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P300-based Brain Computer Interface Experimental Setup

Carolina Arboleda, Eliana García, Alejandro Posada and Róbinson Torres

***Abstract*—A Brain-Computer interface (BCI) is a communication system that enables the generation of a control signal from brain signals such as sensorymotor rhythms and evoked potentials; therefore, it constitutes a novel communication option for people with severe motor disabilities (such as Amyotrophic Lateral Sclerosis patients). This paper presents the development of a P300-based BCI. This prototype uses a homemade six-channel electroencephalograph for the acquisition of the signals, and a visual stimulation matrix; since this matrix contains letters of the alphabet as well as images associated to them, it permits word-writing and the elaboration of messages with the images. To process the signals the software BCI2000 and MATLAB 7.0 were used. The latter was used to program three linear translation algorithms (Stepwise Linear Discriminant Analysis, Lineal Discriminant Analysis and Least Squares) to convert the brain signals into communication signals. These algorithms had a classification accuracy of 90.73 %, 95.75 % and 89.45 % respectively, when using raw data; and of 90.78%, 49.48 % and 53.9 %, when data was previously common-average filtered. The experimental setup was tested in ten healthy volunteers; 5 of them got a 100% success, 1 a 90% success, 2 an around 70% success and 2 a 50% success, in the online free-spelling tests.**

***Keywords*— Augmentative and alternative communication, Brain-Computer Interface, Electroencephalography, Motor disabilities, P300 cognitive evoked potential, Signal processing, Translation algorithms.**

I. Introduction

Since Hans Berger's original publication in 1970, the electroencephalogram (EEG) has been used to evaluate clinic neurological disorders and to perform laboratory-based research on brain-physiology. During all this time, researchers have considered the idea of using EEG to decipher thoughts and, more precisely, to allow patients the communication with others or the control of devices through the direct measurement of his/her brain-activity, disregarding muscular and peripheral information [1, 2, 3]. Although these ideas could be seen like popular fiction, real possibilities to develop brain-controlled devices have been found, due to the strong correlation between EEG-signals and both real or imagined movement and mental tasks [4], and to the fast and continuous development of low-cost EEG multi-channel online analysis software and hardware [1].

As an outcome of this research, Brain-Machine Interfaces (BMI), which include Brain-Computer Interfaces (BCI), were developed [5, 6]. To build a functional BMI, it is necessary to develop a robust signal acquisition and recording system, accurate online algorithms to translate brain-signals into motor activity or messages, a method to provide feedback to the user and, finally, a prosthesis or another device susceptible of being directly controlled by these signals. Once these objectives are achieved, BMI will constitute a very effective technology to restore motor control in patients with Spinal Cord Injury, Amyotrophic Lateral Sclerosis, Cerebral Palsy, among others [7].

Several laboratories have developed BCI systems [8-10, 11-14, 15] for people with different motor disabilities. However, a typical BCI is designed specifically for a particular brain-signal type and a determined neurological disorder; thus, it is not appropriate to the systematic research that is essential for continuous advancement. In response to this problem, The Wadsworth Center (Albany, New York) created a multi-purpose system called BCI2000 [16], which consists of four modules: data acquisition and storage, signal-processing, user application and operator interface. BCI2000 facilitates the experimentation of different BCI methods and, therefore, leads to the development of *personalized BCIs* [5].

In Latin-America, few groups have performed research on BCI. One of the most outstanding is the University of Entrerrío's research group; recently, they designed a P300-based BCI to control a wheelchair [10, 17]. In Colombia, according to the review performed, there were so far no groups conducting research on BCI-related topics, in spite of the large amount of people with motor disabilities that the Statistics National Administrative Department (DANE) reported in 2007 (185,736 people with limitations for arms, hands and legs movement and 125,454 with nervous system disorders) [18]. This fact motivates the scientific Colombian community to perform research in this area.

In this paper, the development of a P300 based BCI experimental setup is presented (P300 is a cognitive evoked potential). This prototype was designed for people with motor disabilities and communication problems. Through a visual stimulation matrix, that contains both alphabet letters and images associated to them, enables the user to write

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C. Arboleda earned a B.S. in Biomedical Engineering at both EIA and CES University (Medellín, Colombia) and, currently, is a member of the EIA-CES Biomedical Engineering Research group (GIBEC), in the bioinstrumentation and signal processing track (phone: 574-416-1492; e-mail: bmcaroa@eia.edu.co).

