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Spectrum Based Feature Extraction Using Spectrum Intensity Ratio for SSVEP Detection

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Abstract— **Recent years, a Steady-State Visual Evoked Potential (SSVEP) is used as a basis for Brain Computer Interface (BCI)[1]. Various feature extraction and classification techniques are proposed to achieve BCI based on SSVEP. The feature extraction of SSVEP is developed in the frequency domain regardless of the limitation in flickering frequency of visual stimulus caused by hardware architecture. We introduce here the feature extraction using a spectrum intensity ratio. Results show that the detection ratio reaches 84% by using a spectrum intensity ratio with unsupervised classification. It also indicates the SSVEP is enhanced by proposed feature extraction with second harmonic.**

I. INTRODUCTION

BCI provides a direct communication between a human or animal brain and a hardware device[2][3]. Electroencephalograph (EEG) measurement is one of the major way to show a will to BCI. The common characteristics used in BCI are mu and beta wave, Event-Related Potentials, and SSVEP[4],[1].

Recent years, there has been great interest in SSVEP based BCI system. SSVEP is the periodic EEG response to a visual stimulus with a defined or periodic flashing. When we focus our attention or interest to a periodic flickering stimulus, the EEG signal, which includes corresponding frequency and its harmonic of stimuli, is recorded at occipital lobe. The largest response is given at a flickering frequency of 15Hz[5],[6],[7]. SSVEP represents the same fundamental frequency as the flickering visual stimulus and its harmonics[8]. The SSVEP based BCI adopts the first harmonic[5], first and second harmonic[9],[10], and higher harmonics[11]. The traditional SSVEP detections use an amplitude spectrum based characteristics to identify the flickering frequency of visual stimuli. For example, M.Cheng employs the sum of amplitude spectra of its fundamental frequency and second harmonic[12]. The feature extraction and clustering using multi-channel EEG signals achieves a high detection ratio and information transfer[13],[14]. If an effective spectrum-based feature extraction is proposed, the simple and reasonable SSVEP detection will be achieved for BCI systems.

In this paper, the spectrum intensity ratio, which is represented as a ratio of target frequency to spectrum component around a target frequency, is adopted to extract an enhanced SSVEP. Results indicate that the spectrum intensity ratio performs higher detection rate than traditional amplitude based features.

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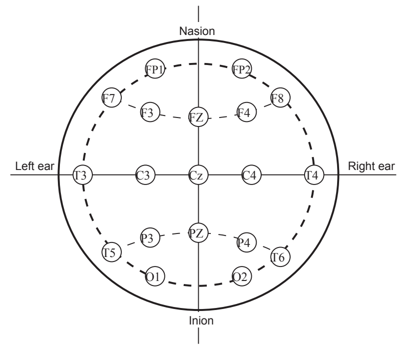

Fig. 1. International 10-20 electrode system

II. RECORDING CONDITIONS

The visual stimulus whose flickering frequency is set by a controller is employed to derive SSVEP. The flickering frequency (F) used in our experiment is 5, 10, 15, 20 and 25 Hz. The recording is performed in the shielded dark room for reducing an electromagnetic noise and an environmental visual stimulus. The visual stimulus (LED) is located 90cm away from the nasion of the subject. The subject seated in a chair in front of LED looks at a flickering stimulus over 120 seconds. EEG data is collected using 19 electrodes, which are placed at the location based on the international 10-20 system (Fig.1). In order to detect an eye movement and blinking, two pairs of electrodes are attached to the right-left side (HEOG) and top-bottom side (VEOG) of a right eye. The reference electrode is placed on both ears. All potentials are digitally sampled at 1000Hz through the BrainAmp MR Plus (Brain Products Co.) for the off-line signal processing. The subject is a right-handed male (aged 22) who has a normal vision.

III. DATA ANALYSIS

The single-trial analysis using an amplitude spectrum is adopted to detect the fundamental frequency of SSVEP. Assume that $x_i(t)$ is the ith segment of 2 seconds length extracted from EEG. The spectrum component of $x(t)$ is expressed as $X(\omega)$. The sum of amplitude spectrum with overlapping is used to enhance the SSVEP. Then, we get

$$Y_i(\omega) = \sum_{j=0}^{M-1} |X_{i-j}(\omega)| \tag{1}$$

where M is the number of segment for sum.

