# Enhancement of SSVEP-based BCI system via SSAEP during Eye Fatigue Period

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*Abstract*— **This paper proposes the auditory evoked potential (SSAEP) stimulation technique as well as its detection algorithm to replace the steady state visual evoked potential (SSVEP)-based brain-computer interface (BCI) system during the visual fatigue period. Optimal speaker position for two commands SSAEP-based BCI system and the possible electrode positions are investigated. With the proposed system, 85% accuracy for two commands can be achieved at T3-T5 and T4-T6 electrode positions by using only one speaker. Besides the replacement, SSAEP-based BCI system can also increase more commands when using together with the SSVEP system.**

## I. Introduction

Visual evoked potential (VEP) is one kind of event related potential (ERP) in which the electrical activities of the brain are excited by visual stimulation. VEP can be divided by the frequencies of flickering; lower than 5 Hz is a transient VEP (TVEP) and higher frequency is called steady state VEP (SSVEP) [1]. VEP is utilized in many biomedical applications such as the diagnosis of some diseases that related to the vision perception and disorder of the brain. Furthermore, brain computer interface (BCI) system usually employs VEP for rehabilitation to restore indirectly a communication between a neural system and the disabled limbs [1-6].

Steady state visual evoked potential (SSVEP) is the brain potential that responded to continuous visual stimulus. Previous studies have tried to propose many signal processing technique for enhancing a performance of SSVEP-based BCI system. However, the main problem occurred in SSVEP-based BCI system is the eye fatigue which is natural response owing to a continuous looking and focusing at the flickering pattern stimulus. This can be cause to a low performance of SSVEP-based BCI system.

According to the previous study of auditory evoked potential (AEP) based BCI system, Hong *et al.* [7] were investigated a brain response to auditory stimulus. They reported that a late positive component (LPC) was interesting for BCI system because LPC has larger amplitude and longer latency than the typical P300 response. Those could be used for BCI. After that they proposed an auditory BCI using active mental response [8]. This technique used the amplitude of N2 and the late positive component (LPC) to detect the non-target and target by mental response from auditory stimulus (a random sequence of spoken digit). For the N2/LPC area comparison, Fisher discriminant analysis and support vector machine (SVM) were used for the target detection. The result showed a high accuracy and potentially could be used for BCI system. Furthermore, the study of EEG characteristic with a response to SSAEP and SSVEP (auditory steady state response ASSR) by using nonlinear dynamical analysis showed the efficient technique for response detection of both [9]. According to the literatures, SSVEP still yields higher performance in BCI. However, during the use of SSVEP, eye fatigue is usually occurred and leaded to the lower BCI system performance.

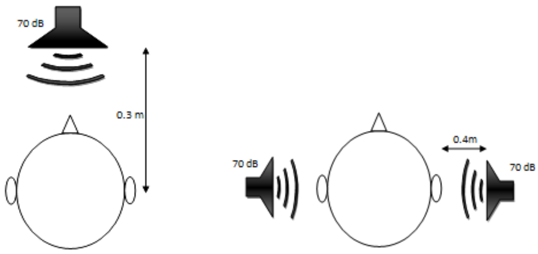
Therefore, in this paper, we propose a new technique to enhance a performance of SSVEP-based BCI system. A combination of SSVEP and SSAEP usage in BCI system is introduced. Auditory stimulation is integrated to the SSVEP-based BCI system as showed in Fig1. Optimal speaker position for two commands SSAEP-based BCI system and the possible electrode positions are investigated.

## II. Proposed Methods

Steady state auditory evoked potential (SSAEP) is the brain response from the continuous auditory stimulation. Many brain responses such as brainstem, middle, late positive components, P300 and SSAEP [8-11] can be occurred by auditory stimulus. By employing SSAEP, SSVEP-based BCI system could produce more commands. Besides, to avoid the low performance during an eye fatigue period of SSVEP-based BCI, a command performed by SSVEP could be replaced with the SSAEP system.

### A. *Auditory stimulation system*

For simplicity, a simulated sound for auditory stimulator is generated. A PIC 16F627A microcontroller is used to generate a pulse at frequency 7 Hz to drive a 70 dB buzzer. In this paper, we propose two patterns of speaker positions. First pattern is to use one speaker located in front of a subject. Second pattern is to use two speakers located at the left and right side of subject. The distance between the each side of the ear to the speaker is approximately 40 cm. Both patterns are showed in Figs. 1(a) and (b), respectively.




(a) (b)

Fig. 1 (a) The proposed single speaker auditory stimulus pattern, (b) the proposed two speakers auditory stimulus pattern.

