Open Architecture for the Control of a Neuroprosthesis by Means of a Mobile Device

Adrián Contreras-Martínez[1], Blanca E. Carvajal-Gámez[1,2](✉), J. Luis Rosas-Trigueros[1], Josefina Gutiérrez-Martínez[3], and Jorge A. Mercado-Gutiérrez[3]

[1] Instituto Politécnico Nacional, SEPI-ESCOM, Av. Juan de Dios Bátiz S/N, Nueva Industrial Vallejo, Gustavo A. Madero, 07738 Ciudad de México, CDMX, Mexico
{acontrerasm, becarvajal}@ipn.mx

[2] Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria de Ingeniería y Tecnologías Avanzadas, Av Instituto Politécnico Nacional 2580, La Laguna Ticomán, Gustavo A. Madero, 07340 Ciudad de México, CDMX, Mexico

[3] Instituto Nacional de Rehabilitación, Calz México-Xochimilco 289, Coapa, Arenal Tepepan, Tlalpan, 14389 Ciudad de México, CDMX, Mexico

Abstract. The Brain-Computer Interfaces (BCI) based on Electroencephalography (EEG), allow that through the processing of impulses or electrical signals generated by the human brain, people who have some type of severe motor disability or suffer from neurological conditions or neurodegenerative diseases, can establish communication with electronic devices. This paper proposes the development of an expert system that generates the control sequences for a neuroprosthesis that will be used in the rehabilitation of patients who cannot control their own muscles through neuronal pathways. This proposal is based on the EGG record during the operation of a BCI under the rare event paradigm and the presence or not of the P300 wave of the Event-Related Potential (ERP). Feature extraction and classification will be implemented on a mobile device using Python as a platform. The processing of the EEG records will allow obtaining the information so that an Expert System implemented in the mobile device, is responsible for determining the control sequences that will be executed by a neuroprosthesis. The tests will be performed by controlling a neuroprosthesis developed by the Instituto Nacional de Rehabilitación in México, which aims to stimulate the movement of a person's upper limb.

Keywords: Brain-Computer Interface · Neuroprosthesis · Mobile devices · EEG · Motor imagination

C. Stephanidis et al. (Eds.): HCII 2020, CCIS 1294, pp. 25–31, 2020.
https://doi.org/10.1007/978-3-030-60703-6_4

1 Introduction

According to the World Report on Disability issued by the World Health Organization (WHO) [1], it is estimated that more than 1 billion people in the world live with some form of disability; of these people, almost 200 million have considerable difficulties executing actions or tasks that are considered normal for a human being. In the medical area, physical rehabilitation has been used for the retraining of people affected by lesions to the nervous system, and it is through functional electrical stimulation (FES) that the motor nerves are artificially activated, causing muscle contractions that generate functional movement by applying electrical current pulses. On the other hand, the brain-computer interfaces (BCI), based on electroencephalography (EEG) provide an alternative for humans to establish communication with external devices, and are helpful for people who have some type of severe motor disability, suffer from neurological conditions or neurodegenerative diseases; This is currently possible because EEG-based BCIs record brain signals in order to create a non-muscular communication channel between mental intentions and electronic devices.

The main noninvasive methods of BCIs include Slow Cortical Potentials (SCPs), evoked potential of the P300 wave, Visual Steady State Potentials (SSVEPs) and Motor Imagination (MI) [2]. This change attracts the subject's attention, forcing him to use working memory to compare the rare or infrequent stimulus with frequent previous stimuli [3]. In this work we propose the development of a system that generates the control sequences through the P300 component for a neuroprosthesis that will be used in the rehabilitation of patients who cannot control their own muscles.

2 Methods and Materials

The general form of the methodology considered in this work is made up of the following steps:

Step 1 Acquisition of signals: The signal acquisition stage aims to record the electrical activity of the brain, which reflects the user's intentions, is carried out through an EEG using electrodes. In this first stage, the registered signal is prepared for further processing.

Step 2 EEG registration: Hardware and Software: A 16-channel biopotential amplifier, model g.USBamp™ from the company g.tec ™, was used, with which the EEG was registered in 10 positions of the International 10–20 System (Fz, C4, Cz, C3, P4, Pz, P3, PO8, Oz and P07) during the operation of the P300 Speller application of the experimental platform for the BCI2000 ™ [4], based on the original Donchin Speller [5].

