Figure 4.2, eZ-Red links HG and home appliances. Thus, eZ-Red needs two interfaces at the same time, wireless network module and IR transceiver module. The primary function of eZ-Red is transforming data format for communication. Because our controlled subjects are IR typed home appliances, transmission and receiving of IR signal are essential. We make use of the merit of wireless network to break the transmission restriction on distance and orientation of IR signal. In this manner, we significantly promote the system usability.

4.1.3 Home Appliances (IR Appliances)

In domestic environment, most of legacy home appliances are controlled and managed by different remote controllers, usually IR based ones. Proposed system is mainly for IR appliances, so we need interfaces for them. Considering the differences on the format of IR control signals produced by different manufactures, these IR control signals, are recorded directly and stored to database (DB). When demanding to use that appliance, system recalls those IR control signals

from database and emits them via our IR transceivers module. Consequently, there is no need to know the detailed content of control signals.

After introducing system components, in next section, we will import the layer notion and illustrate the design of system flow.

4.2 Layers

The purpose of importing layer notion is to equip more complete control mechanisms to our system. Referring to three-layer smart home model, we design respective control mechanism in each layer. From lower layer to upper layer, we design appropriate mechanism based on their applicability and related control techniques.

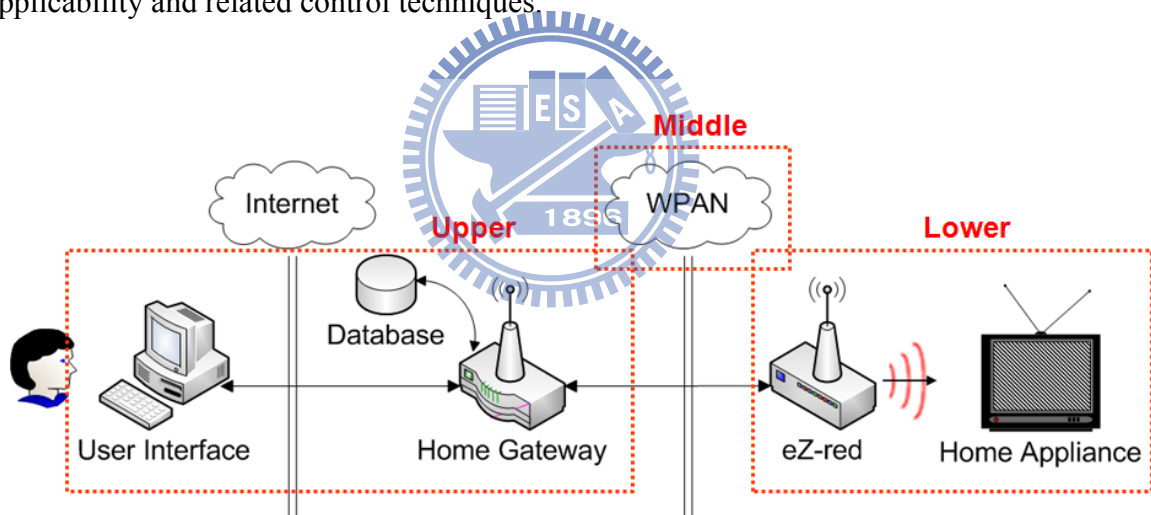


Figure 4.4: Components with layers

The design concept of lower layer is based on physical layer of OSI model. Please refer to Figure 1.1. The primary function is to construct bit stream communication among adjacent nodes. Because our controlled subject is locked on IR-only home appliances, bit stream composed of "0" and "1" is used and transmitted via IR signals.

The design concept of middle layer is based on network layer and transport layer of OSI model. Please refer to Figure 1.1. The primary function is message exchange and data com-

munication in the network among devices. Here, network is a wireless personal area network (WPAN) constructed using wireless network techniques and devices are HG and eZ-Red.

Finally, upper layer is designed according to session layer, presentation layer and application layer of OSI model. Please also refer to Figure 1.1. The primary function is to construct the conversation between users and devices, provide an user interfaces (UI).

	Registration Phase	Control Phase
Upper Layer	User \leftrightarrow HG: Networked Control	
	<ul style="list-style-type: none"> • Registration <ul style="list-style-type: none"> - Grouping Rule - Appliance ID 	<ul style="list-style-type: none"> • Control <ul style="list-style-type: none"> - User Interface
Middle Layer	HG \leftrightarrow eZ-Red: Wireless Deployment	
	<ul style="list-style-type: none"> • Registration <ul style="list-style-type: none"> - eZ-Red Installation 	<ul style="list-style-type: none"> • Control/Communication <ul style="list-style-type: none"> - WPAN
Lower Layer	eZ-Red \leftrightarrow IR Appliance: Device Management	
	<ul style="list-style-type: none"> • Registration <ul style="list-style-type: none"> - Signal Learning (IR: rx) 	<ul style="list-style-type: none"> • Control <ul style="list-style-type: none"> - Signal Translation (IR: tx)

Figure 4.5: System design from the perspectives of layers

Figure 4.5 reveals the system from the aspect of layers. Two phases, registration phase and control phase are included. Registration phase is to do grouping and to distribute appliance ID for incoming appliances, which allows user managing all controllable home appliances easily and efficiently. Control phase is for user giving orders to controlled subject. These two phases are explained in detail in the following two sections.

4.3 Registration Phases

Registration phase includes installation of eZ-Red devices and registration of IR appliances. Referring to Figure 4.1, the relationship between HG and eZ-Reds is one-to-many. Also, the relationship between eZ-Reds and IR appliances is one-to-many. For the sake of efficient management and control, we institute a grouping rule for incoming devices. Entire architecture follows this grouping rule in system construction and device installation.

4.3.1 Grouping

The first step of registration phase is grouping. Grouping is based on coverage of eZ-Red.

The limitation of IR signal transmission is on distance and orientation. Therefore, IR appliances should be located in the emitting range of eZ-Reds to ensure control signals are correct. Since each eZ-Red has its own address, every group is recognized by each eZ-Red address. In addition, considering several IR appliances which are movable like fans, we let IR appliances can belong to more than one group. In case of those registered IR appliances not in-use for a long time which waste DB space, we design deregister to deactivate IR appliance periodically. The period for deregisters can be customized by users. Be aware that each deactivated IR appliance should register again before use.

Appliance ID is assigned by HG for controllability. Because one eZ-Red controls many IR appliances, with appliance ID, eZ-Red can manage IR appliances correctly and precisely. However, because IR communication is unidirectional, eZ-Red may not be aware of leaving or moves around of a appliance.

After defining the grouping rule, we illustrate detailed registration steps in next section. Illustration of registration phase divided into two parts. First part explains eZ-Red installation

process. Second part describes how to add IR appliances into our system.

