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BCI-FES system for neuro-rehabilitation of stroke patients

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Abstract. Nowadays, strokes are a growing cause of mortality and many people remain with motor sequelae and troubles in the daily activities. To treat this sequelae, alternative rehabilitation techniques are needed. In this article a Brain Computer Interface (BCI) system to control a Functional Electrical Stimulation (FES) system is presented. It can be used as a novel tool in easy setup clinical routines, to improve the rehabilitation process by mean of detecting patient´s motor intention, performing it by FES and finally receiving appropriate feedback The BCI-FES system presented here, consists of three blocks: the first one decodes the patient´s intention and it is composed by the patient, the acquisition hardware and the processing software (Emotiv EPOC®). The second block, based on Arduino's technology, transforms the information into a valid command signal. The last one excites the patient´s neuromuscular system by means of a FES device. In order to evaluate the cerebral activity sensed by the device, topographic maps were obtained. The BCI-FES system was able to detect the patient´s motor intention and control the FES device. At the time of this publication, the system it's being employing in a rehabilitation program with patients post stroke.

Key Words: BCI; FES; Neuro-Rehabilitation; Stroke; Emotiv; Arduino.

1. Introduction

According to the 2010 Argentinean National Census of Population and Housing, 12% of the surveyed population has partial or permanent disabilities, of which 16% of those are motor type [1]. Paralysis associated with Strokes is among the leading causes of disability in adults. Moreover, strokes are the second cause of death known in the province of Entre Ríos (Argentina) [2].

There is scientific evidence of certain neurological rehabilitation strategies which help in the functional recovery of people who have had a stroke, but a significant number of them will keep sequelae which will require continuous assistance to succeed in the daily activities. Therefore, the implementation of new therapeutic tools which facilitate the reintegration, autonomy in daily life and the social inclusion of this important population is needed. These innovative therapeutic systems should be reliable and easy to setup, to facilitate its daily clinical use in health institutions.

Brain Computer Interfaces (BCI) can be used as a therapeutic tool to improve the recovery of the voluntary motor control affected by some illness or traumatism [3][4]. In order to perform this type of rehabilitation therapies, the BCI pose a training strategy in which patients evoke brain activity related to movements to facilitate cortical neuroplasticity [5]. Studies have shown that sensory signals of functional desired movement are a perfect feedback which has a positive impact in neuroplasticity [6].

As it is well known, Functional Electrical Stimulation (FES) is a rehabilitation technique that is used to restore function in people with disabilities by exciting the neuromuscular system and to give a proprioceptive and visual feedback of their paralyzed limb [7].

To develop a neuro-rehabilitation program based on a BCI-FES combination approach, we implemented an innovative therapeutic system. It records and processes the brain signals related to upper limb motor imagery/intention of patients. Then it generates a valid order, patient intention related, to command the FES device. In this paper, we present the implementation of this BCI-FES system and the topographic maps of the cortical regions which are activated during the imagination of specific motor tasks in a case of study.

2. Materials and Methods

2.1. System design

The proposed system is shown in figure 1. It consists of three main components: the patient with EEG acquisition device and its processing software, the BCI-FES interface and the FES system.