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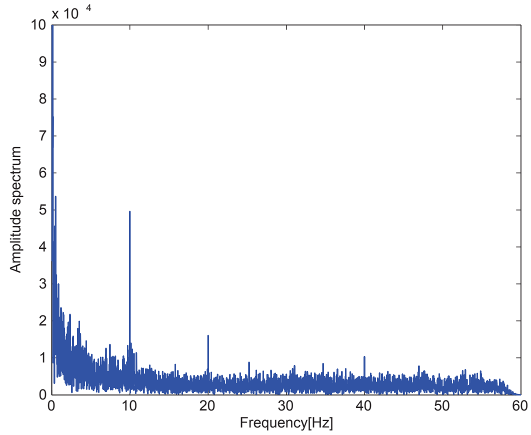


Fig. 2. Amplitude spectrum of EEG recorded for 60 seconds ($F = 10$Hz)

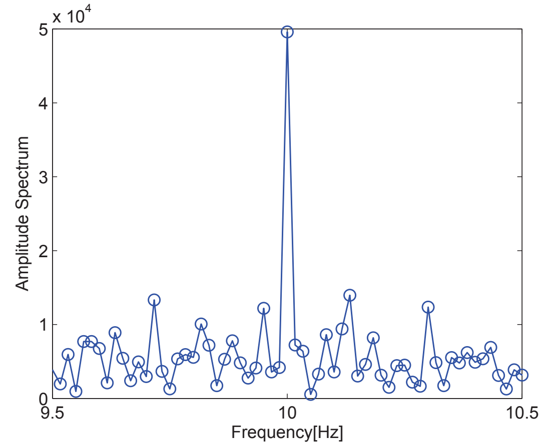


Fig. 3. Amplitude spectrum of EEG recorded for 60 seconds ($F = 10$Hz)

A. Amplitude spectrum (Feature A)

The sum of amplitude spectrum ($Y_i(\omega)$) is used for frequency detection. The frequency of SSVEP for ith EEG segment is estimated as:

$$S_i = \arg\max_{\omega_k} Y_i(\omega_k) \tag{2}$$

where ω_k corresponds to the known flickering frequencies F of LED i.e. 5, 10, 15, 20 and 25 Hz, S_i shows the estimated frequency of SSVEP.

B. Amplitude spectrum with harmonic (Feature B)

It is well known that frequency peaks of SSVEP appear on the flickering frequency and its harmonics. Fig.2 draws the amplitude spectrum calculated from 60 seconds EEG when the subject focuses his attention to the flickering stimulus of 10Hz. We can see the sharp spectrum peaks at 10, 20 and 40Hz which are the harmonics of flickering frequency of 10Hz. The sum of fundamental frequency and its second harmonic is employed to detect SSVEP. The frequency of SSVEP for ith EEG segment is estimated as:

$$S_i = \arg\max_{\omega_k}(Y_i(\omega_k) + Y_i(2\omega_k)). \tag{3}$$

C. Spectrum intensity ratio (Feature C)

The SSVEP origin spectrum peak does not appear around the target frequency (see Fig.(3)). This is useful characteristics to measure strength of SSVEP from a short term EEG. The flickering frequency for BCI system is defined as uniquely as possible. This means that flickering frequencies should not be harmonics from each other. In order to satisfy a harmonic limitation, flickering frequencies are chosen from narrow bandwidth in many researches. If the stimulus is indicated on a common monitor, flickering frequency is also limited to a divisor of refresh rate. In our approach, the spectrum intensity ratio which is represented as a ratio of target frequency to spectrum component around target frequency is employed to extract an enhanced SSVEP.

$$S_i = \arg\max_{\omega_k}\left(\frac{Y_i(\omega_k)}{\sum_{j=-m}^{m} Y_i(\omega_k + j)}\right) \tag{4}$$

TABLE I
PARAMETERS

Length of DFT window	-	2 seconds
Shift width	-	0.2 seconds
Num. of frame for sum	M	5
Frequency width	m	8 samples

where m indicates the number of spectrum components around ω_k.

D. Spectrum intensity ratio with harmonic (Feature D)

In addition to feature C, the spectrum intensity ratio of first and second harmonic is applied to detect the SSVEP.

$$S_i = \arg\max_{\omega_k}\left(\frac{Y_i(\omega_k)}{\sum_{j=-m}^{m} Y_i(\omega_k + j)} + \frac{Y_i(2\omega_k)}{\sum_{j=-m}^{m} Y_i(2\omega_k + j)}\right). \tag{5}$$

E. Detection ratio

In four methods described above, S_i indicates the estimated frequency of SSVEP which yields the maximum value in each feature extraction. Assume that the ω_{ki} represents the flickering frequency of the EEG on ith frame, the detection ratio $R_{\omega k}$ is expressed as:

$$R_{\omega k} = \frac{1}{N}\sum_{i=0}^{N-1}\delta(i) \tag{6}$$

$$\delta(i) = \begin{cases} 1 & (S_i = \omega_{ki}) \\ 0 & (\text{otherwise}) \end{cases}$$

where N is the number of frame.

