Intuitive appliance control system based on a high-accuracy indoor positioning system

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***Abstract*—The recent increase in number of household appliances has resulted in an increase in the number of required remote controls. Multifunctional learning remote controls attempt to reduce the number of controls, but their complexity may confuse users. Recently, an alternative gesture-based control system has also been proposed, but it requires users to perform complicated gestures for turning on or selecting appliances. In this paper, we propose an appliance control system, which leverages the advantages of remote controls and gesture recognition. In our system, a user can select the target device just by pointing to the appliance using a remote control. After selecting the device, the user can control the appliance with buttons displayed on a touch panel attached to the remote control. The system is based on a high-accuracy indoor positioning system embedded in a smart house. We evaluated the proposed system through an experiment, and results show that the system can be used in daily life.**

I. Introduction

With the recent developments in information technology, electronics manufacturers have been releasing home appliances with more and more features, which increase the complexity of controlling them. This, in turn, forces users to learn the various ways of operation of each of their appliances. In the future, as the appliances become more connected to network, complexity of operation will increase and this problem will be more serious. To address this problem, learning remote controls have been released, which allow users to universally control their appliances. Learning remote controls receive and memorize infrared signals sent from different remote controls, and enables users to control various home appliances using one device. However, learning remote controls have many buttons, which can confuse users, especially first-time users and the elderly. Recently, intuitive appliance controls have been studied to reduce inconvenience, burden, and stress caused by having multiple complex remote controls [1]. However, conventional methods have problems and limitations such as requiring AR-markers to be attached to appliances [2], [3], or requiring gestures that are difficult to perform quickly [4]. Therefore, intuitive appliance control interface design is still a field that is open for research.

Nara Institute of Science and Technology (NAIST) has a smart house environment that serves as a test bed for research and experiments related to daily living activities. In the smart house environment, a highly accurate three dimensional indoor positioning system is installed, upon which our proposed system is based. As such, our system assumes that similar smart house systems will be widely-used in the future.

In this paper, we propose a system for selecting and controlling appliances intuitively. We developed a remote control device with three-dimensional positioning sensors that estimate the target device from sensor information and registered appliance positions. In our system, the user selects an appliance by pointing to it with the remote control. After selecting the appliance, the user can the issue controls to it through the appliance-specific menu items displayed on the touch panel of the remote control.

The objective of the proposed system is to make appliance control easy for beginners and the elderly, to have an intuitive control scheme that lessens the stress and burden on users, and to control home appliances collectively with an interface similar to those of conventional remote controls.

To evaluate the developed system, we conducted an experiment with 9 participants. In the experiment, we measured the time to control appliances using conventional remote controls and our system. After the experiment, we asked the participants to answer a questionnaire about our system. The experiment showed that the mean time required to control appliances with our system is 12.5 seconds, while using conventional remote controls takes 9.7 seconds on average. The time difference between the two methods is not too significant, and both are fast enough to control appliances during daily living activities. Based on the answers to the questionnaire, most of the participants appreciated our system's appliance selecting procedure and easy operation. We also found some points for improvement that will be discussed in a later section.

II. Related Work

Recently, novel appliance control schemes have been proposed to address the problems of conventional remote controls. In this section, we classify existing research into three categories and discuss each.

A. AR-based System

Studies have been done on using Augmented Reality (AR) technology to control home appliances intuitively and collectively [2], [3]. In such AR-based systems, users select the target appliance by pointing a camera to an AR-marker attached to the target. After selecting the appliance, the user controls the appliance with the information displayed according to the selected appliance.

The advantage of such systems is that the appliance selecting procedure is intuitive because a user can select a device just by targeting an AR-marker with a camera. Another useful

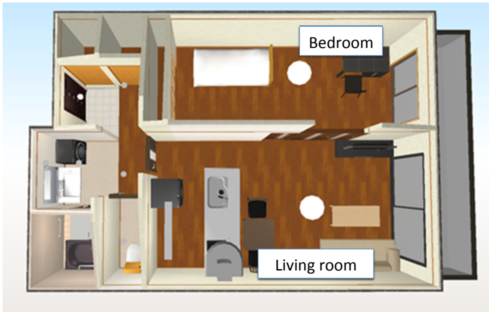

Fig. 1: Floor-plan of the smarthouse environment

feature of AR-based systems is that they can display additional parameters about the appliances (e.g. sound volume and temperature setting) with AR technology. However, there are problems such as decreasing recognition accuracy depending on illumination and distance. Also, such systems require AR-markers to be attached to every appliance in advance.

