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Wireless Sensor Network-Based 3D Home Control System for Smart Home Environment

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Abstract

This paper introduces a proposed 3d home control system that provides realistic home control service for users. We implemented the 3d home control system between user-centered virtual reality and the real world based on wireless sensor networks. This implemented system consists of smart devices that are equipped with virtual reality, the hardware for a real-world representation, and the synchronization software. The main point of virtual reality is that users are able to control home appliances similar to embellishing their home structure. Communication between the components, we designed the own communication protocol and used the wireless personal area network-based Zigbee module. Some experiments were conducted using the proposed model. As a result of the experiment, the proposed home control system performed well as it was designed to.

Keywords*: 3d home control system, Wireless sensor network, Ubiquitous home network service, Virtual reality*

1. Introduction

Wireless sensor network technology is a major area of interest within the field of ubiquitous computing [1]. Most studies in the field of ubiquitous computing have only focused on wireless sensor networks. As ubiquitous computing technology slowly progresses, users have provided adaptive information and services. Virtual reality and wireless sensor networks in the home can be distributed in different scales throughout our home network service. Also, the role of the PC in the world of information has been reduced with the advent of smart devices, and the rapid dissemination of smart devices is changing human life [2, 3]. Smart devices are being utilized in businesses using the Internet, basic office work, as well as phone features and message-sending purposes. Developing killer applications and services for the ubiquitous smart home will confer important commercial value [4]. A great variety of projects and research have developed wireless sensor network services as well [5-14]. It has the potential to control consumer home devices used in everyday life. As compared with previous home networks, the ubiquitous home network using virtual reality offers user activity areas on the user-centric environment, to support more realistic and adaptive home services. It has the potential to control smart devices used for smart life.

Finally, users may experience the convenience of performing activities in an increasingly realistic environment offered by smart home services.

In this paper, we designed a 3d home control system wherein users can control home appliances similar to embellishing their home structure. Using the communication technology of wireless sensor networks with Zigbee (802.15.4), our system can offer better performance and faster connection speeds, while efficiently controlling various home devices. The system can implement real ubiquitous home services via virtual reality and wireless sensor networks in home areas.

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2. 3d Home Control System

The proposed 3d home control system by wireless sensor networks and additional virtual reality application can control consumer home operation devices such as TV, air conditioner, unit heater, and lighting system, etc. Also, it is possible to indicate various smart devices in different areas using IEEE 802.11/802.3/802.15.4.

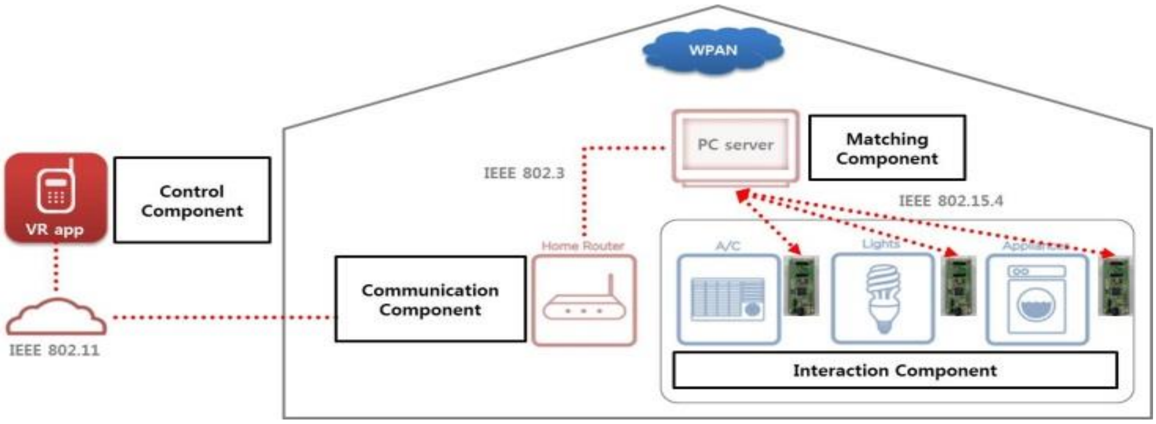


Figure 1. Overview of the Proposed 3d Home Control System

Figure 1 shows an overview of the proposed 3d home control system. Our 3d home control system based on wireless sensor networks consist of various components as follows:

- **Control Component**: This component instructs control commands to the arranged 3D-model on the user-centric virtual environment. These provide methods to control and handle various consumer home devices such as TV, air conditioner, unit heater, and lighting system, *etc*.
- **Matching Component**: This component synchronizes the control component and the interaction component with each other. When the component recognizes the current status of home devices, then the smart device immediately provides status data from home devices.
- **Interaction Components**: These components represent the status of home devices in the real world. It is used instead of home devices. For example, turning on the TV represents the LED display of hardware node.
- **Communication Components**: These components represent wireless personal area network technologies, such as Wi-Fi, 3G, and TCP/IP. These technologies leverage our provided home services to become more effective.

This paper details our proposed system and its implementation. The different sections of this paper are as follows: First, we propose a smarter home control system based on wireless sensor networks and design it to be more flexible with a software component-based approach. Second, we develop protocol to gain adaptive control of the matching component and the interaction components. Third, we implement the VR application that controls component, the hardware that interaction components and software that matching component utilized in our system.

3. System Implementation

To show the feasibility of the proposed architecture, we implement the 3d home control system and sensor nodes for various home devices in a house. We developed all the related hardware and software for our system. In this section, we present the potential ubiquitous home services provided by our system.

3.1. Authoring Tool-based Virtual Reality

We have developed an authoring tool-based VR for the purpose of smart home network systems [15] and the control component of Figure 1. We designed the authoring tool-based VR that will enable users themselves to set the house environment [16]. Specifically, users can set the location of the elements of house such as TV, refrigerator, electric fan, furniture, and light button with the structure in virtual environments.

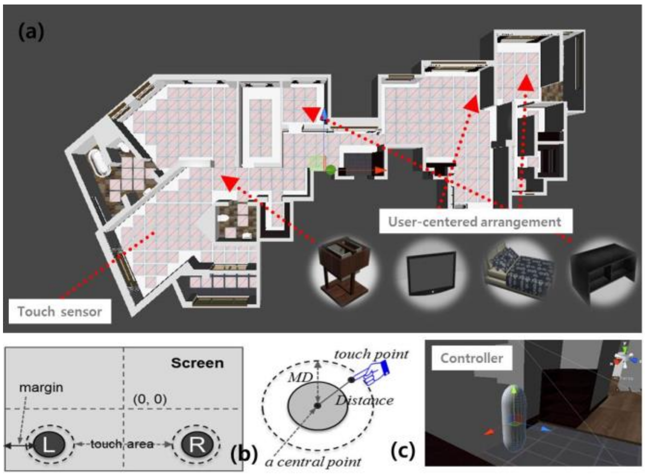


Figure 2. (a) Touch Sensor (b) Virtual Joystick (c) Controller

For home control services, we implemented the authoring tool-based VR on a smart device. The proposed authoring tool-based VR consists of three functions as follows in Figure 2:

- **Touch sensor**: Figure 2(a) shows the touch sensors of constant size disposed in virtual reality space. We designed the selected object from the GUI menu to display that the touch sensor can be allocated. If the user touches one of the sensors on the screen of smart device, it has to be able to place a 3D object into the detected position coordinates.
- **Virtual joystick**: The character moves by virtual joystick as shown in Figure 2(b). It shows the scope of the touch area and button coordinates. By the size of buttons and the margins of the left and right buttons is given by:

$$\text{Lbutton}(x, y) = (\text{-Screen.width}/2 + \text{margin},\ \text{-Screen.height}/2 + \text{margin})$$
$$\text{Rbutton}(x, y) = (\text{Screen.width}/2 - \text{margin},\ \text{-Screen.height}/2 + \text{margin}) \qquad (1)$$

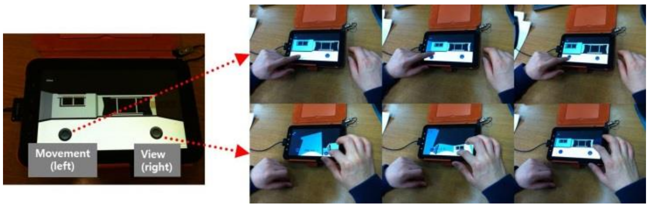
The touch area is set while maintaining the distance between a central point (a, b) and touch point (c, d) on a straight line. If the touch point is out of the area, the coordinates of the virtual stick is set to the x-axis and y-axis coordinate values of the maximum distance (MD). In order to obtain each component (θ, Limit(:)), the angle between (a, b) and (c, d) is obtained as shown below.

