Simple SSVEP Detection Using Spectrum Intensity Ratio and Threshold

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***Abstract*—In recent years, Steady-State Visual Evoked Potential (SSVEP) is often used as a basis for Brain Computer Interface (BCI) [1]. The feature extraction is significant problem to achieve the SSVEP based BCI. Various signal processing and classification techniques are proposed to extract SSVEP from Electroencephalograph (EEG). We introduced a spectrum intensity ratio as a simple characterization and separation of SSVEP. However, it is difficult to classify an unseeing state of subjects. In addition, the comparison with conventional method is not tried yet. In this paper, we adopt a classification using threshold to reject the unseeing state.**

I. INTRODUCTION

BCI is a powerful tool to provide a direct communication between a human or animal brain and a hardware device[2][3]. EEG is one of the useful data to transmit a will to BCI. The major characteristics used in BCI are mu and beta wave, Event-Related Potentials, and SSVEP[4].

Recent years, there has been great interest in SSVEP based BCI. SSVEP is the periodic response to visual stimuli with a defined or periodic flashing. When we focus our attention or interest to these stimuli, the EEG signal, which includes corresponding frequency and its harmonic of stimuli, is recorded. SSVEP caused by flickering frequency of 15Hz[5],[6],[7] gives us the largest response. It shows the same fundamental frequency as the flickering visual stimulus and its harmonics[8]. The major SSVEP based BCI adopts the first harmonic[5], first and second harmonics[9],[10], and higher harmonics[11]. Traditional SSVEP detections use an amplitude or a power spectrum to identify the flickering frequency of visual stimuli. M.Cheng used an amplitude spectra of 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. DFT based feature extraction is employed to extract high-frequency SSVEP[15], however, it requires the baseline spectrum derived from previous EEG data. This means that the subject requires the training time for each trial.

We proposed the spectrum intensity ratio (SIR) to extract an enhanced SSVEP [16]. SIR is a ratio of an amplitude spectrum on target frequency to a spectrum around the target frequency. However, it is difficult to classify an unseeing state of examinees by using SIR. In addition, the number of subject is not enough in the conventional research. In this paper, we propose an unseeing state detection based on simple thresholding. The evaluation is performed by using EEG of 3 subjects.

TABLE I. RECORDING CONDITIONS

Flickering frequency of stimuli (F)	13 to 18 Hz
Recording time for each stimuli	60 sec.
Sampling rate of EEG	1000 Hz
Number of subjects	3

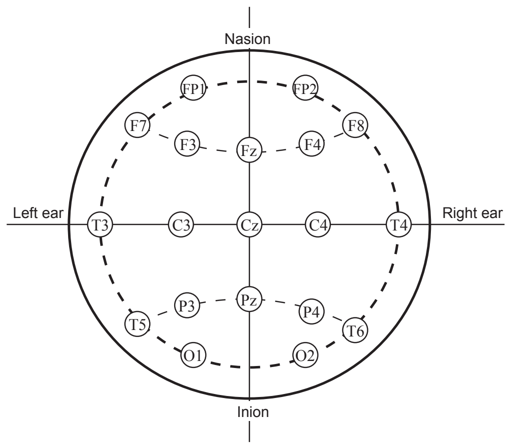

Fig. 1. International 10-20 electrode system. The bipolar channel O1-C3 is used for signal processing.

II. RECORDING CONDITIONS

Table I lists recording conditions for SSVEP task. 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 13, 14, 15, 16, 17 and 18 Hz.

The visual stimulus (LED) is located 50cm away from the nasion of the subject. The subject seated in a chair in front of LED looks at a flickering stimulus over 60 seconds. EEG data is collected using Ag-Cl 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) of a right eye. The reference electrode is placed on both ears.