Step 3 Feature Extraction: The methods to extract features such as Principal Component Analysis (PCA), Independent Component Analysis (ICA) and Common Spatial Pattern (CSP). For the analysis of the data in time-frequency, we find the Fourier Transform by Intervals (STFT), Wavelet Transform (WT), Autoregressive Models (AR) and Adaptive Filter (MF) with the same objective.

Step 4 Classifiers: In this stage, the parameters that classify the signal between different patterns or classes are established. Which can be: neural networks, deep neural networks, the support vector machine (SVM), etc.

Step 5 Control: Finally, the control stage corresponds to direct interaction with the end user. Once the features have been detected and they have been classified as control signals, the implemented application must perform the corresponding actions.

3 Results

To validate the advances in this research, from the EEG record database [6], the following test considerations were taken. A set of test subjects underwent 4 registration sessions organized as follows:….

Session 1. Directed Spelling. Number of sequences per symbol: 15. Record: 1. Target word: HEAT. Record 2: Target word: CARIÑO. Record 3: Target word: SUSHI.

Session 2. Directed Spelling with classification matrix. Number of sequences per symbol: 15. Record 1: Target word: SUSHI.

Session 3. Free Spelling with classification matrix. Number of sequences per symbol: 15. From 1 to 4 registers. Target words chosen by the subject.

Session 4. Free Spelling with fewer intensification sequences. Number of sequences: variable (1 to 15). From 1 to 10 records. Target words chosen by the subject.

3.1 Considerations

In directed spelling registers (sessions 1 and 2), the target words are predefined and the symbols that make them up are indicated one by one, performing 15 stimulation sequences per symbol. A stimulation sequence consists of the random intensification (the symbols contained in a row or column light up in white) of each of the 6 rows and the 6 columns of the symbol matrix. In the records of the free spelling sessions (3 and 4), the target words are freely chosen by the subject and the number of stimulation sequences per symbol in each record varies between 1 and 15, also by choice of the subject. For each of the 10 test subjects considered, each of the 4 EEG (directed spelling) records can be expressed as $x_{i,ch}$ (n), where i Є {1, 2, 3, 4} represents the record number, ch Є {1,2,…, 10} the channel number, n = 1, 2,…, N are the instants of the EEG signal sampling time, and N is the total number of samples from register i, which depends on the number of spelled symbols (5 or 6). Figure 2 shows the EGG signals.

With the EEG raw signal from each of the 10 channels, for each record $x_{i,ch}$ (n), the following is done:

- An EEG epoch is expressed as $x_{i,ch}^{k,y}$ (n), with n = {1, 2, …, 257}, it is defined as a window with 257 samples (after the moment of stimulation) from register i and class k Є {a, u} where k = a indicates an epoch of the attended class and k = u, an epoch of the unattended class.

- The super index k = a corresponds to the synchronized time with the intensification of a row or column of the matrix of the Speller P300, containing a target symbol (infrequent event), and k = u corresponds to a time of EEG associated with a intensification that does not include a target symbol (frequent event). The superscript indicates the type of epoch: the rows (y = f) or columns (y = c).
- In each of the 4 EEG records of each subject, all available times are extracted and divided into 4 groups, Fig. 1. Times attended by rows: $x_{i,ch}^{a,f}$ (n), times attended by columns: $x_{i,ch}^{a,c}$ (n), unattended times of rows: $x_{i,ch}^{u,f}$ (n), unattended times of columns: $x_{i,ch}^{u,c}$ (n).

