Hybrid SSVEP/P300 BCI Keyboard
Controlled by Visual Evoked Potential

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Abstract: This paper presents a two stage Brain Computer Interface (BCI) keyboard system that consumes Electroencephalography (EEG) signals based on two evoked potential detection methods: P300 and Steady-State Visual Evoked Potential (SSVEP). In order to develop a practical daily use EEG system, signals were captured with a standard low cost Emotiv-EPOC system and processed using OpenViBE platform. Fast Fourier Transform (FFT) and sample average were used as feature extraction methods while Linear Discriminant Analysis (LDA) and Support Vector Machine (SVM) were used as classifiers.

1 INTRODUCTION

A system based on Brain Computer Interface (BCI) acquire signals from brain functioning in order to use this information to actuate on computer and it's peripherals. This work rely on Electroencephalogram (EEG).

As a clinical method, EEG is used to measure electrical potentials from electrode positioned at scalp. Several waves, originated from excited and inhibited alternate potentials, produces an extracellular current flow at cortex brain, at certain levels that it is possible to detect with superficial electrodes (Costanzo, 2014).

Using an specialized acquisition software it is possible to store these signals to determine special aspects, classify and relate to a mental state. One special aspect defined by these signals and detected under a certain circumstances is the Evoked Potential (EP). The EP is a physiological brain response determined by an external visual, electrical or auditive stimulus. As described by Chaves et al. (2009), different receptors may be excited and the acquired signal is a sum of different EP.

The P300 is a positive visual EP with a latency time of approximately 300 ms. However, there is an experimental variation with respect to time latency of 250 ms to 600 ms depending on cognitive effort invested by the user attention to the visual event, patients with neurological diseases and possible neurodegeneration (Majaranta, 2011).

The evoked potential signal amplitude depends on the stimulus frequency, as pointed by Majaranta (2011): less frequent stimulus presents larger amplitudes; more frequent stimulus produces lower amplitudes.

Steady-State Visual Evoked Potentials are concentrated in the visual cortex located in the occipital lobe and are induced by flash light at a predetermined frequency. The SSVEP's are formed by a number of components whose frequencies are harmonics of the frequency of stimuli (Majaranta, 2011).

The evoked potential communication between the operator and the computer is binary in the sense of having just two operating states. For example, a device is on or off, move left or right providing a discrete controller (Middendorf et al., 2000).

Figure 1 illustrates system operation in SSVEP or P300 and the expected response in the brain regions activated by each stimulus.

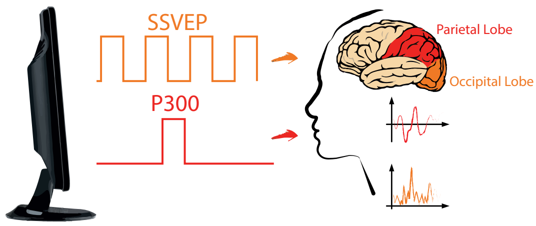

Figure 1: System Illustration.

The classical model for a virtual keyboard adopting P300 was introduced by Farwell and Donchin (1988), known as "Row, Column" (RC), consists in a 6 by 6 matrix that contains the alphabet and the Arabic numerals. The rows and columns of this matrix flash

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randomly in order to provide an evoked potential, in that way, you can know which row and column the user is looking, corresponding to their choice (Amiri et al., 2013).

The RC model has a serious problem due to proximity of the keys. Theoretically, one light pulse near the chosen region should not generate an EP that can be classified as the target letter. But this is not true when analyzing the event in practice. The ”Region Based” model (RB) proposed in Fazel and Abhari (2009) significantly reduces this problem due the way it is structured.

The RB model is composed of two steps, the first step identifies one of keyboard seven regions by light pulses delimited by a circumference that groups the chosen region. After identifying the region, the second step identifies the target letter by independent light pulses generated by each letter in the chosen region.

In order to compare a pure BCI (P300 only) with hybrid BCI (P300 and SSVEP) virtual keyboard in a RC configuration, Townsend et al. (2010) demonstrate that a pure BCI setup had a RC bit rate of 19.85 bits/min with RC accuracy of 77,34% and Yin et al. (2014) presented for a hybrid BCI a RC bit rate of 53.06 bits/min with RC accuracy superior of 95%. Result rates are considerably higher in a hybrid BCI setup.