B. Gesture-based System

Appliance control methods based on gesture recognition have also been the subject of recent studies [4], [5]. There are various methods of recognizing gestures such as processing images from video cameras [4] or estimating acceleration sensor values from special devices [5].

The advantage of gesture-based systems is that beginners and the elderly can control devices easily with body or hand gestures, and these systems do not require smart phones nor remote controls because they use cameras or wearable devices. However, these systems require users to remember the gesture motions for individual appliances. Furthermore, they use gesture motion to select the target device, which may be burdensome or stressful for users.

C. Audio-based System

The use of audio-based appliance control systems have also been studied [6]. These systems recognize user voice commands, which are used to control appliances.

The advantages of such systems are that users can control appliances from anywhere in their homes and that they do not have to use additional devices. In audio-based systems however, users have to memorize voice commands to control appliances. Moreover, it is difficult to improve speech recognition accuracy.

D. Position of This Research

The previous subsection presented the advantages and disadvantages of different appliance control systems. With AR-based systems, the appliance selection method is natural because it is similar to that of conventional remote control methods. In addition, AR-based systems can display control menus that are specific to the selected appliance. With these advantages, AR-based systems are a well-suited interface for collectively controlling home appliances. In some cases however, the system's camera cannot recognize correctly (e.g. in long distances, in dimly-lit environments).

TABLE I: Data format of the position sensor

name	data type	detail
tag_id	integer	ID of sensor tag
time_stamp	timestamp	Receiving time of the data
pos_x	integer	x coordinate (mm)
pos_y	integer	y coordinate (mm)
pos_z	integer	z coordinate (mm)

Fig. 2: The Receiver (top) and the Sensor Tag (bottom)

To solve this problem, we used an indoor positioning system to estimate the desired target appliance. Our system detects the appliance to which the user is pointing through a developed remote control device that has an indoor positioning sensor. Our system aims to be easy-to-use for anyone including beginners or the elderly.

III. Target Environment

In this section, we describe the smart house environment and the indoor positioning system.

A. Smart House Environment

The proposed system was developed in the 1LDK smart house environment of NAIST. The smart house environment is shown in Fig.1. The smart house environment is equipped with various sensors for monitoring the activities of inhabitants. For this study, we use the embedded three-dimensional positioning sensors. All appliances in the smart house can be controlled by infrared signals, and are centrally managed by iRemocon [7], which is a learning remote control that sends infrared signals through a network.

B. Smart House Indoor Positioning System

The positioning system embedded in the smart house is composed of ultrasonic transmitters, which are called sensor tags, and ultrasonic receivers. The system is based on the TDOA (Time Difference of Arrival) method [8]. The position of the sensor tag is estimated as follows: (1) the sensor tag simultaneously transmits radio and ultrasonic waves, (2) the receivers embedded on the ceiling send the arrival times of the radio and ultrasonic waves to the base station, and (3) the base station calculates the coordinates of the sensor tag from the time difference between the radio and ultrasonic waves received by the receivers. Table I shows the data format of the positioning sensor.

Table II shows the absolute value of the difference between the measured and sensor values of the three dimensional

