35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Hybrid SSVEP-Motion Visual Stimulus based BCI System for Intelligent Wheelchair

Yunyong Punsawad, *Student Member, IEEE* and Yodchanan Wongsawat, *Member, IEEE*

***Abstract*—This paper proposes the hybrid BCI modalities for wheelchair control by taking into account weakness of the current BCI systems. The idea is to combine two hybrid BCI systems with the intelligent wheelchair for three states, i.e. normal, fatigue, and emergency states. First system is the hybrid steady state visual evoked potential (SSVEP) and alpha rhythm BCI which is designed to use in the normal state. Second system is the hybrid motion visual stimulus and alpha rhythm which can be employed during the fatigue state (after using the first system). For the experiment, subjects are asked to perform SSVEP system for 30 minutes (until the fatigue states occur). Then, the subjects will be asked to perform the hybrid motion visual stimulus and alpha rhythm testing. The accuracy of the proposed system during fatigue state is approximately 85.62%. With this idea, BCI controlled wheelchair can be efficiently employed in reality.**

I. INTRODUCTION

Brain computer interface (BCI) is a connection between brain and computer by utilizing electrophysiological signal of the brain, e.g. electroencephalogram (EEG) (noninvasive signaling), to provide commands for the rehabilitation or assistive device [1]. One of the most beneficial devices for the severe disable people is the devices that can let them regain the mobility.

Many groups of researchers hence study the possibility to make the BCI wheelchair happened [2-5]. Recently, there are many modalities generally used in BCI, such as 1) sensory motor rhythm (SMR) modality or event-related desynchronized and event related synchronized (ERD/ERS) [6], 2) visual evoked potential (VEP) modality [2, 7], and 3) auditory evoked potential (AEP) modality. Nowadays, VEP modality is reported to (e.g., P300 and steady state visual evoked potential (SSVEP)) achieve the highest accuracy and performance for all kinds of disable people, i.e. it gives high accuracy, requires short time for training, and provides user friendly way for utilizing.

To further enhance the accuracy and performance for the VEP systems, another alternative way is to employ the hybrid BCI systems. For the existing hybrid BCI systems [11], one input of EEG such as P300 or SSVEP [2, 7] may possibly lead to the state of eye fatigue after focusing consecutively on the visual stimulus in the long period of time. EEG-based hybrid BCI can be categorized into three groups, i.e. 1) combination between two kinds of EEG [12], 2) combination between EEG and other physiological signals (e.g. electromyogram (EMG) [13], electrooculogram (EOG) [4]), and 3) combination between EEG and intelligent devices [3].

In this paper, we propose the hybrid BCI system for wheelchair control to avoid the possibility of "being unable to use due to fatigue state". The idea is to combine the hybrid SSVEP-alpha rhythm with the motion visual stimulus-alpha rhythm [8-10]. Besides, the designed intelligent wheelchair can automatically avoid obstacle. It can also be controlled and monitored remotely for the case of emergency. We hope that this system can be practically used for the severe disable people in reality.

Manuscript received January 30, 2013. This work is supported in part by the national research council of Thailand (NRCT) and Mahidol University.

Y. Punsawad is with the Department of Biomedical Engineering, Mahidol University, 25/25 Putttamonthon 4, Salaya, Nakornpathom 73170 Thailand (e-mail: yunyong_pd@hotmail.com).

Y. Wongsawat is with the Department of Biomedical Engineering, Mahidol University, 25/25 Putttamonthon 4, Salaya, Nakornpathom 73170 Thailand (corresponding author, phone: 66-82-889-2138 Ext 6361; fax: 66-82-889-2138 Ext 6366; e-mail: yodchanan.won@mahidol.ac.th).

II. PROPOSED METHODS

A. Hybrid BCI System Architecture

We propose the hybrid BCI system by using a combination between SSVEP, motion visual stimulus, and spontaneous EEG (alpha rhythm) to control the intelligent wheelchair. The control modalities can be designed based on the situation of the user which can be separated into three states, i.e. normal state, fatigue state and emergency.

