Minimal-Assisted SSVEP-based Brain-Computer Interface Device

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Abstract— **Steady-state visual evoked potential (SSVEP)-based brain computer interface (BCI) device is one of the most accurate assistive technologies for the persons with severe disabilities. However, for the existing systems, the persons with disabilities still need the assistance for the long period of time as well as the continuous time usages. In order to minimize this problem, we propose the SSVEP-based BCI system that the persons with disabilities can enable /disable the BCI device by alpha band EEG and control the electrical devices by SSVEP. A single-channel EEG (O1 or O2) is employed. Power spectral density via periodogram at the four stimulated frequencies (6, 7, 8, and 13 Hz) and their harmonics are used as the features of interest. Simple threshold-based decision rule is applied to the selected features. With the minimal need for assistance, the classification accuracy of the proposed system ranged from 75 to 100%.**

Keywords-electroencephalogrm; steady state visual evoked potential; brain-computer interface; neuroprosthesic device

I. INTRODUCTION

Steady state visual evoked potentials (SSVEP) are the brain signals occurred from the natural responses to visual stimulations (e.g. light, flash, or checker board pattern) at specific frequencies. SSVEP is generated by stationary localized sources and distributed sources that exhibit characteristics of wave phenomena inside that brain. SSVEP is useful in research because of its excellent signal-to-noise ratio and relatively robust to artifacts. According to BCI researches, [1-12], SSVEP-based brain computer interface (BCI) device is one of the most accurate assistive technologies for the persons with severe disabilities.

Regarding the stimulation pattern of SSVEP, there are three main types, flickers as the light-emitting diode (LED), the cathode ray tube of a desktop monitor (CRT), and the liquid crystal display of a laptop screen (LCD). Zhenghua W. *et al* [13] claim that SSVEPs occurred from the LED flicker are significantly larger than those evoked by other flickers. Regarding the lead selection for SSVEP, Yijun W. *et al* [14] improve the applicability of SSVEP-based BCI system by acquiring EEGs over visual cortex between Pz and Oz. To retain SSVEP, the reference channel must has lower amplitude of SSVEP than the signal channel. To reduce background noise, it should have similar background activities with the signal channel. Therefore, the ones close to the signal channel, with lower amplitude of SSVEP, could be the candidates of the reference channel.

Regarding the SSVEP-based BCI system, in 2008, Muller-Putz G.R. *et al* [8] proposed an asynchronous (self-paced) four-class BCI based on steady-state visual evoked potentials (SSVEPs) used to control two-axis of electrical hand prosthesis. The four LED flicker were 6, 7, 8, and 13 Hz. EEG was recorded bipolarly posterior to electrode positions O1 and O2 according to the international 10–20-electrode system. The ground electrode was placed at position Fz. The results showed the classification rates from 74 to 88%. In 2009, Hui, S. *et al*. [11] presented SSVEP-based BCI for multi-degree of freedom manipulator control. By using six LEDs flickering (8Hz-20Hz), the results yielded an average accuracy of 72%. In 2010, I. Volosyak and A. Graser [15] introduced the BCI wizard as a system that automatically identifies key parameters to customize the best BCI paradigm for each user and to explore the two most effective BCI based VEP approaches, i.e. SSVEP and P300. The results showed that accuracy and information transfer rate of SSVEP paradigm are higher than P300 paradigm.

However, for the existing systems, the persons with disabilities still need the assistance for the long period of time fully usages of the SSVEP-based BCI system. In order to minimize this problem, we propose the SSVEP-based BCI system that the persons with disabilities can themselves enable /disable the BCI system by alpha band EEG and control the electrical devices by SSVEP.

II. PROPOSED MINIMAL-ASSISTED SSVEP-BASED BRAIN-COMPUTER INTERFACE DEVICE

The processes of the proposed minimal-assisted SSVEP-based BCI device can be described into three main sections as follows:

A. Data Acquisition

By following the 10-20 system, only one-channel SSVEP signal is acquired from the bipolar channel, i.e. O2. Channel Cz is used as the reference electrode and channel Fz is employed as the ground electrode. EEG Amplifier of BIOPAC^{TM} with gain 10,000, analog low pass filter with cutoff frequency at 35 Hz, and the analog notch filter at 50 Hz (for Thailand) are used to preprocess the acquired signal. A sampling rate of SSVEP signal is 128 Hz. NI USB 6008 multifunction I/O is used as the analog-to-digital converter device.