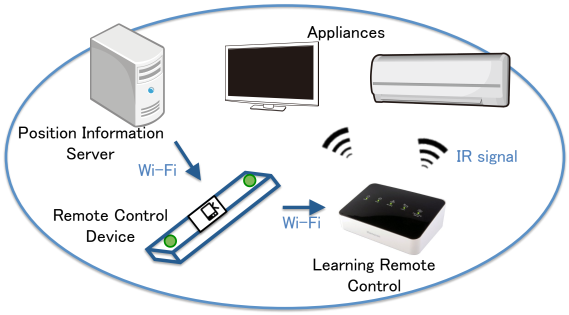

Fig. 3: System structure

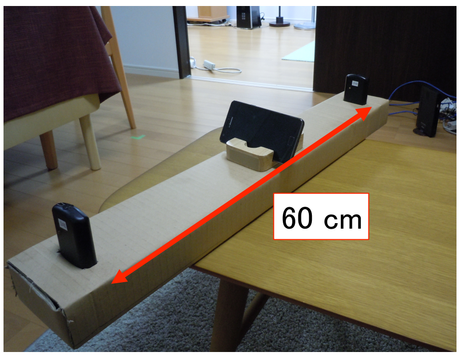

Fig. 4: Prototype of the remote control device

coordinates of four places. The confirmed error value of each is within ± 4 cm.

TABLE II: The absolute errors between the measured values and sensor values

	x	y	z
1	15.6 mm	30.7 mm	3.4 mm
2	31.1 mm	16.5 mm	4.8 mm
3	33.9 mm	13.1 mm	11.5 mm
4	3.4 mm	15.1 mm	18.5 mm

IV. Proposed System

In this section, we explain the structure of system and the algorithm of appliance selection.

A. System Structure

Our system consists of the positioning information server, positioning sensors, the remote control device, and the network learning remote control. The system structure is shown in Fig.3.

Figure.4 shows a picture of the developed remote control device. Positioning sensors are attached at opposite ends of the device. An Android device was used as a touch panel. To control appliances, an Android application was developed that enables communication with iRemocon via the Wi-Fi network.

B. Structure of Remote Control Device

We control most appliances by pointing at them with their specific remote control. In our system, we implemented a

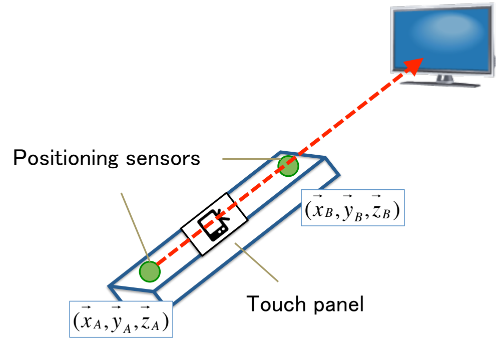

Fig. 5: The operation diagram of the developed remote control device

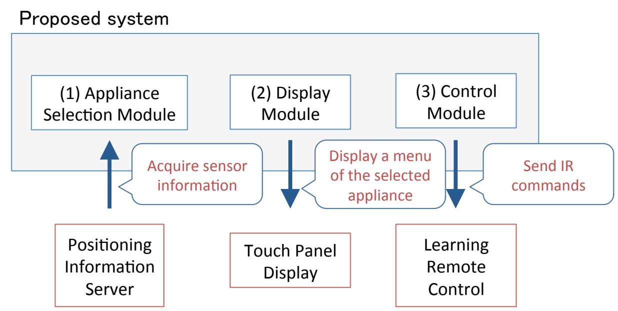

Fig. 6: System architecture

natural control scheme that estimates the target appliance from the values of two positioning sensors attached to our system's remote control device. A touch panel is attached to the center of the device, and the menus displayed on the touch panel changes according to the selected device. The user operates the touch panel to control the selected appliance. Figure.5 shows the operation diagram of our system's remote control.

C. System Architecture

Fig.6 shows the architecture of our proposed system. The system consists of three parts: the appliance selection, display, and control modules.

1) Appliance Selection Module: This module acquires the sensor data from the sensor tag attached to the control device from the server. From the sensor position and previously registered appliance positions, this module estimates which appliance the control device is pointing to.

2) Display Module: This module displays the contents according to the appliance estimated by the appliance selection module.

3) Control Module: Based on the input of the user, this module sends appliance control commands to the leaning remote control.

D. Appliance Selection Algorithm

Here, we explain the appliance selection algorithm from three-dimensional position information.

