Single-Channel, Steady State Visually Evoked Potential-based Brain Computer Interface: a Proof of Principle for Biomedical Daily Use

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Single-Channel, Steady State Visually Evoked Potential-based Brain Computer Interface: a Proof of Principle for Biomedical Daily Use

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Abstract. In this work, the authors propose a low-cost, portable, and comfortable, single-channel Brain Computer Interface, based on Steady-State Visual-Evoked Potential with open source hardware and low computational cost algorithms, for daily use. The system is proved to be capable of overcoming the following state-of-the-art drawbacks: (i) the number of electrodes: a high number of electrodes increases the quality but is less comfortable for the user; (ii) the quality of the signal recorded in the scalp area of interest, typically covered with hair. At this aim, the authors propose: (i) the adoption of a single differential channel acquisition, in this case only three electrodes are used for the recording of the brain signal; (ii) the use of spring loaded pins electrodes in scalp area covered with hair to improve the contact and, as a consequence, the quality of recorded signal. The system as a whole is then tested on a group of people in order to validate its performance in terms of reached accuracy.

1. Introduction
Providing a new way of communication with external devices without muscles or nerves action, Brain Computer Interface (BCI) is a suitable solution for all disabled peoples that want to gain some self sufficiency. Besides biomedical application, this technology can be used in everyday life from able-bodied people, to enhance the human machine interaction. For example, the implementation of a BCI that uses brain signal derived from a visual stimulation, like Steady State Visual Evoked Potential (SSVEP), detected by an Electroencephalogram (EEG) device and a computer can lead to many applications in which, by simply gazing at a flickering icon on the display, an application can be opened, a Skype call can be made, and so on. The SSVEP pattern is the result of the visual stimulation derived by a flickering light source. This produces a stable signal in the brain track that resonates at the flickering frequency and its multipliers, so it can be detected analyzing the signal in the frequency domain. Two major problems limit the expansion of BCI for this application:

(i) many of the BCI devices on sale on the market are multichannel meaning that a significant number of electrodes to improve the quality of the measured signal [1], [2]. This leads to a less comfortable and compact device to wear daily.
(ii) the area of interest of SSVEP signal is the occipital lobe is typically covered with hair, adding further attenuation to the brain signal. Furthermore, for a daily use of BCI would be preferring the use of electrodes that do not need the use of an electrolytic gel to improve the quality of EEG recording.

Thus, this work proposes a single-channel BCI that uses only three electrodes in order to record the EEG signal from the user’s head connected to a low cost open source EEG device. Finally, an algorithm based on Fast Fourier Transform (FFT) is considered and its performance evaluated.

2. The Proposal

The aim of this work is to develop a BCI system for daily use. For these reasons, this system has to fulfill the requirements of comfort in wearing, efficiency, fast response and low cost. In this paper, a SSVEP–based BCI with a single differential channel for the brain potential measurement, made with a low–cost open–source EEG device, is proposed. All the electrodes are dry, in order to avoid electrolytic gel.

2.1. Acquisition System

SSVEP signals were recorded at 256 samples/s using the low cost, fully open hardware and software device Olimex EEG-SMT, a project of OpenEEG Community and Olimex engineers [3]. In these experiments, a single channel was used connecting two active electrodes to the positive and negative input of the EEG device, placed on Oz and Fz points according to 10-20 placement standard, and a passive electrode for common mode noise rejection [4], set on the wrist in contact with skin where no brain potential is measured. All the electrodes were manufactured by Olimex. The Oz electrode has the peculiarity of silver spring loaded pins soldered on it to improve the contact with the scalp in the occipital region, typically covered with hair, and, as a consequence, the brain signal quality. The recording of the brain potential is performed using the open source software BrainBay [5]. The BrainBay set-up for this experiment is shown in Fig. 1.

2.2. SSVEP Generation

A stimulus made of a 2x2 matrix made of four white images of fixed dimension flickering at different rates (10-16 Hz with an increment of 2 Hz) on a black background, was developed on an LCD PHILIPS, Brilliance 190S screen with 1280x1024 resolution and 60 Hz refresh rate. A sinusoidal modulation of the image luminosity was chosen in order to let the image flicker at rates that are not a refresh rate fraction [6]. The stimulus generation has been implemented.
using the Matlab free tool "Psychtoolbox" [7]. Each image contains a black number at its center to improve the user focus on the image and limit the influence of the adjacent flickering squares for the duration of the stimulus. The details of the designed stimulus are shown in Fig. 2.