4.3.2 eZ-Red Installation (Middle Layer)

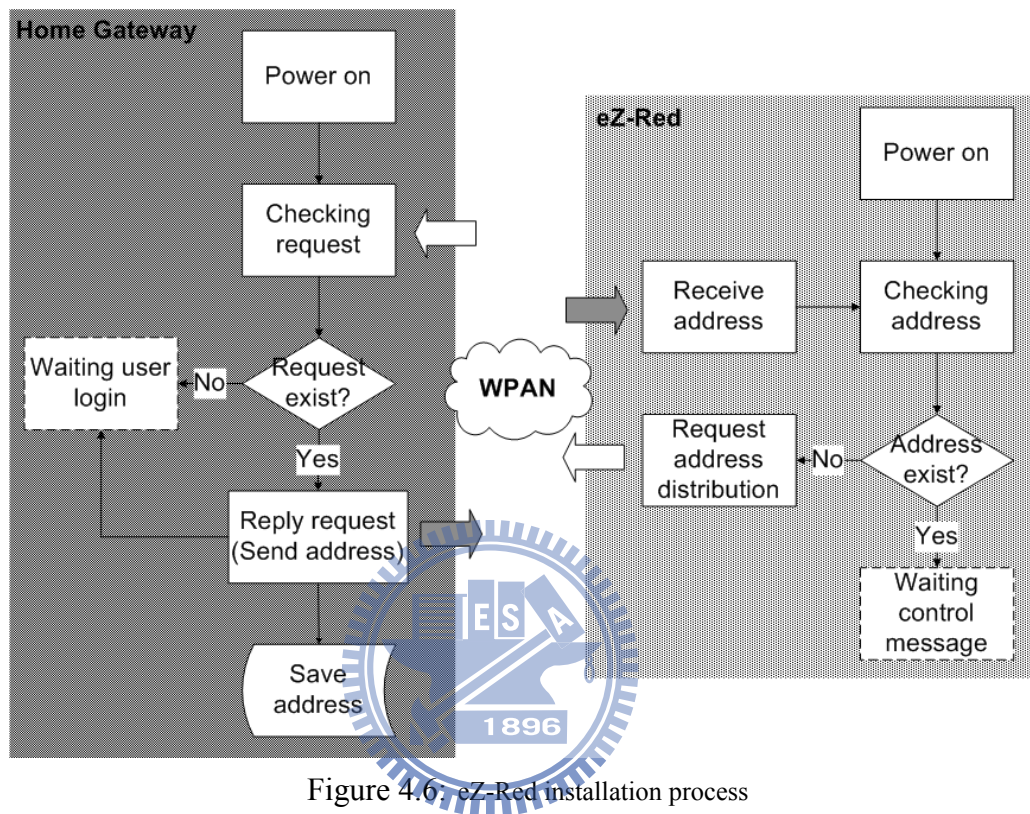


Figure 4.6. eZ-Red installation process

In the beginning, eZ-Red devices should be added into system. As Figure 4.6 shows, after HG was powered on, it checks if any eZ-Red asks for address. If so, HG distributes an address for eZ-Reds and this address is recorded at the same time. If not, HG enters in next stage, waiting for user login.

At the eZ-Red side, when powered on, eZ-Red do self-check for address. If so, it enters in next stage, waiting for control messages from HG. If not, this eZ-Red device is identified new for system. This eZ-Red requests HG for address. Every eZ-Red should be distributed an address, or system cannot send message for it. On the contrary, an eZ-Red getting an address means it has been installed into system successfully. We build WPAN in this manner as our middle layer.

4.3.3 IR Appliances Registration (Upper and Lower Layer)

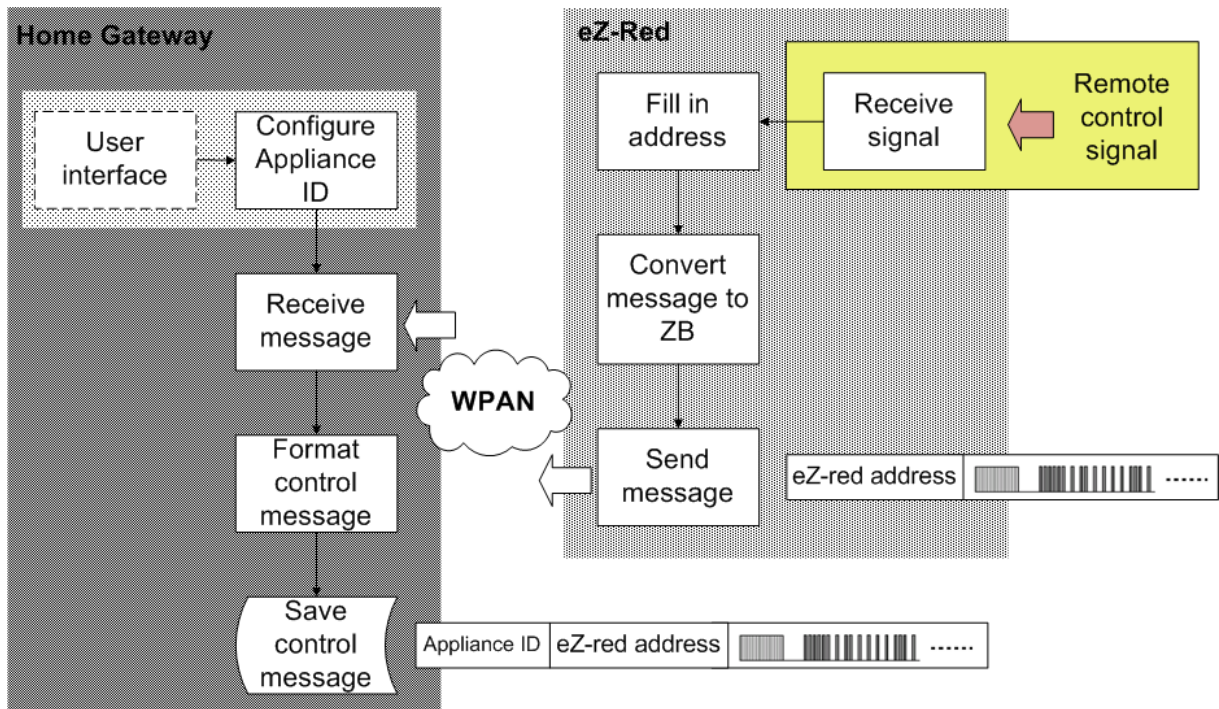


Figure 4.7: IR appliances registration

With WPAN, new IR appliances can be quipped into system. We configure appliances ID using upper layer and learning IR signal in lower layer. As Figure 4.7, before register IR appliances, user should login first and then configure an appliance IDs for joins appliance.

For the signal learning, user manually transmits IR commands using the remote controller of IR appliance. After receiving, eZ-Red packs them with its address and forwards these messages to HG. This action called signal learning. Registration is made by receiving IR signals by designated IR transceiver module on eZ-Red device.

