# Comparison Between Wire and Wireless EEG Acquisition Systems Based on SSVEP in an Independent-BCI

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***Abstract*— This paper presents a comparison between two different technologies of acquisition systems (BrainNet36 and Emotiv Epoc) for an Independent-BCI based on Steady-State Visual Evoked Potential (SSVEP). Two stimuli separated by a viewing angle $< 1^{o}$ were used. Multivariate Synchronization Index (MSI) technique was used as feature extractor and five subjects participated in the experiments. The class is obtained through a criterion of maxima. The left and right flicker stimuli were modulated at frequencies of 8.0 and 13.0 Hz, respectively. Acquisition via BrainNet system showed better results, obtaining the highest value for accuracy (100%) and the highest ITR (35.18 bits/min). This Independent-BCI is based on covert attention.**

## I. Introduction

Brain Computer Interfaces (BCIs) are especially relevant for users with reduced motor abilities [1], [2]. Thus, a BCI was defined as a means of helping people with neuromotor complications. Nowadays, this concept is extended to applications that improve the quality of life of any person.

BCI can be developed using the SSVEP. The principle of a dependent SSVEP-based BCI is to activate commands through gaze control. Nevertheless, some SSVEP-based BCIs do not depend on gaze control [3], [4], [5], [6], and are defined as an Independent-BCI, This kind of BCI is controlled by the subject attention without requiring neuromuscular control of head or eye. This is a very important aspect of those SSVEP-BCIs, because Independent-BCIs have specific users. For instance, patients with amyotrophic lateral sclerosis (ALS) and with locked-in syndrome, who may not control their eye/head movements and therefore might not be able to use dependent BCIs. An Independent-BCI can also be used to applications in daily life, such as the use of a portable system able to select commands on a small screen.

Researchers have developed various techniques for optimization of the classification performance in terms of extraction of features. Among these methods, Multivariate Synchronization Index (MSI) [7] has been adopted by our research group due to its goods results [8].

Initially, in [9] the effects of spatial attention on SSVEP were studied. In the work performed by [3], it was shown that there was a reduction in 20% of precision when a volunteer did not perform eye movements compared to another who did it. In that study, the terms attended or unattended mean overt and covert attention. In [4], something similar was performed using flickering letters in a CRT monitor. Six out of eleven physically and neurologically healthy subjects demonstrate reliable control in binary decision-making, achieving at least 75% of correct selections in at least one out of only five sessions, each of approximately 12 min duration. Fig. 1 shows the parameters of visual stimulation presented in those works [9], [3], [4] and in this work.

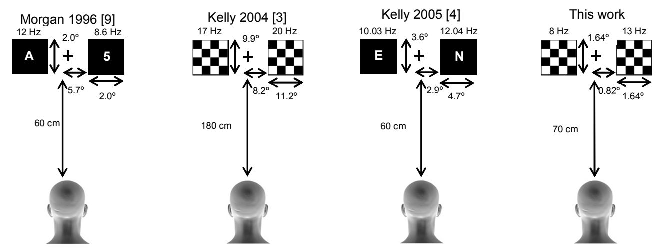


Fig. 1. Parameters of visual stimulation of four works of Independent SSVEP-BCI.

This work evaluated two different types of acquisition systems. One communication by wire and communication with PC trought TCP-IP (BrainNet-36 equipment), and the other by wireless (Emotiv Epoc equipment). Moreover, the acquisition protocols were designed to allow a visual angle subtended lower than $1^{o}$.

## II. Methods

### A. Subjects and EEG preparation

Five healthy male subjects, ages from 27 to 33 years old, were recruited to participate in this study. The mean and standard deviation of the ages were 29.8 and 2.17, respectively. The experiments were performed according to the rules of the ethics committee of the UFES/Brazil, under registration number CEP-048/08.

All measurements were noninvasive and the subjects were free to withdraw at any time without any penalty. Previously, a selection of volunteers was performed and topics related to precautions as visual problems, headaches, family history with epilepsy and problems related to brain damage were consulted. All volunteers reported not present any problem in these topics. Fig. 2 shows a volunteer using the two acquisition systems, wire (Fig. 2(a)) and wireless (Fig. 2(b)).

