

# Brain Computer Interface Via Stereoscopic Images in CAVE

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**Abstract.** The electroencephalogram signals of steady-state visual evoked potentials were recorded for three subjects in immersive virtual environment. A machine learning technique of support vector machine with single trial EEG data for 1.0 seconds resulted in 92.1 % of averaged recognition rate in selecting a virtual button among two. The online demonstrations in CAVE showed good performance in position control of a simple 3D object.

## 1 Introduction

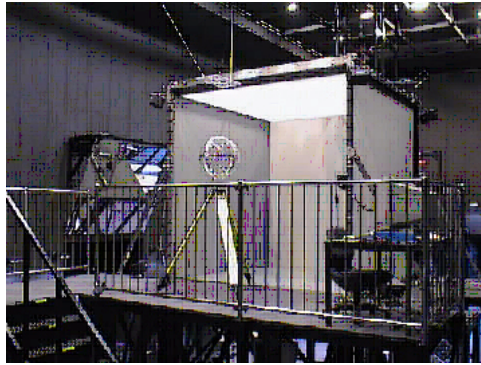
It is so exciting to consider that we could operate a variety of devices only by brain activities. The brain computer interface (BCI) is a communication channel with which the computer or machine can be operated [1]. In recent, the BCI has been investigated in immersive virtual environment [2]. The novel works on walking from thought via motor imagery tasks was performed there. The immersive projection technology in virtual reality was expected to be suitable to evaluate in advance the BCI developed in the real world.

The purpose of this paper is to show the possibility to detect the brain activity of steady-state visual evoked potential (VEP) [3] induced by two virtual stimuli in immersive virtual environment for future applications. In later section, only by using the VEP, the position of a virtual object will be briefly controlled in real time.

## 2 Experimental Method

The virtual cubes were used as visual stimuli in our experiment. The visual stimuli were presented in CABIN, which is an extended multi-screen display system from CAVE [4] to have a five-screen configuration (Fig. 1). Two virtual cubes illuminated with constant frequencies of 4.80 Hz and 6.86 Hz, respectively. Note that, in novel studies of BCI based on the VEP, the visual stimuli were virtual buttons with a few degrees of visual angles on a computer monitor [5, 6].

The subject was sitting on a luxury arm chair about 2.0 m in front of the front screen, wearing a LCD shutter glasses to obtain stereoscopic images. Adopting non-invasive electroencephalogram (EEG) technique, three electrodes ( $O_1$ ,  $O_2$  and  $O_z$ ) were attached over visual cortex. The EEG signals were amplified and were band pass filtered between 0.5 and 30 Hz. The analogue data was sampled at 100 Hz in an A/D converter to be stored in a PC.



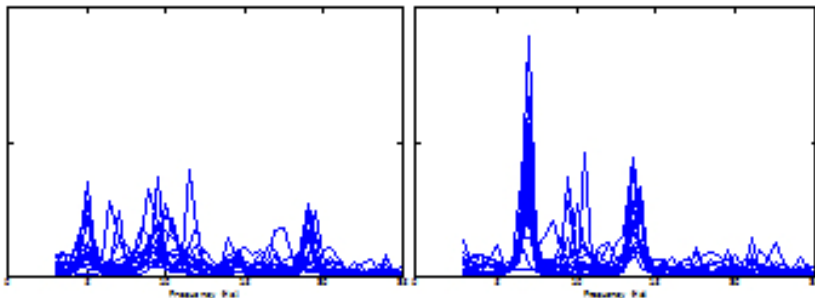
**Fig. 1.** The overview of immersive virtual environment

For all three subjects, two types of experimental task were imposed. The task 1 was to gaze and focus attention to a visual stimulus of 6.86 Hz illumination, and task 2 was of 4.80 Hz illumination. The task 1 and 2 were performed by turns. One trial lasted 30 seconds, and after that the subjects took about one minute rest.

### 3 Offline Analyses

The recorded EEG data was analyzed in offline in the following procedures; (1) The extraction of features of steady-state VEP, (2) The machine learning, and (3) The estimation of recognition rates.

The features were extracted from the linear combination of voltage value of three electrodes on visual cortex, expecting the reduction of environmental noise. The result of estimated power spectral density is shown in Fig. 2 for one subject. The steady-state VEP was observed and the power spectral densities from 3 Hz to 25 Hz, with 1.0 second of analyzing time period, were used to construct a feature vector.



**Fig. 2.** The left and right figure show the estimated power spectral density of single trial EEG data, for a visual stimulus of 4.80 Hz and 6.86 Hz, respectively. The 15 densities are superposed in each figure, dividing one trial sequence data for 30.0 seconds into 2.0-seconds segments.

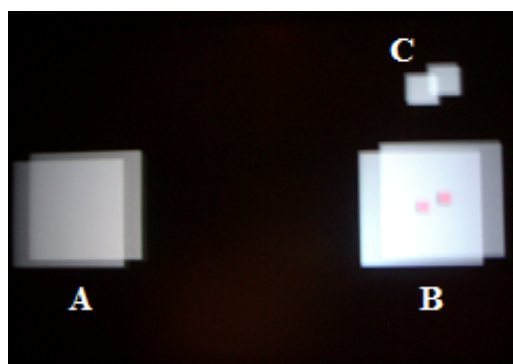
In the process of machine learning, we adopted support vector machine (SVM) [7]. To estimate the recognition rate, a leave-one-out method was applied. By using the mentioned feature vectors, the averaged rate was found to be 96.7 %, 89.7 %, and 90.0 % for three subjects, respectively. The average was 92.1 %. These high recognition rates would be promising for online experiments in the following section. We expected that the VEP enabled the user to control the position of a simple 3D virtual object.

## 4 Online Control

We demonstrated a preliminary experiment on online control of a simple virtual object floating in CAVE. The online control system consists of three modules; (1) The EEG data acquisition module, (2) The signal processing module, and (3) The image rendering module. The data acquisition module was the same with that in the offline analyses. After the data acquisition, the digitized EEG data was transmitted to a signal processing server through the Ethernet. At the server, the SVM classification was performed, and the discrimination result was transmitted to the workstation of CAVE for real-time image renderings.

In the online experiments, the visual stimulus A and B might have a role to be a virtual button to control the position of a specific virtual object C (Fig. 3). The user was instructed to gaze and focus attention to a red-coloured fixed point. The fixed point changed its position every 10 seconds between the fixed point on the center of stimulus A and B. It was expected that the steady-state VEP induced by the virtual button would be adequately processed to yield the command to control the position of the cube C. During the online session, the user obtained the visual feedback of the stereo images with LCD shutter glasses.

It was found that the position control of a virtual cube C was successfully performed reflecting the user's intention to select the virtual button A or B, while the time delay and the error control was observed.



**Fig. 3.** The virtual button A, B and controlled object C in online experiments

## 5 Summary

We investigated the steady-state VEP in immersive virtual environment. The EEG signals, induced by visual stimulus of stereoscopic virtual object, were recorded and analyzed. It was found that, in button selecting tasks, the recognition rate was 92.1 % averaged for all three subjects, and the position of a 3D object could be controlled only via the steady-state VEP in real time. This technology of brain CAVE interfacing would enable us to realize intuitive and non-muscular manipulations of objects. We expect that non-invasive BCI in immersive virtual environment will be one of the research paradigms of the next generation of virtual reality, that is, “Virtual Reality 2.0” for people who enjoy it.

## Acknowledgement

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