*B. EEG acquisition*

The temporal region of the brain usually represents an auditory response. Although we use both temporal T3 and T4 for recording EEG signal, the investigation of efficient reference electrode positions, i.e. T3-C3, T4-C4, T3-T5, T4-T6, to reduce the common mode noise are also needed to be investigated to confirm the appropriate reference channels. For the mentioned positions, Fz is used as the ground electrode. The two-channel differential EEG signals are recorded by EEG amplifier of BIOPAC$^{TM}$ system (One channel from the left temporal and one channel from the right temporal). The electrode positions are according to the international 10-20 electrode placement system. For the preprocessing, a 50 Hz analog notch filter is used to remove a power line noise. Furthermore, those signals are filtered by another analog band pass filter with cut off frequency between 1 to 35 Hz. The sampling rate of 200 Hz is used.

*C. Algorithms*

The algorithm for auditory response detection of SSAEP can be summarized as follows:

**1. Calibrating Process**

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

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

where $n$ represents selected fundamental frequencies, i.e. 7 Hz. $BL_n$ represents the baseline parameter of the fundamental frequency $n$. $BL_{1n}$ and $BL_{2n}$ represent the baseline values of two harmonics of fundamental frequency $n$ which can be calculated as

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

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

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 harmonic frequencies is denoted as $f_{2n}$. 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 200, we can get maximum frequency of 100 Hz) over the number of sample to read (in this paper, we acquire 2-second data to process each command, i.e. 400 samples, hence $r$ = 100/400 = 0.25).

**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:

$$f_n = \max\left(f_{1n}, f_{2n}\right) - BL_n \tag{4}$$

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

$$f_{1n} = \begin{cases} mean(\mathrm{f}_{1n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{1n}\mathrm{Hz}, \mathrm{f}_{1n+r}\ \mathrm{Hz}) & ,\text{if } \mathrm{f}_{1n} >= \mathrm{BL_n} \\ 0 & ,\text{if } \mathrm{f}_{1n} < \mathrm{BL_n} \end{cases} \tag{5}$$

$$f_{2n} = \begin{cases} mean(\mathrm{f}_{2n\text{-}r}\ \mathrm{Hz}, \mathrm{f}_{2n}\mathrm{Hz}, \mathrm{f}_{2n+r}\ \mathrm{Hz}) & ,\text{if } \mathrm{f}_{2n} >= \mathrm{BL_n} \\ 0 & ,\text{if } \mathrm{f}_{2n} < \mathrm{BL_n} \end{cases} \tag{6}$$

$f_n$ is selected as the maximum value among $f_{1n}$ and $f_{2n}$. 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. $BL_7$.

**3. Decision Making**

As the feature is carefully selected, the simple decision rule can be used, i.e. **1) case of 1 command:** if $f_n$ from one of the channel is greater than zero the command is selected **2) case of 2 commands:** if $f_n$ of left channel is greater than $f_n$ of right channel, the left command is selected. Right command is similarly selected.

## III. TESTING AND RESULTS

The testing consists of two sections as one command test and two commands test (Left and Right) with the same system. Two groups of subject, first group is for finding the efficient electrode positions and accuracy of the speaker position pattern for one command. Another group is for testing the accuracy of having two commands. The environmental setup can be shown in Fig. 4

TABLE I
THE ORDER OF TESTING SSAEP SYSTEM

| *Speaker Position* | *Proposed reference electrode* | |
|---|---|---|
| | *Left* | *Right* |
| Fig.1(a) | T3-C3 | T4-C4 |
| | T3-T5 | T4-T6 |
| Fig.1(b) | T3-C3 | T4-C4 |
| | T3-T5 | T4-T6 |

TABLE II
THE RESULT OF PROPOSED ONE COMMAND OF SSAEP FOR BCI SYSTEM

| *Subject* | *Speaker Position* | *Proposed reference electrode* | *% Accuracy* |
|---|---|---|---|
| 1 | Fig.1(a) | C | 60 |
| | | T | 90 |
| | Fig.1(b) | C | 40 |
| | | T | 30 |
| 2 | Fig.1(a) | C | 60 |
| | | T | 90 |
| | Fig.1(b) | C | 20 |
| | | T | 20 |
| Average | 1 stimulator | | 75 |
| | 2 stimulator | | 27.5 |

*1) The proposed one command of SSAEP for BCI system*

There were two voluntary subjects to test a performance of our proposed speaker patterns and electrode positions. Two speaker patterns in Fig. 1 were tested. Each subject performed 2 trials of each pattern according to the proposed electrode positions (Table I). In each trial the subject performs 10 times selection. The baseline of each EEG channel is collected before all trials of testing.

