AR Smart Home: a Smart Appliance Controller Using Augmented Reality Technology and a Gesture Recognizer

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***Abstract*— Recently, smart speakers have become commercially common operation methods for controlling home appliances, and they have solved some of the problems with remote control operations. However, smart speakers also have some problems. For example, it is difficult to use voice recognition in a noisy environment. In addition, it takes a long time to check the current status of home appliances because users have to ask their smart speakers questions or give commands and wait for answers. To investigate other remote operation methods, we propose AR Smart Home, which uses the augmented reality technology and gesture recognition technology. Through evaluating the prototype system, we found that operating home appliances with gestures and interacting with virtual 3D home appliances instead of the actual home appliances are acceptable in terms of usability.**

Keywords- Augmented Reality; Smart Home; Universal Control

I. INTRODUCTION

Recently, new information technologies have been developed to make our daily lives more comfortable and reduce our levels of stress. In particular, technologies based on the Internet of Things enable us to access various devices over the Internet. For example, one of the major changes in our daily lives is how to operate home appliances. Until now, we have operated various home appliances using various remotes. However, in such an environment, multiple remotes are scattered in the room, and users may lose track of where a required remote control is. In addition, since each remote control may have different operation methods, users need to learn each operation method and use it properly. A common remote control operation method is pushing buttons, but there are new operation methods; for example, Siri Remote [1] can operate an Apple TV [2] to access some video content. Users can move a cursor on the display or select something by touching or sliding on the flat panel of Siri Remote. Recently, smart speakers, such as Google Home [3] and Amazon Echo [4] have solved the problem of having multiple remotes. By introducing these smart speakers in our home, we can operate various home appliances by voice command. However, due to the characteristics of smart speakers, it is difficult to operate them in noisy environments. In addition, when users check the current statuses of their home appliances, it takes a long time to activate their smart speakers by voice and wait for the answers. We propose a new home appliance operation method that can solve these problems.

In this paper, we propose Augmented Reality Smart Home, which uses the Augmented Reality (AR) technology and gesture recognition technology. With AR Smart Home, it is possible to manipulate home appliances through gestures by interacting with 3D virtual objects corresponding to home appliances displayed in the room. In addition, users can recognize the current status of various home appliances by looking at how the 3D virtual objects are operating. In this paper, we evaluate the operation methods of various home appliances using augmented reality and gestures via the prototype application.

We conducted a user study to evaluate AR Smart Home using the prototype application. We found that the augmented reality technology and a gesture recognition technology for home appliance operation are acceptable in terms of usability. We also found that visual information displayed in personal space is preferred to be the minimum and that switching the operation target by gaze is intuitive. In addition, we found that assigning the same gestures to similar operations makes it easier to remember the gestures.

This paper is divided into the following sections. Section II shows the background and related work of our study. Section III explains the system architecture of AR Smart Home. Section IV describes the preliminary survey we conducted for investigating how to apply the augmented reality technology in AR Smart Home. Section V describes the design of AR Smart Home based on the results extracted from the preliminary survey in Section IV. Then, we explain our conducted user study for evaluating the prototype application in Section VI. Section VII shows the results and the analysis of user study. Finally, we conclude and describe the future work in Section VIII.

II. BACKGROUND AND RELATED WORK

Recently, the augmented reality technology has been developed, and head-mounted displays, such as Microsoft HoloLens [5] and Magic Leap [6] have appeared. This

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technology is becoming more familiar in our lives. With the technology, virtual information can be expressed in the real world [12]. The development of this technology may greatly change the perceptions and experiences in our daily lives.

Kim et al. [13] proposed a universal remote controller that consists of a touch screen, buttons, a speaker, and a haptic dial that returns tactile feedback. The universal remote controller provides a simple and intuitive operation method for users using the menu screen displayed on the screen and tactile feedback on the dial. However, the shown scenario deals with only one home appliance, and it is difficult to switch the current operation target when users operate multiple home appliances.

Wang et al. [14] proposed a user-centered control system for home appliances that consists of a versatile infrared controller, a task-based web application and a server that communicates between the application and the controller. They conclude that control methods of home appliance may become more user-friendly and enjoyable by combining sensor technologies and other services.

