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Design of Web-based Smart Home with 3D Virtural Reality Interface

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***Abstract*—In this paper, the design of the a web-based Smart Home system is introduced. The proposed system provides a web interface through which users are able to check the home status and control the domestic appliance remotely as long as they have a PC system connected to the Internet. In order to give users a more vivid way to access the Smart Home system, a web based 3D interface with virtual reality technology is proposed in this paper. The rooms, appliances and furniture are reconstructed in the web-based interface. Users can "look around" in the virtual home remotely. They are able to check the security alarms, control the appliances in the 3D virtual reality similar as they do in real homes.**

Keywords-smart home; web-based interface; 3D virtual reality; wireless network

I. INTRODUCTION

Recently, smart home has emerged as a hot spot both in academic and industrial communities [1]. Smart Home is the term commonly used to define a residence that integrates technology and services through home networking to enhance power efficiency and improve the quality of living. With the advent of the smart devices including Smart TV and smart pad, the various types of service [2] for smart home are expected to appear in the market.

A lot of smart home features such as home entertainments, surveillance and access control, resource effective management [3], home appliances automation, environmental control, assistive computing and healthcare came into birth so that lead to a promising industrial market in last two decades [4].

Today's Internet is evolving into an "Internet of things," as soon there will be more than one trillion connected devices. By 2013, 1.2 billion connected consumer electronics devices are expected in the more than 800 million homes with broadband connections.

With the rapid development of the Internet, new smart homes are moved out from the home onto the network where users are able to monitor and control the domestic appliances remotely check the status of the home from any place any where as long as they have Internet access.

In recent years, web-based 3D technologies have been widely used in many applications such as online games [5], urban management [6], remote experimentation [7] and GIS [8] *etc*. 3D objects can be imported and rendered in web browsers. If the homes can be reconstructed in web based virtual reality world, the users can access their homes remotely in a more vivid way.

In this paper, the design of a web-based smart home is introduced. It can be accessed remotely using web browsers. Web-based 3D technology is adopted in the design to provide a more vivid remote access interface. They are able to "walk around" in the virtual homes and control the appliances freely as if they are at home.

II. STRUCTURE OF SMART HOME

A. General Strucrue

It is a trend that telephone, television and computer networks merging in one optical fiber network with the development communication technology. The proposed Smart Home system is based on the Triple Play communication architecture as shown in Figure 1.

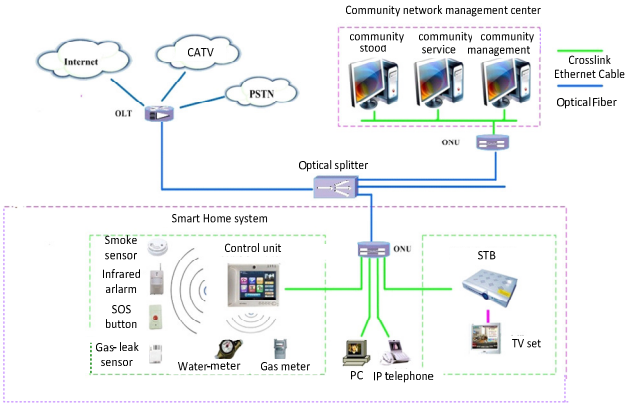

Figure 1. Typical structure of smart home with triple play communication architecture

The proposed Smart Home system uses wireless communication to control various domestic appliances in order to reduce the cost of cabling and increase the flexibilities. Small wireless communication modules are installed on domestic appliances, meters and security sensors so they can be accessed by the control unit through wireless communication.

The Control Unit is also connected to a central web server located in the community center. The users are able to control the appliances, monitor the real-time images and check the power consumption at home through the web server remotely. Moreover, if any security alarm is trigged, the message is also transmitted to the central web server where a text message is sent to the corresponding user's mobile phone automatically.