$$\text{Distance} = \sqrt{(a-c)^2+(b-c} \tag{2}$$

$$\theta = 180 \times \arctan\left(\frac{b-d}{a-c}\right) \times \tag{3}$$

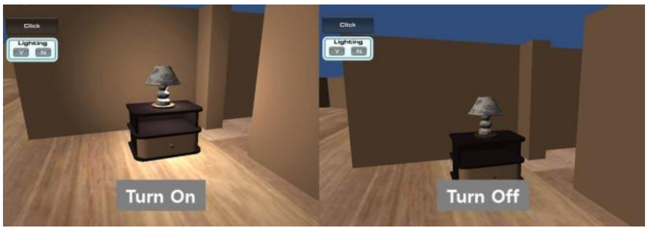
$$\text{Limit}\, x = MD \times \sin\theta, \text{Limit}\, y = MD \times cc \tag{4}$$

Controller: The controller was designed as a first-person point for realism. Figure 2(c) shows the camera settings for a first-person viewpoint and the implemented scene. In the case of a first-person controller, it controlled the movement and direction through the camera placed in front of the character.



(a) Virtual Joystick

(b) Touch Sensor



(c) Power Equipment

Figure 3. Implementation of Virtual Reality on Smart Device

In uploading virtual reality to a smart device, Figure 3(a) shows the test results of left button and right button. To provide values that detected horizontal and vertical movement by left button, direction by right button is input to the controller. The controller then moves by the input values. We have designed several of the 3D objects. The user can select 3D objects that have been created from the GUI menu. When the user selects one of 3D objects, space for arranging the object is displayed on the screen (Figure 3(b)). Users can decorate their home environment, and home appliances can be placed in a similar position realistically. Also, we designed the same behavior for home devices and 3D objects (Figure 3(c)). For example, while the power of the actual device is on, the power equipment is also on in the 3D objects within the smart device.

3.2. H/W to Represent the Real World

In this paper, we implemented the H/W for the representation of the real world as shown in Figure 4(a). Communication of between the H/W and S/W based on standards protocol is done with RS232 UART. Implemented communication of H/W of the master node and slave nodes using Zigbee RF module based WPAN.

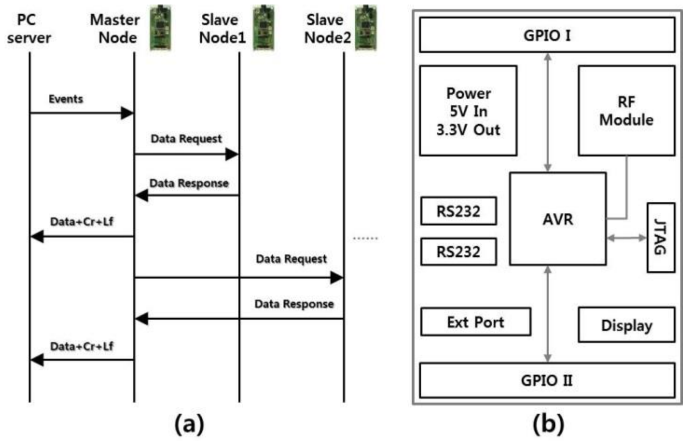


Figure 4. (a) Communication of H/W (b) Composition of H/W

Configuration of the test board with the AVR MCU and RF module based Zigbee is composed of the Power Block, Processor Block, RF Block, and External Interface as shown in Figure 4(b). The external power supply of H/W was designed to be available as Battery and 5V Adapter, shared H/W of Master node and Slave nodes for use. The master node is used to monitor and command the UART, the slave node as designed structure is used to monitor the UART as necessary.