System acquires control commands and eZ-Red address using previous mentioned methods and then attaches on appliances ID to become control messages. These control messages are stored in DB. Basically, registration phase is completed here. In next section, we start to illustrate control phase. Before that, system should maintain a control list and shows them to users via

UI.

4.4 Control Phases

When control list is created, user can select target, home appliance, and assign commands. Referring Figure 4.5, control phase cross three different layers. Our illustration is based on these layers.

4.4.1 Select Controlled Target (Upper Layer)

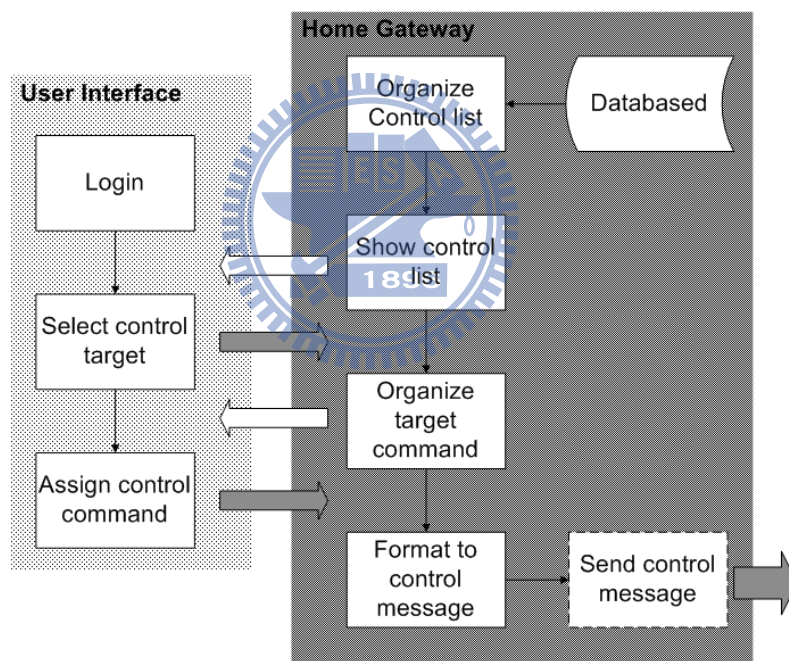


Figure 4.8: Communication in upper layer

As Figure 4.8, this part is designed in upper layer. Users can select target and assign commands via UI. After HG got assigned target and commands, it finds out correct appliance ID, eZ-Red address and corresponding control commands and integrates them into a control message.

4.4.2 Control Message Transmission (Middle Layer)

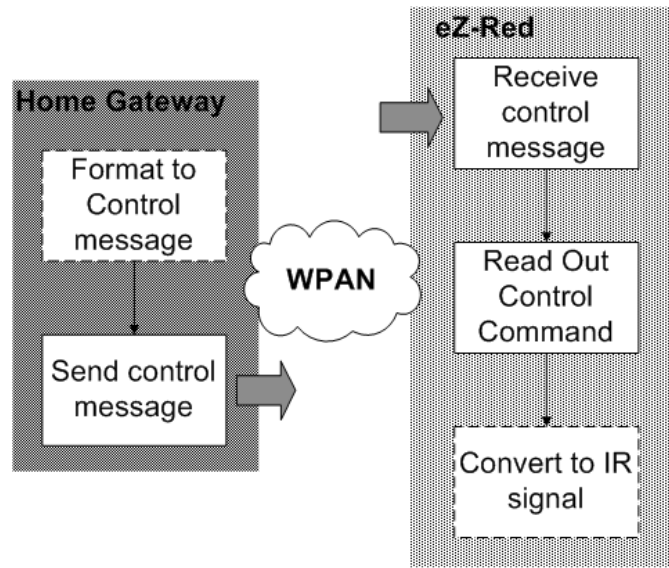


Figure 4.9: Message transmission in middle layer

Middle layer is responsible for transmitting control messages to eZ-Red devices via wireless network. As Figure 4.9, HG formats control messages into wireless signals and dispatches them out. When particular eZ-Red receives the control messages, it reads out control commands. The path of control messages is in the light of eZ-Red address. That is the reason we choose it for grouping IR appliances.

4.4.3 IR Communication (Lower Layer)

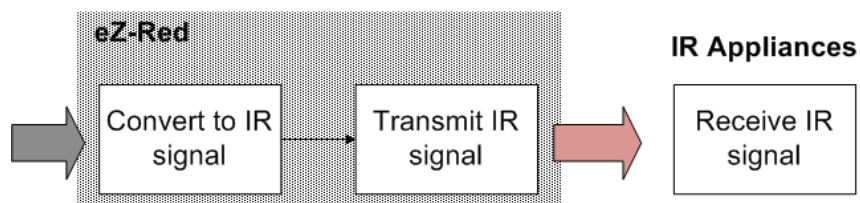


Figure 4.10: IR signal translation in lower layer

The primary function of lower layer is to construct bit stream communication between eZ-Reds and IR appliances. Thus, we design an IR transceiver module for IR communication.

IR communication can be separated into transmission and receiving. Transmission is used for signal translation. Receiving is designed for signal learning. As shown in Figure 4.10, when control messages arrived at the eZ-Red, which belongs to the group of assigned IR appliance, eZ-Red reads control commands from control message, transforms to IR signals and emits them via IR led.

4.5 Summary

We propose architecture to complete smart home system, whose controlled subjects are multiple legacy home appliances. This architecture contains several crucial components, including user interface (UI), home gateway (HG) and eZ-Reds. Also, we import layer notion to design our control system. Upper layer is designed for communication between users and the system and data processing. Thus we design CMU responsible for providing UI and data processing. Middle layer is for network transportation. We use WPAN for data transportation. Based on our definition on legacy home appliances, we design an IR transceiver module for controlling via IR signals.

Integrated all components and control system, we propose an intact registration and control flow. To help home appliances acquiring correct control commands, we also establish a grouping rule.

Figure 4.11, shows overview of our entire architecture. From user-end to IR appliance-end, each layer has corresponding functions. We believe that these functionalities promote integrity of smart home system.

To demonstrate proposed architecture, we implement an actual control system with legacy home appliances. This control system is illustrated in the next chapter.