B. Visual stimulation

A Light Emitting Diode (LED) is used as the stimulator for visual stimulation. According to our experiment as well as the literature in [13], the 3x4 dots matrix LED is selected. The users are recommended to be a part to the stimulator not more than approximately 90 cm. The frequency ranges between 6 to13 Hz are selected according to our experiment and the literature in [8].The PIC 16F627A microcontrollers are used to modulate square wave for different frequencies flickering LEDs.

C. Feature Extraction and Classification Algorithms

At first the signal is filtered by the 5-40 Hz digital band pass filter. For the proposed system, we use 4 fundamental frequencies, i.e. 6, 7, 8, and 13 Hz. Each frequency has its harmonic frequency. However, according to the limitation of our bandpass filter (5-40 Hz), we will take into consideration only the fundamental, 1st , and 2nd harmonic frequencies as shown in Table I.

TABLE I
FUNDAMENTAL, FIRST HARMONIC AND SECOND HARMONIC FREQUENCIES

Fundamental frequency (Hz)	1st harmonic Frequency (Hz)	2nd harmonic frequency (Hz)
6	12	18
7	14	21
8	16	24
13	26	39

C.1 Calibrating Process

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

$$BL_n = \max(BL_{1n}, BL_{2n}, BL_{3n}) \quad (1)$$

where n represents four fundamental frequencies, i.e. 6, 7, 8, and 13 Hz. N is the total amount of fundamental frequencies used, i.e. N=4. BL_n represents the baseline parameter of the fundamental frequency n. BL_{1n}, BL_{2n}, and BL_{3n} represent the baseline values of three harmonics of fundamental frequency n which can be calculated as

$$BL_{1n} = mean(\mathrm{f}_{1n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{1n}\mathrm{Hz}, \mathrm{f}_{1n+r}\ \mathrm{Hz}) \quad (2)$$

$$BL_{2n} = mean(\mathrm{f}_{2n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{2n}\mathrm{Hz}, \mathrm{f}_{2n+r}\ \mathrm{Hz}) \quad (3)$$

$$BL_{3n} = mean(\mathrm{f}_{3n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{3n}\mathrm{Hz}, \mathrm{f}_{3n+r}\ \mathrm{Hz}) \quad (4)$$

where the amplitude of power spectral density (using Welch periodogram method) at each fundamental frequency is denoted as f_{1n}. The amplitudes of power spectrum of its first and second harmonic frequencies are denoted as f_{2n} and f_{3n}, respectively. The neighboring frequency (r) can be calculated as the ratio of maximum frequency obtained from the selected sampling rate (in this paper, with sampling rate of 128, we can get maximum frequency of 64 Hz) over the number of sample to read (in this paper, we acquire 2-second data to process each command, i.e. 256 samples, hence r = 64/256 = 0.25).

C.2 Feature Extraction Process

The amplitude of the power spectral density, f_n , obtained from Welch periodogram method is extracted as our feature as the following process:

$$f_n = \max\left(f_{1n}, f_{2n}, f_{3n}\right) - BL_n \quad (5)$$

where f_{1n}, f_{2n}, and f_{3n} can be calculated as

$$f_{1n} = \begin{cases} mean(\mathrm{f}_{1n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{1n}\mathrm{Hz}, \mathrm{f}_{1n+r}\ \mathrm{Hz}) & ,\text{if } \mathrm{f}_{1n} >= \mathrm{BL_n} \\ 0 & ,\text{if } \mathrm{f}_{1n} < \mathrm{BL_n} \end{cases} \quad (6)$$

$$f_{2n} = \begin{cases} mean(\mathrm{f}_{2n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{2n}\mathrm{Hz}, \mathrm{f}_{2n+r}\ \mathrm{Hz}) & ,\text{if } \mathrm{f}_{2n} >= \mathrm{BL_n} \\ 0 & ,\text{if } \mathrm{f}_{2n} < \mathrm{BL_n} \end{cases} \quad (7)$$

$$f_{3n} = \begin{cases} mean(\mathrm{f}_{3n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{3n}\mathrm{Hz}, \mathrm{f}_{3n+r}\ \mathrm{Hz}) & ,\text{if } \mathrm{f}_{3n} >= \mathrm{BL_n} \\ 0 & ,\text{if } \mathrm{f}_{3n} < \mathrm{BL_n} \end{cases} \quad (8)$$

f_n is selected as the maximum value among f_{1n}, f_{2n}, and f_{3n}. To further avoid the artifact and to simplify the classifier, if f_n is less than *Threshold*, it is set to zero. *Threshold* can be obtained as the average among all four baseline values, i.e. BL_6, BL_7, BL_8, and BL_{13}.

