International Journal of Smart Home
Vol. 9, No. 6 (2015), pp. 173-182
http://dx.doi.org/10.14257/ijsh.2015.9.6.19

Design of Smart Home System Based on WiFi Smart Plug

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Abstract

This paper presents a low-cost and flexible solution to control and monitor home appliances using Smart Plug devices. The Smart Plug is a power switch which can be accessed via WiFi connection. It integrates two temp sensors, a current sensor and an IR-emitter. Users can plug devices into the Smart Plug to remotely switch power on/off, get information of device's power consumption and ambient temperature, and eventually control the nearby devices using the integrated IR-emitter. There are two ways to access Smart Plug, that is, either connecting it directly in WiFi Ad-Hoc mode or connecting it with a router in WiFi infrastructure mode and accessing online with IP-connectivity. The paper utilizes RESTful based Web services in which the overall system architecture is client/server model and the Web client uses JavaScript and Ajax to transfer data. An Android-based Smartphone application employs standard operations such as Get and Post requests that return responses to communicate between the remote user and the Web server. Depending on the use cases, users can use Smart Plug as lighting switch, timing switch, infrared controller and temp regulator.

Keywords: *Smart Plug, REST, WiFi, Smart Home, Android Smartphone*

1. Introduction

The Internet of Things (IoT) is the network of physical objects that contains embedded technology to communicate sense and interact with their internal states and external environment [1].

IoT technology can be applied to smart home. It offers some new ideas and broad space for development, aiming at improving the quality of life and making it more comfortable and smart. We can use a smart phone or tablet to control a variety of devices which are connected to the network, for example smart home system [3,4,5] could monitor the energy consumption of household appliances. The user can also customize the light's switch on and off time. Smart home thermostat can automatically adjust the indoor temperature according to the user time schedule to improve energy efficiency. Once been widely used, IoT will have wide-ranging impact on our work and life which would allow people to do things in a few simple and convenient way to conserving energy and reducing waste.

WiFi Smart Plug has the following advantages:

1) When Smart Plug is with embedded WiFi [6] module, its wireless signal strength is much stronger. It has higher data transmission rate, when the client sends a command, the server can response quickly.

2) Wireless Smart Plug reduces wiring trouble, which means better scalability and mobility.

3) Smart Plug application gives the possibility to control several smart devices at once by touch of a button.

ISSN: 1975-4094 IJSH

4) Smart Plug can remote control and monitor home lighting situation. Light switch has dimming control function. WiFi Smart Plug can infinitely adjust the brightness of the lights, creating a specific atmosphere for specific lighting scenes.

2. The Status Quo of Smart Plug Development

On the present stage, a variety of intelligent sockets with different forms and functions have appeared in the market which basically can be divided into the following categories: leakage protection type, timing type, main road controllability type, remote type and measurement type. Smart Plug has internal-integrated a microcontroller that can handle home situation intelligently, but current smart socket only has some single functions such as protect, monitor or control. It's difficult to achieve intelligent and remote control. The requirements for Smart Home system have not yet been fulfilled.

Smart home system is the application of networking technology. The smart home system used in this article has intelligent, information-oriented features. Besides the power distribution function, it still has the following features:

1) Control function. If home appliance is plugged in, owners can turn it on or off with power outlet. Many home appliances and devices can be controlled by the Smart Plug, such as lights, air conditioners, televisions and etc.

2) Communication function. The smart socket needs to communicate with the master controller to transfer data to it or respond a command from the main controller to ensure the normal operation of the smart home system. Smart socket and the master controller constitute an effective communication network in which communication should be stable and fast.

3) Monitor function. This function allows users to monitor the status of Web servers and various devices, such as voltage, current and power consumption. House owners can analyze the electrical appliances load which provides a reference for electrical usage so that they can reduce the amount of electricity usage during on-peak times. By shifting the majority of electricity usage to off-peak, users can save money and help support a cleaner environment.

4) Timing function. The function was mainly designed for users to automatically turn on appliances, using devices such as electric water heaters, washing machines work during off-peak periods, thereby saving electricity. Control devices remotely with smart home application can schedule your devices to turn off when you aren't home.

5) Other functions. Besides the above feature, our smart home system also has some other functions, such as abnormal protection, earth leakage protection and so on.

Various electrical devices are respectively attached to the Smart Plugs for power supply. It's limited to one device per Smart Plug in theory, and the Android app quickly connects with your existing WiFi network. Likewise, when power is failure, the Smart Plug remains switched off and it will automatically exit the network. While Smart Plug with corresponding sensors can sense electrical energy consumed and board temperature in real-time, and upload the data to the Web server through the Internet. With an included app for Android devices (phones or tablets), users can control the connected appliances wherever they are.