In normal state, the user can control wheelchair by using SSVEP technique meanwhile an assistance can use the remote system to help the user to control the wheelchair. In fatigue state, when the user has eye fatigue from using the SSVEP technique, the user can change to use the motion visual stimulus technique. In addition, the assistance can still use the remote control system. For emergency, the system can send alarm to the assistance.

B. Hybrid SSVEP- Alpha Rhythm BCI System

Steady state visual evoked potentials (SSVEP) [14] is the brain signals generated by stationary localized and distributed sources that exhibit characteristics of wave phenomena from visual stimulations such as light, flash, or checker board pattern at some specific frequencies. SSVEP is useful in research because of its excellent signal-to-noise ratio and relatively robust to artifacts.

For our hybrid SSVEP-alpha rhythm, three flickering frequencies are employed to command the wheelchair to turn left (6 Hz), turn right (8 Hz) and go forward (7 Hz) (Fig. 3(b)). Stop and backward commands are provided by alpha rhythm (it can be easily produced by eyes closing or relaxing).

This system can achieve high performance. However, the user cannot get high accuracy during the fatigue state (after using for approximately 30 minutes). Hence, the user can change SSVEP

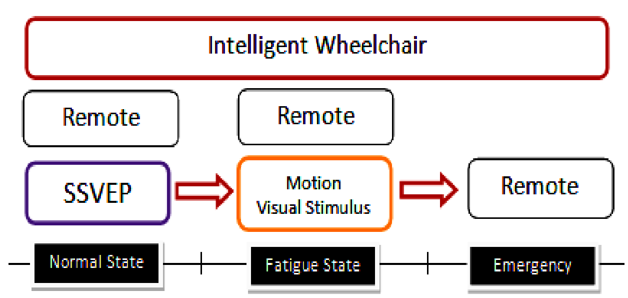


Fig. 1. Hybrid BCI for wheelchair control

modality to the motion visual stimulus-alpha rhythm mode by staring at the 13Hz SSVEP pattern (Fig. 3(b)).

C. Hybrid Motion Visual Stimulus- Alpha Rhythm BCI System

Motion visual stimulus is the novel technique of VEP. The direction of motion can activate the visual and motor system of the brain [14]. This technique was utilized in BCI systems in [8-10]. For the comparison with SSVEP, the accuracy of the motion visual stimulus is lower than the SSVEP. However, it can reduce the eye fatigue. Therefore, the user can switch to this system during the fatigue state. The motion visual stimulator is shown in Fig. 3(a). There are three directions of the motion visual stimulus, i.e. left direction for left command, right direction for right command, and up direction for forward command. The black bars are moved to each direction. For stop command, alpha rhythm is also used.

D. EEG Acquisition and Real-Time Processing

Two bipolar channels of EEG are acquired. The electrode positions are located on both sides of the occipital lobe at positions O1 and O2. The reference electrodes are C3 and C4, respectively, to enhance the occurring of the SSVEP signal. The electrode positions are according to the international 10-20 electrode placement system. The EEG signals are acquired via BIOPAC^{TM} MP100 system. For the signal processing, those signals are filtered by analog bandpass filter with cut off frequencies at 1 and 35 Hz. A 50 Hz analog notch filter is used to remove the power line noise. The analog to digital (A/D) conversion NI USB 6009 multi-function data acquisition card is used to convert analog EEG signals to digital data with the sampling rate of 256 Hz.