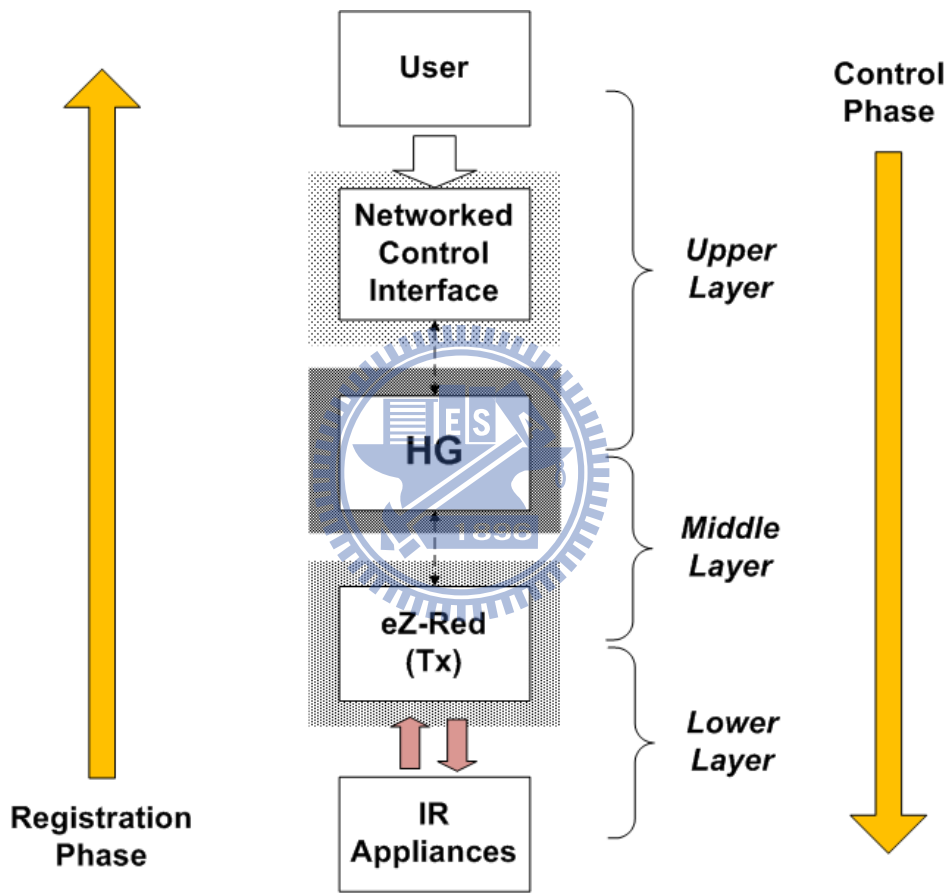


Figure 4.11: System overview

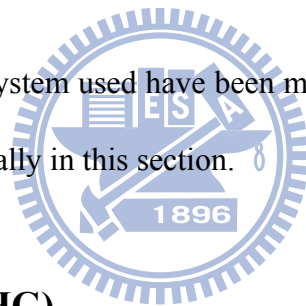
Chapter 5

Implementation

In this chapter, we implement an actual control system to control legacy appliances. The illustration is divided into two parts, hardware and software. A simple scenario is designed to demonstrate how control progresses.

5.1 Hardware

Components of proposed system used have been mentioned in section 4.1. These components are introduced systematically in this section.



5.1.1 Home Gateway (HG)

Computer Unit

More and more domestic devices are embedded with network functions. Home gateway in charge of domestic devices interconnections and external connections has gained much attention. In general, home gateway is implemented using routers and modems. In our implementation, a personal computer is used to simulate the home gateway. The operating system used is Microsoft Windows XP. User interface ran on the home gateway is discussed in section 4.1.1.

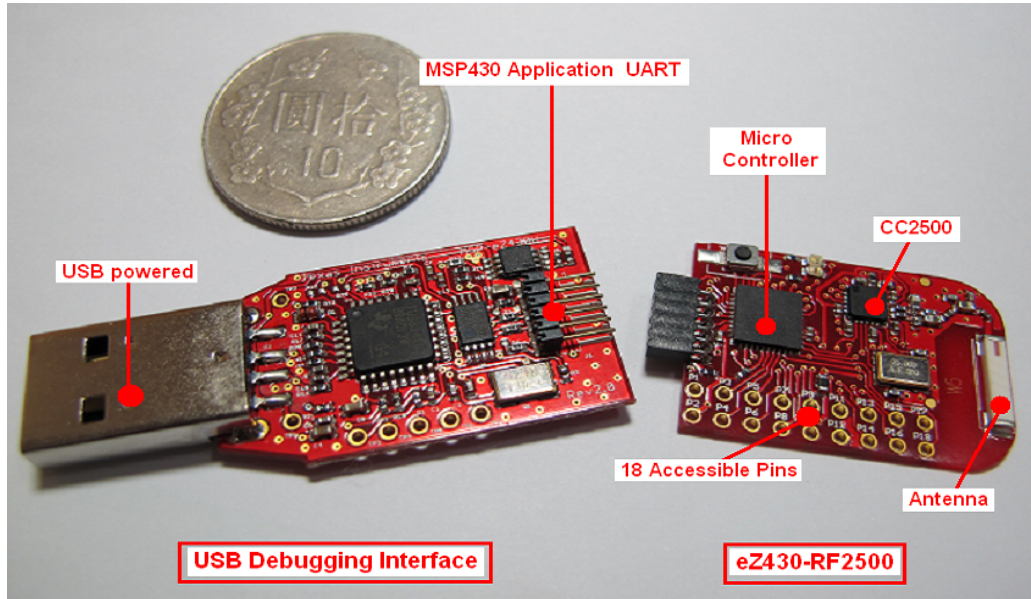


Figure 5.1: Wireless network module

Wireless Network Module

In addition, the communication between HG and eZ-Red is implemented using WPAN (Wireless Personal Area Network). To answer this demand, an experimental board, eZ430-RF2500 development tool [22] is adopted. It has a wireless module using CC2500 [23], which is a low-cost, low-power 2.4GHz RF transceiver, and its microprocessor of eZ430-RF2500 is MSP430F2274. This experimental board is manufactured by Texas Instruments, and shown in Figure 5.1 on the right.

Another device also used is the USB debugging interface, shown in Figure 5.1 on the left. The functionality of the USB debugging interface is as those JTAG provides. Also, this debugging interface offers a UART tunnel, which lets eZ430-RF2500 communicate with PCs.

The integrated developing environment (IDE) used for eZ430-RF2500 is the Code Composer Studio (CCS), and the version used is 4.1.3. The debugging tool in this IDE automatically communicates with the USB debugging interface and helps writing programs into eZ430-RF2500.

