Alpha rhythm onset detector based on localized EEG sensor

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***Abstract*— The goal of this study is to detect the onset of alpha rhythm in the electroencephalography (EEG) signal after eye closure. We developed an algorithm that detects the alpha rhythm onset by analyzing the FFT of an EEG signal, obtained by means of a localized sensor in the occipital zone, developed with specific characteristics for alpha rhythm acquisition. The EEG signal of eight subjects was recorded while they were performed a simple task of opening and closing the eyes and annotated the eye closure event with a manual triggering switch. The results show that, in average, the latency of the alpha rhythm onset in this group of subjects is 1.01 s, with a standard deviation of 0.49 s.**

***Keywords*— Electroencephalography (EEG), eye closure, alpha rhythm, Fast Fourier Transform (FFT), signal processing.**

I. Introduction

The development of systems for automatic detection and classification of electroencephalography (EEG) signals have been a matter of wide interest in the scientific community. The goals of the research in this area range from medical studies, such as the classification and clustering of signals in the context of polysonographic studies of neurological and respiratory disorders during sleep [1] to research in brain computer interfaces (BCI), such as a system which allows to switch on and off an electronic device through the closure of an eye by inducing of alpha rhythm [2]. The EEG alpha rhythm consists of electromagnetic oscillations with frequencies between 8 and 12 Hz and arises when the subject is in a relaxed state with the eyes closed or in drowsy states with the eyes opened. These waves are attenuated and become fused with other rhythms when the subject has the eyes opened in states of focused attention or in situations of tension [4]. The attenuation of alpha rhythm when the subject opens his eyes is superior in the occipital area [5]. Therefore, it is possible to identify one's state of alertness through the automatic detection of alpha rhythm [6] in the EEG.

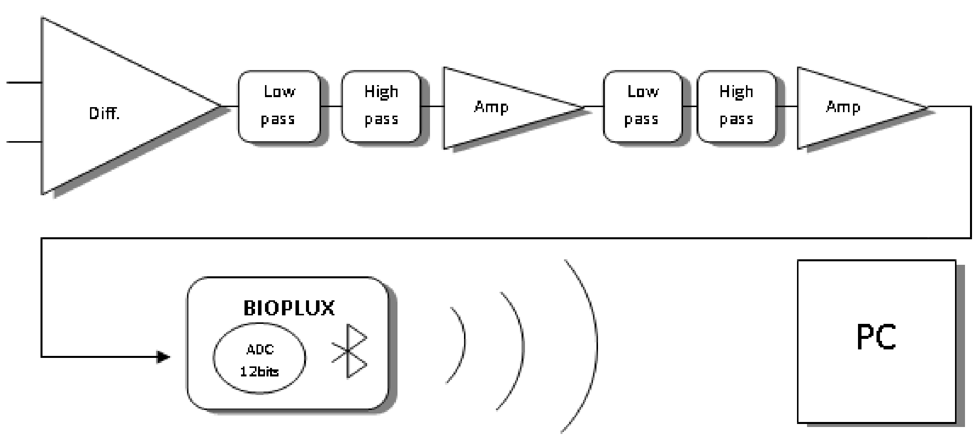
In this paper we present a hardware and software system to study the latency of detection of the alpha rhythm following the eye closure.

II. Materials and Methods

We developed a miniaturized localized EEG sensor to acquire the signals and the collected data were processed offline for detection of alpha rhythm. In the following sections, the hardware, as well as the signal acquisition and processing procedures, will be described.

Hardware

For the acquisition and conditioning of EEG signal, a miniaturized sensor was developed. Figure 1 depicts the schematics of the sensor. The signal is acquired by two electrodes assembled in a differential configuration which measure the electrical activity at two nearby points of the cortex. Therefore, a high amplification is needed.



F*ig. 1* - Diagram illustrating the acquisition and conditioning electronics.

The conditioning circuit consists of two filtering levels with passing band between 1.2 Hz and 50 Hz and two amplification stages, totalizing a gain of 60000. This system magnifies the signal after filtering undesired frequencies in each conditioning stage. In order to minimize the noise, we also shortened the distance between the electrodes and the signal conditioning hardware, consequently increasing the signal-to-noise ratio (SNR). Applying an elastic strap over the pre-gelled electrodes during the signal acquisition procedure provides further maximization of the SNR. This ensures a better contact between the skin and the electrodes, therefore no conductive gel is needed.

The EEG analog to digital conversion and bluetooth transmission to the computer was performed using a bioPLUX research [7] signal acquisition system, which has a 12 bit ADC and a sampling frequency of 1000 Hz.

Signal Acquisition Procedure

EEG signals were recorded from a sample of eight healthy volunteers: five men and three women with ages ranging from 21 to 43 years (mean 27 ± 10.99 years), height 156–183 cm (mean 171 ± 9.3 cm) and weight 55–87 kg (mean 71 ± 9.5 kg).

The subjects were asked to stay in a relaxed state and perform a simple task of opening and closing eyes. In order to minimize eventual artifacts, the subjects performed the test in a quiet environment, with minimum distracting elements.

The task consisted of the following procedure: 15 s with eyes opened and 15 s with eyes closed. The subjects closed and opened the eyes at the analyzer's order and marked the event of eye closure by pressing an analog switch. This procedure was repeated three times, collecting three closing eyes events from each subject.