2.3. Data Processing

After the stimulus generation and the data acquisition, that occur simultaneously, the data is then processed in order to obtain the recognition of user intention. The most common solution for the process of detecting the peak of the flicker frequency consider the use of the FFT technique [8], [9]. The code was written in Matlab R2017b and were executed on a PC with 2.4GHz processor and 8 GB RAM. This algorithm uses the in-built Matlab FFT instruction to identify the EEG frequency components. For the detection of the tone at the frequency corresponding to that of the gazed stimulus, it is implemented a threshold classification in which the fundamental and second order harmonic are considered. The threshold is chosen as twice the average amplitude of the samples in the range between the fundamental and the last second order harmonic (8-36 Hz). Then a combination of the amplitude of fundamental and second order harmonic were considered. In Eq. 1 is described the adopted feature:

\[ d_{si} = (A'_{si} - m'_{si}) + (\alpha_i * A''_{si} - m''_{si}) \]  

where \( A'_{si} \) and \( A''_{si} \) are the maximum amplitudes of the fundamental and second order harmonics, respectively, of the frequency corresponding to i-th stimulus while \( m'_{si} \) and \( m''_{si} \) are the average of the amplitudes evaluated in the intervals of the fundamental and second order harmonics, respectively, of the frequency corresponding to the stimulus i-th. The contributions of the second harmonics are weighed according to a coefficient \( \alpha_i \) that can be different for every stimulus frequency. The maximum of this parameter, \( d_{max} \), and of the fundamental amplitude, \( A'_{max} \), are evaluated among all the stimuli and if \( A'_{max} \) overcomes the threshold, the stimulus corresponds to the \( d_{max} \) frequency band.

3. Experimental Procedure

To test the efficiency and reproducibility of the whole system developed, a group of 10 people, all able-bodied and dextrous, with normal to corrected vision, was asked to participate to the above experiment. The group of people was made of 6 men and 4 women with an average age of 28 years. They sit on a chair, conveniently placed at a distance of about 60 cm from the screen on which the stimuli were generated, in a room where the surrounding environment was made as dark as possible and any source of light was shut off. Furthermore, users were asked to stay as much as possible in a stable position and not to make sudden movements with the head but they were free to move their heads to better orientate theirs gaze at the desired icon.

The user was asked to observe any of the four flashing icons, for a fixed time interval: 30 s, 20 s and 10 s. This experiment was repeated 5 times; each repetition was alternated with 10-20 seconds of rest to prevent the user from sight fatigue. At the end of the measurement, the acquired data was processed through the FFT based algorithm written in MATLAB language.

4. Results

This paragraph shows the results of the experiments aimed at the validation of the proposed BCI. In particular, the results are shown in terms of True Positive (TP), all of the trials in which the intention of the user was correctly detected and, as a consequence, the accuracy of the BCI.

In Fig. 3 is shown the average performance of the proposed BCI with respect to the stimulus duration and to the user gender. The increasing of the accuracy is proportional to the increasing of the stimulus duration, reaching a 90% value with 30 s of gazing. Besides, the obtained results show that soldering pins on the electrode to improve contact with the scalp is a reliable solution
Figure 3. Average and standard deviation of the True Positive rates for male and female subjects, with respect to the stimulus duration $T$.

that increases the system performance. During the test the users did not report pain in the occipital area caused by the spring loaded pins electrode.

5. Conclusions
Brain Computer Interface is a widely developed topic for biomedical applications aimed at restoring completely or partially the lost abilities of people with neurodegenerative disorders. In this paper, the groundwork for a daily use BCI has been laid: in particular, the idea was to develop a low cost, single channel, SSVEP based BCI. This work demonstrated that with a low cost, open source EEG device, only three dry electrodes, that work without electrolytic gel, of which one is a spring loaded pin electrode to improve contact in occipital area, the achieved accuracy of 90%, with a stimulus duration of 30 s, makes the developed SSVEP-based BCI accurate and efficient enough for biomedical applications. Further improvements can be the reduction of the stimulation interval and the development of a lighter algorithm, in terms of computational costs, to implement a BCI system for limited resources devices as a tablet or a smartphone.

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