3. Related Work

3.1. Short-Range Wireless Communication

Wireless communication between a smart phone and a Smart Plug is the key to implement the home automation system [2]. The widely-used wireless technologies include Bluetooth, ZigBee, WiFi and etc. Different requirements are supported slightly

and differently by the various wireless technologies. In the following section, their differences are explained in detail (see Table 1):

Table 1. Wireless Connectivity Techniques

Protocol	Bluetooth	Zigbee	WiFi 802.11
Data Rate	1 Mbit/s	20,40,250 Kbit/s	11,54 Mbit/s
Range	10m	10~100m	>100m
Networking Topology	Ad-hoc, small networks	Ad-hoc, peer to peer, star, or mesh	Point to hub
Frequency	2.4GHz	2.4GHz	2.4 and 5GHz
Power Consumption	Low	Very low	High
Typical Applications	Inter-device wireless connectivity	Industrial control and monitoring, sensor networks, building automation	WLAN connectivety

Table 1 indicates the main drawback of Bluetooth is the limited range of operation (Maximum up to 10m). The smart home system is unable to cope with mobility and can only be controlled within the vicinity. ZigBee is suitable for low data rate applications with limited battery power due to its low power consumption which leads to a long lifetime. But in practical applications, ZigBee needs complicated application layer gateway when accessing the Internet. It cannot achieve end-to-end data transmission and control neither. Thus for high data rate implementations, WiFi would be better solutions because there is no need for extra application layer gateway.

WiFi is a local area wireless technology that allows an electronic device to exchange data or connect to the internet using 2.4 GHz radio waves. It has the advantages of high data transmission rate, wide coverage, wireless and strong anti-jamming capability.

Compared to the traditional intelligent home furnishing system using cable network, the application of WiFi technology reduces wiring trouble and has better scalability, mobility. Therefore the use of wireless intelligent control model is the inevitable choice of intelligent home furnishing development.

This paper presents the design and implementation of a new type of home automation system that uses WiFi technology as a network infrastructure for connecting its components.

3.2. Infrared Protocol

The picture below shows a typical pulse train of the NEC protocol. With this protocol the LSB is transmitted at first. In this case, Address $59 and Command $16 are transmitted. A message is started by a 9ms AGC burst, which was used to set the gain of the earlier IR receivers. This AGC burst is then followed by a 4.5ms space, which is then followed by the Address and Command. Address and Command are transmitted twice. The second time all bits are inverted and can be used for verification of the received message. The total transmission time is a constant because every bit is repeated with its inverted length [7].

Figure 1. NEC Protocol Transmission

E.g., the transmission of the address word "10011010" and the command data word "01101000" is performed by sending the bits "10011010'01100101'01101000'10010111".

Implementing a web server on Smart Plug to store infrared code programmed and customer could input commands through android application. IR remote library lets customer send IR remote codes in multiple protocols. It supports NEC, Sony SIRC, Philips RC5 and Philips RC6.

To ensure accurate output frequencies and duty cycles, the PWM timer is used, rather than delay loops to modulate the output at the appropriate frequency. Method mark() sends a mark by enabling PWM output and delaying the specified time. Method space() sends a space by disabling PWM output and delaying the specified time.

4. Hardware Architecture and Implementation

The complete Smart Plug hardware, packages and software suit with reference source code for the Smart Plug embedded application and Android based mobile applications will be described as follows.

The Smart Plug hardware includes a microcontroller, a clock chip, a 1M byte EEPROM, a WiFi module, 2 temperature sensors, a current sensor, an infrared emitter and a button. Figure 2 depicts a block diagram of the Smart Plug.

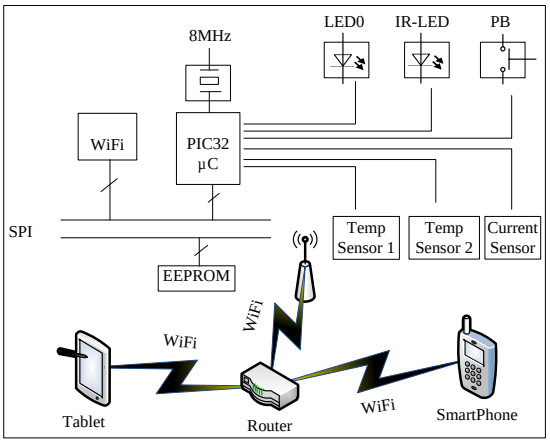

Figure 2. Diagram of Smart Plug Block

The Smart Plug uses PIC32MX340512H chip as its microcontroller. The microcontroller is based on the 32-bit high-speed RISC Harvard architecture. It has its own special features such as fast, low-cost, high reliability, rich peripheral resources, and strong I/O pin driver capability and so on. So PIC 32 can meet the hardware requirements of the smart outlet.