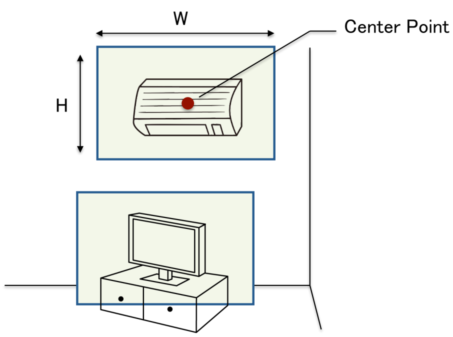

Fig. 7: Three-dimensional model of the appliances

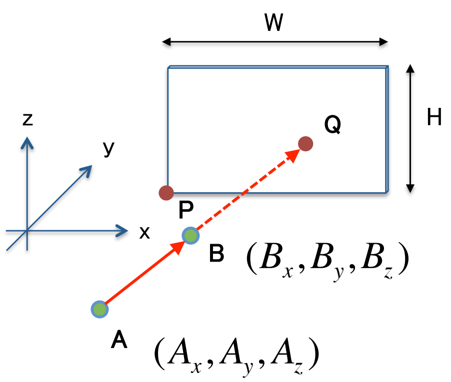

Fig. 8: Calculation for the interaction point

As shown in Fig.7, home appliances are modeled in our system as a detection plane with the following parameters: center point, width (W), and height (H). Modeled appliances are placed in a virtual three-dimensional space.

The procedure of detecting appliances is as follows. The detection plane of an appliance and the coordinates of sensors are represented by following formulas (shown in Fig.8).

$$ax + by + cz + d = 0 \tag{1}$$

$$A = (A_x, A_y, A_z) \tag{2}$$

$$B = (B_x, B_y, B_z) \tag{3}$$

Here, the interaction point (Q) between the detection plane and

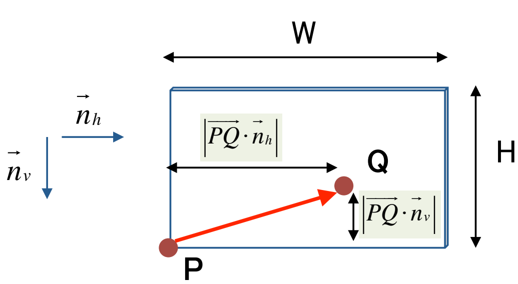

Fig. 9: Calculation of the distance on the plane

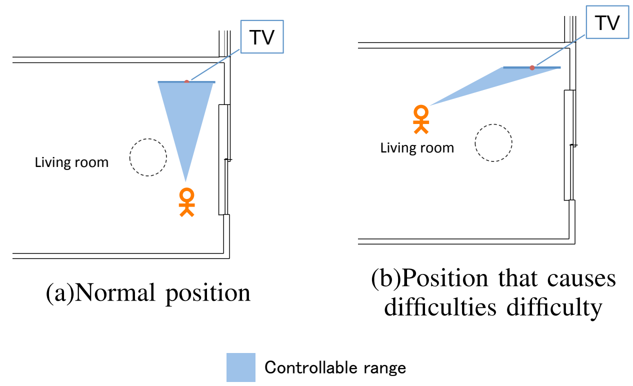

Fig. 10: The problem caused by angle

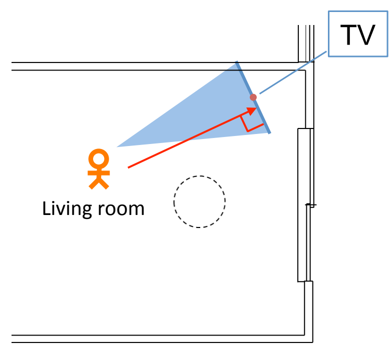

Fig. 11: The direction of the plane was adjusted to be perpendicular to the user

the straight line made from the two sensor points is calculated as follows.

$$Q = \begin{bmatrix} Q_x \\ Q_y \\ Q_z \end{bmatrix} = k \begin{bmatrix} B_x - A_x \\ B_y - A_y \\ B_z - A_z \end{bmatrix} \tag{4}$$

$$k = \frac{d}{a(B_x - A_x) + b(B_y - A_y) + c(B_z - A_z)} \tag{5}$$

As shown in Fig.9, we define two parallel unit vectors with the sides of the detection plane as $\overrightarrow{n_h}$ and $\overrightarrow{n_v}$, and the point closest to the origin as P. We then calculate the inner products between $\overrightarrow{PQ}$ and $\overrightarrow{n_h}$, $\overrightarrow{n_v}$. If they satisfy conditions (6) and (7), the system regards the straight line passing through the detection plane, and judges that the remote control is pointing to the appliance.