E. Algorithms

For the SSVEP algorithm, we employ our previous work in [8]. Hence, in this paper, the algorithms on using the motion visual stimulus specifically for wheelchair control, implemented with LabVIEW^{TM}, can be summarized as follows:

Left and Right: *Motion visual stimulus SSVEP* [8]

Calibration

Before using the proposed system, some baseline parameters need to be acquired as follows:

$$BL_{Oi} = max\,(BL_7, BL_{14}), \qquad i = 1, 2 \qquad (1)$$

where BL_n represents the baseline value at the frequency n. BL_7 and BL_{14} represent the baseline values of two harmonics of the fundamental frequency 3.5. However, we do not employ 3.5 Hz because it may contain the motion artifact. BL_{Oi} are the baseline frequencies at EEG channels O_1-C3 or O_2-C4. BL_n can be calculated as

$$BL_n = mean\,(BL_{n-r}, BL_n, BL_{n+r}), \qquad n = 7, 14 \qquad (2)$$

where BL_{n-r} and BL_{n+r} are the baseline at the neighboring frequency of n Hz. r is the frequency resolution.

Feature Extraction

The amplitude of the power spectrum f_n obtained from fast Fourier transform (FFT) method is used to extract the motion visual stimulus SSVEP feature of interest as the following process:

$$PS_{Oi} = f_{Oi} - BL_{Oi} \qquad i = 1,2 \qquad (3)$$

where PS_{Oi} is the difference of magnitude of power spectrum between f_{Oi} and BL_{Oi}, f_{Oi} can be calculated as

$$f_{Oi} = max\,(f_{3.5}, f_7, f_{14}) \qquad i = 1,2, \qquad (4)$$

where f_n can be calculated as

$$f_n = mean\,(f_{n-r}, f_n, f_{n+r}) \quad n = 7 \text{ and } 14, \qquad (5)$$

where r is the frequency resolution calculated via the sampling rate.

Decision Making

The simple decision rule can be used to compare PS_{O1} and PS_{O2}. The decision of two-class classification (Right or Left) can be made according to Table I. From equation (3), if $f_{Oi} < BL_{Oi}$, we will get negative number, hence in this case, we will define $PS_{Oi} = 0$.

Forward and Backward: *Motion visual stimulus attention and alpha rhythm* [4].

Calibration

At first, we need to find the average among the magnitude of power spectrum from channels O1 and O2 of the alpha band frequency (8-13 Hz) and beta band frequency (14-26 Hz), denoted as PS_{alpha} and PS_{beta}, respectively. Then, we calculate the threshold value T_{attend} as follows:

$$T_{attend} = \Delta_{O1} - \Delta_{O2}, \qquad (6)$$

where

$$\Delta_{O1} = |PS_{alpha\,O1} - PS_{beta\,O1}|, \qquad (7)$$
$$\Delta_{O2} = |PS_{alpha\,O2} - PS_{beta\,O2}|. \qquad (8)$$

After that the user will be asked to close both eyes and recorded the maximum power spectrum at O2 among alpha band frequency (8-13 Hz) denoted as PS_{max}, then we calculate for the threshold value T_{alpha} by

$$T_{alpha} = PS_{max} - (PS_{max}/4) \qquad (9)$$

Feature Extraction

Attention index is defined as

$$P_{attend} = \Delta_{O1} - \Delta_{O2}, \text{ and} \qquad (10)$$
$$P_{alpha} = PS_{alpha\;O2.} \qquad (11)$$

Decision Making

According to equations (6)-(11), if $P_{alpha} > T_{alpha}$ then we make the decision as backward commands. If $P_{attend} > T_{attend}$, then we make the decision as forward commands. Otherwise, if $P_{Attend} < T_{Attend}$ and $P_{alpha} < T_{alpha}$, there are no action. This decision making can be summarized in Table II.

F. Intelligent Wheelchair

Since safety issue is the most important for the user when using the BCI-based wheelchair. In this paper, a general electric wheelchair is modified to be the intelligent wheelchair. Ultrasonic

TABLE I
SUMMARY OF DECISION RULE FOR LEFT AND RIGHT

Commands	*Decision rule*
Left	$PS_{O1} > PS_{O2}$
Right	$PS_{O1} < PS_{O2}$
No decision	$f_{O1} < BL_{O1}$ *and* $f_{O2} < BL_{O2}$

sensors are attached around the wheelchair to automatically avoid an obstacle such as wall or step.