It is possible to create a hybrid system that integrates multiple BCI techniques working sequentially or simultaneously but not limited to only two techniques as discussed here. For example, Slow Cortical Potentials (SCP), Event Related Desynchronization (ERD) or Event Related Synchronization (ERS) (Amiri et al., 2013) can be used for the development of hybrid systems that will try, as possible, maximize positive point and minimize negative point of each technique.

The proposed interface model and design resembles the hybrid system described by Yin et al. (2014) that defines an analysis combining hybrid systems using the ”Row, Column” (RC) model and ”Region Based” (RB) processing techniques.

This paper propose a keyboard layout with a focus on usability employing a standard QWERTY keyboard that can be used by people who already used a keyboard, those who never used and those that can not use such device. As a probabilistic model, this interface is well suited for all users.

2 MATERIAL AND METHODS

The development of this BCI system is based on a sequential hybrid system. The first protocol of acquisition is defined by SSVEP method and second by P300 as presented in Figure 2.

Figure 2: Hybrid System Sequence Application.

The first step is defined by the use of SSVEP to identify a single target among seven distinct regions in the keyboard detailed in Figure 3. Once the region is identified, the second step is specified via P300; a single key within the defined region as presented in Figure 4.

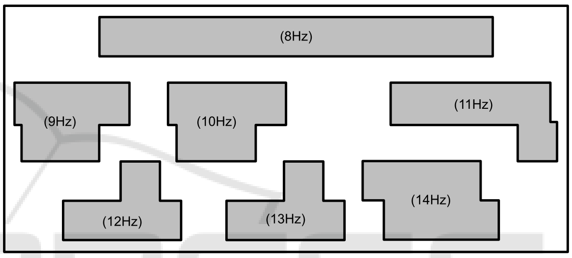

Figure 3: Frequency Map Region for SSVEP.

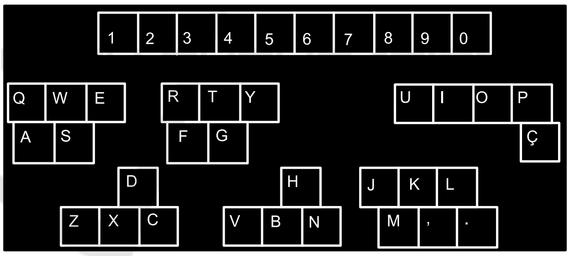

Figure 4: Virtual Keyboard Layout.

The purpose is to optimize and to reduce the issues experienced with the exclusive use of P300, due to the proximity of the virtual keys on the keyboard that generate undesirable EP signals, SSVEP was used to build the system interface based on regions proposed in Fazel and Abhari (2009).

The SSVEP is commonly designed for applications that require a high number of input variables. Difference between the minimum frequency which can be detected is 0.2 Hz, the field of application is usually in the range between 5 Hz to 50 Hz. (Amiri et al., 2013).

There is a dependency between the frequency of stimulation and amplitude of SSVEP. In Amiri et al. (2013), the authors demonstrate the relationship of frequencies and amplitudes. This relation is not linear and the greatest amplitudes occur between 12 and 15 Hz. Amiri et al. (2013) also describe that it is possible to choose the frequency band based on the signal amplitude: the greater the amplitude, easier to capture and interpret the signal.

Apart from signal amplitude aspect, there are two other variables to be considered. The first, describe the frequency range between 15 Hz and 25 Hz with good signal reading, but there is a higher risk for patients having photo- induced seizures. The second is directly related to the Visual Flickering Limit Frequency with regard to the image luminance modulation frequency noticed by the user. The frequency ranges from 15 Hz to 100 Hz and depends on the lighting conditions, the vision (peripheral or central) field, the apparent angle of the object and the individual characteristics (Stolfi, 2008).

Stolfi (2008) also described that for the luminescence levels found in computer monitors, the Visual Flickering Limit Frequency is near 70 Hz and that there is a greater chance to occur visual fatigue to the user as higher as the difference between maximum and operation flickering frequency (Amiri et al., 2013).