We used one bipolar EEG sensor, positioned at the left occipital region of the head. The two electrodes were located in the region between the C3 and O1 sites of the 10-20 EEG disposition system [8]; the ground electrode was placed over the radius styloid process – Figure 2. We used AgCl pre-gelled disposable dry detection surfaces fixed with an elastic band strap

Signal processing

The collected EEG data were analyzed offline using Python with the numpy and scipy packages. Signal processing algorithms were developed with the purpose of automatic detection of the onset of the alpha rhythm.

Prior to the application of the alpha rhythm detection algorithm, data were low-pass filtered using a smoothing filter with a moving average window of 20 points.

Data from each subject were segmented to isolate signal fragments with eyes-closure events and analyze them individually. The signal segmentation was performed using as reference the switch activation signal, which marked the eye closure events. The detection algorithm was, then, applied to each segment.

Alpha rhythm detection is based on the frequency analysis of the EEG signal. The algorithm computes the FFT of the signal using a 500 ms (500 samples) sliding window which is shifted by one sample after the FFT is computed.

This operation is repeated until the last sample of the signal is reached. For each window, the algorithm checks whether the dominant frequency lies in the range of 9 to 12 Hz by computing the ratio between the maximum peak amplitude of the FFT components between 9 and 12 Hz and the maximum peak amplitude:

$$\mathrm{Max}(\ \mathrm{FFT}[9\text{-}12\mathrm{Hz}]\ ) / \mathrm{Max}(\mathrm{FFT}) > 0.9 \qquad (1)$$

If this condition is fulfilled, it is accepted that there is alpha rhythm in the analyzed data window. The onset of the alpha rhythm is, then, assumed as the time instant that immediately proceeds the end of the window where the alpha rhythm was detected.

The latency between the closure of the eyes and the onset of alpha rhythm is computed as the time interval between the switch activation and the detected alpha onset.

Fig. 2 - Electrodes scheme and acquisition system

III. Results

Figure 3 shows an example of the alpha rhythm detection for a specific subject. In this case, the latency of detection of the alpha waves was 0.808 seconds. The results were similar in other subject's eye closure events.

Table 1 shows the mean and standard deviation of the time between the closure of the eyes and the detection of the alpha rhythm in each subject and the mean of the results over all subjects.

From 24 fragments analyzed, the algorithm detected alpha rhythm in all cases, and in only one the detection occurred more than 2 seconds after the trigger activation (2.65s).

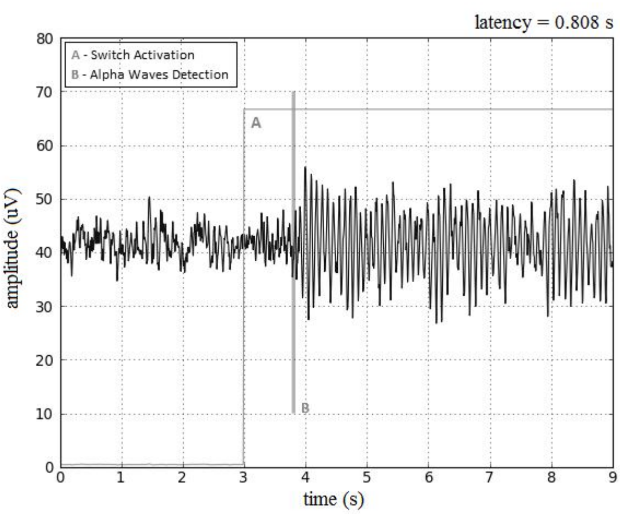


Fig. 3 - Detection of the alpha rhythm on the EEG signal following eye closure.

Subject	Mean (s)	Std (s)
Sub1	0.74	0.16
Sub2	0.58	0.12
Sub3	1.17	0.30
Sub4	1.63	0.98
Sub5	0.87	0.22
Sub6	0.69	0.24
Sub7	1.00	0.34
Sub8	1.39	0.29
All Subjects	1.01	0.49

Table 1 – Mean and standard deviation of the alpha rhythm latency for each subject and all the subjects.

IV. Conclusions

Although the sensing hardware was still a prototype, this study showed that it is possible to properly record EEG signal with minimum discomfort to the subjects, given the small form factor of the sensor and the fact that there is no need of applying conductive gel in the scalp or removing hair. This is an improvement relative to the usual EEG recording devices.

The latency of the alpha rhythm detection ranged between 0.58 s and 1.63 s, with a standard deviation ranging from 0.12 s to 0.98 s. In average, the alpha rhythm was detected 1.01 s after closing the eyes, with a standard deviation of 0.49 s. The high value for standard deviation may be justified by taking into account the procedure that was employed during the test to annotate the events of eye closure. As the annotation was made manually by the subject with a triggering switch, the synchronization of the two events is not perfectly guaranteed, which introduces an error from subject to subject.

V. Future work

In future investigations we intend to use electrooculography (EOG) techniques to detect the events of eye closure, replacing the manual switch, that introduces an inter and even intra-subject error in the determination of the alpha-rhythm latency. In order to further reduce external noise, we intend to eliminate the cables that connect the electrodes to the conditioning circuit, integrating both components inside the same physical packaging.

Another goal is to implement the same detection algorithm in real time and developing an electronic device that sends an alert with the detection of the alpha rhythm.

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