There are other related studies using the augmented reality technology for home appliance control, such as [15] and [16]. However, few studies have evaluated applying the augmented reality technology to operation methods of home appliances in terms of usability.

III. System Architecture of AR Smart Home

This section describes the overall architecture of the AR Smart Home system.

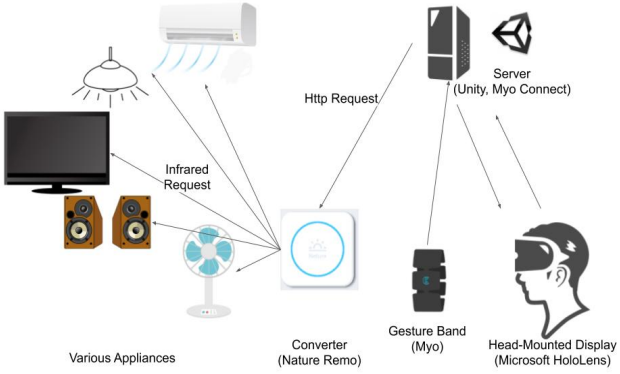

Figure 1. AR Smart Home System architecture.

Figure 1 shows the system architecture of AR Smart Home. The system uses Nature Remo [7] to operate home appliances by sending an HTTP request. The API of Nature Remo receives the HTTP request, and then Nature Remo sends preregistered infrared signals to home appliances. The system also includes Microsoft HoloLens to apply the augmented reality technology to display 3D virtual objects corresponding to each home appliance in the room. In addition, the system includes Myo [8] for gesture interaction with 3D virtual objects displayed in the room. By attaching Myo to the user's arm, various movements of the arm can be recognized. We implemented an application that organizes the processes of displaying 3D virtual objects through HoloLens, recognizing gestures through Myo and sending HTTP requests to Nature Remo. The application is implemented by Unity [9] and C#. The application uses the toolkit of Myo for the Myo gesture recognition and Mixed Reality Toolkit [10] for the HoloLens gesture recognition. The application also uses UnityWebSocket [11] for sending a HTTP Request. The sequence of the system is summarized as follows.

(1) The user performs a gesture in front of a 3D virtual object displayed through HoloLens.

(2) The application recognizes the gesture and sends a HTTP request to Nature Remo.

(3) Nature Remo receives the HTTP request and sends a preregistered infrared signal.

(4) The target home appliance receives the infrared signal and performs the defined operation.

In the early prototype, 3D home appliance objects corresponding to four home appliances (display, air conditioner, audio speaker, and lighting) are displayed in front of the user. The “air tap” gesture, which is bending the index finger in the user’s sight, is implemented as an operation method activated by a gesture. Users “air tap” the 3D virtual object for it to display "Power On", "Volume Up", or other buttons above the object. Users “air tap” the button again to end the operation of the corresponding home appliance. Figure 2 shows the use of the early prototype.

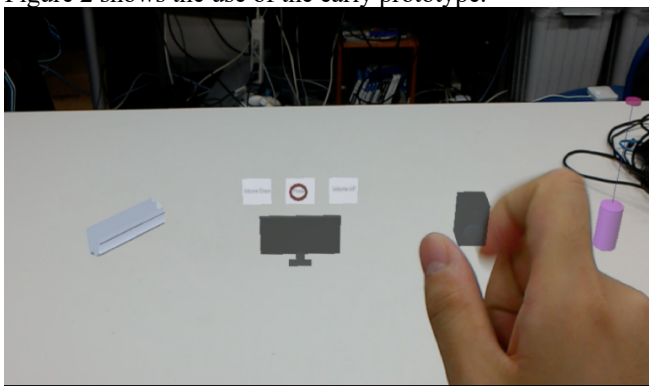

Figure 2. Using the early prototype application.

In Figure 2, the user is turning on the display by “air tapping” the button above the 3D virtual object displayed.