E. García earned a B.S. in Biomedical Engineering at both EIA and CES University (Medellín, Colombia) and, currently, is a member of the EIA-CES Biomedical Engineering Research group (GIBEC), in the bioinstrumentation and signal processing track(e-mail: bmeliga@eia.edu.co).

A. Posada earned a B.S. in Biomedical Engineering at both EIA and CES University (Medellín, Colombia) and, currently, works as a supporting engineer at World Medical (e-mail: bmalpos@eia.edu.co).

R. Torres earned a PhD in Electrical Engineering at the Poly-technique University of Valencia (Valencia, Spain). Currently, he is the director of the EIA-CES Biomedical Engineering Research group (GIBEC) and coordinates the Bioinstrumentation and signal processing track of the EIA-CES Biomedical Engineering Program. He is an IEEE member(e-mail: pfrotor@eia.edu.co).

messages. To acquire and process the signals, as well as to program the translation algorithms, BCI2000 and MATLAB were used.

II. Material and Methods

A. Materials

Hardware: Eight gold cup electrodes, conductive gel (TEN20 and bentonite), operational amplifiers (TL071, AD620), isolation amplifiers (AD210), laptop PC, National Instruments acquisition software and hardware and an impedance-measurement circuit.

Software: MATLAB 7.0, BCI2000.

B. Methods

1) Signal acquisition and conditioning

To acquire the P300 signal, a six-channel electroencephalograph was designed and built. Fig. 1 shows the modules each channel has.

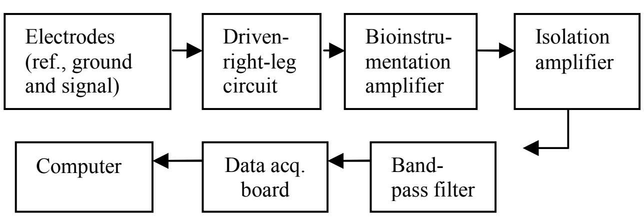

Fig. 1. Blocks diagram of each channel of the developed electroencephalograph

Earth and reference electrodes were located, respectively, on right and left mastoids; the rest, on Fz, Cz, Pz, Oz, C3 and C4 [17]. To measure electrical impedance between the electrodes and the scalp, a simple impedance-measurement circuit was designed [19]. Two conductive gels were used to reduce impedance: TEN-20 [20] and bentonite [19]. After the electrodes, a passive high-pass filter to eliminate the DC voltage produced by them was implemented and to minimize the common-mode voltage, we connected a reference electrode to a driven-right-leg circuit [21].

The active Butterworth band-pass filter implemented (0.3 Hz-15 Hz) was a fifth-order one. Its purpose was eliminating the other EEG signals and, at the same time, electromagnetic 60 Hz noise, electrocardiographic and electromyographic activity.

To digitize the signals, a National Instruments DAQ USB-6016 and a BCI2000 contribution were used. Sample frequency was set to 512 Hz.

2) Signal processing

To process the EEG signal, a Graphical User Interface (GUI) was built in MATLAB 7.0. The function "load_bcidat", included in BCI2000 off-line analysis tools, was used to charge the acquired data. *Load_bcidat(files)* turns in three matrixes: *signal, states* and *bciParams*, *files* corresponds to a .dat archive that contains the information acquired by the electrodes. The first matrix, *"signal"*, contains the EEG signal that was recorded during the test time. The second matrix, *"bciParams",* contains the parameters defined before the test: block size, sample frequency, offset and the channel gain, among others. Finally, the matrix "states" contains two vectors that will be very important to process the training signals: *Stimuluscode* and *Stimulustype.* The former contains the information about the start and the total duration of the stimulus for each icon of the matrix. It is composed by numbers that represent the icon that has been stimulated and the stimulus duration (this numeration is done by *BCI2000*). The second vector is binary and is equal to one when an icon that was selected for training is illuminated, and equal to zero in the rest of cases. With these vectors the signals are separated in two groups: "Epochs with P300" and "Epochs without P300". The GUI "Analysis off-line P300" was created to graphic both of them.