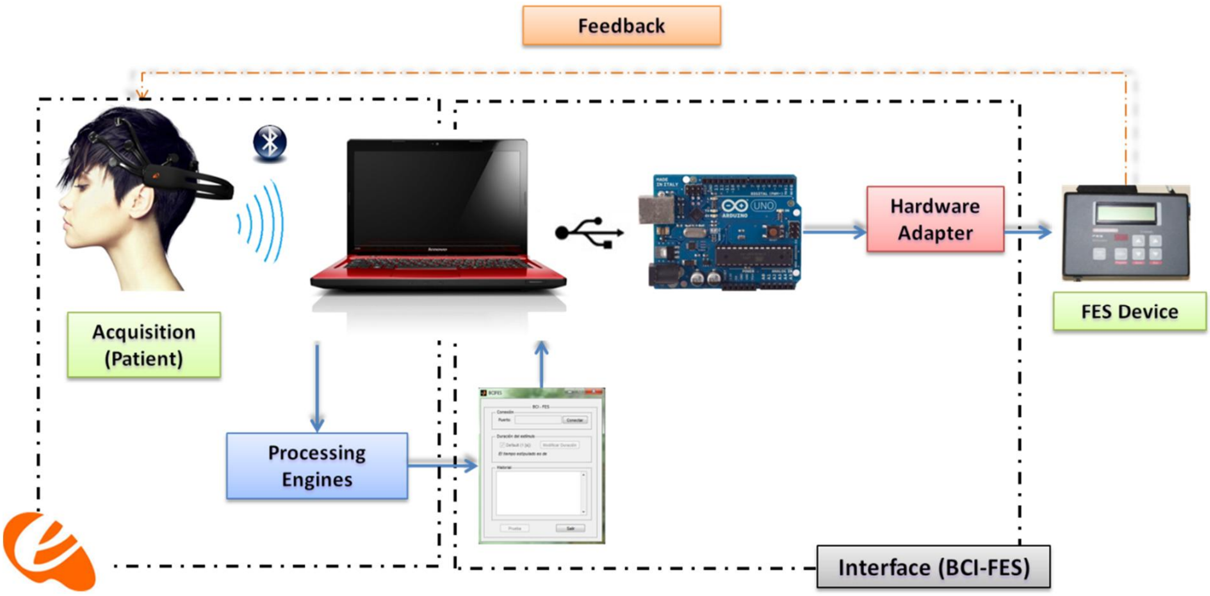

Figure 1. Block diagram of the BCI-FES proposed system. The first block which decodes the intention of the patient, is composed by the patient, the acquisition hardware and the processing software (Emotiv EPOC®). The second block, which transforms the information of the previous block into a valid command signal, is composed by the BCI-FES interface. The last block, which excites the muscular tissue, is composed by the FES device.

2.1.1. Acquisition and Processing.

To record EEG signal from the subject, an Emotiv EPOC EEG® headset (Emotiv Systems Inc., San Francisco, USA) was employed. This headset is a wireless, easy to setup and portable tool. It gives good flexibility and movement to the user compared with other systems.

This Emotiv EEG headset has 14 electrodes (saline sensors) locating at AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, O2 (figure 2) and two additional sensors that serve as CMS/DRL reference channels (one for the left and the other for the right hemisphere of the head). The Emotiv EEG's 14 data channels are spatially organized using the International 10–20 system. The sampling rate is 128 Hz, the bandwidth is 0.2–45 Hz, and the digital notch filters are at 50 Hz and 60 Hz [8].

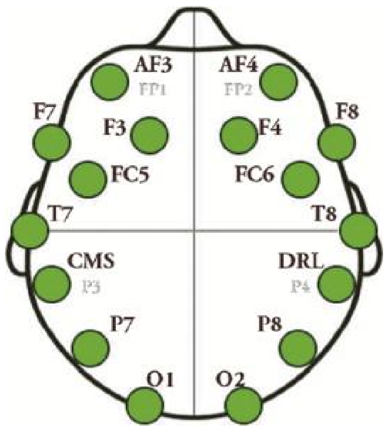

Figure 2. Sensor placement of the 14 data channels in the Emotiv EEG [8].

After setting the Emotiv system into the head of the patient, the system automatically recognized the impedance of the electrodes and indicates if the noise-signal level is acceptable. The signal is sent by Bluetooth to the PC where it is processed by the Emotiv software.

The Emotiv Software has a training block where the desired features in the EEG can be set. It has an user-friendly graphic interface where it can be seen a 'cube' and it is possible to set different movements depending on the number of features to be obtained. To obtain the features for this neuro-rehabilitation tool, it has been selected only 1 (one) feature (the extension of the wrist), which was associated with the movement of the 'cube' to bottom of the screen. Figure 3 shows the graphic interface of the system in which it can be found the electrodes condition (A), the different features to train (B) and the outcome of the system (C). The valid output of the system is a character which it is selected by the user.