IV. Preliminary Survey

We conducted a preliminary survey to investigate how to apply augmented reality technology for AR Smart Home. This section describes our survey. We conducted the survey according to the following steps. First, an overview of AR Smart Home is given to participants and then they learned about the concept by watching a video and using the early prototype application. After that, participants answered questionnaires. Figure 3 shows a subject using the early prototype. In the preliminary survey, questionnaires were conducted on 78 people.

The contents of the questions are as follows.

(1) What kind of 3D virtual objects would be useful to represent home appliances?
(2) What functions would be useful on screens and operation methods?

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Table 1 shows the answers to Question 1, and Table 2 shows the answers to Question 2.

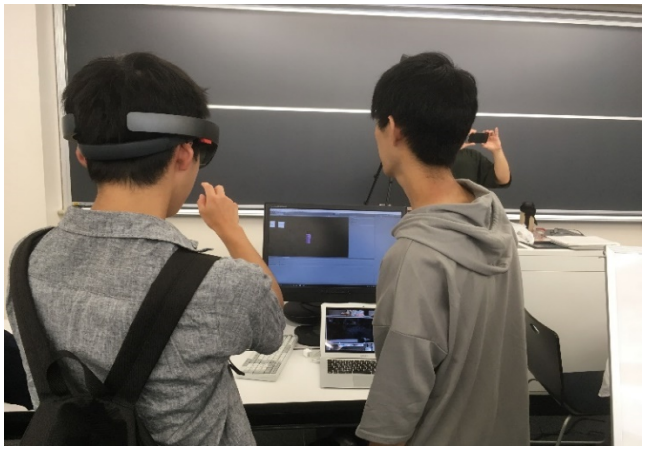

Figure 3. Using the early prototype application in a preliminary survey.

TABLE I. THE ANSWERS TO QUESTION 1.

Answers	Num
3D virtual objects of home appliances	12
Animated characters with the same characteristics as home appliances	11
Other objects with characteristics similar to those of home appliances	5
3D virtual objects identified by color	3
Control panels of home appliances	3
Illustration of home appliance	2
Special tools and control panels based on fictional devices	2
Others	11

TABLE II. THE ANSWERS TO QUESTION 2.

Answers	Num
Feedback effects indicating control and appliance status	13
Large and simple screens for users to easily recognize objects	10
Customization function that allows you to move an object to a desired position	8
Screens where all objects are visible	2
Application of AI assistants	2
Others	10

In Question 1, we investigated what kind of 3D virtual objects are suitable to represent actual home appliances. The most common answer was "3D virtual objects of home appliances corresponding to actual home appliances" because users can easily understand what they are operating.

In Question 2, we investigated the required functions of the operation screen and operation method in AR Smart Home. The most common answers were "a function for displaying feedback on user's input and effects indicating the current status of home appliances" and "a function for placing 3D virtual objects in a desired position". There were also many responses, such as "3D virtual objects should be simple, large and easy to look at".

V. DESIGN OF AR SMART HOME

We improved the early prototype described in Section III in terms of the operation screen and the operation method based on the results of the preliminary survey described in Section IV. This section describes the improved design of AR Smart Home. It is assumed that home appliances operated with AR Smart Home can be operated with a remote control without touching the actual appliances, such as air conditioners, TVs, audio speakers, fans, lighting, and curtains. Figure 4 shows the use of the prototype application.

Figure 4. Using the prototype application.

Figure 5 shows a screen of the prototype application. Based on the results of the preliminary survey, we applied 3D virtual objects that are the same shape as the actual home appliances. These 3D virtual objects are white in their initial state.

Figure 5. A screenshot of the prototype application.

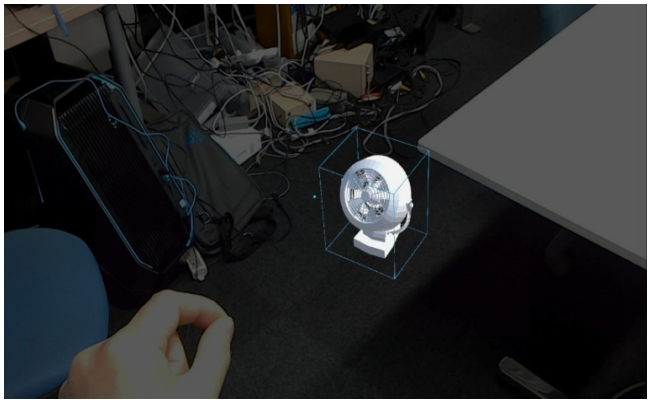

Figure 6. Placing a 3D virtual object.