According to Table II, the average accuracy of the first auditory stimulation pattern in Fig.1 (a) was 75% and second pattern in Fig.1 (b) was 27.4%. The first auditory stimulation pattern yields better performance than the second pattern because the two sound sources (with the same frequency) may reduce the hearing concentration. Furthermore, according to Table II, T3-T5 and T4-T6 yield the best accuracy.

*2) The proposed two commands of SSAEP for BCI system*

Two volunteer subjects were recruited to test a performance of our proposed two commands system (left or right selections). According to the results of the one command system, channels T3-T5 and T4-T6 were selected. For each speaker position (Figs. 1(a) and (b)), the subject needed to

1) concentrate on hearing with left or right ear with no eye movement,

2) concentrate on hearing with left or right ear together with moving eye to the selected direction,

3) concentrate on hearing with left or right ear together with moving eye to the opposite direction.

Each subject needed to perform 6 trials for 10 times according to Table III.

The results of two command system using SSAEP and our proposed algorithm were shown in Table IV. We can see that in some trial we can achieve 100% accuracy. Moving the eye to the left or right would not help the hearing pathway.

## IV. DISCUSSION

The first auditory speaker position (Fig. 1(a)) was shown to be an efficient stimulator for SSAEP system according to the Table II and Table IV. The low accuracy of two speakers in Fig. 1(b) might come from the difficulty in concentrating for the sound. Besides, the results reported that EEGs acquired at the temporal T3 and T4 and used the references near that position like T5 and T6, respectively.

## V. CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed the suitable speaker position for SSAEP-based BCI system. By using only one speaker, we can easily have 2 commands. To enhance the performance, corresponding eye movement pattern is also investigated whether it has effect with the hearing system. Electrode positions as well as the reference channels are also explored.

According to the proposed method, we can combine it with

TABLE III
THE PERFORMING FOR PROPOSED 2 COMMANDS
.

| *Trial* | *Hearing concentration* | *Eye movement* |
|---|---|---|
| 1 | Left | - |
| 2 | Left | Left |
| 3 | Left | Right |
| 4 | Right | - |
| 5 | Right | Right |
| 6 | Right | Left |

TABLE IV
THE RESULT OF PROPOSED TWO COMMAND OF SSAEP FOR BCI SYSTEM

| *Speaker Position* | *Command* | *Eye movement* | *Average % Accuracy* |
|---|---|---|---|
| Fig.1(a) | Left | - | 70 |
| | | Left | 40 |
| | | Right | 40 |
| | Right | - | 100 |
| | | Left | 50 |
| | | Right | 70 |
| Fig.1(b) | Left | - | 65 |
| | | Left | 40 |
| | | Right | 30 |
| | Right | - | 40 |
| | | Left | 70 |
| | | Right | 30 |
| Total | Concentration | | 67.5 |
| | Concentration with Looking follow side | | 45 |
| | Concentration with Looking opposite side | | 47.5 |

the SSVEP approach to solve the fatigue problems from using SSVEP alone. The proposed architecture is shown in Fig.3. This is a replacing of SSVEP commands to solve an eye fatigue period showed in Figs. 2 and 3.

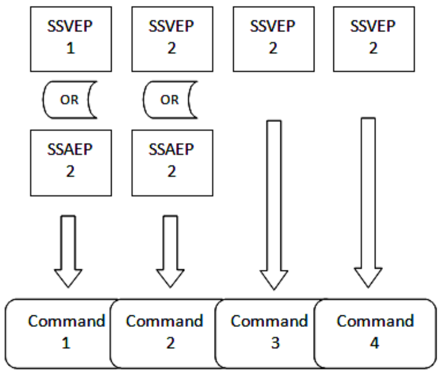



Fig. 2 Proposed architecture of SSAEP replacing for SSVEP command

## ACKNOWLEDGMENT

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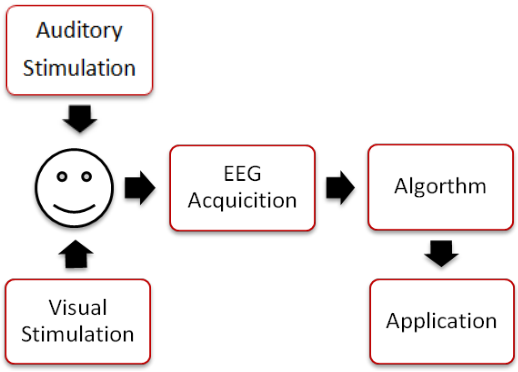


Fig. 3 Schematic of SSVEP-SSAEP based BCI system

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Fig. 4. The experimental Setup