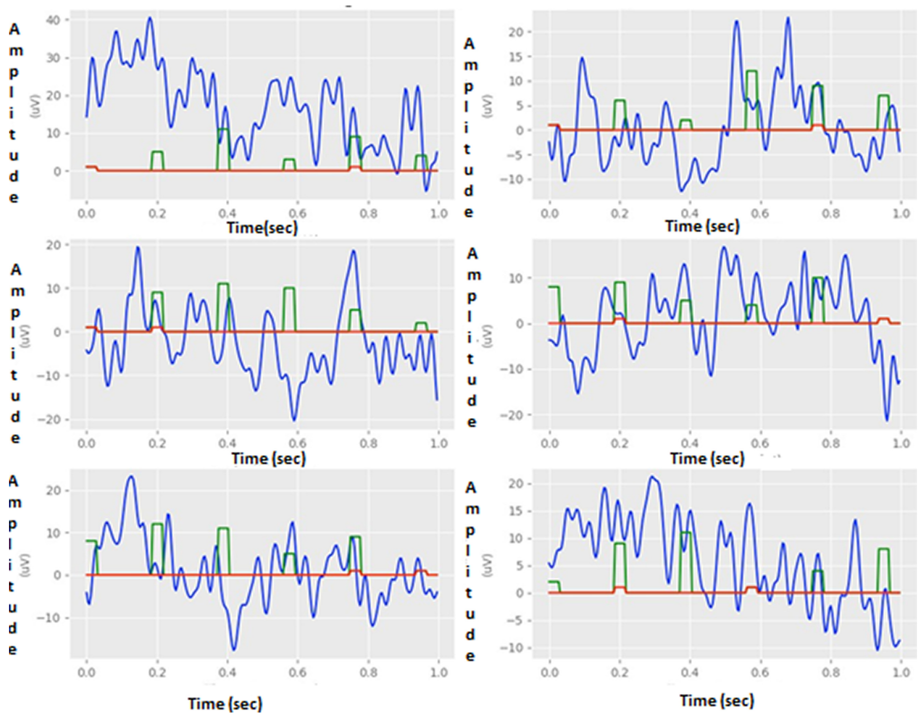

Fig. 1. Signal recording EEG in the target times.

The information from Record 1 of the Directed Spelling of Session 1 that has been specified in the previous section, was processed using Python tools and a total of 890 epochs were identified, of which 149 correspond to epochs attended and 741 to epochs not catered for. From said grouping, what is specified in Table 1 is obtained.

Table 1. Number of times for record 1 of Directed Spelling.

Letter	Attended	Not attended
C	29	140
A	29	139
L	29	142
O	29	147
R	29	140

From the extracted signals, the average of the records of the times attended and not attended by letter is calculated, through Directed Spelling and the registration channel, obtaining the information records shown in Figs. 2, 3 and 4.

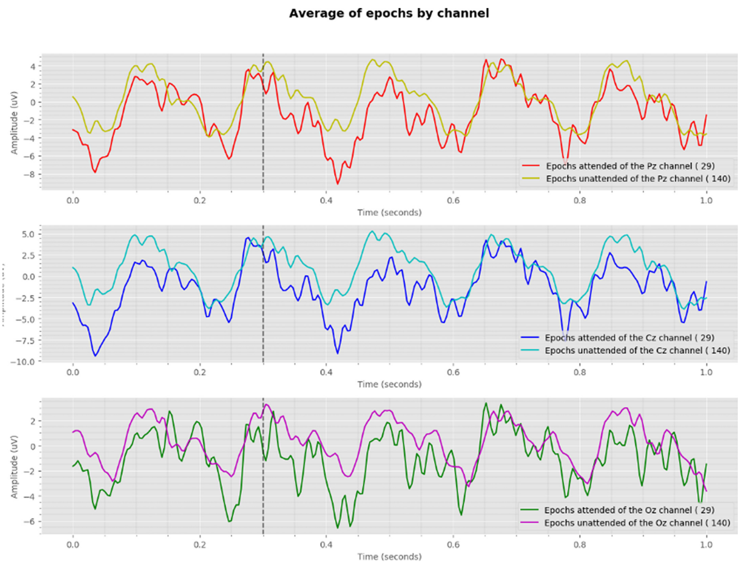

Fig. 2. Average recording of EEG signals of channels *Pz, Cz, Oz* that correspond to the times attended and not attended for the letter "C" of Directed Spelling.

As can be seen in Figs. 2, 3 and 4, the information that corresponds to the average of the times attended and not attended by the recording channel are very similar, this corresponds to the measurement of the signal power content versus the frequency of the channels that are of interest Pz, Cz and Oz.