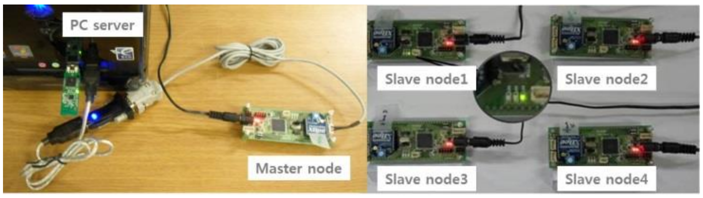


Figure 5. Master Node and Slave Nodes

H/W is composed of master node and slave nodes, which are implemented for the representation of the real world as shown in Figure 5. In addition to this, the master node is connected via RS232 communication with the PC server. Slave nodes are connected to wirelessly communicate with the master node based on WPAN. A result of executing the power on/off of the slave node1 in virtual reality, the data that was input from the virtual reality data on/off/state received and sent to H/W through the program execution is confirmed.

In this paper, we excluded electromechanical properties such as ‘open the door’, ‘open the curtains’, ‘turn the TV’, and ‘turn the boiler’. We confirmed that delivered through the LED by transferring data up to the previous stage. We also confirmed the H/W’s LED of ON and OFF status as shown in Figure 5.

3.3. S/W for Synchronization of VR and H/W

The synchronization S/W for smart home control to control home devices (H/W) via a smart device (VR) is shown in Figure 6. We designed the synchronization S/W as follows:

- **Communication setting**: Users can perform RS232 communication setting for data transmission between PC server and H/W nodes.
- **Data type conversion**: Users can convert the data type to be transmitted and received.
- **Send sample data**: It is intended for testing, which can be used to control and monitor by transferring the sample data to the H/W nodes.
- **Display the data number**: This displays the number of the received data and transmitted data to the H/W nodes.
- **Display the received data**: This displays information about the received data from the H/W nodes.
- **H/W state monitoring**: This displays the connection information, control information, and transmitted information by the PC server.

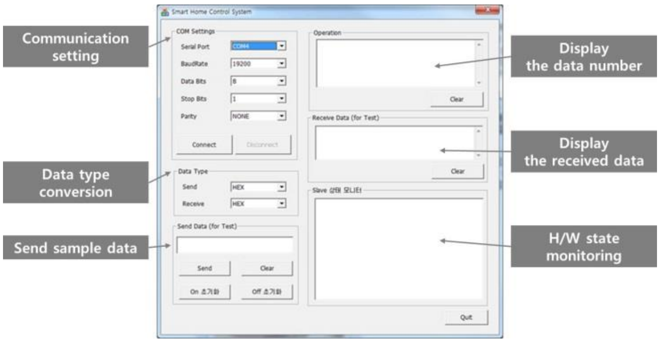


Figure 6. S/W for Synchronization

3.4. Data Transmitter and Receiver

Our implemented system is composed of VR on a smart device, H/W node for real-world representation, and synchronization S/W. The synchronization S/W is performed to communicate with the smart device by TCP/IP and with the master node by UART. Also, communication between master node and slave nodes are constructed based on Zigbee. We designed a protocol for matching the smart device (VR) and home devices (H/W). In this section, we will introduce a development for the communication protocols between the VR and synchronization S/W, and between synchronization S/W and H/W node. Figure 7 shows that the protocol between VR on a smart device and synchronization S/W is composed of fields as 'Start flag (Start of Transmission)', 'Serial (device)', 'Data', 'Blank' and 'End flag (End of Transmission)'. Also, it was designed as a total of 5 bytes. Details of the communication protocol are as follows:

- **Start/End flag**: These fields are appended to the front and rear of packet.
- **Serial**: This field is the unique number of the user and data counter.
- **Data**: This field is the type of data information to represent the current state of the home device.
- **Blank**: This is extra field.