This criterion represents that the how many flames are detected as ω_k. In this paper, the evaluation is performed by using 60 seconds EEG when the subject looks at the stimulus.

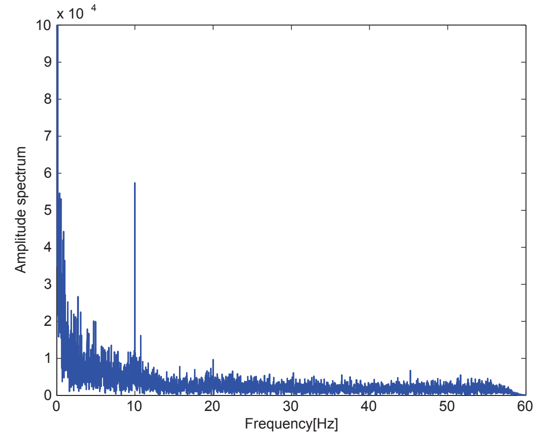


Fig. 4. Amplitude spectrum of EEG recorded for 60 seconds ($F = 5$)

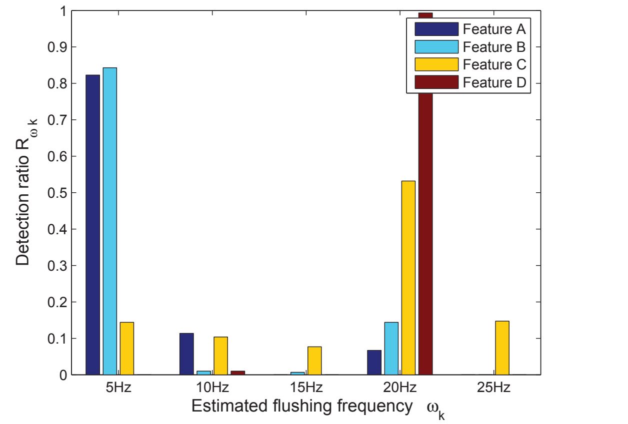
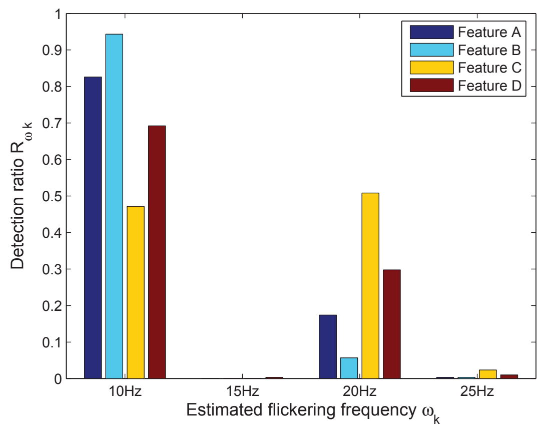
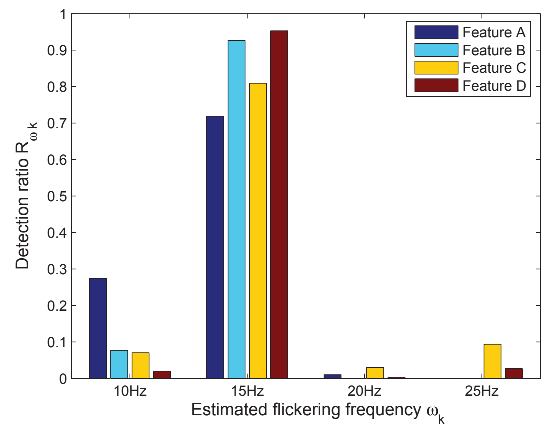


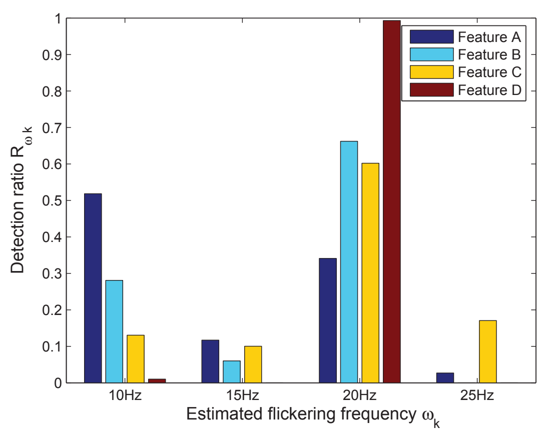
Fig. 5. Detection ratio for $F = 20$Hz when $F = 5$ is used as one of SSVEP frequency