The 3D virtual objects can be placed at the desired position by the user moving his or her hand and "air tapping" while putting the cursor on the target. In addition, the 3D virtual objects can be rotated by the user moving his or her hands and "air tapping" while putting the cursor on the target. Figure 6 shows how a user places a 3D virtual object.

Users can deliver commands to the target by performing gestures while placing the cursor displayed in the center of the sight on the target; then, the operation of the corresponding home appliance is completed. Table 3 shows the names of the gestures and their descriptions. Table 4 shows the correspondence of gestures to the operations of the home appliances.

Users can view the results of the operations and the current status of home appliances by seeing feedback. First, we describe the feedback related to the results of the operations. When the cursor is placed on the object and the object is selected as the operation target, the object changes from the original color to yellow. When the cursor is removed, the object returns to the original color. As shown in Table 4, “wave right” has the effect of increasing the volume or temperature of a target, and “wave left” has the effect of decreasing them. Therefore, when “wave right” is performed, the effect of red particles rising from the bottom of the target is displayed. Additionally, when “wave left” is performed, the effect of blue particles descending from the top of the target is displayed. Figure 7 shows the effects displayed when each gesture is performed. In Figure 7, the top figure shows the effect of raising the temperature on the air conditioner, and the bottom figure shows the effect of lowering the temperature on the air conditioner.

Next, we describe the feedback related to the current status of home appliances. As shown in Table 4, each home appliance can be turned on by performing “make a fist”. So that users can immediately recognize whether the power is turned on by looking at the object, the object turned on by performing “make a fist” changes green. When the object is turned off by performing “make a fist”, the object returns to the original color. An air conditioner has a cooling mode and a heating mode, and users cannot recognize which mode an air conditioner is in unless they feel the temperature on their skin. To make it easier to recognize which mode an air conditioner is in, the object becomes red when heating is set, and the object becomes blue when cooling is set.

In addition, the volume, fan speed, set temperature, and other states are displayed in text on the panel that is displayed above the object when the cursor displayed in the center of the sight is placed on the object.

TABLE III. GESTURES FOR OPERATING APPLIANCES.

Gestures	Descriptions
Make a fist	making a fist
Wave right	bending a wrist to the right
Wave left	bending a wrist to the left
Double-Tap	tapping an index finger and middle finger twice
Spread fingers	spreading fingers

TABLE IV. CORRESPONDENCE OF GESTURES AND OPERATIONS.

Appliances	Operations	Gestures
Air Conditioner	turning on the power raising the temperature lowering the temperature switching mode (heating, cooling) switching fan speed (low, medium, high)	Make a fist Wave right Wave left Spread fingers Double-Tap
Television	turning on the power increasing the volume decreasing the volume switching to the next channel	Make a fist Wave right Wave left Double-Tap
Audio Speaker	turning on the power increasing the volume decreasing the volume	Make a fist Wave right Wave left
Fan	turning on the power switching fan speed (low, medium, high)	Make a fist Double-Tap
Lightning	brightening / darkening	Make a fist
Curtains	opening / closing	Make a fist