## III. System architecture and visual stimulus

The BrainNet-36 is an equipment used for EEG signal recording manufactured by Lynx Tecnologia Ltd. From this acquisition system, 12 EEG channels were recorded at 600

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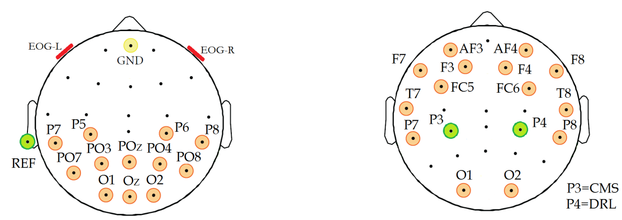
(a) (b)

Fig. 2. (a) Flickers stimuli and BrainNet-36 wire acquisition system; (b) flickers stimuli and Emotiv Epoc wireless acquisition system.

samples, band-pass filtered at 1-100 Hz and with the reference at the left ear lobe. The GND was placed on the forehead. Using the extended international 10-20 system, the electrode positions were P7, PO7, PO5, PO3, POz, PO4, PO6, PO8, P8, O1, O2 and Oz (Fig. 3(a)). Additionally two bipolar channels of EOG, one left side and one on the right side (EOG-R and EOG-L) were used to confirm that the volunteers performed the tasks effectively without muscle strain on the eyes.

On the other hand, the Emotiv Epoc Headset includes 14 channels (plus CMS/DRL references, P3/P4 locations) (Fig. 3(b)). The electrodes positions are described using the 10-20 international system too. This device has a 128 Hz sample rate.




(a) (b)

Fig. 3. (a) Electrodes location in BrainNet-36 system; (b) electrodes location in Emotiv Epoc system.

The volunteers sat on a comfortable chair, in front of a 17-in LCD display, 70 cm far from it and were asked to watch a stimulation screen generated by an FPGA-based subsystem (Xilinx Spartan3E). Such stimulation screen consists of two squares (checkerboards 4×4) presented simultaneously to the user (Fig. 1). For both acquisition systems, the flickering frequencies were 8.0 Hz (left) and 13.0 Hz (right).

## IV. Experimental Tasks

The experiments were performed in an offline way. During the first five seconds a cross fixed on the screen is shown to the volunteers. Before finishing the five seconds, a beep is issued and the volunteer has to fix his/her attention (covert attention) on the stimulus located on the left side during thirty seconds. Then the volunteer takes five seconds for a break, and in the next thirty seconds, he/she fixs his/her attention to the right side, ending in 70 seconds. This selection was performed making a minimum visual angle to select the stimulus covertly.

## V. Data Analysis

The data were segmented and windowed (1 s, 2 s, 4 s and 6 s, each one with overlapping of 50%). Then, a spatial filtering is applied using a Common Average Reference (CAR) filter and a band-pass filter between 3-60 Hz with the twelve channels. The evoked potentials are extracted from the occipital electrodes (O1, O2 and Oz) for BrainNet system, and electrodes O1 and O2 for Emotiv System.

In order to confirm the data obtained, EOG signals were acquired from each volunteer (Fig. 4), confirming that effectively the volunteers did not exceed the limit of 1° of visual range, important requirement for an Independent-BCI.

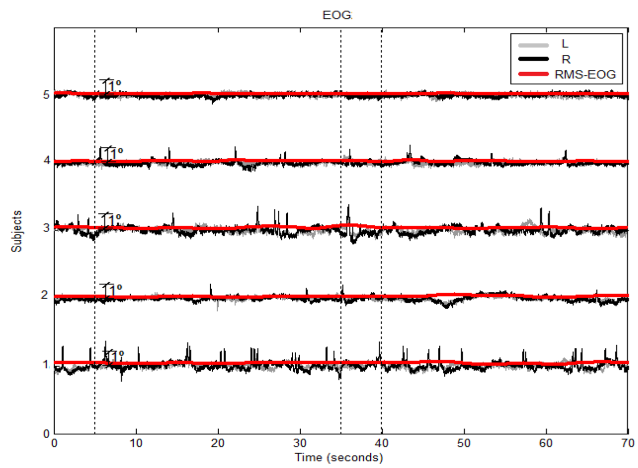



Fig. 4. EOG analysis of each volunteer.