Moreover, we include the tele-monitoring system by using a web camera and remote system. This system is very useful for a practical BCI wheelchair since the patient can stay alone for a while, meanwhile the assistance can also monitor the patient via the wireless system through the internet access. Furthermore, the assistance can also remotely control the wheelchair via the internet when the patient need some help such as during the fatigue state or emergency.

TABLE II
SUMMARY OF DECISION RULE FOR FORWARD AND BACKWARD

Commands	***Decision rule***
Forward	$PS_{Attend} > T_{Attend}$
Backward	$PS_{alpha} > T_{alpha}$
No decision	$PS_{Attend} < T_{Attend}$ and $PS_{alpha} < T_{alpha}$

III. EXPERIMENT

Before the paradigm testing, we perform the brief study on the topographic brain mapping to make sure that our assumption on the electrode placement and visual stimulation are valid.

Topographic Brain Mapping during Motion Visual Stimulus

There are three volunteer subjects to perform our experiment. At first, 19-channel EEG placed following the 10-20 electrode placement system is acquired. The software NeuroGuide is employed for providing brain topographic mapping and brain connectivity. The example result is shown in Fig. 2.

In brain topographic mapping, we consider the occipital area to distinguish brain response with motion visual stimulus. For left horizontal direction motion visual stimulus (←) the result shows, right occipital area O2 and parietal area P4 has more response. In the same way, left occipital area O1 and parietal area P3 has more response with right horizontal direction motion visual stimulus (→). The up vertical direction motion visual stimulus (↑) presented an interesting result, we cannot efficiently see the response at occipital. However, the response can be observed at the frontal area F3 and F4 which function as the motor planning. This response can also be observed at the motor area C3 and C4 more than the resting state.

For brain connectivity analysis, the phase lag is used to investigate the phenomenon of motion visual stimulus. The blue line illustrates the slow sharing data rate among channels and red line illustrates the fast sharing data rate than the normative database. The changes of the brain activity are found in alpha and beta bands.

TABLE III
PERCENT ACCURACY OF HYBRID MOTION VISUAL STIMULUS SSVEP AND ALPHA RHYTHM BCI SYSTEM

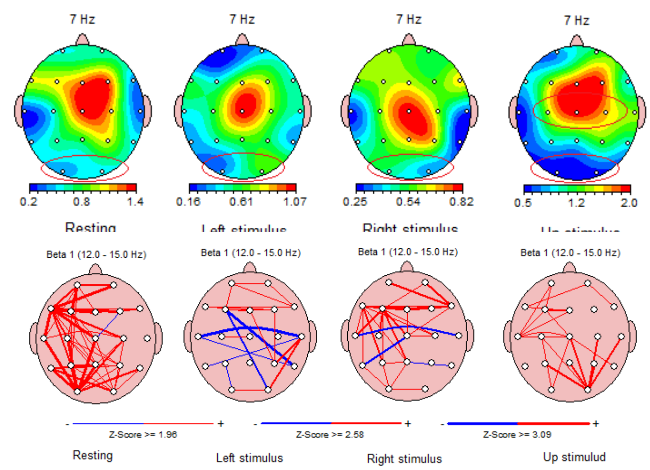
%Accuracy / ***Subject***	***Left***	***Right***	***Forward***	***Backward***	***Total***
T.	90	80	70	100	**85**
N.	95	95	75	100	**91.25**
M.	65	75	85	100	**81.25**
P.	95	75	80	100	**87.5**
K.	75	85	65	100	**81.25**
C.	80	90	75	100	**86.25**

The brain connectivity at the resting state shows that each electrode is sharing the information very fast. This might be because the people need to think about the paradigm.

For the left horizontal direction motion visual stimulus, O2 shares data rate faster than O1. For the right horizontal direction, O1 is activated faster than O2. For the up vertical direction motion visual stimulus, the brain connectivity shows that both O1 and O2 are sharing the data to the central areas (C3,C4 and Cz) very fast.