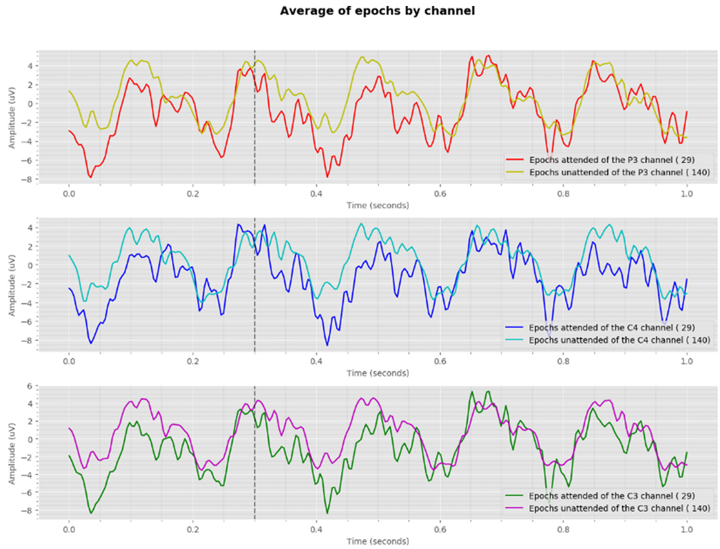

Fig. 3. Average recording of EEG signals of channels *P3, C4, C3* that correspond to the times attended and not attended for the letter "C" of Directed Spelling.

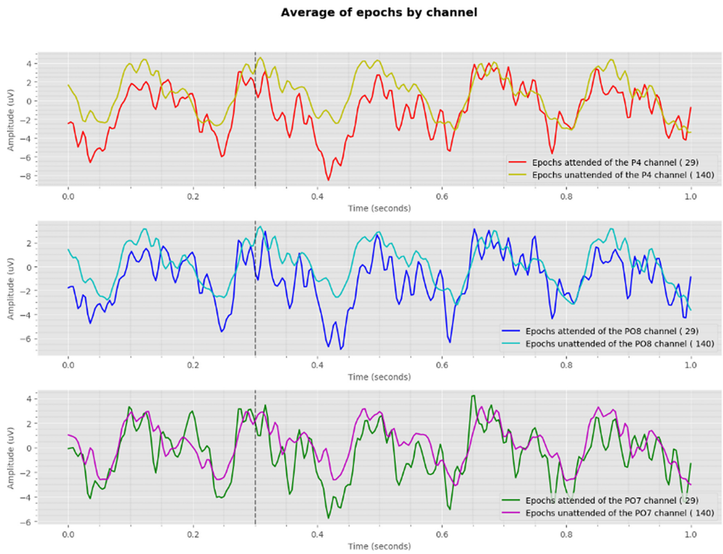

Fig. 4. Average recording of EEG signals of channels P4, PO8, PO7 that correspond to the times attended and not attended for the letter "C" of Directed Spelling.

4 Conclusions

In the course of this research, the registration of the EEG signals is obtained for a population of 10 individuals with different abilities, who were presented with the test board to start the acquisition of the signals. The acquired signals were subjected to the corresponding filtering as well as the extraction of the signal spectrum to detect the frequency in which it presents the greatest energy, this point being considered as the center of attention of the individual in the letter they wish to express. From the previous process already established, the corresponding acquisitions will be made to extract the pertinent characteristics and continue with the selection of the training and classification algorithm on mobile devices.

Acknowledgments. The team work thanks the Instituto Politécnico Nacional, the Instituto Nacional de Rehabilitación y a la Secretaria de Educación, Ciencia, Tecnología e Innovación de la Ciudad de México for the support, resources and facilities provided for the development of this research.

References

1. Organización Mundial de la Salud and Banco Mundial, Informe mundial sobre la discapacidad (2011)
2. Ortner, R., Allison, B.Z., Pichler, G., Heilinger, A., Sabathiel, N., Guger, C.: Assessment and communication for people with disorders of consciousness. JoVE **126**, 1–8 (2017). https://doi.org/10.3791/53639
3. Mercado, J.: Implementación de una nueva estrategia de identificación del potencial P300 para interfaces cerebro-computadora utilizando información espectral del eeg. Master's thesis, Universidad Autónoma Metropolitana Iztapalapa, August 2016
4. Schalk, G., McFarland, D., Hinterberger, T., Birbaumer, N., Wolpaw, J.: BCI2000: a general-purpose brain-computer interface (BCI) system. IEEE Trans. Biomed. Eng. **51**(6), 1034–1043 (2004). https://doi.org/10.1109/tbme.2004.827072
5. Farwell, L., Donchin, E.: Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. Electroencephalogr. Clin. Neurophysiol. **70**(6), 510–523 (1988). https://doi.org/10.1016/0013-4694(88)90149-6
6. Ledesma-Ramirez, C., Bojorges-Valdez, E., Yanez-Suarez, O., Saavedra, C., Bougrain, L.: An open-access P300 speller database. In: Fourth International Brain-Computer Interface Meeting, May 2010