BCI based Hybrid Interface for 3D Object Control in Virtual Reality

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Abstract— **People attempts to apply the virtual reality (VR) technology in various fields recently, however, there are many limitations to apply the VR technology in existing interfaces in various fields such as 3D object control. To solve this problem, we propose a combination of eye-tracking and BCI technique to control 3D objects in a three-dimensional VR as an alternative interface. In our proposed interface, users select a virtual 3D object in VR by eye-gazing which is detect by the eye-tracking module of the system and manipulate the object by concentrating their mind via the BCI module. To evaluate the performance of our system, subjects perform the same experiments using the proposed system comparing to other existing interfaces. The result shows that the proposed interface has similar or better performance than other interfaces. This result suggests that our proposed interface can be used as an alternative interface of VR.**

Keywords- Virtual Reality (VR), Brain-Computer Interface, Electroencephalography (EEG), Eye-tracking, 3D Object Control

I. Introduction

Virtual reality (VR) is used widely in various fields such as healthcare, education, entertainment, and simulation. This technology gives new sensation to the people with the virtual environment in which users are able to experience and manipulate the virtualized contents. Although VR technologies itself has been advanced in the term of graphic and sensation, they still require the use of interface devices such as mouse and joystick to control the contents in 3-dimensional (3D) environment of VR. This kind of interfacing devices could reduce the users' immersion and restrict the users' behaviors because they can only secure their eyesight inside head mounted display (HMD). Furthermore, this restriction could confuse the users with conflicts in sensorimotor neural system of what they see and control in virtual and real space, respectively.

To solve this problem, we proposed a combination of eye-tracking and brain-computer interface (BCI) as an alternative interface that is capable of controlling objects efficiently in 3D virtual space without any confusion. Our system allows people to point the objects in their interest by eye gazing and manipulate them on their demand by thinking. Unlike other works which share similar our goal [1, 2], our approach differs in many ways. The most distinctive feature is the unencumbered user activity in physical space. There are no conventional external interfaces. User can interact with virtual objects naturally and easily in a single system.

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To evaluate the performance of our system, our hybrid interface is tested through target selection and action experiments. Eye movement is interpreted as cursor movement to select object on x and y-axis and noninvasive BCI is used to pull the selected object on z-axis.

The rest of this paper is organized as follows: Section 2 presents a detailed method of this proposed work. Sections 3 presents experimental setup and experimental results. Section 4 presents a discussion on our experimental results, future work and application. Lastly, section 5 presents conclusion.

II. Methods

A. Virtual Reality System

We used an Oculus Rift DK1 with 1280x800 resolution display for providing the 3D virtual environment to subject. Virtual environment is constructed using Unity to be compatible to the Oculus Rift. The 3D virtual environment consists of a subject, task objects and the user perspective-projection point. The virtual subject is at the center of the virtual space and five task objects (red, yellow, green, blue, and purple sphere) form a circle arc in front of the virtual subject in the same distance. The user perspective-projection point marks what the user see or indicate using mouse in the 3D virtual space and convert its surface color from black to white to indicate whether the mouse is in the task object.

B. Eye Tracking System

To select objects in 3D virtual space, we used the custom-built eye-tracker installed in the lower-right corner inside of the Oculus Rift. It takes user's eye image in real time. In addition, four small infrared (IR) LEDs were set up around the camera to enhance the contrast between the pupil and iris in order to detect the user's pupil effectively.

The eye tracking system is implemented based on previous study [3]. First, it extracts features of pupil and iris edge points from each captured image by using adaptive threshold. Then, it eliminates outliers among the feature points using the Random Sample Consensus (RANSAC). After that, the algorithm returns the center point of estimated pupil ellipse and finally is mapped to the user gazing point on the screen based on coefficients which were calculated from Multiple Linear Regression (MLR) at the calibration procedure for horizontal and vertical axis, respectively. The user gazing point is used in the virtual reality

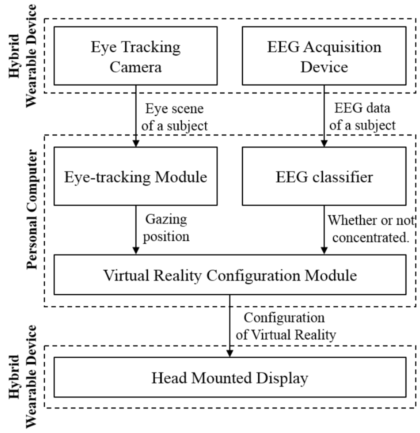

Figure 1. Overview of the proposed interface system.