Amiri et al. (2013), cite that the best frequencies to work are the lowest. These frequencies provide larger amplitudes that may offer better performance during the classification step. However, lower frequencies also can cause some discomfort to the user. In Figure 3 is indicated the operating frequencies for each of the regions.

The Emotiv EPOC (Emotiv, 2011) is used to capture EEG signals. The entire interface was built using OpenViBE (Renard et al., 2010) platform and customized with Python (Oliphant, 2007; Pérez and Granger, 2007) program language. The process flow is:

1. User choose a letter and it should look closely at it;
2. acquisition of EP signals;
3. preprocessing (FFT is used for SSVEP and average for P300);
4. classification and recognition of EP (SVM is used for SSVEP and LDA for P300);
5. feedback process at the touch of previously chosen key;
6. EEG signal is filtered from 1 Hz to 20 Hz in order to prepare data for classification.

The keyboard was developed in Python and connected to an OpenViBE box that send control data to "Data_interface" file. The preprocessing, classification and recognition of EP was developed using Python as well. All sequence processing is detailed in figure 5 (the dotted region was made with OpenViBE and the other was made in Python).

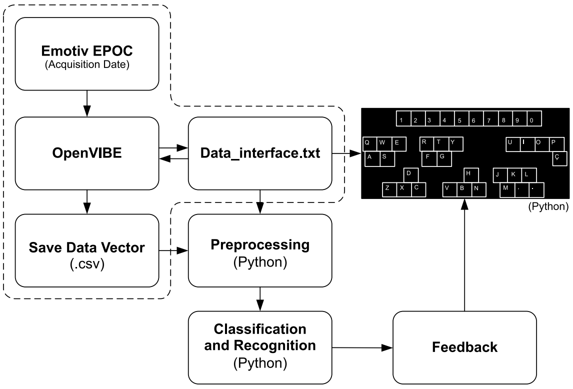

Figure 5: Project Model.

As a more accessible equipment, with respect to cost, Emotiv EPOC has only 14 electrodes located at specific regions. For the analysis of P300 there is the recommendation to use an occipital electrode in the mid-line, 5 cm above the inion, and occipital electrodes right and left, each 5 cm lateral to the mid- line electrode (Duffy et al., 1999). Figure 6 is a map that contains electrodes that are usually used to capture the P300 in red, and in green the Emotiv EPOC electrodes closer to this positions, and in blue other EPOC electrodes.

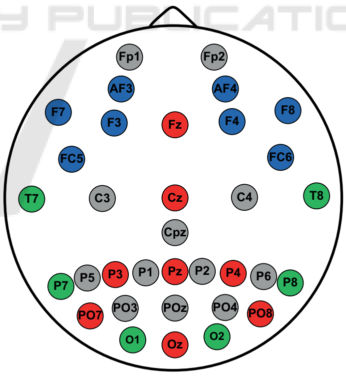

Figure 6: EEG Electrode Map Position.

The Emotiv EPOC was previously used for P300 acquisition as described in Ekanayake (2010), where the author concludes that the Emotiv EPOC can indeed capture signals from the P300 for scientific purposes and also certify the ability of this device to capture signals from the SSVEP.

All tests were developed with Matlab, Python and OpenViBE. Experimental data for the analysis of P300 were:

- Flash duration: 0.1 s

- Standby time without flash: 0.5 s
- Number of samples: 10
- Number of repetitions: 1
- Filter 1 to 20Hz

After specify this settings, it was used the average calculus described in Equation 1 for the first analysis.

In Equation 1: "X" is the data matrix; "a" is the number of samples "b" is the window analysis; "M" is the average matrix; "y" is the average vector position to $y \leq b$:

$$M_{1,y}(X_{a,b}) = \sum_{i=0}^{n} \frac{X_{i,y}}{n} \quad (1)$$

For SSVEP analysis it was used a frequency of 10 Hz and a filter with a 1 Hz to 20 Hz and 1 second time window for the FFT.

A normal volunteer participate in 10 experimental sessions to train and validate acquired data in separate P300 and SSEVP acquisition.