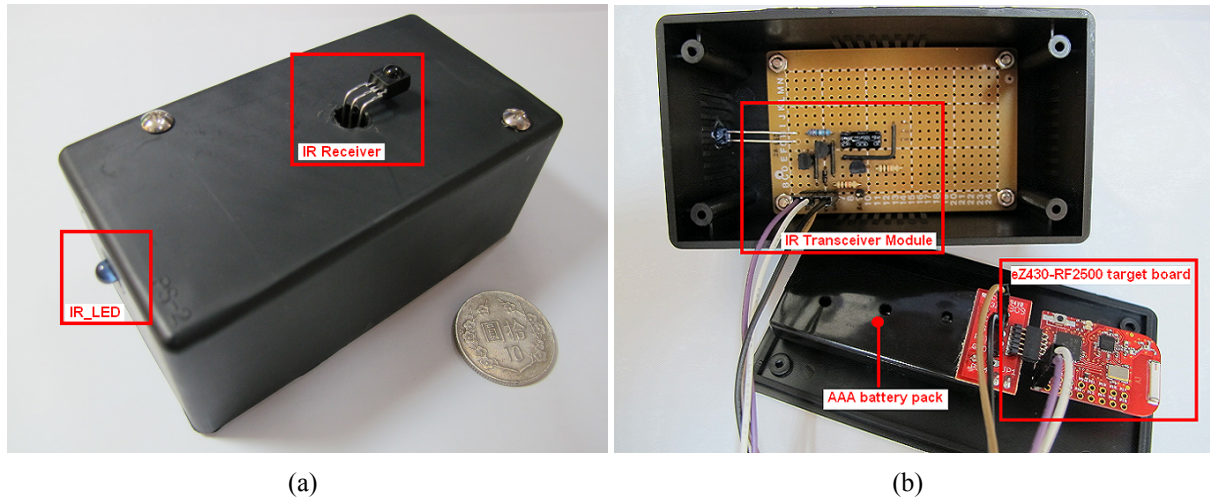
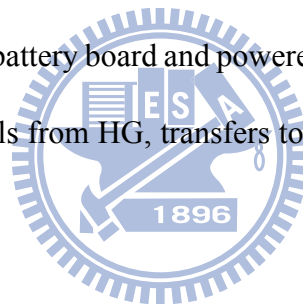


Figure 5.2: eZ-Red device

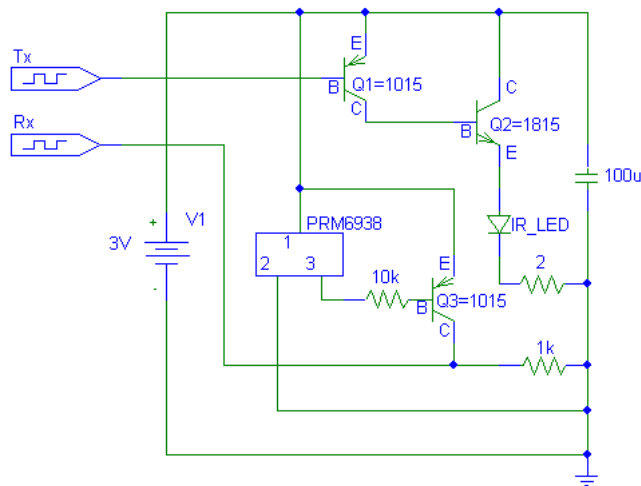
5.1.2 eZ-Red Device

The eZ-Red is composed of a wireless network module and an IR transceiver module. The eZ430-RF2500 is plugged on a battery board and powered using two 3A batteries. Here, eZ430-RF2500 receives wireless signals from HG, transfers to IR format and transmits IR signals via the IR transceiver module.

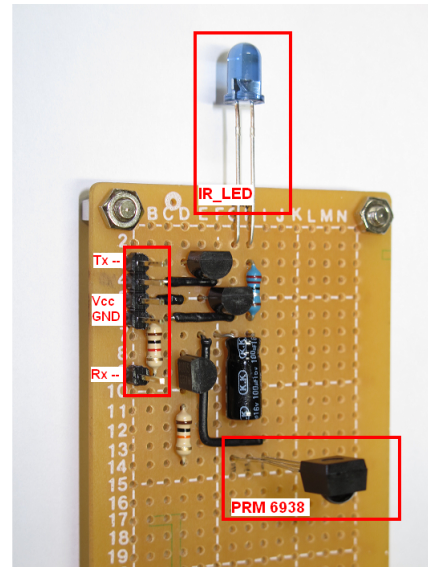


IR Transceiver Module

The circuit diagram of IR transceiver module is shown in Figure 5.3(a) drawn using PSpice. This module is composed of IR led, IR sensor and some simple electronics components. IR led is as the IR transmitter, transmitting IR signals to control home appliances. The IR sensor used is PRM6938 as an IR receiver. PRM6938 is a remote control photosensitive IC. Figure 5.4 show its circuit block diagram. ICs which belong to the same type are equipped with amplifiers (AMPs), band-pass filters (BPF) and adjustment circuits. Several basic operations like filtering and amplifying are made before eZ430-RF2500 receiving IR signals. When activating learning mechanism, eZ430-RF2500 receives IR signals via the IR transceiver module.



(a) Circuit design



(b) IR transceiver module

Figure 5.3: IR transceiver module circuit design

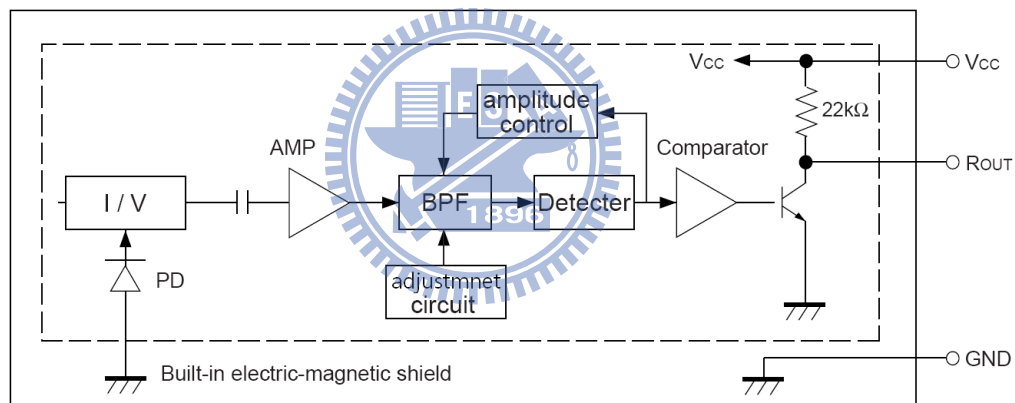


Figure 5.4: Block diagram of RPM6900 series IR receiver module [24]

5.1.3 Home Appliances (IR Appliances)

Most remote controllable home appliances are controlled using infra-red signals. We choose a common IR remote controlled electrical fan for demonstration, which is shown in Figure 5.5 (a). Besides, a product called infrared remote control socket can also be used, which is shown in Figure 5.5(b). The product type of the infrared remote control socket is HM-01K3. The rated voltage is 250V and its maximum power is 500W. As so, those home appliances without remote controlled function can also be powered on/off using this device. The infrared remote control