B. Structure of the Hardware

The network architecture of smart home system inside the home consists of two parts, as shown in Figure 2. The Control Unit is the central device of the system. It mainly consists of the main board, LCD screen, CMOS camera, wireless module, microphone and speaker. The main board is based on Samsung's S3C6410 ARM11 processor and integrates various functions such as video signal processing, camera control, USB, SD card, LCD screen, Ethernet. It is also equipped with a buzzer, a temperature sensor, a back-up lithium battery holder to ensure that the system time is not lost after power failure and other equipments.

In addition to the control unit, smart home system has many kinds of modules, such as security modules, domestic appliances control modules, smart meter modules. The security modules include window and door magnetic sensor, smoke sensor, gas leak sensor, infrared sensor, SOS button, etc. The domestic appliances control modules are used to control appliances, including light, air conditioner, curtain *etc*. The smart meter modules are used to collect the real time reading of the electricity, water and gas meters. The environmental monitoring modules are used to monitor the environment in house, including temperature and humidity. In addition, the smart socket can measure the real time status of the appliances, including voltage, current and power. These modules are connected to the central Control Unit using wireless communication. The status of the domestic devices is transmitted to the control unit in real time.

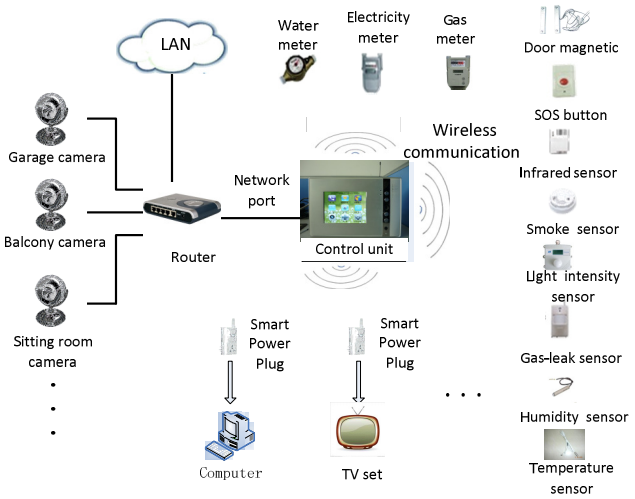

Figure 2. Structure of the Smart Home system

The Smart Home System uses wireless network to establish the communication between the control unit and home devices (such as appliances, security alarms and smart meters *etc*). The wireless module communicates with a variety of sensor modules, domestic appliances control modules, data acquisition modules by a nRF905 single-chip wireless transceiver which operates at 433MHz band. The use of the wireless network has simplified the system structure and reduced the cost of cabling greatly comparing with the wired solutions.

III. SOFTWARE STRUCTURE OF THE CONTROL UNIT

The operating system running in the Control Unit is Linux and the embedded software is developed using Qt which is a cross-platform application and UI framework. The device table represented in XML (Extensible Markup Language) form is the data core of the Control Unit software. Each device such as domestic appliances, security sensors has a corresponding element in the XML, where its, id, type, locations and status etc are specified. The control Unit can operate on the devices through wireless communication according to information stored in the XML device table. Figure 3 is an example of a light represented in the XML table. The XML elements are synchronized with the real devices. Every time an operation is implemented on a device or the status of a device changes, the corresponding XML elements are modified.

```
- <status>
    <location>Meetingroom</location>
    <type>Light</type>
    <id>85</id>
    <isclosed>yes</isclosed>
  - <task>
      <time>15:15:31</time>
      <isclosed>no</isclosed>
    </task>
</status>
```

Figure 3. An example of device table

Figure 4 shows the software structure of Control Unit. The network communication module establishes TCP connection channels with central web server. It get the information of the home devices from the XML table and transmit them to the web sever. The wireless communication module keeps connection with home devices. It receives the real time information from the home devices and implements the corresponding modification on the XML table.

If one of the security sensors is trigged, it sends a message to the Control Unit through wireless communication. The corresponding status of the XML is modified. Then the alarm message is transmitted to the central server where a text message is sent to the user's mobile phone.