Paradigm and Testing

Six volunteer subjects (difference subjects form the topographic mapping study) perform the proposed system, two female and four male. Each subject is collected the parameters for calibration. Subjects have 30 minutes time for training. Since the motion visual stimulus BCI will be employed instead of the SSVEP-based BCI for our wheelchair control in fatigue stat, subjects must perform SSVEP system for 30 minute to create the eye fatigue situation. After that the subject will be asked to perform the hybrid motion visual stimulus-alpha rhythm system for testing a performance of the system. Each subject performs 2 times of the experiment, 20 trials per time, 4 commands per trial. Subject must focus on each motion visual stimulator, i.e. left, right, forward, backward, respectively. For backward command, subject will be asked to close their eyes.



(b)

Fig. 2. (a) Brain topographic mapping with motion visual stimulus (b) Brain connectivity with motion visual stimulus

IV. RESULTS

According to the results in Table III, the performances of the proposed system for each of the four commands are ranging between 75% - 100%.

All subjects have the average accuracy in performing all four commands ranging between 81.25% - 91.25%. In total, the accuracy of this system is approximately 85.62%. Since the results are collected while the subjects are in the fatigue state after performing SSVEP-based BCI, hybrid motion visual stimulus-alpha rhythm BCI system can still achieve a high performance. However, the highest accuracy is still lower than the general SSVEP based BCI system (approximately 90%). Therefore, the combination among two hybrid systems (SSVEP and Motion visual stimulus) can be benefited to the BCI-based wheelchair.

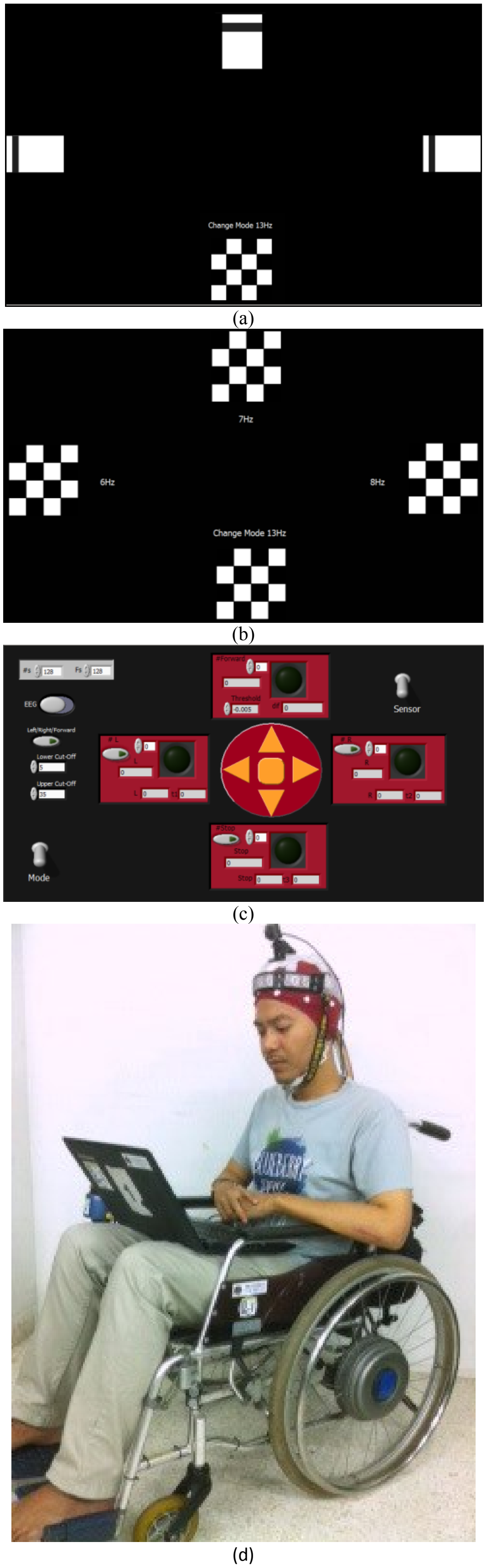


Fig. 3 (a) Motion visual stimulator (b) SSVEP stimulator (c) GUI of motion visual stimulus based BCI (d) Proposed BCI controlled wheelchair

V. Conclusion

In this paper, we have proposed the novel solution of hybrid BCI for wheelchair control. By combining two hybrid systems, we can keep a high performance even during the eye fatigue state. Moreover, the sensors for the obstacle avoidance are also setup for further safety issue to avoid the accident during error periods from the BCI system.