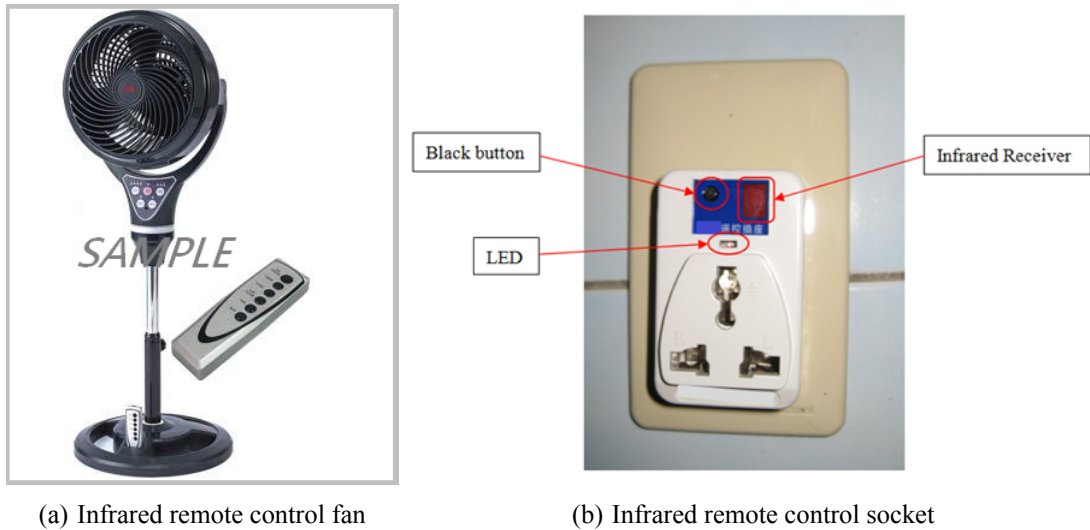


Figure 5.5: eZ-Red device

socket is capable of learning IR control signals. Press the black button about three seconds. The LED starts blinking, which identifies learning mode. Press a button on any remote controller and target on the infrared receiving window. The IR signal is learnt after this procedure. Next time, previous set button on that remote controller can be used to activate the infrared remote control socket. We take this device into our demonstration.

5.2 Software

As mentioned in section 4.2, we design respective control mechanism in each layer. Illustrations on who these mechanisms built are introduced in this section.

5.2.1 Upper Layer

To make out-of-house control possible, web server should be construct as UI on HG. Since we use personal computer as HG, we use the built-in web server, the Internet Information Services (IIS). The UI is implemented as webpage, so any device with a browser could link to UI. User can choose home appliances and set operating commands on UI.

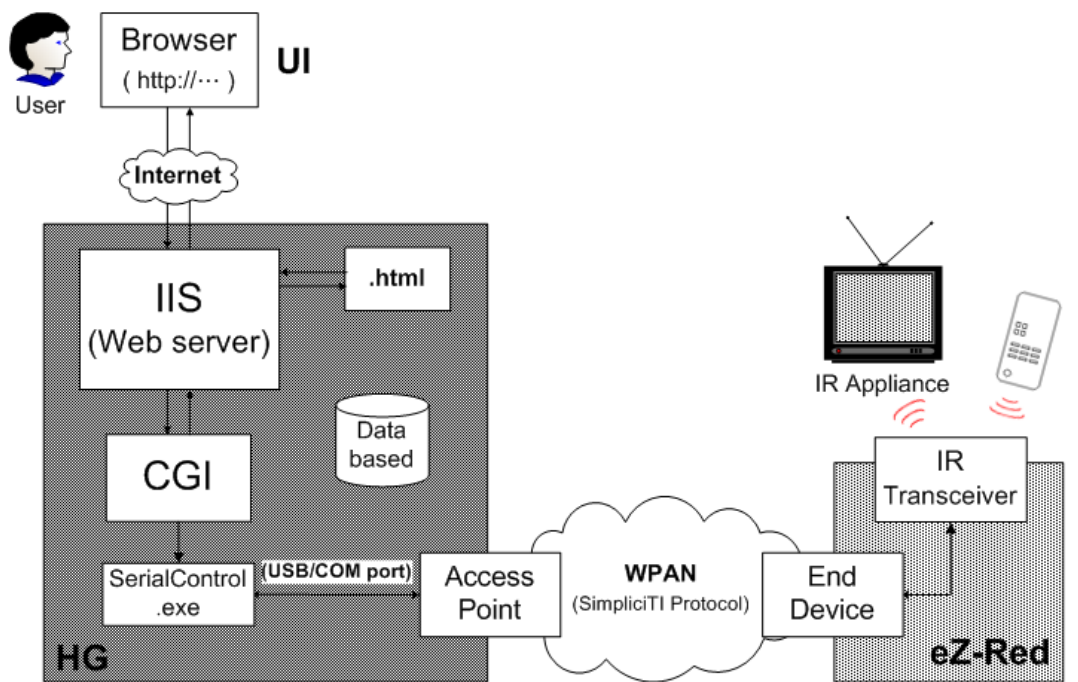


Figure 5.6: Software implementation for each layer

Because UI is a webpage and our control messages should pass to wireless network module, CGI (Common Gateway Interface) is needed to communicate with the wireless network module. CGI is a dynamic web technology and it is used to answer web requests. UI calls CGI directly using HTML form method as follows.

```
<FORM METHOD="PUT" action="./cgi_test.cgi">
```

We build CGI using C language. After UI called CGI, two actions are executed. One is return message telling that commands are executed. The other is passing user's commands to another executive file named SeiralControl.exe. SeiralControl.exe transmits user's commands to eZ430-RF2500 via serial port, which is responsible for communication between HG and eZ430-RF2500.

5.2.2 Middle Layer

We design using wireless network modules to build a WPAN in middle layer. Any wireless network protocol can be used, including Simpliciti RF protocol or ZigBee IEEE 802.14.5 protocol. We build a one-to-many wireless network using Simpliciti RF protocol [25], it is Texas Instruments proprietary network protocol. The Simpliciti protocol conceptually supports OSI three-layered model, as shown in Figure 5.7. We develop our application using APIs they provided in application layer. Those APIs offer initialization, configurations and sending/receiving messages between peers. In network layer, NWK manages the Rx and Tx queues and dispatches their frames to their destinations. The Data Link/PHY layer performs basic frames read/write interface to the radio by MRFI (Minimal RF Interface).