Another important function of the Control Unit is to control and monitor domestic appliances. If provide a unified user interface to control all the appliances. For example, if a user wants to operate a certain appliance on the Control Unit such as tuning on a light, the Control Unit will send a command to the corresponding appliance through wireless communication and modify the XML document at the mean time.

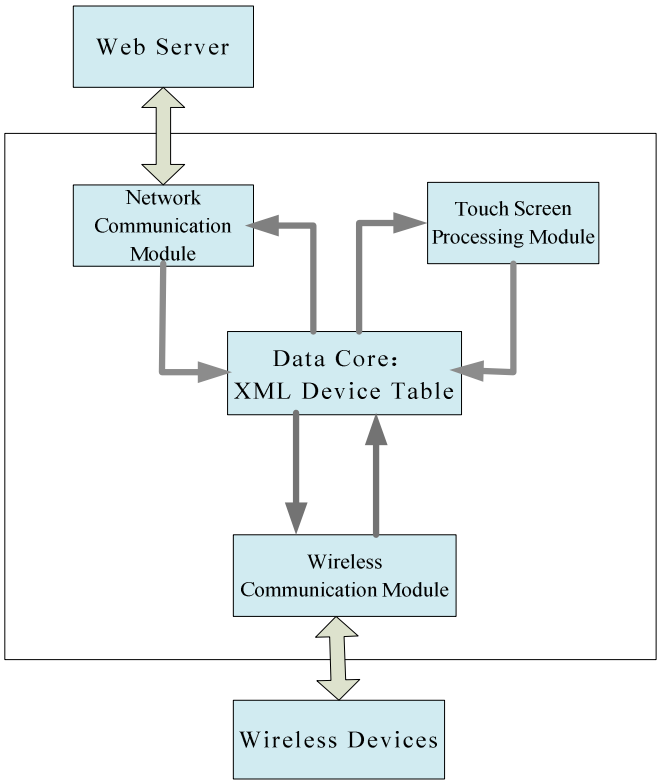

Figure 4. Software structure of control unit

IV. WEB-BASED REMOTE ACCESS INTERFACE

The Smart Home system provides a web-based remote interface for users. By a simple click of the mouse on web application, users are able to remotely and conveniently operate and control domestic appliances.

Web-based smart home remote control platform adopts B/S structure with a three-tier structure, as shown in Figure 5. In the overall architecture, Tomcat web server and MySQL database are deployed in the central server located in the community center. Three software modules are designed and implemented in the web server. The Communication Module is responsible for data communication between the wireless devices and Control Unit through the TCP protocol. JSP and Servlets are deployed to dynamically generate web interface for users to remotely manipulate the domestic electronics.

MySQL database is deployed as the middle layer which is the kernel data structure of the web server. All the information such as the user list, device list and security alarm record are stored in the database.

Web services server consists of database server and local servers, it communicates with the Control Unit through TCP connections. A variety of data provided by the Control Unit is sent to the server in XML form. Security alarm status, power consumption information and indoor environment information are packed in XML document and sent to the server.

Web Services server has played the role of a bridge in the whole system. It can not only obtain data form the Control Unit, but also pass the commands (such as tuning on or off a appliance) to from the web client to the Control Unit. These commands are also packed in XML which can be parsed and executed by the Control Unit.