C.3 Decision Making

As the feature is carefully selected, the simple decision rule can be used, i.e. the maximum value among f_6, f_7, f_8, and f_{13} can be classified as its associated electrical device. The classifier would not give any decision, if all the four values are set to zeros.

C.4 Enable/Disable System

Besides the modified algorithm from [8], this paper also proposes the module that can make this BCI system require minimum assistance from the caretaker.

To obtain the threshold, T_α , for enable/disable BCI system, the user needs to perform another quick software calibration (besides the one in C.1) by closing the eyes and record the maximum power spectral density (PSD), P_{max} , in alpha band (9-11 Hz) similar to [16]. T_α can be automatically calculated as

$$T_\alpha = P_{max} - (P_{max}/4) \quad (9)$$

In real-time process, to enable the system, the user needs to close his/her eye until the power spectral density of the raw data exceeds T_α. After that the system will proceed to the SSVEP mode as usual BCI system (Fig.1) to control the electrical device. The system will be automatically disable within 4-sec once no command is selected. If one of the commands is selected, the system will also automatically disable. If the user wants to use BCI device, he/she needs to enable the system again. This concept makes much sense to the case of electrical device control, e.g. when the user turns on TV, he/she wants to watch TV, the system should be automatically disable. If the user would like to turn off TV or turn on other devices, he/she can simply enable the system using alpha band and selects the command via SSVEP again. With this concept, less assistance is needed during a day.

III. Experimental Results

After collecting two baseline values (one from eye-close and another one from eye-open session, each section requires 15-seconds), 4 subjects are asked to perform the random commands in Table II.

TABLE II
ALL 12 COMMANDS FROM TOP ARRANGED FROM LEFT TO RIGHT, FIRST ROW TO SECOND ROW

#Com	TV	Fan	Lamp	Radio	Lamp	TV
Freq	8	6	7	13	7	8
#Com	Radio	Fan	Fan	TV	Lamp	Radio
Freq	13	6	6	8	7	13

TABLE III
CLASSIFICATION ACCURACY AND TIME CONSUMING, #COM DENOTES THE NUMBER OF COMMANDS, SCORE DENOTES THE NUMBER OF CORRECT CLASSIFICATION

Subject	#com	score	%Acc	Total time (sec)
J	4	4	100	40
	8	6	75	95
	12	10	83.3	168
N (Beginner)	4	4	100	33
	8	7	87.5	66
	12	12	100	133
C (Beginner)	4	4	100	37
	8	8	100	88
	12	11	91.67	166
V (Beginner)	4	4	100	34.9
	8	7	87.5	85.7
	12	9	75	120
T	4	4	100	29.8
	8	7	87.5	69
	12	10	83.3	123
Average			100	34.94
			87.5	80.74
			86.7	142

TABLE IV
ALGORITHM EFFECTIVENESS OF SUBJECT C (BEGINNER) COMPARE WITH THE PREVIOUS WORK [8]

# Com	Previous work [8]			Proposed method		
	Score	Ideal time	Total time	Score	Ideal time	Total time
8	8	64	75	8	80	88
12	9	96	126.8	12	120	133

Table III illustrates that proposed system yields classification accuracies ranging from 75% to 100 %. For the proposed system, each command consists of two actions, i.e. 1) enable system by closing the eyes, and 2) on/off the electrical device by looking at the flickering LEDs. For each command, the proposed system uses the maximum time of 10 seconds. For multi-command usage, we also need to count the time consuming between commands (e.g. occurred from user resting, thinking). For 4 commands, the total times are varied from 29.8s to 40s. For 8 commands, the total times are varied from 66s to 95s. For 12 commands, the total times are varied from 120s to 168s. Subjects N, C and V are beginner and show 87.5% of average classification accuracy. These results elucidate that the system is easy to use even for the beginners.

Table IV compares the effectiveness between the previous work and the proposed system (beginner). With various commands, the accuracies of the proposed system is higher. For each command the ideal time of the previous work is 8s. It should be noted that we pick up the result of subject C. The results from other subjects are also comparable. However, as mentioned previously, with comparable time consuming, the subject used the proposed system can enable the BCI system by him/herself without any assistance from caretaker.