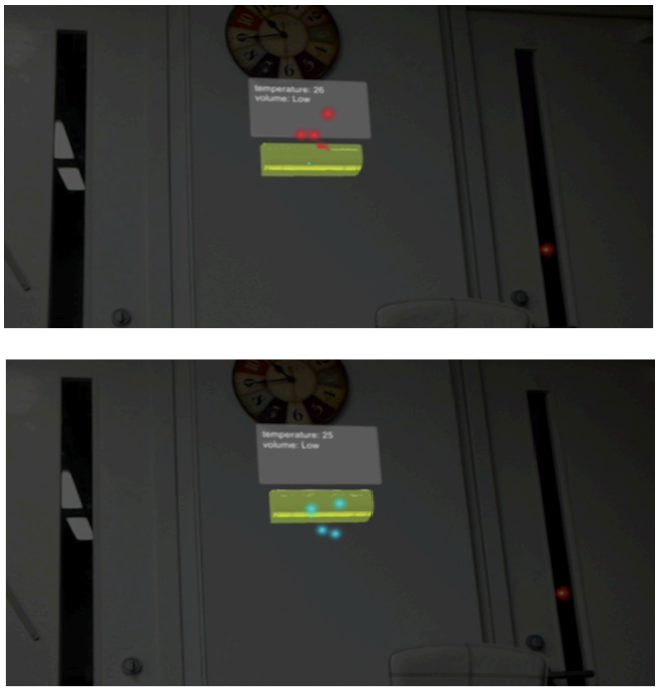

Figure 7. Effects of 3D virtual objects.

VI. USER STUDY

This section describes the user study we conducted to evaluate the prototype application. To evaluate the operation method using the augmented reality technology and gesture recognition technology, we conducted the user study without actually sending requests to home appliances. It was assumed that the home appliances were working as expected in the user study. In the user study, 10 participants aged 21-27 years participated. We conducted the user study according to the following steps. First, participants were told about the concept of this study and how to use the prototype application. After wearing the HoloLens and the Myo device, they customized

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the location of 3D virtual objects representing home appliances and operated the prototype application according to the given scenario. Finally, they answered a questionnaire using a 5-level Likert scale and answered questions in a semi-structured interview. To evaluate the usability of the system, we used the System Usability Scale (SUS) questionnaire [17]. The scenario given when participants operated the prototype application is as follows.

(1) You open the door of your room. Since the room is dark, you turn on the light in front of the door.
(2) Since you feel cold, you turn on the air conditioner and set the mode to the heating mode, the temperature to 20 degrees and the fan speed to medium.
(3) You want to watch a news program, so you turn on the TV and set the volume to 20.
(4) After finishing watching TV, you turn off everything and go to bed.

VII. RESULSTS AND ANALYSIS

This section describes the results of the user study described in Section VI and the analysis. We used the SUS questionnaire to evaluate the usability of the system. Table 5 shows the SUS items of the questionnaire. Figure 8 shows the average score for each question. The average SUS score was 70.0. According to [18], this average was within the acceptable range. We found that the usability of the prototype application was acceptable in terms of satisfaction.

TABLE V. SUS QUESTIONNAIRE ITEMS.

ID	Questionnaires
Q1	I think that I would like to use this system frequently.
Q2	I found the system unnecessarily complex.
Q3	I thought the system was easy to use.
Q4	I think that I would need the support of a technical person to be able to use this system.
Q5	I found the various functions in this system were well integrated.
Q6	I thought there was too much inconsistency in this system.
Q7	I would imagine that most people would learn to use this system very quickly.
Q8	I found the system very cumbersome to use.
Q9	I felt very confident using the system.
Q10	I needed to learn a lot of things before I could get going with this system.

TABLE VI. OUR QUESTIONNAIRE ITEMS.

ID	Questionnaires
Q11	Could you use the system without being stressed?
Q12	Is it suitable that the 3D home appliance object is displayed for interaction?
Q13	Is the feedback scale suitable?
Q14	Is it easy to switch home appliances by switching your gaze?
Q15	Did you use the gestures you learned as you intended?

In addition, we used some questions that we developed. Table 6 shows these items of the questionnaire. Figure 9 shows the average score for each question.

We provide the responses to each question that was raised in the interview after the questionnaire.

Figure 8. Scores for the SUS questionnaire.