It is possible to clock a PIC MCU from an external oscillator up to 40MHz. In this project, we use an 8 MHz external oscillator. An EEPROM can be used to store MPFS2web page images and custom application structures. The HTTP2 web server module and its associated MPFS2 file system module allow the Microcontroller PIC32 to

act as a web server. This facilitates an easy method to view status information and control applications using any standard web browser.

The WiFi module (MRF24WB0MB) is designed to be used with Microchip's TCP/IP software stack. The software stack has an integrated driver that implements the API that is used in the modules for command and control, management and data packet traffic. MRF24WB0MB single operating voltage chooses typical 3.3V, ranges up to 400m.

There are two types of WiFi network topology, Ad-hoc mode and infrastructure mode. WiFi module embedded on the Web server, its initial state is Ad-Hoc mode. Firstly, open WiFi settings, connect smartphone or tablet to the web server, when the connection is established, enter the URL in browser's address bar, select the MPFS2 pages storage path, upload file MPFS .bin. When it's done, it will automatically jump to the index page, so user can control or monitor home appliances and devices using a web page. If user connect web server to router in WiFi infrastructure mode, he/she has to redirect to configuration web page, click the button to scan wireless network, then manually joining the network. Once the server is connected to the network, smart phones need to re-connect to the local area network. Using the discovery function in Android app to find all nodes that correspond to the smart devices installed in the network.

Remote control transmitter is controlled by the Microchip microprocessor PIC32, running at a frequency of 16 MHz from internal RC oscillator. Commands are transmitted via infrared radiation emitted by the IR LED with a wavelength of 950nm. TSAL5300 can be used. The max continuous current is 100mA. When pressing a button or sending combination commands, the transmitter sends the corresponding code.

5. Software Development

The proposed Smart home system consists of three main modules, the web server, the web page GUI and the software package (smart phone application).

During the configuration stage, the WiFi module embedded in the Smart Plug establishes connection with a Local Area Network using a static IP address. To optimize the process of connection, we have used static IP address instead of acquiring an IP via Dynamic Host Configuration Protocol (DHCP). Once the Smart Plug has been initialized, it enters into an idle state until any command is received from the remote user. Upon successful reception of command strings from the smart phone app, it will decode them and appropriate control actions will be taken. These actions can be either actuation or sensing [3].

5.1. Mobile Software Design

The android application for the Smart Plug needs to achieve the following six functions:

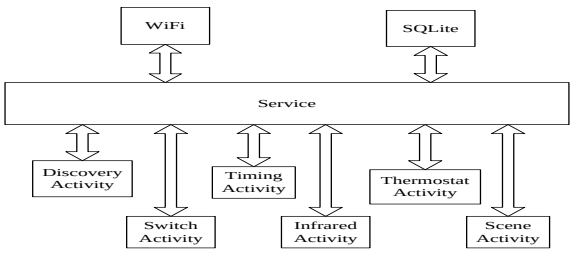

Figure 3. Smart Plug Application Framework

5.2.1. Discover Activity: Implement the 'network discovery devices' function in the application.

The discovery process is a key feature of the app. Without it we would not be able to interact dynamically with the smart devices. In essence, it works like this:

1) Searches the network for active nodes.

2) Finds all nodes that correspond to the smart devices installed in the building.

3) Adds these devices in a table of a database created with SQLite.

4) Parses an XML file that exists in each Smart Plug. This file has important information which is going to be added to the database.

On click of the "Search" button a Discover page is displayed. This view contains only the “discover” button and the list of discovered devices with their respective network IP. As shown in Figure 4 of the screen-shot.