The GUI to process signals, allows the selection of the decimation frequency, the time window (i.e. the signal in ms after the visual stimulus that will be analyzed for the presence of P300), the maximum number of iterations that the translation algorithm will perform (just necessary for the stepwise lineal discriminant analysis) and the group of channels that will be considered. Furthermore, it offers the possibility to use a common average reference (CAR) filter.

First, the groups of signals, "Epochs with P300" and "Epochs without P300" are filtered and then decimated. The function *filter (*Matlab) is used to filter the signals. The CAR filter, when chosen, is applied later.

3) Translation algorithms

After filtering and decimating, the class marker vector *label* is generated. Label= 1 in the positions where signal has P300, and Label=-1, in the positions where the signal does not.

Three linear translation algorithms were programmed to label the signal: Fisher's linear discriminant (FLD), Least squares (LS) and Stepwise Lineal Discriminant Analysis (SWLDA). We developed linear algorithms, because they are simple to program, do not demand high computer cost (like neuronal networks, e.g.), and have showed a very good performance [22].

FLD and LS were coded in MATLAB 7.0, and the function *stepwisefit,* included in the same software, was used for SWLDA. The latter has an extra value because it allows the selection of channels that did the best P300 signal discrimination.

4) Stimulation matrix

In the BCI2000 window called "application", the stimulation strategy to evoke P300 is defined. A 4x3 (rows x columns) matrix was created (Fig. 2) due to the fact that this matrix dimension showed a good classification performance in earlier experiments [23]. This matrix allowed the direct selection of concrete actions of daily life, feelings and simple communication sentences, like "I am ok" or "I am not ok". Furthermore, it allowed writing words with the letters associated to each icon. In this way, the user could write messages with icons or words.

Fig. 2. 4 rows x 3 columns stimulation matrix It has letters and icons.

5) Experiments

To test our brain computer interface we first located electrodes on user's scalp. Then, we performed four training experiments. In each of them, the subject has to spell a 4-character word. The objective of training is to make the system able to recognize the P300 potentials of each user.

In our system, each letter (or icon) flashed 30 times (15 the corresponding row and 15 the corresponding column). The letters remained intensified for 100 ms, and not intensified for 300 ms.

If the user wanted to select a specific letter, he had to count the number of times it flashed. The fact of counting allows the generation of the P300 evoked potential. For example, suppose that in the first training experiment the user had to spell the word IDEA. When letter "I" flashed, the user had to count, but, for instance, when letter "B" twinkled, the user did not have to. In this case, P300 did not appear after B's flash, but after I's.

With the training data and any translation algorithm, the weights vector could be generated. This vector was charged in BCI2000 and the free-spelling mode experiment was carried out. In this kind of test, the user selected the word he wanted to spell, counting 30 times each desired letter (icon).

6) Statistical analysis

To test the BCI experimental setup, five males and five females between 14 and 25 years were taken, all of them without motor disabilities. For each person, the percentages of classification with all the translation algorithms (with and without CAR respectively) were calculated and the algorithm with the best classification percentages was used in the free-spelling mode test.

III. Results

The homemade electroencephalograph developed worked out properly. Table I shows the classification percentages obtained with the different translation algorithms, for each volunteer. Fig. 3 shows the success percentages for each subject, in the free-spelling mode experiments. In these experiments, the translation algorithm with the best classification percentage for each user was used. When the user was right in the row, but not in the column, and vice versa, a 50% success was assumed.

TABLE I. CLASSIFICATION PERCENTAGES OBTAINED FOR EACH VOLUNTEER WITH THE THREE TRANSLATION ALGORITHMS PROGRAMMED

	Raw			Comon Average Filter		
	SWLDA	LDA	LS	SWLDA	LDA	LS
1 (F)	94	94	94	94	81	81
2 (F)	88	94	94	88	0	88
3 (M)	75	94	81	94	88	13
4 (M)	69	88	88	69	44	56
5 (F)	100	100	100	100	100	94
6 (M)	81.25	87.5	62.5	81.25	6.25	12.5
7 (F)	100	100	94	94	13	38
8 (F)	100	100	81	100	50	50
9 (M)	100	100	100	100	100	94
10 (M)	100	100	100	87.5	12.5	12.5
Average	90.725	95.75	89.45	90.775	49.475	53.9