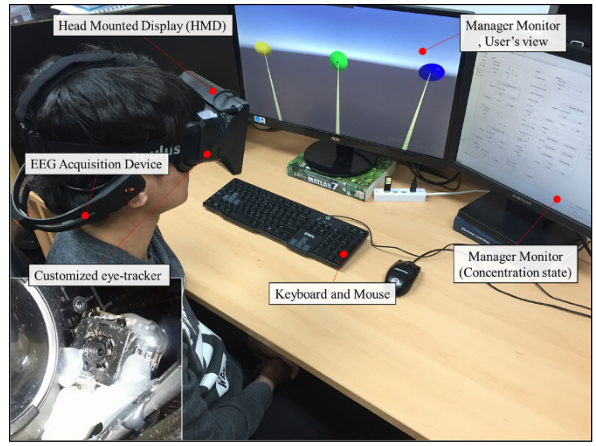

Figure 2. Experimental setup and the position of interface tools

system to present user perspective projection point and to determine what the user see in the virtual space.

C. Brain-Computer Interface system

We used the commercial EEG acquisition headset, Emotiv EPOC (Emotiv Systems Inc., USA), to obtain EEG signals in real time [4]. It consists of 14 EEG channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4) and CMS(P3)/DRL(P4) references according to the international 10-20 systems. It uses the wireless transmission with a sampling rate of 128 Hz.

The obtained EEG signals are used to determine whether the user's mental state is the concentration state or not. We used the EEG signals processing algorithm in previous study [5] to classify two-class, concentration and non-concentration state. We use the Common Spatial Patterns (CSP) algorithm to extract features to identify the concentration state of user [6]. The EEG signals were filtered between 8 to 30 Hz, which is often associated with active concentration. CSP computes the spatial filters (w) that efficiently discriminate the signal that maximizes the following function.

$$\mathrm{J(w)} = \frac{w^T E_1 {E_1}^T w}{w^T E_2 {E_2}^T w} = \frac{w^T {C_1}^T w}{w^T {C_2}^T w}$$

where E_1 represent a set of EEG signals corresponding to the concentration, and E_2 represent non-concentration state. C_1 and C_2 denote the spatial covariance matrix of the concentration and non-concentration state assuming a zero mean for EEG signals. The optimization problem is transformed to a standard eigenvalue problem using the Lagrange multiplier method. Then, we make a classifier to discriminate concentration and non-concentration class by using Support Vector Machines (SVM) with a linear kernel [7].

III. EXPERIMENTS

Five healthy male subjects (26-36 years of age; mean age: 28.6 years) voluntarily participated in our experiment. All of subjects were right-handed, no neurological disorders and eyes diseases and capable of using the Oculus Rift. The focus of Oculus Rift is adjusted to subject's vision through the interchangeable lens.

A. EEG Classifier Training and Eye-tracker Calibration

In EEG classifier training, a subject observes the two command, "Concentration" and "Rest", randomly appeared on the HMD for 5 seconds with 2 seconds interval to get ready for the next command between them. Each command is shown for five times in a training session. If the subject sees the "Concentration" command, he has to concentrate their attention. Otherwise, he has to relax. The training session was repeated two times to collect training EEG data.

For eye-tracker calibration, each subject underwent a standard nine-point calibration procedure. There are nine calibration points arranged in a checkerboard pattern on VR. However, we set to show only one calibration point at a time so that a subject is able to concentrate on the calibration procedure. We measure the relative position of a subject's pupil for 2 seconds while he is gazing at the calibration point. After calibration is performed, we can determine whether its estimation of a subject's eye position is indeed close to the known position in the virtual space.

B. Experimental Setup and Task

The experiment starts as a subject sit comfortably in front of the computer where the VR environment is set. After wearing the BCI device and HMD with eye-tracker, a subject performs the EEG classifier training and eye-tracker calibration process.

In the experimental task, subject has to select the task object (colored sphere) on VR using mouse or eye tracking and then act to pull it toward him by utilizing keyboard or BCI. The experiment consists of four parts according to the combination of the interfaces to perform selection and action including (mouse, keyboard), (mouse, BCI), (eye-tracking, keyboard), and (eye-tracking, BCI). The subject perform experiments using combination of interface in the named order. We recorded the performance time to select and act to evaluate the performance of each combination of interface. The performance time includes the time to find the mouse and keyboard in front of a subject.

C. Experimental Results

We evaluated the efficiency of each combination of interface tool using performance time. The performance time of each step, selection and action, were averaged for all subjects. Table 1 presents the performance time for each subject and interface tools. The proposed hybrid interface yields the second-best performance except for the subject C who report the trouble to maintain continuous concentration and eye-tracking at the same time.

Table 2 shows the performance time for each interface device. The performance time of using Mouse and eye-tracking was the time of selection step. And the performance time of using keyboard and BCI was the time of action step. The result shows that using eye-tracking as the interface tool to select the object yield 5-times faster performance time than using a mouse. And using a keyboard as the action tool yield 2.4 times faster to complete the action step than BCI.

From the result of total performance time shown in Fig. 3, although using the combination of eye-tracking and keyboard was best, our system which is the second best system only takes 6.7 seconds longer than the best combination. Since our interface provides better immersive state to the user without any confusion, these disadvantages can be sufficiently counterbalanced.