Acknowledgment

This project is supported in part by the national research council of Thailand (NRCT) and Mahidol University, Thailand.

References

[1] J. R. Wolpaw, et al., “Brain-computer interfaces for communication and control, ” Clinical Neurophysiology, **113**(6): p. 767-791, 2002.

[2] S.M.T. Muller, T.F. Bastos-Filho, and M. Sarcinelli-Filho. "Using a SSVEP-BCI to command a robotic wheelchair," *IEEE International Symposium* in *Industrial Electronics (ISIE), 2011*.

[3] J. R. Millan, et al. "Asynchronous non-invasive brain-actuated control of an intelligent wheelchair,". *Annual International Conference of the IEEE* in *Engineering in Medicine and Biology Society, 2009. EMBC 2009.*

[4] Y. Punsawad, Y. Wongsawat, and M. Parnichkun. "Hybrid EEG-EOG brain-computer interface system for practical machine control,". *Annual International Conference of the IEEE*.in *Engineering in Medicine and Biology Society (EMBC), 2010*

[5] K. Tanaka, K. Matsunaga, and H.O. Wang, "Electroencephalogram-Based Control of an Electric Wheelchair.," IEEE Trans. on Robotics,. **21**(4): p. 762-766. 2005

[6] H. Dandan, et al., "Electroencephalography (EEG)-Based Brain Computer Interface (BCI): A 2-D Virtual Wheelchair Control Based on Event-Related Desynchronization/Synchronization and State Control,". IEEE Trans on Neural Systems and Rehabilitation Engineering, **20**(3): p. 379-388.

[7] G. Pires, M. Castelo-Branco, and U. Nunes, "Visual P300-based BCI to steer a wheelchair: A Bayesian approach," *30th Annual International Conference of the IEEE* in *Engineering in Medicine and Biology Society, 2008. EMBS 2008.*

[8] Y. Punsawad and Y. Wongsawat, "Motion visual stimulus for SSVEP-based BCI system," *Annual International Conference of the IEEE* in *Engineering in Medicine and Biology Society (EMBC), 2012*

[9] Z. Dan, et al. "Integrating the spatial profile of the N200 speller for asynchronous brain-computer interfaces," *Annual International Conference of the IEEE*.in *Engineering in Medicine and Biology Society,EMBC, 2011*

[10] G. Fei, et al., "A brain computer interface based on motion-onset VEPs," *30th Annual International Conference of the IEEE* in *Engineering in Medicine and Biology Society, 2008. EMBS 2008.*

[11] B. Z. Allison, et al., "Toward smarter BCIs: extending BCIs through hybridization and intelligent control," J Neural Eng. 2012

[12] G. Pfurtscheller, et al.," Self-Paced Operation of an SSVEP-Based Orthosis With and Without an Imagery-Based &Brain Switch; A Feasibility Study Towards a Hybrid BCI,". IEEE Trans on Neural Systems and Rehabilitation Engineering,. **18**(4): p. 409-414.

[13] R. Leeb, et al. "Multimodal Fusion of Muscle and Brain Signals for a Hybrid-BCI". *Annual International Conference of the IEEE*.in *Engineering in Medicine and Biology Society (EMBC), 2010*

[14] F.-B. Vialatte, et al., "Steady-state visually evoked potentials: Focus on essential paradigms and future perspectives,". Progress in Neurobiology. **90**(4): p. 418-438.