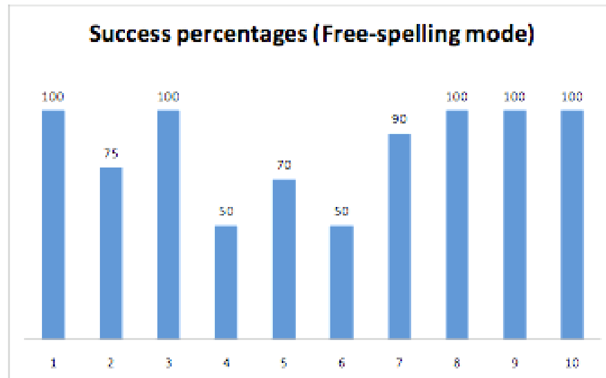

Fig.3.Success percentages for each volunteer in the free-spelling mode experiments

IV. Discussion

It is necessary to be careful in order to guarantee user's security and to take action to reduce noise propagation in order to minimize its impact on EEG signals; therefore, the design of circuitry with earth ground planes, adequate wires shields and circuits to eliminate common-mode voltages is strongly recommended.

When surface electrodes are used to record bio-potentials, conductive gels are necessary to reduce skin impedance. Thus, to guarantee the efficiency of a specific gel, impedance measurements are recommended. For this purpose, simple impedance measurement systems can be built. Both bentonite and TEN-20 worked out very well in our experiments, regarding that the former is much cheaper than the latter.

On the other hand, to ensure a satisfactory signal transmission, it is necessary to adequately locate the electrodes and ensure their complete adhesion to the user's scalp. If the gel does not guarantee this, adhesive bandages should be used. Another important factor to take into account is that the conductive gel's effectiveness diminishes with time. That is why, EEG signals recorded at the beginning have better quality than the signals acquired at the end of the tests.

Although the goal is to obtain a peak in 300 ms, sometimes it does not happen, because the P300 presence strongly depends on the user concentration and on the quality of the acquired signal. Therefore, what really means is that the classifier finds a characteristic feature 300 ms or any other time less than 1000 ms after the stimulus.

Due to the fact that a BCI user must evidence a very high concentration level, it is important to provide him/her a comfortable position. Therefore, cushion chairs are suggested.

Stimulus and inter-stimulus duration must be defined according to the user, so he/she can easily detect the flashes. Moreover, icons must be optimally distributed across the screen and have an adequate size. If a low-RAM computer is used, it is recommended to use two computers, instead of one: one for the EEG signals recording and another one for visual stimulation and translation and signal processing algorithms execution.

To assure computational efficiency, it is recommended to use decimation processes, since the amount of EEG data is usually very big and can even be redundant [10].

Classification percentages above 70% evidence the user has a characteristic feature that can be recognized by a translation algorithm.

In some experiments (see Table I), a null (when using LDA) and very low classification percentages were obtained (when using LDA and LS). This could be explained by the fact that these algorithms do not perform a channel selection, what makes that in some cases they come up with singular or near to singular matrixes. That is why channel-selection algorithms (such as SWLDA) are strongly recommended.

Finally, it is crucial to modify the stimulus duration, matrix design, and number of flashes for this BCI to be effectively useful for users with motor disabilities.

V. CONCLUSION

A P300-based BCI experimental setup was built. The six-channel electroencephalograph and the signal processing algorithm worked satisfactorily for the programmed translation algorithms, which led to a good classification, as the success percentages were always above 50% for ten healthy volunteers. Testing the BCI experimental setup with people with motor disabilities will be the next step to validate its real effectiveness. We are in contact with the foundation "Aula Abierta" in Medellin, Colombia, to start the process with children with motor disabilities; the idea is to validate this BCI prototype, and to include new algorithms that work with mu and beta rhythms.

Finally, it is important to highlight the fact that this is the first approach to the BCI world in our country and there are a lot of applications that can come out from it (BCI-controlled-wheel-chairs, BCI-controlled-prosthesis, among others) and many other EEG signals to discover that can solve many problems for handicapped people in the region.

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