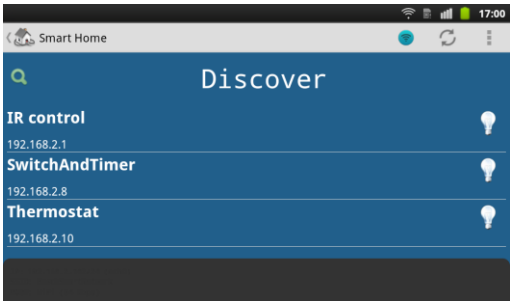

Figure 4. Discovery Network Devices

5.2.2. Switch Activity: The architectural principle that lies at the heart of the smart devices is Representational State Transfer (REST) which controls tiny web browsers embedded on these devices [8]. REST increases interoperability between the parts of distributed applications. It does this in a very lightweight and simple manner and focus mainly on resources and not functions as is the case with WS- web services [9]. The best of REST is that it uses the web as a platform and exploits all the features inherent to HTTP such as authentication, authorization, encryption and compression.

REST has been presented as a Web-based interaction for controlling household appliances with Web techniques such as HTTP caching and push messaging. Also a Web-based graphical user interface has been developed to manage the home devices.

Practically each time information is requested, like actual temperature or energy consumption of the load of the switch or even when a switch is switched on or a temperature is set, in all these cases the required command is fulfilled by formulating using a standard URL [10]. For instance, typing http://192.168.2.101/device_intercface?switch_status=On in a browser or requesting the same URL from the application, requests the status resource of the switch and with the command POST sets it to On.

An example to understand the whole process and algorithm is the turning on of the Smart Switch. The button btnOn is responsible for this command.

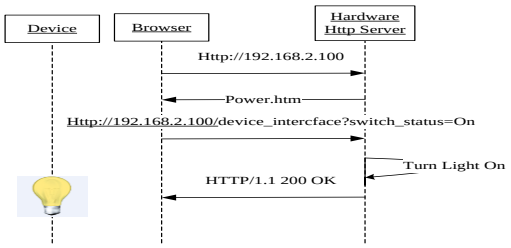

Figure 5. Message between Web Server and Browser

urlOn is the string which represents the url being sent to the Ajax callback method. In this case it is: final String urlOn = "http://" + ip + status_url + "?switch_status=" + "On", where ip is the address of the device, status_url is the postfix of the xml filename and switch_status is the tag that has to be changed to On.

5.1.3. Timing Activity: The main function of TimingActivity page is setting timer. Users could set custom labels for timers and set the start date and start time. The device which is plugged into Smart Plug will automatically execute the command switch on/off when the alert is triggered.

In this work, the Alarm Manager is used to handle a timing event. It involves an Android system lock mechanism. The system detects if there is no active events for a while and it will turn off some unnecessary services to reduce the resources and power consumption. The AlarmManager holds a CPU wake lock as long as the alarm receiver's onReceive() method is executing. This guarantees that the phone will not sleep until you have finished handling the broadcast. Once onReceive() returns, the Alarm Manager releases this wake lock.

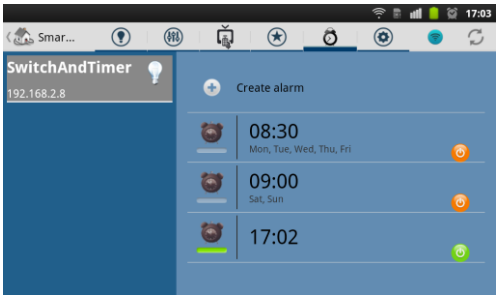

Figure 6. Timing Activity

5.1.4. Infrared Activity: Implemented a web server on Smart Plug to store infrared code programmed and customer could input commands through Android application. IR remote library lets customer send IR remote codes in multiple protocols. It supports NEC, Sony SIRC, Philips RC5, and Philips RC6.

Here are the details of the sending library

.The transmission code is straightforward. To ensure accurate output frequencies and duty cycles, the PWM timer is used, rather than delay loops to modulate the output at the appropriate frequency. Method mark() sends a mark by enabling PWM output and delaying the specified time. Method space() sends a space by disabling PWM output and delaying the specified time.

As it can be seen it is separated into two different parts. The left side being the list of available Infrared devices and the right side the command window of the selected Infrared device, once it is selected, the color is grey.

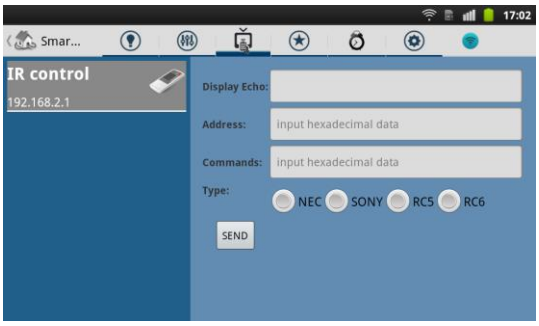

Figure 7. Infrared Control

The user interface is shown in Figure 7. Infrared Control is implemented via HTTP GET method. For the actual execution of the HTTP requests, we use an instance of the DefaultHttpClient class, which, as its name implies, is the default implementation of an HTTP client, i.e. the default implementation of the HttpClient interface. We also use the HttpGet class (in order to represent a GET request) and provide the target URL for its constructor argument. The HTTP client executes the request and provides an HttpResponse object which contains the actual server response along with any other information. For example, we can retrieve the response status code and compare it against the code for successful HTTP requests (HttpStatus.SC_OK). For successful requests, we take reference of the enclosed HttpEntity object and from that we have access to the actual response data [5].

