

High frequency SSVEPs for BCI applications

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Introduction

In addition to the usual clinical purpose of diagnosing visual pathway and brain mapping impairments, the steady state visual evoked potential (SSVEP) can serve as a basis for brain computer interfaces (BCI)[1, 2].

Compared to other types of BCIs, SSVEP based BCIs provide higher information transfer rates (*bitrate*) with minimal user training, and require fewer EEG channels (see Figure 1). This type of BCI appears then as being the most likely to be deployed in the consumer's market in the near future.

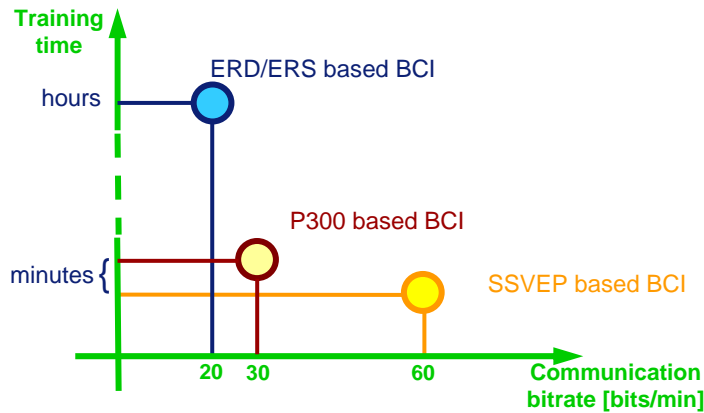


Figure 1. Typical training time versus communication bitrate for the three main types of noninvasive BCIs. An in-depth description of the BCI types can be found in [3].

The SSVEP is the oscillatory wave appearing in the occipital leads of the electroencephalogram (EEG) in response to a visual stimulus modulated at a certain frequency (e.g. pattern reversed checkerboard, flickering LEDs). The frequency of the SSVEP matches that of the stimulus or its harmonics.

In SSVEP based BCIs, visual stimulus modulated at different frequencies are simultaneously presented to the user. Each pattern is associated with an *action* in an output (active) device. When the user focuses his/her attention on a certain pattern, the corresponding stimulating frequency (or its harmonics) dominantly appears in the spectral representation of the EEG signals recorded at occipital sites. The action associated to the dominant frequency is performed.

The choice of the stimulating frequencies in a BCI application must ensure that the responses are as unique as possible. Thus, the stimulating frequencies are neither harmonics nor sub-harmonics from each other.

The amplitude of the SSVEP is not the same for different stimulation frequencies or different subjects. In fact, the largest SSVEP amplitude occurs, in average, at a stimulation frequency of about 15 Hz [4] (see Figure 2).

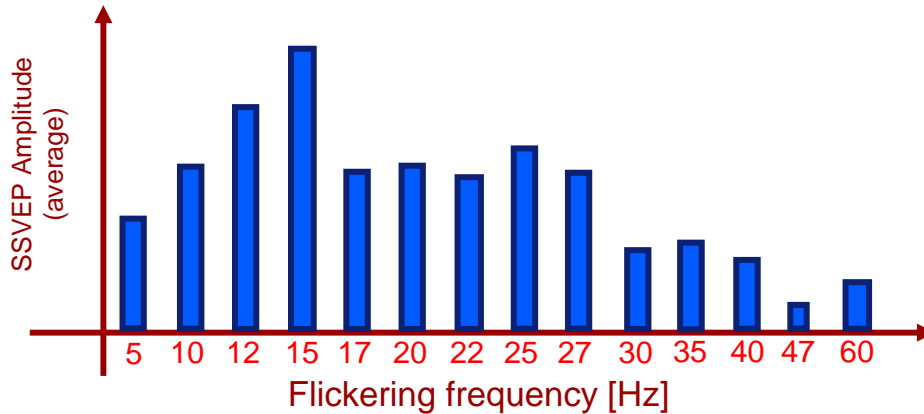


Figure 2. Average SSVEP amplitude in function of the stimulation frequency. Extracted from [5].

Because of easier SSVEP detection, the stimulation frequencies are chosen in the frequency band 5 – 30 Hz. In spite of its favorable detection properties, this band presents two major inconveniences, namely:

- according to visual perception studies, stimulation frequencies in this band are rather annoying for the subject
- the risk for inducing photoepileptic seizures is higher for stimulation frequencies in the 15 – 25 Hz [6]

To be deployed in the consumer’s market, SSVEP BCIs must overcome these issues. A simple solution consists in using higher stimulation frequencies. From empirical and subjective evidence, the low stimulation threshold can be set to 40 Hz.