In Fig. 4, signals of gray color refer to the signals of EOG-L channel (left side). On the other hand, the signals in black color represent the EOG-R channel (right side), and the red line is defined as the RMS of the average, i.e., the RMS-EOG of each volunteer. Importantly, the vertical dotted lines are the points of interest, because they represent temporal changes in attention (5-35 – left stimulus, 40-70 – right stimulus).

The aforementioned technique for feature extraction is described as follows:

### A. Multivariate Synchronization Index (MSI)

MSI is a method to estimate the synchronization between the actual mixed signals and the reference signals as a potential index for recognizing the stimulus frequency. In [7] was proposed the use of a $S$-estimator as index, which is based on the entropy of the normalized eigenvalues of the correlation matrix of multivariate signals. Thus, the MSI technique creates a reference signal from the stimulus frequencies used in the SSVEP-based BCI system, similarly to Canonical Correlation Analysis (CCA) method. For more details, see [7].

$N_h = 3$ harmonics were used in the analysis. The synchronization index between the signals (O1, O2 and Oz for BrainNet or O1 and O2 for Emotiv) and each reference signal was calculated, and then obtained $k$ indices or classes ($S_1$,

$S_2$,...,$S_k$). Finally, the class is obtained through a criterion of maxima.

## VI. Experimental Results

In addition to the accuracy rate, the Command Transfer Interval (CTI) and Information Transfer Rate (ITR) were also computed. The CTI was defined as the total experimental time (Ttotal) divided by the number of total output digits or letters (Ntotal), i.e., Ttotal/Ntotal. Thus, it follows that the values of CTI is the window length (1, 2, 4 and 6s) for each case. The most common measure to assess the performance of a BCI system is the Shannon's Information Transfer Rate (ITR) [10], which is defined by Equation 1 [11].

$$\frac{\text{Bits}}{\text{Command}} = \log_2 K + P\log_2 P + (1-P)\log_2\left(\frac{1-P}{K-1}\right),$$

$$\text{ITR} = \frac{\text{Bits}}{\text{Command}} \cdot \frac{60}{\text{CTI}}, \quad (1)$$

where $K$ is the total number of stimuli and $P$ is the accuracy.

Table I and II show the quantified data with the ITR values calculated for each window length for the two acquisition systems.

Table III shows confusion matrices for each subject for a window length of 4s.

TABLE III
Comparison Between BrainNet and Emotiv Epoc Confusion Matrix for window length of 4s.

| **BrainNet** Condition | | | **Emotiv** Condition | | |
|---|---|---|---|---|---|
| Subject 1 | **8 Hz** | **13 Hz** | Subject 1 | **8 Hz** | **13 Hz** |
| **8 Hz** | 92.86% | 40.00% | **8 Hz** | 71.43% | 33.33% |
| **13 Hz** | 7.14% | 60.00% | **13 Hz** | 28.57% | 66.67% |
| Subject 2 | **8 Hz** | **13 Hz** | Subject 2 | **8 Hz** | **13 Hz** |
| **8 Hz** | 78.57% | 33.33% | **8 Hz** | 78.57% | 20.00% |
| **13 Hz** | 21.43% | 66.67% | **13 Hz** | 21.43% | 80.00% |
| Subject 3 | **8 Hz** | **13 Hz** | Subject 3 | **8 Hz** | **13 Hz** |
| **8 Hz** | 100.00% | 6.67% | **8 Hz** | 78.57% | 46.67% |
| **13 Hz** | 0.00% | 93.33% | **13 Hz** | 21.43% | 53.33% |
| Subject 4 | **8 Hz** | **13 Hz** | Subject 4 | **8 Hz** | **13 Hz** |
| **8 Hz** | 100.00% | 20.00% | **8 Hz** | 100.00% | 6.67% |
| **13 Hz** | 0.00% | 80.00% | **13 Hz** | 0.00% | 93.33% |
| Subject 5 | **8 Hz** | **13 Hz** | Subject 5 | **8 Hz** | **13 Hz** |
| **8 Hz** | 100.00% | 6.67% | **8 Hz** | 78.57% | 26.67% |
| **13 Hz** | 0.00% | 93.33% | **13 Hz** | 21.43% | 73.33% |

Fig. 5 and 6 show the classifier output for sequences of data of 30s (data segmented in regions of interest) for each kind of acquisition system, in order to show changes in the classification of a data packet during the protocol.

