Development of an Online Home Appliance Control System Using Augmented Reality and an SSVEP-Based Brain-Computer Interface

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Abstract—In this study, we implemented a new home appliance control system by combining a steady-state visual evoked potential (SSVEP)-based brain-computer interface (BCI), augmented reality (AR), and internet of things (IoT) technologies. The visual stimuli were presented on a see-through head-mounted display (HMD), while the recorded brain activity was analyzed to classify the control command, and the home appliances were controlled through IoT. The average classification accuracy of the SSVEP-BCI-based control system was 92.8%, with an information transfer rate (ITR) of 37.4 bits/min. The proposed system exhibited an excellent performance, surpassing the best results reported in previous studies regarding external device control based on BCI using an HMD as rendering device.

Keywords—augmented reality, brain-computer interface, electroencephalography, internet of things, steady-state visual evoked potential

I. INTRODUCTION

Brain-computer interfaces (BCIs) have been emerging as a promising tool to assist daily life activities of the elderly and the people with physical disability for past decades. Recently, with the outstanding advances in the augmented reality (AR) device and internet of things (IoT) technology, a home appliance control system often referred to as “smart home” has become an attractive option to aid the daily tasks of those people. In this study, we implemented a new home appliance control system by combining electroencephalography (EEG)-based BCI, AR, and IoT.

II. METHODS

We adopted a steady-state visual evoked potential (SSVEP)-based BCI paradigm for the implementation of a fast and robust BCI system. In the first experiment, we compared the BCI performance of different types of visual stimuli in AR environment to determine the optimal visual stimulus. In the second experiment, with the optimal stimulus chosen in the preceding experiment, we evaluated the feasibility of the proposed system by controlling home appliances in real-time with 17 participants. The visual stimuli were presented in AR environment with a see-through head-mount display (HMD), while the recorded brain activity was analyzed to classify the

control command and the home appliances were controlled through IoT (Fig. 1). For the classification of SSVEP responses, a recently developed algorithm called the extension of multivariate synchronization index [1] was adopted. Repetitive eye blinks in a short time period, identified by an electrooculogram (EOG), were used as a switch to turn the control system on/off, such that our system was operated solely by the user without aid from others.

Figure 1. (a) A schematic diagram of the proposed home appliance control system. The visual stimuli were presented to the user via a Hololens, which was controlled by the middleware. The physiological signals recorded from the user were analyzed by real-time signal processing software, and then sent to the middleware. Based on the analysis results, the middleware generated an appropriate command and delivered this to the selected home appliance. The experiment was conducted in an environment in which the Hololens, middleware, signal processing program, and home appliances were all connected to the same Wi-Fi network. (b) Real pictures of the developed platform.

This work was supported by Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government(MSIT) (2017-0-00432 , Development of non-invasive integrated BCI SW platform to control home appliances and external devices by user's thought via AR/VR interface).

III. RESULTS

In the first experiment, grow/shrink stimulus, a star-shaped flickering object with changing size, was selected as the optimal stimulus eliciting SSVEP response most effectively compared to the others. In the second experiment, all users could turn on/off the system whenever they want with the eye-blinking-based switch, and carried out all the device control tasks without having difficulty. It took about 2.6 s on average to switch on/off the system and the mean false positive rate of the switch operation was 0.015 times/min. Average classification accuracy of the SSVEP-BCI-based control system was 92.8% with an information transfer rate (ITR) of 37.4 bits/min (Table I). The proposed system showed excellent performance which surpassed the best results reported in the previous studies on external device control system based on BCI (Table II).

TABLE I
THE EXPERIMENTAL RESULTS OF EXPERIMENT II

Subject	Total Trials	Correct Trials	Incorrect Trials	Accuracy (%)	ITR (bits/min)
P1	39	39	0	100	48
P2	44	40	4	90.9	34.0
P3	44	40	4	90.9	34.0
P4	45	42	3	93.3	37.0
P5	39	39	0	100	48
P6	39	39	0	100	48
P7	50	43	7	86.0	28.7
P8	48	41	7	85.4	28.1
P9	44	41	3	93.2	36.8
P10	40	39	1	97.5	43.0
P11	43	41	2	95.4	39.7
P12	48	42	6	87.5	30.2
P13	39	39	0	100	48
P14	41	40	1	97.6	43.1
P15	49	41	8	83.7	26.4
P16	45	42	3	93.3	37.0
P17	55	46	9	83.6	26.3
Mean				92.8	37.4

IV. DISCUSSION

With the outstanding advances in medicine, healthcare, and therapeutics, life expectancy is gradually increasing, and thus the social burden of caring for elderly and paralyzed people will soon become serious. The smart home system could provide a plausible solution to circumvent this problem. To the best of our knowledge, this is the first study which combined AR, IoT, and BCI to develop an external device control system. Additionally, the experimental results demonstrated that the proposed BCI-based home appliance control system can be utilized in practical scenarios. In conclusion, we developed a practical self-paced home appliance control system for the people with physical disability and the elderly, which has a potential to significantly elevate their quality of life.

TABLE II
COMPARISON OF PERFORMANCES WITH PREVIOUS BCI-BASED EXTERNAL DEVICE CONTROL STUDIES

Study	Accuracy (%)	ITR (bits/min)	Necessity of Calibration	Rendering Device
Kishore et al. [2]	87	24.7	Y	VR-HMD
Takano et al. [3]	79.4	5.4	Y	AR-HMD
Wang et al. [4]	83.3	4.6	Y	AR-HMD
Si-Mohammed et al. [5]	90	8.7	Y	AR-HMD
Proposed System	92.8	37.4	N	AR-HMD

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