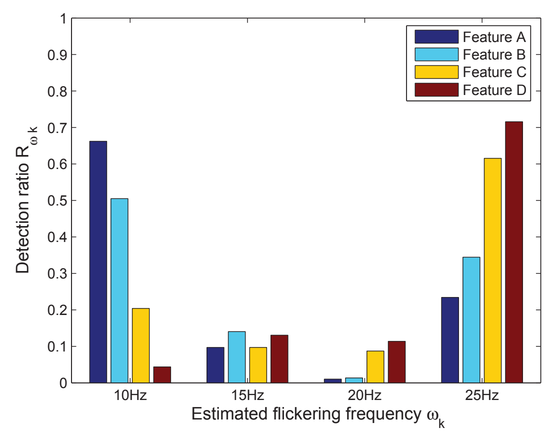
(a): Detection ratio for $F = 10$ Hz



(b): Detection ratio for $F = 15$ Hz



(c): Detection ratio for $F = 20$ Hz



(d): Detection ratio for $F = 25$ Hz

Fig. 6. Detection ratio for four visual stimuli. Four bars represent the detection ratio by using four features.

IV. EXPERIMENTAL RESULTS

A. Parameters and electrode selection

Table I lists parameters for SSVEP detection. DFT is applied to EEG recorded for two seconds by 19 electrodes. This window shifts at the interval of 0.2 seconds. The number of frame to calculate the sum of amplitude spectrum is 5 related to M in (1). Note that one detection result at ith frame is given by 3 seconds EEG. The bandwidth for spectrum

TABLE II
AVERAGED DETECTION RATIO (EXCLUDING $F = 5$)

Feature	A	B	C	D
Ratio[%]	53	72	62	84

intensity ratio is 8 samples corresponding to $\omega_k \pm 4$Hz to avoid an overlap in each flickering frequency.

The data selection is important factor to extract SSVEP efficiently. Right occipital lobe shows the better response for flickering visual stimuli[1],[8]. On the other hand, the clear oscillation is given by subtracting EEG recorded at Cz from occipital lobe[15]. Therefore, the EEG signal $x(t)$ employed herein is represented by O2$-$Cz.

B. Results

The amplitude spectrum of EEG with $F = 5$ shown in Fig.4 indicates that the harmonic component at 10Hz is greater than a fundamental flickering frequency. Therefore, the second harmonic of 5Hz is detected as a fundamental frequency of SSVEP. Fig.5 which represents a detection ratio for $F = 20$, shows that the SSVEP is detected as 5Hz by using feature A and B. The main cause of this mis-detection is a high amplitude spectrum in low-frequency band. From Fig.2 and Fig.4, the spectrum amplitude is moderately-increased in low-frequency band. Therefore, the detection result shown in below is performed by flickering stimuli excluding 5Hz.

Fig.6(a)-(d) draw a detection ratio when the flickering frequency is 10, 15, 20 and 25Hz. Four color bars represent the detection ratio calculated by four feature extractions, respectively.

Detection ratios in Fig.6 (a) are classified into two results:
(i) Detect as 5 and 10Hz (feature A and B): The accuracy of feature A and B is greater than its feature C and D. One possible reason is the increasing of amplitude spectrum in low-frequency band. Moreover, SSVEP is mis-detected as 10Hz in Fig.6(c)-(d). This means that the amplitude spectrum-based features are influenced by a low-frequency brain waves.
(ii) Detect as 10 and 20Hz (feature C and D): By using the spectrum intensity ratio, SSVEPs are detected as second harmonic 20Hz since SSVEP is recorded on the first, second and fourth harmonics (see Fig.2).

From Fig.6(b)-(d), SSVEP is correctly estimated by using spectrum intensity ratio. We can also confirm that feature D yields the best detection ratio. The reason is that the first and second harmonics from 15 to 25Hz are independent of each other. From Fig.6 (c), the flickering frequency is correctly detected by using feature D. However, from Fig.6(a), detection results in 20Hz include some false detections. The detection ratio in $F = 25$ (Fig.6(d)) is less than others since SSVEP amplitude is decreased with frequency increasing in the frequency band higher than 15Hz[6].

The averaged detection ratio for 4 features is shown in Table II. Table II demonstrates the feature parameter, which yields maximum detection ratio, is feature D, where the accuracy is 84%. These results show that the spectrum intensity ratio adopted here represents significant characteristics of SSVEP.

V. CONCLUSION

In this paper, we introduce the spectrum based feature extraction for SSVEP detection. Results show that the detection ratio is 84% by using a spectrum intensity ratio with unsupervised classification while the simple feature using spectrum amplitude performs 72%. It is confirmed that the SSVEP is more enhanced by using spectrum intensity ratio. In order to avoid the false-positive detection due to harmonics, we need to apply a suitable classification technique. This is a future task.

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