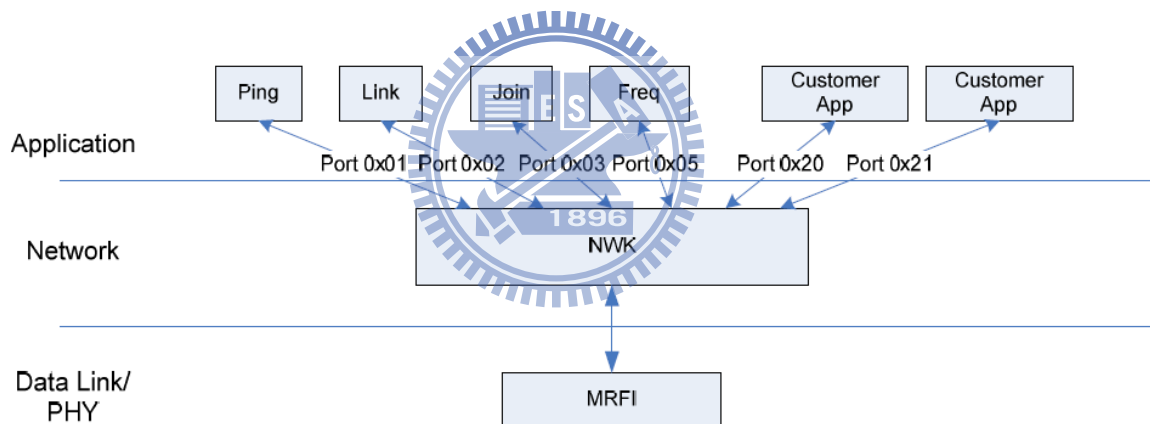


Figure 5.7: The architecture of Simpliciti protocol, [25]

We use Simpliciti APIs to design an Access Point (AP) device and several End-Devices (EDs) to build WPAN. Here, those used APIs are described as follows.

SMPL_Init () Initialize the radio and the Simpliciti protocol stack.

SMPL_Link () Send a broadcast link frame and wait for replies.

SMPL_LinkListen () Listen for broadcast link frame.

SMPL_Send () Send data to assigned peer.

SMPL_Receive () Check the input frame queue if any frame received.

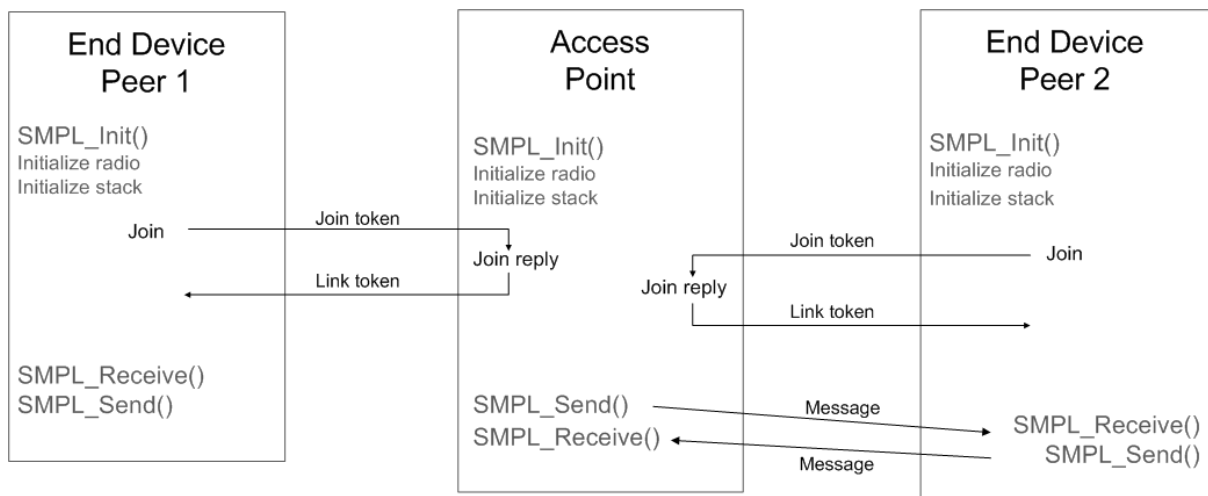


Figure 5.8: Algorithm of AP-to-ED communication

Figure 5.8 shows the communication flow of AP and ED. After initializing, the AP waits for link request from any ED. Once ED is initialized, it sends a Joint token and its address to AP asking for linkage. Joint token is used by AP to identify EDs in the specific network. The Joint token can also be used to identify different applications. While EDs are connected, AP or EDs can send/receive messages to/from each other.

5.2.3 Lower Layer

Section 5.1 mentions that IR photosensitive IC preprocesses received IR signals, like basic signal amplifying, filtering and demodulating, providing a clean logic-level output with only the serial data present. Hence, eZ430-RF2500 gets IR signals near square waves as Figure 5.9 shows. We wire IR transceiver to GPIO (General Purpose Input / Output) on eZ430-RF2500 and use MSP430 trigger mechanism to analysis IR signals. When triggered by falling or rising edge, the elapsed time is recorded. These elapsed times are used to recognize zero or one bits.

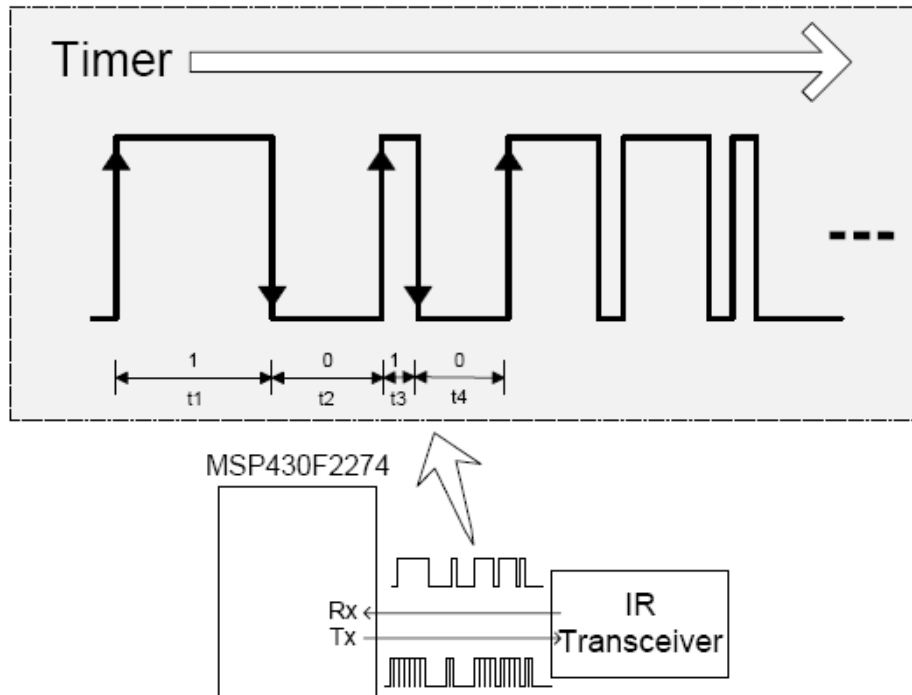


Figure 5.9: An example of receive signal

5.3 Scenarios

The scenario is shown in figure 5.10. There are two legacy home appliances to be controlled in home environment. Illustrations are made on every step in control phase.