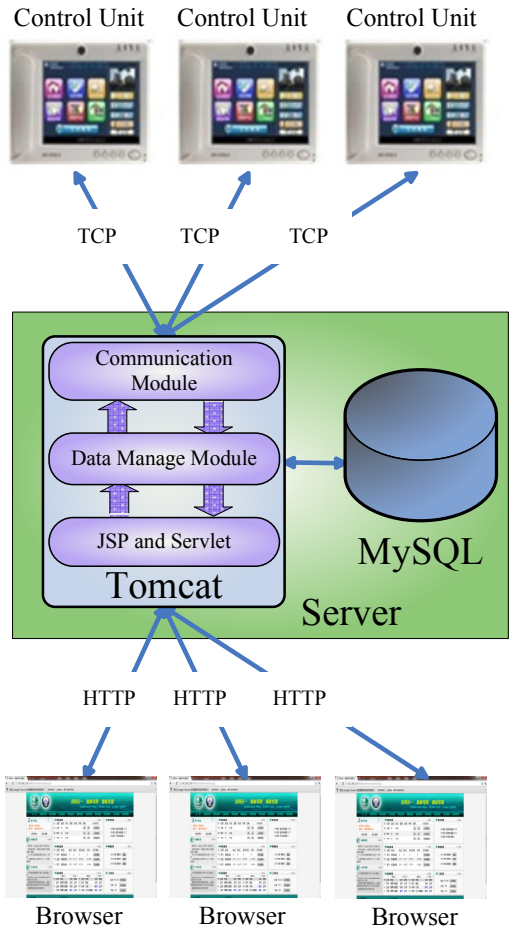

Figure 5. Overall architecture

The web-based Smart Home interface is shown in Figure 6. It can be seen that the main page containing user information, home appliance control, power monitoring, alarm monitoring, indoor environment, video monitoring, meter information *etc*.

Figure 6. Main Page

The web pages for the Smart Home system are different from conventional ones, which are mainly based on information publication. Ajax engine is introduced into the web so that the client browser uses asynchronous mode to communicate with the server. The web-based interface keeps requesting the status of the Smart Home devices from the web server. Therefore, every time there are changes (such as that an alarm is trigged) happened on the web server, if can be reflected on the web based interface immediately.

V. WEB-BASED 3D VIRTUAL REALITY

The web-based 3D virtual reality technology is adopted for the design of the smart home systems. When users login in their home remotely using their web browser, a web-based 3D interface is also provided for them. Their homes are reconstructed in the web browsers using 3D virtual reality. They can "walk into" their virtual homes and control the appliances remotely similar to the way they do in their real homes.

A. 3D Modeling

Components (appliances, furniture and rooms) of the smart homes must be modelled in 3D before it can be imported into the web-based user interface. There are many commercial software available for the 3D model design, such as 3DS Max, Solid Works and Pro/E *etc.* The original 3D models to be displayed in the web-based interface are firstly designed using the software and then converted into a common format which can be recognised and decoded by Flash 3D engines.

In this case, 3DS Max is selected as the 3D model development tool. The models designed in the 3DS Max are exported into the Wavefront .obj format for the Flash 3D engine. Figure 7 is an example which shows the 3D model of room being designed in the 3DS Max environment.

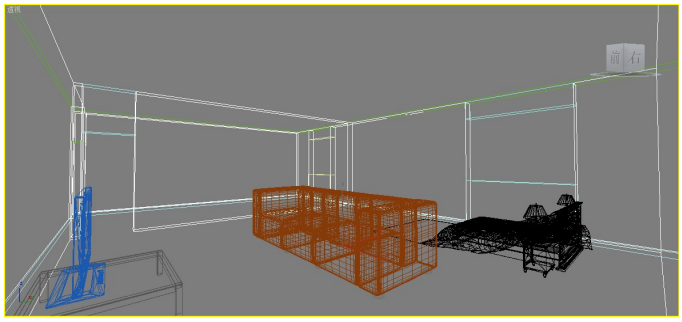

Figure 7. A 3D room designed in 3DS Max

When designing the 3D models, the complexity of these models must be considered carefully. The quality and the complexity of the 3D models have to be balanced. Even though the most powerfully 3D Flash is more than capable of processing tens thousands triangles, too complex models always result in big target files. In the internet environment, the long wait for downloading these files to the web browsers should be avoided as much as possible.