In this paper, we propose a method for detecting SSVEPs elicited by stimulation frequencies beyond 40 Hz.

Detection of SSVEPs resulting from high stimulation frequencies

The amplitude of the SSVEP resulting from higher stimulation frequencies (*high-SSVEP*) is considerably lower than in the 6 – 16 Hz band. Thus, using classical spectral methods to detect the high-SSVEP are in general insufficient.

A simple method to detect a high-SSVEP can be derived from the usual methods in evoked potential detection, i.e. taking averages that are time – locked with stimuli. When the stimulus consists in a flickering LED, the stimulus signal can be obtained by measuring the light emitted by the LED using a photodiode (PD). Most commercial EEG acquisition devices offer the possibility of recording the EEG together with external signals such as the one from the PD. The drawback of this method for BCI applications is that the averaging can delay the online operation and consequently reduce the bitrate.

We consider the EEG signal containing the high-SSVEP as composed of a baseline having a spectral content in one over f (frequency) and a very small oscillatory signal, i.e. the high-SSVEP. According to this model, we can use the recently proposed phase-rectified signal averaging (PRSA) method which is able to detect tiny oscillatory components buried in noise [7]. This method does not require the signal of the stimulus. The algorithmic details of this methods can be found in [7].

Early results

Two male subjects S1, S2 aged 23 and 25 respectively participated in two recording sessions where the SSVEP was measured for stimulating frequencies in the range 40 to 50 Hz. The EEG was acquired using a BIOSEMI system and the SSVEP was estimated from the bipolar signal between electrodes Oz and Cz.

The stimuli were generated using a LED commanded by a square-wave current. The “ON” state of the current was at 20 mA and lasted for 20 ms. To render different stimulation frequencies the duration of the “OFF” state (at 0 mA) was modified.

The amplitude of the SSVEP was estimated using two methods:

- ◆ Taking averages that are time – locked with the stimuli (*averaging*), i.e. following the usual approach in evoked potential detection
- ◆ Using the PRSA

Figure 3 shows the estimate of the SSVEP amplitude using both methods for both subjects. The averaging method can be considered as reference since it uses the signal from the stimulus and is commonly used in evoked potential research. For subject S1, the PRSA results coincide well with that of the averaging method. For subject S2, discrepancies appear for high (>44 Hz) stimulation frequencies.

The PRSA appears as a promising method to detect high–SSVEPs. This method does not require special assumptions about the nature of the signal and is computationally effective [7]. In addition, the signal from the PD is not required to estimate the SSVEP.

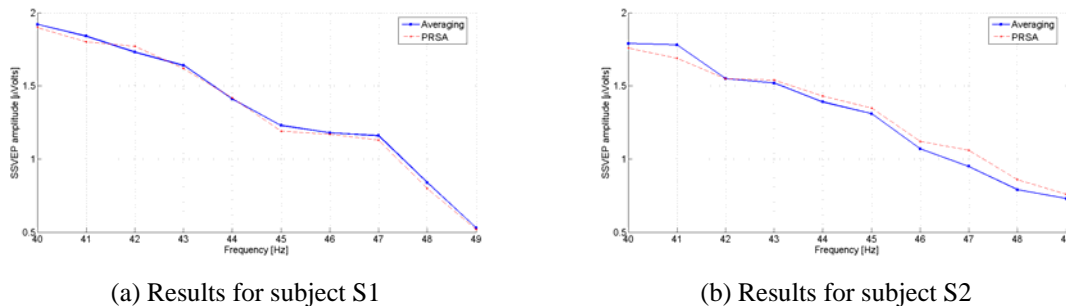


Figure 3. Amplitude of the SSVEP estimated using two methods: taking averages that are time locked with the stimuli (averaging) and using the PRSA (a) Subject S1 (b) Subject S2

Conclusion and future work

The deployment of SSVEP based BCIs into consumer’s market requires the stimuli to be transparent (non - annoying) to the user, and safe. In this paper we advocate for the use of high – frequency (> 40 Hz) stimulation patterns in BCI applications. Detecting high–SSVEPs is more challenging than detecting SSVEPs in the 15 – 25 Hz band.

Among the several possibilities to detect high–SSVEPs, we have presented the PRSA which from the results obtained seems to be very promising.

The next steps in this work will consist in studying how the PRSA behaves in presence of several stimuli at different frequencies. In addition, further subjective tests are necessary in order to test the effectivity of our method in an actual BCI application.

Reference

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