$$0 \leqq |\overrightarrow{PQ} \cdot \overrightarrow{n_h}| \leqq W \tag{6}$$

$$0 \leqq |\overrightarrow{PQ} \cdot \overrightarrow{n_v}| \leqq H \tag{7}$$

In a situation like Fig.10-(b), users may have difficulty in selecting an appliance based on its position in the house.

In our system, as shown in Fig.11, to rotate each detection plane of the appliance, the system enable user to control at any position in the home.

V. Experimental Evaluation

To evaluate our system, we conducted an experiment with 9 participants. In the experiment, the participants operated appliances using conventional remote controls and our developed remote control device. The participants performed 10 operations for each control method, and the time durations it took to control the appliances were measured. After the operation of the appliances, we asked participants to answer a questionnaire about the proposed system.

A. Usability

According to Nielsen [9], usability is a multifunctional concept associated with the following attributes:

1) *Learnability*
- How easy is it for users to learn the way to use the interface.
2) *Efficiency*
- Once users have learned the interface, how efficiently can they perform tasks.
3) *Memorability*
- How easily can they reestablish proficiency after a period of not using the interface.
4) *Errors*
- How many errors do users make.
5) *Satisfaction*
- How pleasant is it to use the interface.

The attribute to be focused on is different depending on the purpose of the interface, but the interface design should aim to satisfy these five principles. To evaluate the usability, we can identify the interface's most important usability problems. Also, it is important to improve these usability problems to make the interface easy to use.

The questionnaires give to the participants after appliance operation is related to these five attributes.

B. Experiment Environment

This experiment was conducted in the smart house environment where the proposed system was developed. The target appliances used in the experiment were a television, an air-conditioner, a fan, a room light, and an audio player.

When users control appliances, they have to select the specific remote control of a device from among the others in the homes. To reproduce such a situation, the participants had to select the remote control specific to the target appliance from among 15 remote controls on a desk.

We used a smart phone as the touch panel on the developed device. The icon of selected device is displayed on the touch panel, and users operate the device by a tap or swipe gestures. Fig.12 shows an example of how the touch panel is operated. To evaluate the learning curve of operating the device and the first impressions about the operation, the participants operated the device without the prior explanation of how the system works.

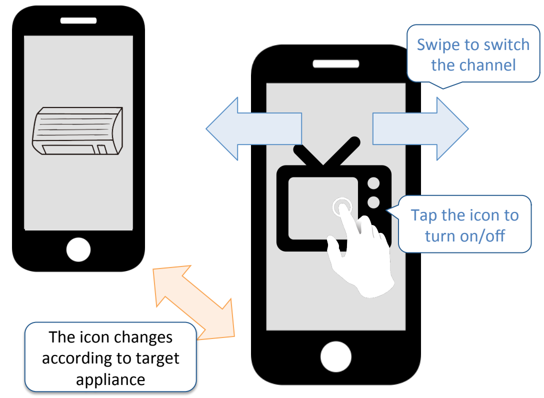

Fig. 12: Touch screen operation

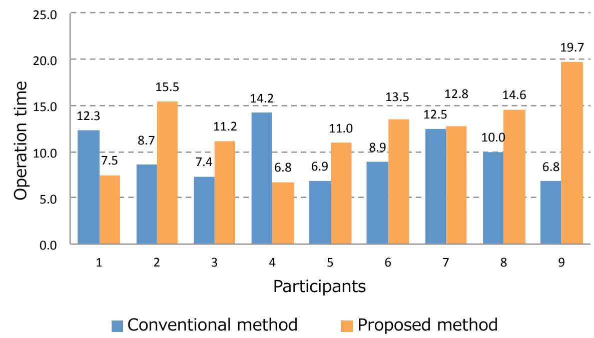

Fig. 13: Average operation times of the participants

C. Experimental Procedure

Each participant was first asked to operate conventional remote controls. Then they were asked to operate our system. The procedure of experiment is as follows:

1) The experimental procedure was explained to each participant
2) The participants were informed which appliances were to be used for the experiment
3) The participants were asked to perform tasks using conventional remote controls
4) The participants were asked to perform tasks using our system
5) The participants were asked to answer a questionnaire about our system

The tasks involved simple operation commands for each appliance (e.g. turning the TV on, turning the TV off), and were randomly assigned to each participant.