B. 3D Rendering

3D models in can not be displayed in the web browser directly. It must be imported and rendered in Flash Controls. There are several 3D Flash engines available and most of them are open source software. Paperverion3D, Away3D and Sandy3D are examples. However, some early version of 3D engines only support software rendering. Without GPU (Graphic Processing Unit) acceleration, only relatively simple 3D applications can be implemented in the web-based interface, which had significantly limited the growth of the web-based 3D technologies.

The release of Flash 11 had changed the situation. Flash 11.0 starts to support hardware accelerated 3D rendering, which makes it possible to designed more complex 3D applications. Stage 3D which is a set of 3D API in Flash 11 enables advanced 3D capabilities on both PC and mobile platforms. In order to help developers to quickly design 3D web-based applications, Proscenium which is an ActionScript code library built on the top of Stage 3D has also been released. Using Proscenium, models designed in 3D design software can be easily imported and rendered into Flash Controls. The structure of a 3D Flash Controls is depicted in Figure 8.

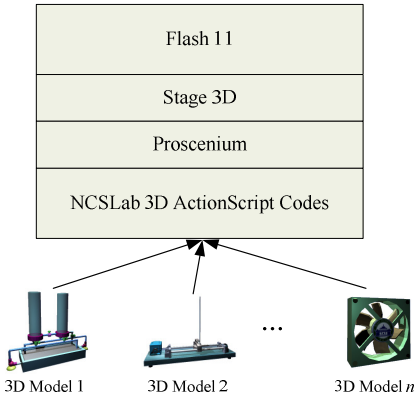

Figure 8. Structure of a 3D Flash Control

Using the resources provided by Stage 3D and Proscenium, 3D models designed in the 3DS Max environment are imported into Flash Controls which are embedded into web browser. Therefore, they can be embedded and displayed in the web-based interface. Apart from the 3D engine, some supporting codes are also designed. These codes are able to communicate with the Web Server and dynamically control the animations of the 3D components.

C. Web-based 3D Interface

Figure 9 shows the structure about how the 3D models are displayed in the web-based interface. The Tomcat Web Servers create the NCSLab web pages dynamically using JSP/Servlet Technology. These pages are downloaded to the web browsers and generate the web-based interface.

On the user's web browser, AJAX scripts embedded in the HTML codes are designed to deploy the 3D Flash Controls in the web-based interface. These codes download and the corresponding 3D Flash Controls and embed them into the web

browser. The 3D Flash Controls are also able to obtain real-time data from the web server. The motions of the 3D models can be manipulated according to the real-time experimental data collected from the web server, which gives the synchronization between the animations and real test rigs.

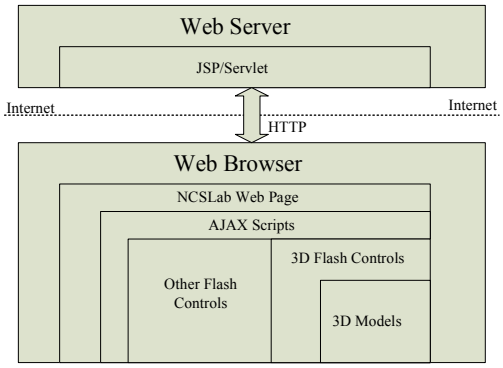

Figure 9. Structure of 3D web-based interface

Even the same 3D Flash Controls running in different circumstance may have different configurations. These configurations are generated dynamically in the XML form by the JSP/Servlet codes running on the web servers. The AJAX scripts pass the XMLs to the 3D Flash Controls where the 3D components are displayed properly according to these configurations.

Figure 10 shows a virtual home reconstructed in the web browser. The real home is displayed in the 3D virtual environment. Users are able to look around in the "virtual home" freely using the mouse the keyboards. They can check the security alarms, control the appliance freely similar to the way they do in real homes.