5.1.5. Thermostat Activity: The command window on the right is itself divided into two different parts: the left parts gives information about the state of the thermostat and the actual room temperature, and the right part indicates that the temperature can be set.

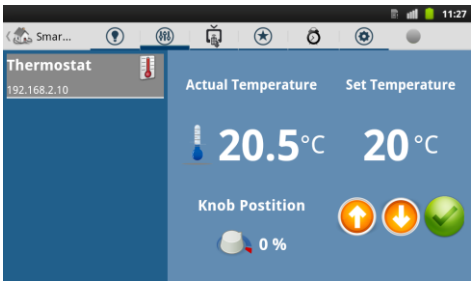

Figure 8. Thermostat Activity

5.1.6. Scene Activity: This activity gives the possibility to control several smart devices at once by the touch of a button. It is also one of the points which need to be developed further. This project covers only the basic features and the concept of this fragment. It has a similar feel to the other fragments, meaning it is made out of two parts, see Figure 9.

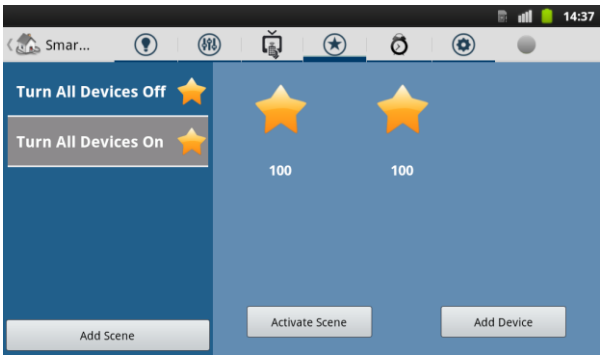

Figure 9. Scenes Activity

The left part lists the present scenes. At the bottom of this list, there is a button called Add scene. By touching it, we can create a new scene. At this point, we can only add the name of the scene. Further commands will be added later.

After creating a scene, we can add or remove devices that are going to be controlled by that scene. These devices can be chosen from the table of saved devices. A service needs to be added to the selected devices (Figure 10. Add Device to Scene). This service is the command we want this device to perform, i.e. turning off a switch or lowering the thermostat temperature. These services can be changed later as well. After finishing the setting up of the scene we can activate it by pressing the button below called "Activate Scene". At this point the app will run all the present commands for each device of the scene. The devices will perform accordingly.

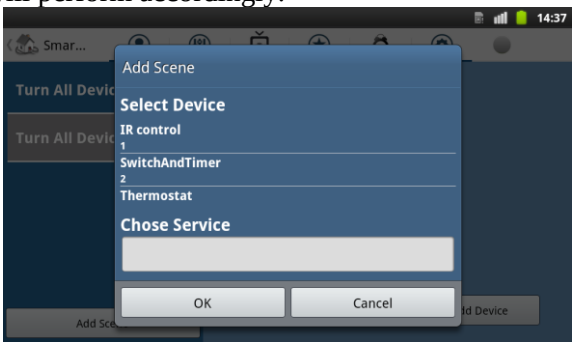

Figure 10. Add Device to Scene

6. Conclusion

This paper proposes and implements a novel "Smart Plug" related to "Smart Home ". The Smart Plug is cost-effective and flexible to use. Android App is capable of controlling the smart appliance in an entire house (lights, doors, temperature, TV and etc.). The system is based on RESTful web services which are applied to communicate between the remote users and home devices. In order to make our life and surroundings more charming and convenient, subsequent system function allows people to control the home appliances through voice, and achieve a true sense of "intelligent life".

Acknowledgements

The authors gratefully acknowledge the support of Shanghai Engineering Research Center Project (No. GCZX14014, 14001), the Innovation Fund Project For Graduate Student of Shanghai (No. JWCXSL1402), Shanghai Key Science and Technology Project

in Information Technology Field (No. 14511107902) and Shanghai Leading Academic Discipline Project (No. XTKX2012) .

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