3 RESULTS AND DISCUSSION

Making a comprehensive analysis of Figure 7, the electrodes that better detect a P300 signal are O1, O2 and P7 positions with a window time ranging from 250 ms to 450 ms showing responses very close to the expected P300 curve.

Also the electrodes P7 and O2 (mainly P7) contain a signal range that is similar to the P300, but contain a lot of noise. Figure 7 confirms the fact of being able to capture good signals from the P300 (low noise) using the O1 electrode Emotiv EPOC.

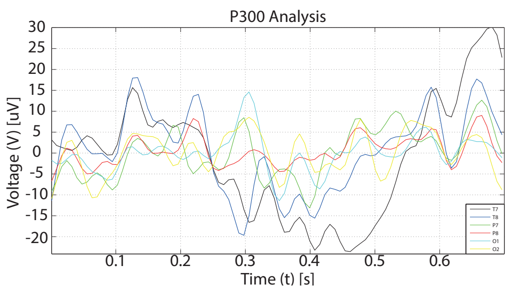

Figure 7: P300 Analysis.

The noise retrieved from the electrode P7 and O2 are residual background activities that can be attenuated using averaging technique (Equation 1) which enhances EP and reduces the noise from the number of repetitions of the stimulus.

Brain residual activity can be considered random compared to the EP; the averaging enhances P300 signal compared to the residual activity, that have a variable pattern.

Table 1: Evoked Activity Enhancement (adapted of (Duffy et al., 1999)).

Stimulus Repetition	Signal/Noise Intensification
10	3.16:1
25	5:1
49	7:1
81	9:1
100	10:1
200	14.14:1

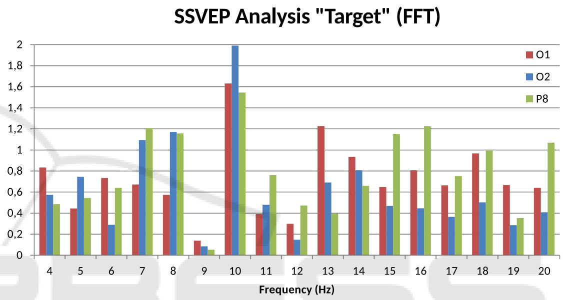

Figure 8: SSVEP Analysis Target.

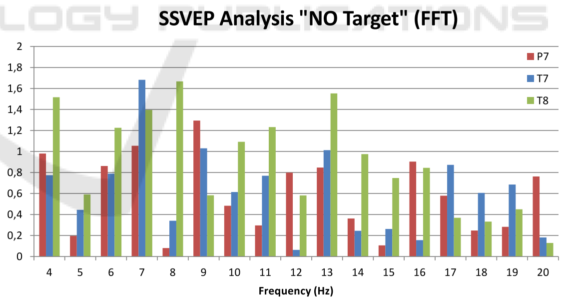

Figure 9: SSVEP Analysis No Target.

The experimental analysis for 10 Hz SSVEP is presented in Figures 8 and 9. Figure 8 shows the electrodes O1, O2 and P8 peaked at 10 Hz proving the capacity of the Emotiv EPOC to capture signals from the SSVEP. However, Figure 9 shows other electrodes (P7, T7, T8) that display noise.

The P300 is usually captured by electrodes in the parietal lobe CPZ and PO7 (Majaranta, 2011) or Fz, Cz, Pz, Oz, PO7, P3, P4 and PO8 (Amiri et al., 2013) not available in Emotiv EPOC device. It was experimentally proven that the electrodes O1, O2 and P7 (for P300) and O1, O2 and P8 (for SSVEP) have useful EP with Matlab post processing.

4 CONCLUSION

The P300 is used when there are many different variables in the system. However, the influence of a pulse near the point of choice creates an undesirable EP and affect the proper functioning of the classifier. The proposed interface reduced processing time and increased hit rates as previously reported in Yin et al. (2014).

The combination of the two EP techniques reduces processing time when the user has picked the letter as discussed in Yin et al. (2014). With the layout shown in Figure 4 the letter select time is reduced with the usability of a standard QWERTY keyboard and the time to write of a word with the system is also reduced.

A future experiment is in development to include healthy and disabled subjects in a single P300 and SSEVP sessions.

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