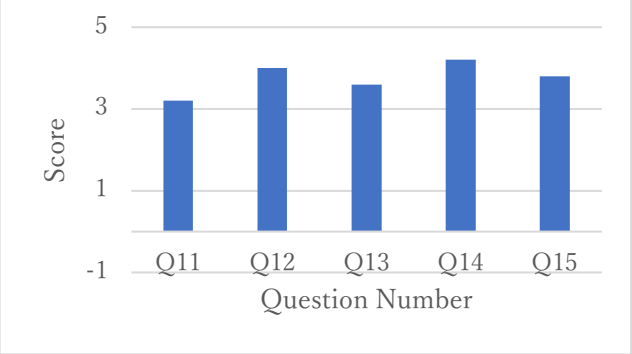

Figure 9. Scores for our questionnaire items.

In Q11, we investigated whether participants experienced stress when using the prototype application. Many of the participants who gave a relatively low score said, “There was something wrong due to the low recognition accuracy of Myo, but there was no stress about the use of gestures as operations if the accuracy was good.” The system relies on the Myo function for gesture recognition, so it may be necessary to consider using another device to improve the accuracy of gesture recognition; however, we found that there is no stress in operating home appliances with gestures.

In Q12, we investigated whether it is appropriate to use 3D virtual objects representing home appliances instead of actual home appliances as the interaction target. The most common response was “It is intuitive and appropriate.” In addition, there were responses, such as “The light object did not look like a light.” and “It was difficult to adjust the line of sight to the light object compared to other objects because the light object was slender.” It is necessary to improve the system by selecting objects in consideration of operability, such as selecting objects with wide shapes.

In Q13, we investigated whether the size scale of 3D virtual objects and the feedback displayed in the screen were appropriate. Most of the participants responded “I don't like displaying objects and feedback with ornate decorations in my room, so the simplicity of the system was just right.” There was also the related response of “It is better to display them only when they are needed.” We found that people usually prefer minimum visual information displayed in personal space, such as a room where people usually live.

In Q14, we investigated whether the method of switching the operation target by switching the line of sight is

appropriate. Most of the participants responded that “It was easier to switch by line of sight than to change the remote control.” There was also a response that “I would look at the operation target even if I use the remote control”. We found that switching the operation target by gaze is intuitive.

In Q15, we investigated whether users can remember some gestures and use the gestures in their daily lives. Most of the participants responded that “If I get used to the system, I can handle gestures.” There are similar operations in the operation of various home appliances, such as “turning on the power” and “raising and lowering something”. We found that assigning the same gestures to similar operations makes it easier for users to remember and handle the gestures even if there are multiple gestures. There was also a response that “Human errors are likely to occur less often with gesture operations than with remote control operations.” In remote control operations, various operations are performed by pressing a button. On the other hand, operation methods using several gestures can be easily distinguished from one other, and errors due to human recognition can be reduced.

In the interview, we also asked the question, "How would you place objects of home appliances in your room?". The most common response was "I would place them close together because when I look at them, I can operate various home appliances." One of the strengths of using augmented reality technology is that we can replace home appliances that have physical constraints with 3D virtual objects and place them at any position in the room without fear of them being lost.

VIII. Conclusions and Future Work

In this paper, we proposed AR Smart Home, which uses augmented reality technology and gesture recognition technology. We also evaluated the prototype application by a user study. Using gestures to operate home appliances is not stressful, and it is intuitive to interact with 3D virtual objects representing home appliances instead of actual home appliances, so the system is acceptable in terms of usability. We found that visual information displayed in personal space is preferred to be the minimum and that switching the operation target by gaze is intuitive. In addition, we found that assigning the same gestures to similar operations makes it easier to remember the operation gestures.

In the next step, we would like to remove various constraints in the current design. In the current design, gestures that can be recognized are limited to those recognized by Myo and HoloLens. By implementing other gestures, it will be possible to incorporate many other current remote-control operations. Then, it will be necessary to investigate how many gestures users can remember and use in daily life. In the research, we conducted the user study on the premise that users can use augmented reality technology and gesture recognition technology in their daily life. However, users have to equip some devices in order to use the system and it may limit the comfort. In this aspect, we should conduct more study. In addition, a function that can customize the correspondence between operations and gestures will be necessary. It may also be necessary for users to be able to define various shapes of objects for the operation target, as there are various shapes of home appliances. Depending on the user's mood, arranging various objects and creating a favorite room can make the prototype more enjoyable to use.

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