D. Results

1) Operation time: The average operation times for ten remote control operations of the participants are shown in Fig.13.

Two of the nine participants were able to control the appliances using our system with a shorter average time. However, the other participants controlled the appliances faster

TABLE III: Result of the questionnaire

Question item	Mean value	# of participants				
		1	2	3	4	5
(1) Was learning how to operate the system easy?	3.8	0	0	4	2	3
(2) Were you able to complete the tasks efficiently?	3.8	0	0	2	6	1
(3) Can you easily remember how to operate the system?	4.7	0	0	0	3	6
(4) Did you make only a few mistakes?	3.6	0	2	2	2	3
(5) Were you able to handle the system well?	3.3	0	2	2	5	0

using conventional remote controls. A possible explanation for this result is that the participants had no prior knowledge about how our system works. Also, our system at times could not detect the appliances because of the deterioration in the accuracy of the positioning sensor. The accuracy of the sensor decreased whenever the participants held the sensor too close to their bodies or covered the sensor.

The average operation time of using the conventional method is 9.7 seconds, and the average time of using our method is 12.5 seconds. When compared to the conventional method, the average operation time of our system is fast enough and can considered as viable for daily use.

2) Questionnaire: The questions and the results of the questionnaire are shown in Table III. Table III summarizes how the participants answered the questionnaire. Each participant was asked to answer each question with a number grade from 1 to 5, with 1 corresponding to "Disagree" and 5 to "Agree". The mean values of the number grades are also shown on the table.

For question 1 ("Was learning how to operate the system easy?"), 5 out of the 9 participants answered that system is easy to learn while the others were neutral. Some participants had difficulty in performing the touch or swipe motions with smart phone and commented that "It may be difficult for people who are not familiar with smart phone operations." From these responses, we learned that the interface should be designed to also cater to people who are unfamiliar with smartphone operations. For question 2 ("Were you able to complete the tasks efficiently?"), 7 out of the 9 participants gave positive answers. They commented, "We found not having to pick specific remote controls efficient." For question 3 ("Can you easily remember how to operate the system?"), all the participants gave positive answers. They remarked that "The system can be operated without thinking too much," and that "The system is intuitive.". For question 4 ("Did you make only a few mistakes?"), 5 out of the 9 participants had positive answers, but some people had negative answers. A participant commented that "I mistake a operation because only the icon was displayed on the touch panel.". For future work, we will improve the user experience with the menus displayed on the panel. For question 5 ("Were you able to handle the system well?"), some participants experienced the same level of difficulty because of the reasons stated in question 4. A participant also commented that "Sometimes the system couldn't detect the appliance.". The failure in detection is due to the deterioration in the accuracy of positioning sensor. The accuracy of positioning sensor decreases depending on the situation. For future work, the accuracy of the positioning sensor must be maintained.

VI. Conclusion

In this paper, we proposed an intuitive appliance control system and reported the results of an evaluation experiment. The result of the experiment showed that the operation time of conventional remote controls and proposed system were not so different, and we confirmed that our proposed method is viable for daily use. Through the user evaluations from a questionnaire, we confirmed the efficiency and the intuitiveness of the proposed system. However, we found some points for improvement in the user interface of the touch panel. Furthermore, the accuracy problem of the sensors should be addressed in further studies.

As another future work, an interface should be developed that caters to users who are unfamiliar with smartphone operations. The new interface should use buttons that imitate conventional remote controls. To address the accuracy deterioration, we are considering using the embedded sensors of smart phones (e.g. acceleration sensor, geomagnetism sensor) to support positioning information.

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