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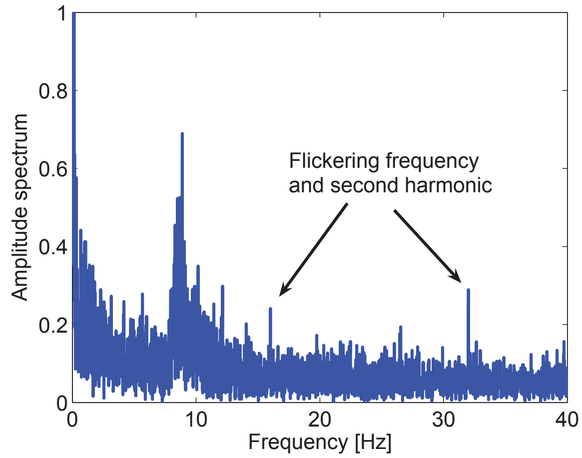

Fig. 2. Amplitude spectrum of EEG recorded for 60 seconds ($F = 16$Hz)

All potentials are digitally sampled at 1000Hz for the off-line signal processing. A high-pass filter (cut-off 0.1Hz) and a low-pass filter (cut-off 250Hz) is applied to the collected EEG data through the amplifier. Three subjects (3 males aged 22-23) volunteered for recording. All subjects have normal vision.

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 [17]. We employed a bipolar channel O1-C3 for signal processing.

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 on the flickering stimulus of 16Hz. We can see the sharp spectrum peaks at 16 and 32Hz due to SSVEP. However, EEG strongly includes low-frequency component due to spontaneous activity.

III. DATA ANALYSIS

The single-trial analysis using an amplitude spectrum is a simple and major way 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 of $x_i(t)$ is expressed as $X_i(\omega)$. 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.

A. Amplitude spectrum

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:

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

$$\Omega_i = \arg\max_{\omega_k}(S_i(\omega_k)) \tag{3}$$

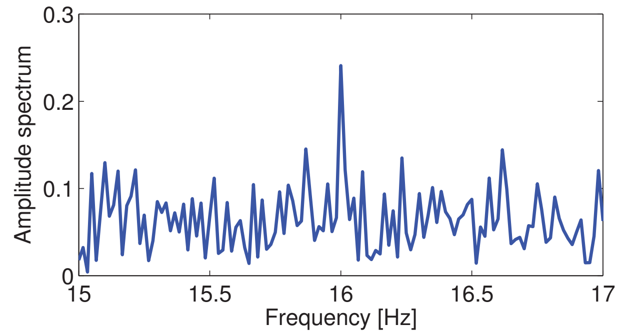

Fig. 3. Amplitude spectrum of 60 seconds EEG (around 16 Hz)

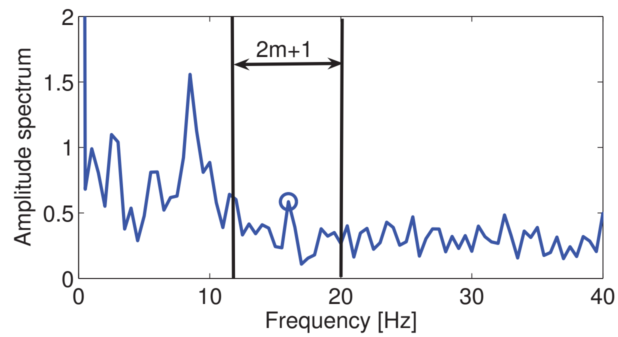

Fig. 4. An example of short term spectrum $Y_i(\omega)$ ($F = 16$Hz)

where ω_k corresponds to the interest frequencies F of LED i.e. 13, 14, ..., 18Hz, Ω_i indicates the estimation result.

B. Spectrum intensity ratio

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.

In general, an amplitude spectrum of EEG is enhanced in the low-frequency band due to spontaneous activity. It is difficult to detect a high-frequency SSVEP by using an amplitude spectrum. The spectrum ratio between a recorded EEG and baseline signal is used to reduce the low-frequency components and spontaneous noises. However, the baseline method requires the normalizing spectrum calculated from the previous EEG signals [17]. In order to reduce the pre-recording task, the SIR is employed to extract an enhanced SSVEP. This parameter is represented as a ratio of target frequency to spectrum component around target frequency(see Fig. 4). The SSVEP detection with spectrum intensity ratio is performed as:

$$S_i(\omega_k) = \frac{Y_i(\omega_k)}{\sum_{j=-m}^{m} Y_i(\omega_k + j)}, \tag{4}$$

$$P_i(\omega_k) = S_i(\omega_k) + S_i(2\omega_k), \tag{5}$$

$$\Omega_i = \arg\max_{\omega_k}(P_i(\omega_k)). \tag{6}$$

where ω_k corresponds to the interest frequencies F of LED i.e. 13, 14, ..., 18Hz. The parameter m indicates the bandwidth for feature extraction. We call this detection technique as SSVEP classification.