TABLE I.
TASK TIME FOR EACH SUBJECT AND INTERFACE TOOLS

Subject	Combination of Interface Tools	Average Task Time(SD) (sec)		
		Selection	Action	Total
A	M.K	9.76(1.34)	5.00(0.07)	14.76(2.29)
	M.B	7.62(0.83)	14.69(1.52)	22.30(2.92)
	E.K	1.57(0.31)	6.07(0.18)	7.64(1.30)
	E.B	2.09(0.31)	10.78(0.89)	12.87(2.91)
B	M.K	10.88(1.76)	5.13(0.17)	16.01(2.47)
	M.B	10.60(0.99)	18.17(1.95)	28.77(3.81)
	E.K	1.67(0.30)	5.70(0.04)	7.37(1.20)
	E.B	2.61(0.51)	12.09(0.77)	14.70(3.37)
C	M.K	10.96(3.28)	5.73(0.10)	16.69(2.70)
	M.B	8.82(0.75)	19.17(2.77)	27.99(4.92)
	E.K	0.80(0.61)	6.74(0.56)	7.54(1.92)
	E.B	3.35(0.71)	16.65(0.34)	20.01(4.20)
D	M.K	6.67(0.76)	5.42(0.05)	12.09(1.50)
	M.B	8.66(1.24)	9.18(0.65)	17.85(2.62)
	E.K	0.67(0.07)	6.52(0.15)	7.19(1.82)
	E.B	1.54(0.35)	8.82(0.60)	10.35(2.60)
E	M.K	9.27(1.00)	4.95(0.05)	14.23(2.16)
	M.B	12.43 (0.98)	20.00(2.59)	32.43(5.50)
	E.K	1.26 (0.16)	5.99(0.31)	7.25(1.47)
	E.B	1.82 (0.31)	9.94(0.58)	11.76(2.89)

M.K: Mouse and Keyboard, M.B: Mouse and BCI, E.K: Eye-tracking and Keyboard, E.B: Eye-tracking and BCI

TABLE II.
TASK TIME FOR EACH INTERFACE TOOLS

Subject	Average Task Time(SD) (sec)			
	Mouse	Eye-tracking	Keyboard	BCI
A	10.85(1.58)	1.54(0.28)	5.47(0.52)	14.97(5.03)
B	7.67(1.00)	1.10(0.43)	5.97(0.55)	9.00(0.18)
C	9.89(1.07)	2.08(1.27)	6.23(0.51)	17.91(1.26)
D	10.74(0.14)	2.14(0.47)	5.41(0.29)	15.13(3.04)
E	8.69(1.07)	1.83(0.26)	5.53(0.54)	12.73(1.95)
Mean (SD)	9.57(0.97)	1.74(0.54)	5.73(0.48)	13.95(2.29)

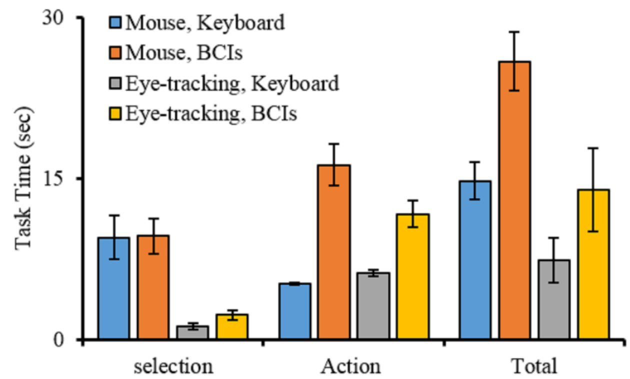

Figure 3. Average task time for each steps according to the combination of interface tools.

IV. DISCUSSIONS

The result supports the feasibility of our proposed interface that uses eye-tracking and BCI to control 3D object in VR. However, it requires more complex and detailed object control test in VR to prove its performance. For that, we could consider different actions applicable to our interface such as rotation and scale changes. The eye-tracker, EEG acquisition device and

HMD can also be one of the important component in our interface that can be replaced with the better tools or tried with different kind of techniques such as using more EEG nodes to yield better performance.

VR technology has already been used in various fields such as entertainment, medical, military training and simulations. It is because VR technology can solve the conventional problems that take a lot of time and cost in training and simulation. Providing better interface to VR technology will improve the user experiences and the performance of VR technology. Interface using the bio-signal give a more immersive and better immediate response. In these aspects, the study of EEG based VR interface will be important part in the future.

V. CONCLUSION

In this paper, we propose an alternative and better interface to control 3D objects in VR environment. Although the proposed system gives less efficient than using the keyboard with the eye-tracking, it shows a better efficiency than the different combination of conventional interfaces. Unlike the combination of existing interfaces, our interface gives the user the better immersive experience in the virtual space without any confusion and the user can move more freely. We are confident that our proposed interface can be used in a variety of virtual environment fields and we assure that this hybrid interface will make a good contribution in the development of VR technology.

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