Step 1 User open a browser, enter IP address and link.

Step 2 After login, user's browser shows UI. Select a target and operating command, and then press 'SET'.

Step 3 HG receives user's commands and activates CGI. The CGI program gets user's commands and passes them to SerialControl.exe.

Step 4 According to user's commands, SerialControl.exe finds out control codes and ED address, and passes these data to AP via serial port.

Step 5 AP receives control codes with target ED address and transmits those using RF signals.

Step 6 ED (eZ-Red) receives control codes and passes them to IR transceiver module. IR transceiver module then emits those signals using IR LED.

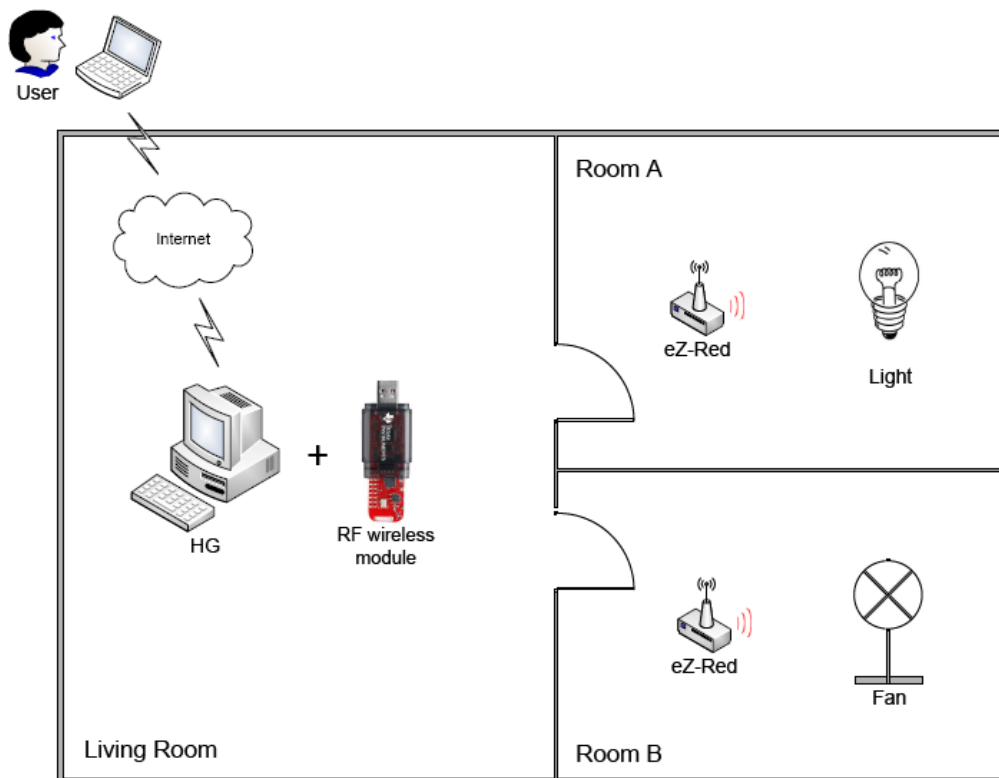


Figure 5.10: Scenario

Step 7 The targeted home appliance executes assigned operations.

5.4 Discussion

In this section, we discuss related researches and proposed method according to smart home model. In Web-based remote control method, Nakamura adapts home appliances to home network system using web services. Based on web protocols, services on different platforms may be interoperated, reducing interoperability problems in the upper layer. They also equip PC or handheld devices with IR transmitters and implement a set of Ir-APIs to assist devices sending IR signals. However, the limitation is that only those home appliances in the IR emitting range are controllable because IR transmitter is wrapped with PC or handheld devices. Another shortcoming is their user interface is not user-friendly.

Criteria	Web-based Remote Control	ZigBee-based Remote Control	IR Control in Wireless Network	Proposed Architecture
Upper Layer (Networked Control)	Δ (CLI)	X	√	√
Middle Layer (Wireless Deployment)	X	√	Δ (Wired/RS485)	√
Lower Layer (Devices Management)	Δ (No Device Registration)	√	Δ (No Device Registration)	√

√ : Supported
 Δ : Not complete
 x : Not supported

Figure 5.11: Comparison

In ZigBee based remote control, Park's applies a ZigBee based universal remote control system to control and manage multiple legacy appliances. There are only two components used, Z-URC and Z2IR. The Z-URC generates all control commands for multiple legacy appliances, while the Z2IR converts control messages into IR typed signals. Park's performs a home server in their control system, but does not discuss about the actual connection mechanism. That is the reason we consider upper layer in their system is not complete enough.

In IR control in wireless network, Tang's new utility patent is the most ideal one according to three-layer smart home model. In upper layer, a host is built to link to server with cables or without via the internet. In middle layer, the wireless network interface and RS-485 interface on the server can be used to communicate with upper or lower layer. In lower layer, the IR remote control device is used to control legacy home appliances. When signal is blocked or home appliances are too far to be reached via IR signals, an IR transfer unit can be plugged in to solve these problems. However, it is still a new utility patent without actual implementations.

In proposed method, we design three mechanisms in each layer. We use a personal computer to simulate home gateway (HG). UI is designed as webpage in upper layer on HG, so user can link to UI and remotely control home appliances. In middle layer, we use RF wireless network to transmit control commands, which allows users control home appliances without limitations on IR emitting range. In lower layer, we design an IR transceiver module as our physical transmitting device, so our control system is capable of communicating with legacy home appliances using IR signals.

5.5 Summary

In this chapter, the detailed hardware and software implementations based on proposed system architecture are introduced. A simple domestic environment is also built to demonstrate proposed method. Comparing with other control methods, our proposed method is more systematic based on the smart home three-layered model and has a complete control flow.

Chapter 6

Conclusion

In this thesis, we propose an architecture to manipulate multiple legacy home appliances using wireless personal area network (WPAN) in home environment. Wireless network modules and IR transceiver modules are used as data transmission devices. We introduce layered concept to divide smart home control system into upper layer, middle layer and lower layer. Upper layer is mainly for applications, providing users an interface to control the system. Middle layer is as network transmission layer, which is responsible for data transmission between the Access Point (AP) and End-Devices (EDs). Lower layer is used to define physical transmitting medium. Besides, proposed control mechanism includes two phases, registration phases and control phases. The registration phase deals with the rule of device grouping, while control phase describes control methods on legacy home appliances. To demonstrate, we implement a simple but actual home environment. We believe that, introducing network layered concept makes smart home control system more systematic and general for control procedures.

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