SSVEP-Based BCI Stimulation Frequency Selection Training and Detection Approaches

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Abstract. In recent years, there has been increased interest in using steady-state visual evoked potentials (SSVEP) in brain-computer interface (BCI) systems because of its fast and reliable communication. A training procedure capable of individually evaluating the suitable stimulation frequencies to be part of a SSVEP based asynchronous BCI application as well as the spatial distribution of the evoked response has been developed. 5 novel detection methods suitable to be implemented in a real-time BCI application are compared. Both training and detection methods were evaluated for the construction of a 2 degrees of freedom BCI application with promising results. The most successful one has been integrated within the assistive technologies free open source platform AsTeRICS.

Keywords: EEG, SSVEP, Enobio, BCI, AsTeRICS

1. Introduction

Our approach presents 5 detection methods based on different aggregation functions to be used in an asynchronous self-paced SSVEP based BCI application. We describe the main stages of the system, namely for training (selecting the best frequencies and its spatial distribution) and for detecting the VEP.

2. Method

2.1. SSVEP Response

SSVEP is a resonance phenomenon manifested as oscillatory components in the user's EEG matching the frequency of an external stimulation source and its harmonics. Since the spectrum of spontaneous brain activity shows a log-decrease in power with increasing frequency, it might be difficult to discriminate event-related peaks from ongoing brain activity in the high part of the spectrum. Supposing that the energy level at the stimulation frequency is larger than the energy of its adjacent frequency bins, the following feature f has been defined to evaluate the response at the stimulation frequency bin denoted as f_{flicker} (in Hz).

$$f(f_{flicker}) = \frac{2 \cdot PSD(f_{flicker})}{PSD(f_{flicker}-1)+PSD(f_{flicker}+1)} + \frac{2 \cdot PSD(2 \cdot f_{flicker})}{PSD(2 \cdot f_{flicker}-1)+PSD(2 \cdot f_{flicker}+1)} \quad (1)$$

2.1. Training Procedure

SSVEP is a subject dependent phenomenon where the elicited response depends on the stimulation frequency. Hence it is necessary to individually evaluate the best stimulation frequencies to be used. A training method has been developed for this purpose being also in charge of delivering the spatial distribution of the evoked response. The training procedure is performed through a set of training measurements composed of N non-stimulation periods of duration Tn followed by N stimulation periods of duration Ts where the visual stimulus is presented at f_{stim}. Spatial filters are calculated at each stimulation period according to [Friman et al., 2007]. Each calculated spatial filter is applied to the entire training signal. Stimulation and non-stimulation periods are extracted and f (1) calculated at $fstim$ in a sliding window. The area under the ROC curve (AUC) is evaluated, where the features corresponding to the stimulation periods are marked as the positive class and the ones to the non-stimulation periods as the negative class. The spatial filter with the largest AUC is chosen to be used in the detection process. Lastly the Ns stimulation frequencies selected to be used in the BCI application, which present this same number of freedom degrees, will be the ones corresponding to the training measurements delivering the largest AUC.

2.2. Detection Procedure

The goal of the detection process is to determine which stimulation frequency was responsible of eliciting the SSVEP. For each frequency under evaluation the vector W is built by concatenation of the f calculated upon Eq. 1 in a sliding window as in the training. Data fusion of vector W components is carried out based on one of the following aggregation techniques: arithmetic mean (M1), Euclidean mean (M2), geometric mean (M3), harmonic mean (M4) and ordered weighted averaging (M5) delivering the aggregation value *K*. The stimulation frequency selected as the one responsible of eliciting the evoked potential is the one corresponding to the largest *K*.

2.3. Experimental Procedure

This study compares the 5 former aggregation procedures w.r.t. SSVEP detection performance. Four subjects S1 to S4 participated in six recording sessions. Stimulation frequencies evaluated were 12, 14, 16, 18, 20 and 22 Hz. Each session consisted of one recording per stimulation frequency. In each recording, $Ts=4\,s$ and $Tn=8\,s$, 15 sequences of stimulation/non-stimulation periods were presented. In order to reproduce the set-up of a binary BCI application, visual stimulus was rendered using two stimulation LED sources. The stimulation source on the right of the subject presented the stimulation frequency under evaluation, while the one on the left a random frequency among the others selected for the experiment. The user was told to attend the stimulation source on his right without blinking during the stimulation. EEG was acquired using 3 Enobio® channels placed in O1, Oz and O2.

3. Results

Each recording was split into 3 training intervals formed by 5 stimulation/non-stimulation periods each in order to evaluate the best two stimulation frequencies for each subject. We compute the AUC associated to each parameter in each training interval, and the average of these AUCs. Table 1 presents the averaged AUC calculated for each stimulation frequency. The two stimulation frequencies that delivered the largest average AUC for each user (in bold in the table) were chosen as the ones to be used in the detection performance evaluation for the different aggregation methodologies. For each subject the detection performance evaluation was performed based on 3-cross-fold validation. So we compute the remaining detection parameter, spatial filter coefficients, over 1 training interval and measure the performance of the proposed aggregation techniques on the other 2. Table 2 shows the average of the positive detection percentage per subject and per aggregation operators compared.

Table 1. *Training procedure average AUC.*

	12Hz	**14Hz**	**16Hz**	**18Hz**	**20Hz**	**22Hz**
S1	**0.93**	0.81	**0.85**	0.79	0.77	0.82
S2	0.67	0.66	**0.70**	0.67	0.69	**0.77**
S3	0.91	**0.92**	0.90	**0.92**	0.91	0.82
S4	0.56	0.69	**0.86**	0.77	**0.82**	0.78

Table 2. *Positive Detection percentage and mean ITR.*

	M1	**M2**	**M3**	**M4**	**M5**
S1	96.6	93.3	98.3	98.3	96.6
S2	88.3	85.0	88.3	90.0	90.0
S3	100	100	100	100	100
S4	91.6	91.6	91.6	88.3	91.6
Avg	94.2	92.5	94.6	94.1	94.6
ITR	0.68	0.61	0.70	0.68	0.70

4. Discussion and Future Work

A training procedure capable of delivering the stimulation frequencies that elicits the largest response and its spatial distributions has been successfully implemented. This leads to the implementation of very reliable SSVEP detection working in real-time. The SSVEP detection for the selected stimulation frequencies shows an excellent detection accuracy for every subject as shown in the described tests. Geometric mean and ordered weighted averaging methods deliver the best results but with no significant difference with the other methods.

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