IV. Conclusions

In this paper, we have proposed the SSVEP-based BCI system that makes the persons with severe disabilities require less assistance from the caretaker. With the modified feature extraction methods from the literature as well as the alpha band control enable system, the proposed system can achieve the mentioned goal for minimal-assisted BCI device. With the comparable time consuming, the proposed system yields the classification accuracies ranging from 75% to 100 %. The prototype of the proposed system is named as "iThink2" for convenience. With the user friendly GUI designed and wireless control to manipulate the electrical device, the complete system of iThink2 can be shown in Fig.2.

Acknowledgment

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V. References

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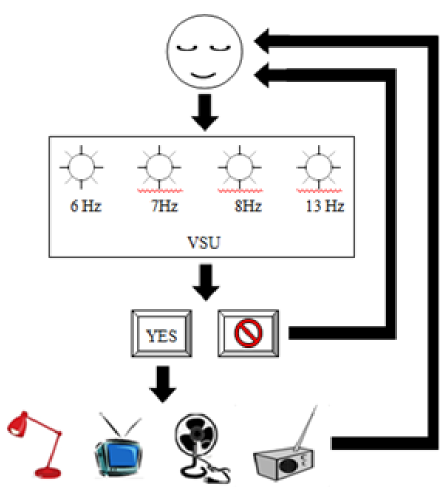
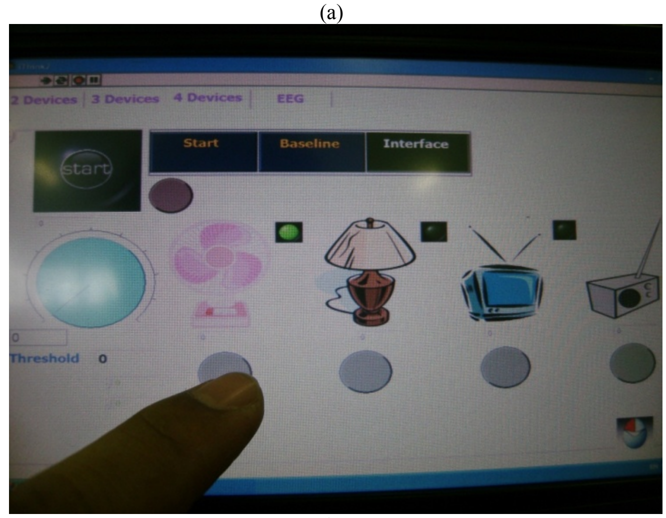
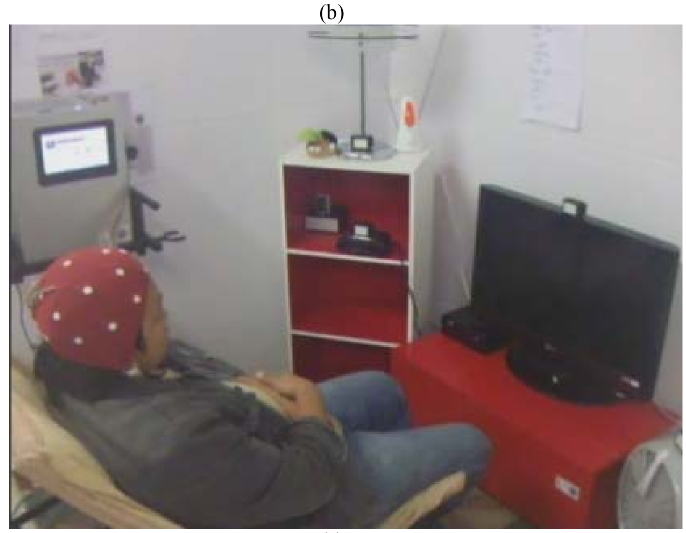


Fig. 1 The user closes the eyes and then the stimulator is enable, then the user can control the electrical devices via SSVEP.

(a)



(b)



(c)

Fig. 2 Minimal-assisted SSVEP-based BCI device (iThink2) (a) LED visual stimulator, (b) User friendly GUI with touch screen monitor, and (c) Overall system of iThink2: Control box on the left hand side will wirelessly control the visual stimulation pattern and on/off selected electrical device according to the classification