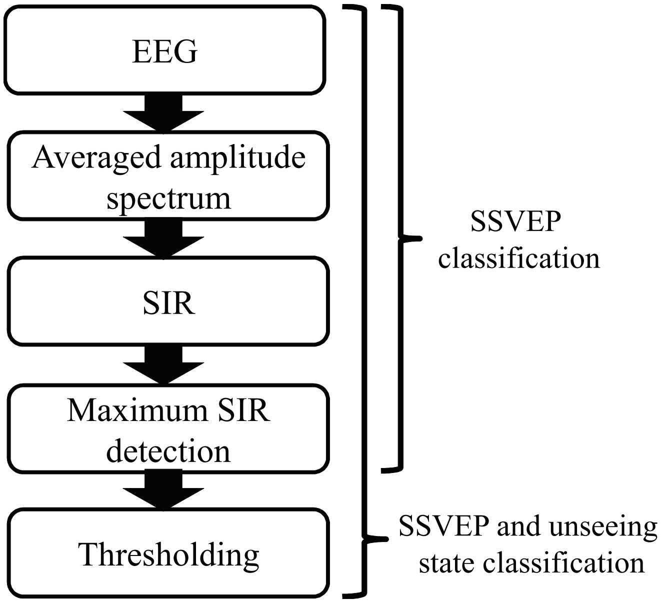

Fig. 5. Calculation flow for SSVEP and unseeing state classification

TABLE II. PARAMETERS

Length of DFT window	-	2 seconds
Shift width	-	0.2 seconds
Num. of frames for sum	M	5
Frequency width	m	9 samples

C. Unseeing detection

The unseeing state indicates that the subject does not focus his attention on the visual stimulus. The conventional SSVEP classification using SIR does not focus on unseeing state. It is assumed that the subject is always looking at stimulation. We adopt adaptive threshold using average μ and standard deviation σ of SIR to detect unseeing state. The threshold T_i on ith frame is defined as:

$$\mu_i = \frac{1}{L-1} \sum_{\omega_k \neq \Omega_i} P_i(\omega_k), \tag{7}$$

$$\sigma_i = \sum_{\omega_k \neq \Omega_i} \frac{(P_i(\omega_k) - \mu_i)^2}{L-1}, \tag{8}$$

$$T_i = \mu_i + \alpha\sigma_i. \tag{9}$$

where, α is a constant number, L is the number of flickering frequency for visual stimuli. To evaluate the unseeing detection technique, we record 60 seconds EEG when the subject does not watch visual stimuli. If the SIR satisfies;

$$P_i(\omega_k) > T_i, \tag{10}$$

$P_i(\omega_k)$ is classified as (6). When (10) is not satisfied, $P_i(\omega_k)$ is detected as unseeing state. The calculation flow of SSVEP and unseeing state classification is shown in Fig. 5. We employ the amplitude spectrum based detection as conventional research. Instead of SIR, the amplitude spectrum in 3 is used for conventional method[16].

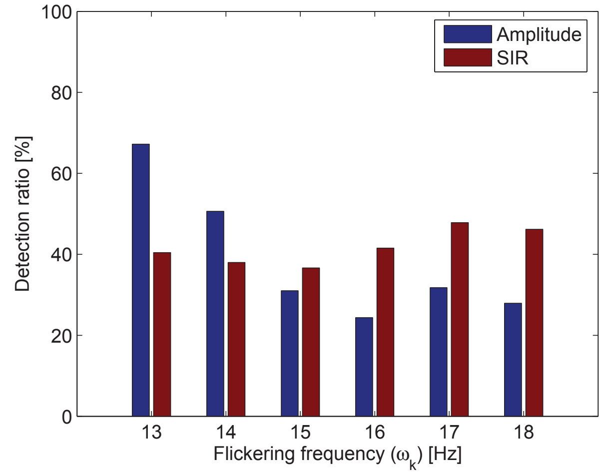

Fig. 6. Averaged detection ratio of SSVEP classification. The detection ratio shows the mean of three subjects.