## VII. Discussions and Conclusions

The results have clearly shown that it is possible to obtain an acceptable degree of classification for the realization of an Independent-BCI with stimuli very close (viewing angle <1°).

Subjects 3 and 5 were both stimulated by checkerboards using the BrainNet acquisition system, obtaining the highest hit rates and confirming the excellent level of attention during the experiments (see Table III and Fig. 5). On the other hand, Subject 4, who used the Emotiv Epoc acquisition system, obtained the most acceptable result for this case (see Table III and Fig. 6).

A better way to visualize what happens in the frequency spectrum of the subject 5 is shown in Fig. 7, where it is possible to see that for the Oz electrode, the frequency spectrum is visibly highlighted and strongly marked in the first 30 seconds, similarly to the 30 seconds remaining. It indicating of this way, the acceptable degree of attention of the subject.

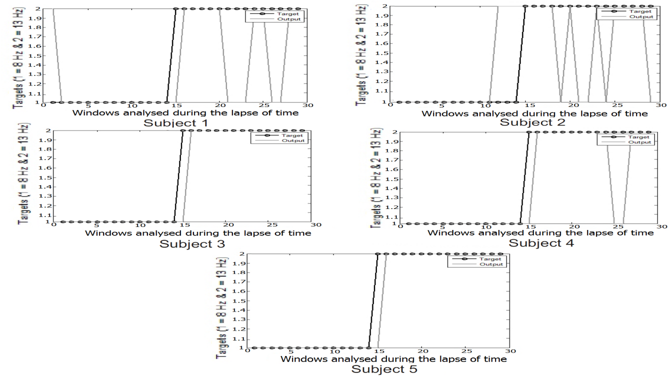



Fig. 5. Output of the classifier for sequences of data with stimulation using BrainNet acquisition system and window length of 4s.

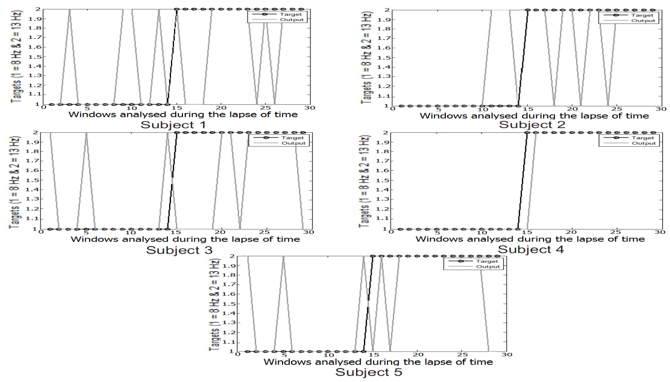



Fig. 6. Output of the classifier for sequences of data with stimulation using Emotiv acquisition system and window length of 4s.

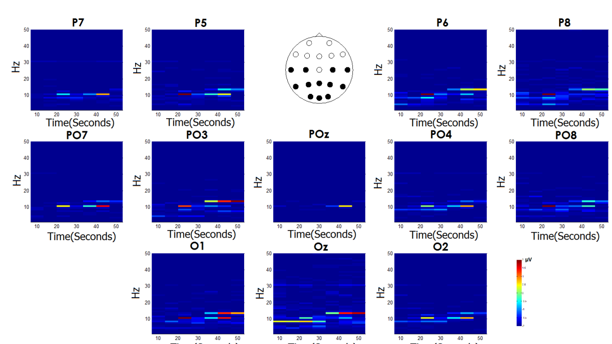



Fig. 7. Frequency spectrum of the subject 5 using BrainNet acquisition system.