VI. CONCLUSIONS

In this paper, a web-based smart home system with 3D virtual reality is introduced. In this system, wireless network is used to establish communication between the Control Unit and home devices. Comparing with the wired solution, it is able to simplify the system structure and save the cabling cost greatly. A web server is deployed in the community center. Therefore, users are able to login the web server and access their homes remotely using web-based interface. 3D virtual reality technologies are also used in the system. Rooms, appliances and furniture are reconstructed in the 3D web-based interface. Users can "look around" in the virtual home remotely. They are able to check the security alarms, control the appliances in the 3D virtual reality similar as they do in real homes.

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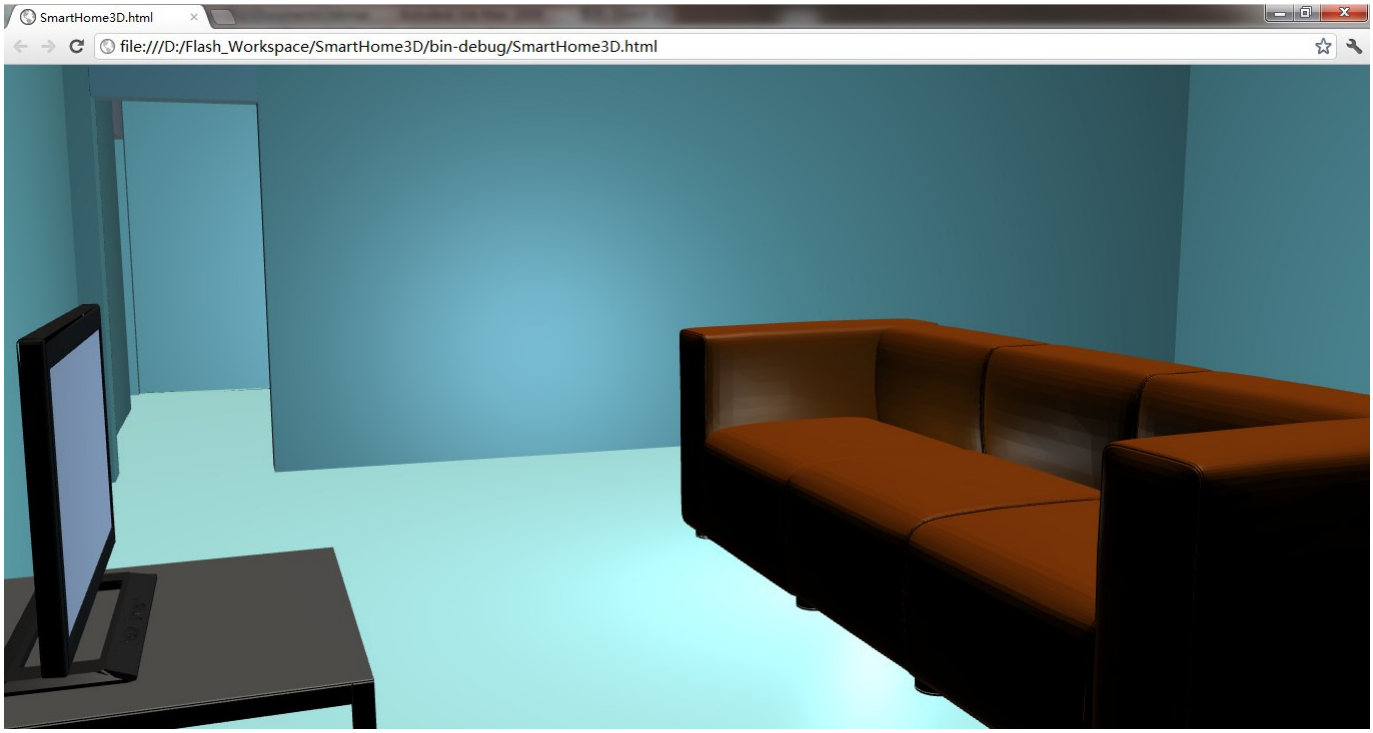

Figure 10. 3D room Displayed in web-based interface

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