D. Detection ratio

Ω_i indicates the estimated frequency of SSVEP which yields the maximum value in each feature extraction. The detection ratio $R_{\omega k}$ is expressed as:

$$R_{\omega_k} = \frac{1}{N} \sum_{i=0}^{N-1} \delta(i) \tag{11}$$

$$\delta(i) = \begin{cases} 1 & (\Omega_i = \hat{\omega}_{ki}) \\ 0 & (\text{otherwise}) \end{cases}$$

where N is the number of frames. The $\hat{\omega}_{ki}$ represents the flickering frequency of the EEG on ith frame. This criterion represents that the how many frames are detected as $\hat{\omega}_k$ and unseeing state. In this paper, the evaluation is performed by using 420 seconds EEG when the subject is looking at 6 stimuli. We prepare the 30 seconds EEG as unseeing state.

IV. EXPERIMENTAL RESULTS

A. Parameters

Table II lists parameters for feature extraction and detection of SSVEP. DFT is applied to EEG recorded for 2 seconds. The window for DFT 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 m for the SIR corresponds to $\omega_k \pm 4.5$ Hz to have a good intensity ratio.

B. Detection results (SSVEP classification)

At first, we confirm the detection performance of amplitude spectrum and SIR. Fig. 6 draws averaged detection ratios for 3 subjects. From Fig. 6, the detection ratio is increasing with a flickering frequency. The detection ratio for amplitude spectrum is decreased with increasing of flickering frequency. One possible reason is the increasing of amplitude spectrum at 10 Hz (see Fig. 2). The SSVEP of 13, 14 Hz is enhanced by the large amplitude spectrum in lower band. This means that a

TABLE III. DETECTION RATIO FOR 3 SUBJECTS [%]

Subject	A	B	C
Detection ratio (Amplitude)	41.1	38.3	37.0
Detection ratio (SIR)	47.1	41.0	37.2

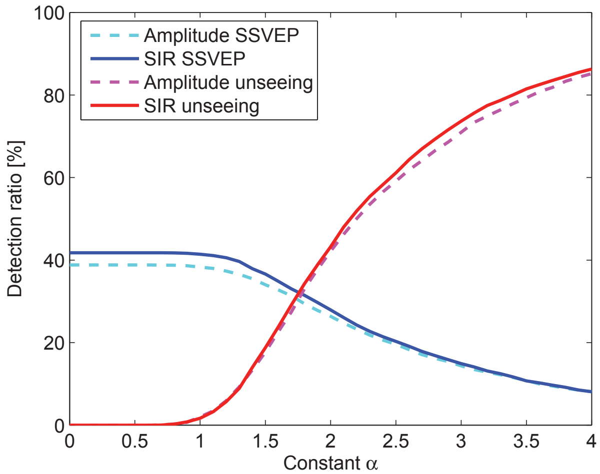

Fig. 7. Detection ratio for SSVEP and unseeing state.

high detection ratio on 13, 14 Hz of amplitude spectrum is not effect of SSVEP. Table III lists the detection ratio of SSVEP for 3 subjects. Ratios represent the averaged detection ratio from 13 to 18 Hz. From this table, the detection ratio of all subjects is improved by using SIR.

On the other hand, the detection ratio of wide-band setting (F = 10, 15, 20 and 25 Hz) is 90% [16] while the SSVEP detection proposed here indicates 40%. From this fact, SIR is useful for the wide-band setting.

C. Detection results (SSVEP and unseeing state classification)

The detection ratio of SSVEP and unseeing state depends on the constant value α. Fig. 7 shows the relationship between detection ratio and α. Note that the detection ratio for SSVEP represents the averaged value from 13 to 18 Hz. From this figure, the detection ratio of unseeing state is improved rapidly around $\alpha = 1.3$, while the ratio for SSVEP is degraded with α. In comparison with amplitude spectrum and SIR, the detection ratio is improved by using SIR.

V. CONCLUSION

In this paper, we introduce the spectrum based feature extraction for SSVEP and unseeing state detection. Results show that the detection ratio is 40% for narrow band SSVEP detection. It is confirmed that the SSVEP is not enhanced by using spectrum intensity ratio in the narrow band condition. On the other hand, the unseeing state is detected by using simple threshold. The detection ratio for unseeing state and SSVEP of improved by using SIR. Future task is to unseeing state detection for wide band conditions and define a suitable constant α.

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