TABLE I

ITR [BITS/MIN] WITH THE CORRESPONDING ACCURACIES [%] AND DIFFERENT WINDOW LENGTHS USING BRAINNET.

| **Window length** | **1s** | | **2s** | | **4s** | | **6s** | |
|---|---|---|---|---|---|---|---|---|
| Subjects | Acc.(%) | ITR(bits/min) | Acc.(%) | ITR(bits/min) | Acc.(%) | ITR(bits/min) | Acc.(%) | ITR(bits/min) |
| 1 | 51.52 | 0.05 | 61.55 | 1.17 | 76.43 | 3.18 | 75.00 | 1.89 |
| 2 | 56.29 | 0.69 | 62.76 | 1.43 | 72.62 | 2.30 | 78.89 | 2.57 |
| 3 | 76.66 | 12.97 | 85.00 | 11.71 | 96.67 | 11.84 | 95.00 | 7.14 |
| 4 | 74.95 | 11.28 | 86.67 | 13.01 | 90.00 | 7.97 | 90.00 | 5.31 |
| 5 | 91.67 | 35.18 | 96.67 | 23.68 | 96.67 | 11.84 | 95.00 | 7.14 |
| Mean $\pm$ std | 70.21 $\pm$ 16.34 | 12.03 $\pm$ 14.22 | 78.53 $\pm$ 15.60 | 10.20 $\pm$ 9.36 | 86.48 $\pm$ 11.32 | 7.43 $\pm$ 4.57 | 86.78 $\pm$ 9.31 | 4.81 $\pm$ 2.48 |

TABLE II

ITR [BITS/MIN] WITH THE CORRESPONDING ACCURACIES [%] AND DIFFERENT WINDOW LENGTHS USING EMOTIV EPOC.

| **Window length** | **1s** | | **2s** | | **4s** | | **6s** | |
|---|---|---|---|---|---|---|---|---|
| Subjects | Acc.(%) | ITR(bits/min) | Acc.(%) | ITR(bits/min) | Acc.(%) | ITR(bits/min) | Acc.(%) | ITR(bits/min) |
| 1 | 50.00 | 0.01 | 57.76 | 0.53 | 69.05 | 1.61 | 68.89 | 1.06 |
| 2 | 63.90 | 3.40 | 67.93 | 2.85 | 79.29 | 3.96 | 68.34 | 0.99 |
| 3 | 56.35 | 0.71 | 61.21 | 1.10 | 65.95 | 1.12 | 80.00 | 2.78 |
| 4 | 87.45 | 27.30 | 93.28 | 19.34 | 96.67 | 11.84 | 100.00 | 10.00 |
| 5 | 72.32 | 8.95 | 81.50 | 9.27 | 75.95 | 3.06 | 89.45 | 5.14 |
| Mean $\pm$ std | 66.00 $\pm$ 14.61 | 8.07 $\pm$ 11.31 | 72.33 $\pm$ 14.82 | 6.62 $\pm$ 7.91 | 77.38 $\pm$ 12.02 | 4.32 $\pm$ 4.35 | 81.33 $\pm$ 13.60 | 3.99 $\pm$ 3.76 |

Fig. 8 presents the frequency spectrum of the subject 4 using Emotiv Epoc system. For this case, O1 electrode can be visualized more clearly, defining the attention to the determined stimuli.

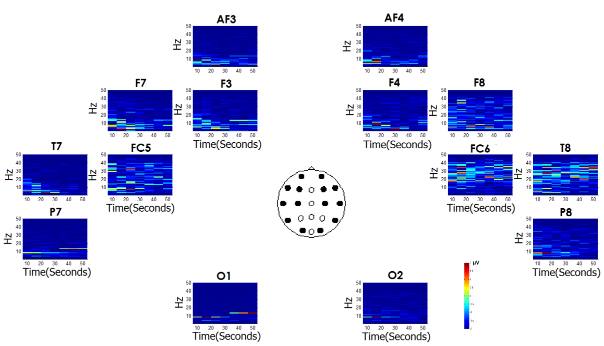



Fig. 8. Frequency spectrum of the subject 4 using Emotiv Epoc acquisition system.

In general, the best results were obtained when the subjects used the BrainNet System, but this is obviously relative due to the intervariability of information between subjects, according to Tables I and II. The highest value of accuracy was 100% and the highest ITR was 35.18 bits/min in all cases analyzed. These results are very important, because we would be in a position to control different devices with the lesser angle subtended by the eye showed in the literature for this mode. Furthermore, this Independent-BCI will help ALS patients improve their ability to communicate.

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