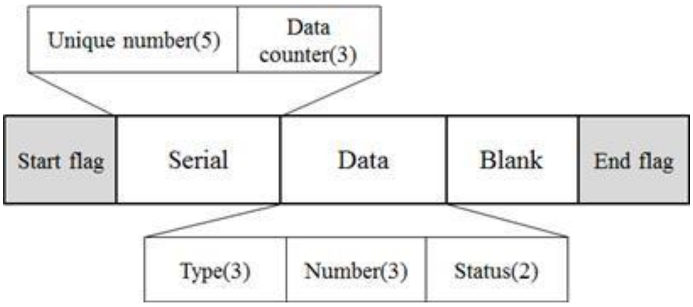


Figure 7. The Protocol of between VR and S/W

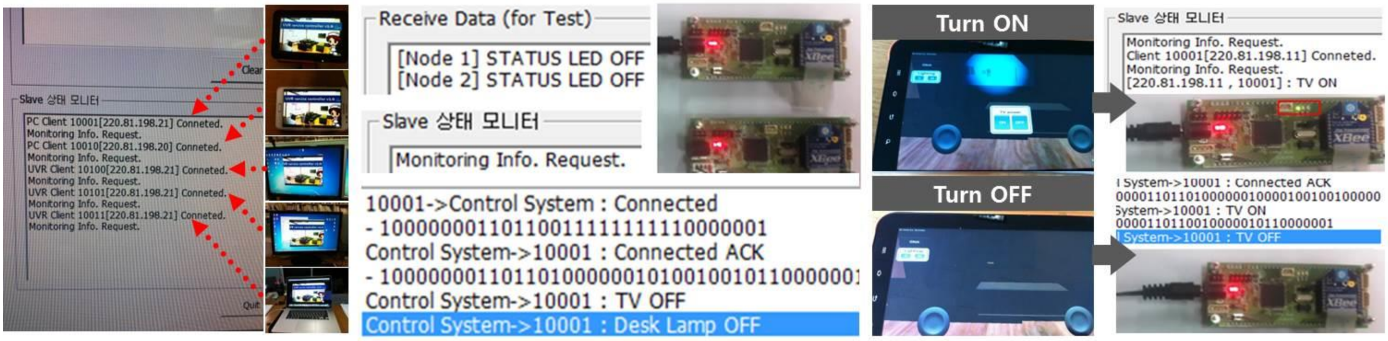
We designed the protocol for communication and control between synchronization S/W and H/W node, where there are composed fields as 'Start flag', 'Node number', 'Message type', 'Control data', 'LRC_High', 'LRC_Low' and 'End flag' in Table 1. 'LRC_Low' and 'LRC_High' each means low byte and high byte of value obtained from 'STX' to 'Message type' by XOR.

Table 1. The Protocol of between S/W and H/W

No.	Field	Value	No.	Field	Value
1	Start flag	0x02	5	LRC_HIGH	STX~VAL high byte
2	Node number	0x30~0x39 (for test)	6	LRC_LOW	STX~VAL low byte
3	Message type	0x30 (control request)	7	End flag	0x03
		0x31 (control response)			
		0x32 (status request)			
		0x33 (status response)			
4	Control data	0x30 (device Off)	-	-	-
		0x31 (device On)			
		0x41 (ACK)			
		0x42 (NACK)			

In this paper, the performance evaluation that the smart home control system proposed is operating in the design process. First, during the performance evaluation method of the system, it was confirmed that the 3D object is located exactly in virtual reality space by the book that is installed in the smart device. When the location of the 3D object is clicked, we confirmed the execution of data in the H/W node is to design as specified through the synchronization S/W. In addition, we evaluated the performance using typical PC-based client programs when there are multiple connections. Figure 8 shows the overall results of the proposed system.

We constituted a VPN (Virtual Private Network) for security in the process of data transmission between the smart device (or client based PC) and synchronization S/W, set 5-users to be able to connection. Figure 8(a) shows the process of connecting to the synchronization S/W via a VPN from a different type of smart devices (2) and PC-based clients (3). Figure 8(b) shows the process of sharing with each other the status of the H/W nodes and control signal of objects between users that are connected or multiple connections of serial authentication. Figure 8(c) shows that the LED is 'ON' from the H/W node when executing 'Turn on the TV' from the client (such as smart device or PC) based on VR.



(a) (b) (c)

Figure 8. Results of the Proposed System

4. Conclusions

In this paper, we presented a new smart home control system based on VR to make home network service more comfortable and realistic. We implemented the proposed smart home control system and developed related S/W and H/W. Also, we confirmed that the input data from virtual reality on a smart device is performed to H/W via S/W as specified in the protocol designed. We do expect that our work contributes toward the development of ubiquitous home network service. As a part of future work, we will need to apply a method of personal authentication for privacy protection in our home control system to solve security problems that may arise.

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