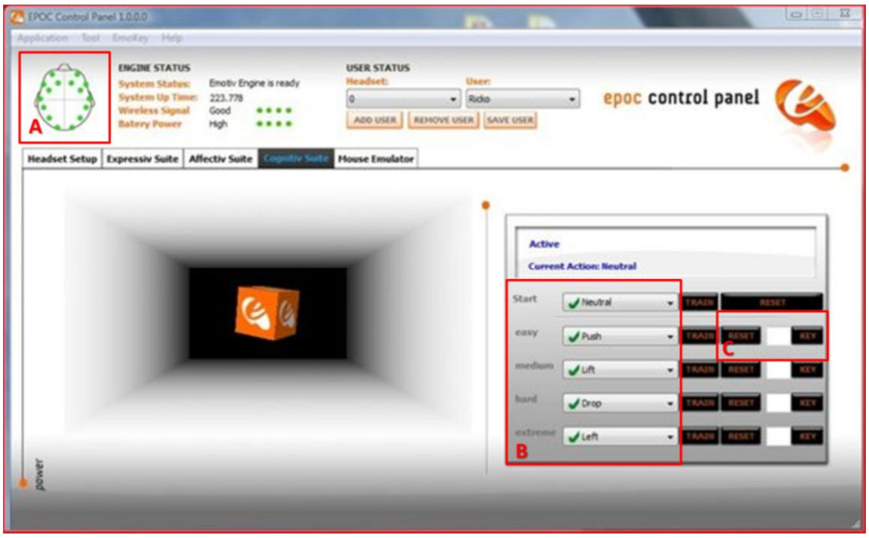

Figure 3. Software Emotiv® EPOC: Interaction screen (explanation in text).

The BCI's calibration is formed by 2 (two) sessions: the first session records the baseline level of the brain signals (in the software is indicated as 'Neutral'); the second session records the achievement of the movements of the cube linked with a real intention of the patient (in the software, it is indicated as 'Push, Lift, Drop, Left, etc.'). In this case the movement intention of the wrist extension is recorded.

This means that the calibration of the action that the software identifies as a movement of the cube is linked with the intention of the movement of the wrist. At the end of this calibration, a brain activity baseline is obtained. Then, each time that the software identifies this same pattern, the cube will move indicating that the intention is achieved.

2.1.2. BCI-FES Interface. The output of the first block is a character which is used to activate the FES device. For doing this, hardware based on Arduino's technology and software based on MatLab's environment have been designed.

The hardware is a portable embedded system with an Arduino UNO Rev3® (Arduino, Italy) which is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It simply connects to a computer with a USB cable. The Arduino UNO can be programmed with the open-source Arduino Software (IDE) and its environment is written in Java.

The BCI-FES software was written in C++ using MatLab® (MathWorks Inc., Massachusetts, USA) environment. This software converts the output of the Emotiv system into a valid command input for the ArduinoUNO board. It is made of three blocks: the first block evaluates the connection of the ArduinoUNO to the computer and identifies its connection port; the next block sets the electrical stimulus duration which helps the physiotherapist to control the stimulation; and the last block shows the status of the device. It also has a test button.

The output signal of this interface is a 5[V] pulse with a duration set by the user. This signal activates the FES device, which is a normal-closed system, so it is necessary that the ArduinoUNO generates a 'false value' as a valid command to activate the FES device. An adapter made of an opto-isolator (4N28, Motorola Inc., USA) has been designed which in 'activated condition' keeps the electrical loop of the FES device closed, and in 'non-activated condition' opens the electrical loop of the FES device allowing it to stimulate.

2.1.3. FES Device. The FES Stimulator® (Flexicar S.A., Argentina) is a two channels controlled stimulator designed to stimulate the neuromuscular system in order to generate a muscular contraction. This kind of stimulation is used in many injuries of the Central Nervous System where the muscles and the nerves are healthy. It has skin surface electrodes and the intensity and duration of the train pulse can be set easily by the user. The type of current is defined as biphasic symmetric rectangular. The rise and fall of the stimulation can be adjusted to prevent a sudden contraction that might induce a stretch reflex of the muscles.

Figure 4 shows the information pathways through the different blocks of the BCI-FES system.

2.2. Topographic Maps.

In order to evaluate the cerebral activity recorded by the Emotiv EEG headset®, cortical cerebral topographic maps were obtained from a subject who had no history of neurological diseases and was untrained in using BCI systems. Informed consent was obtained prior to experimentation.

EEG signal was recorded by g.MOBIlab^{+} (g.tec Medical Engineering®, Austria) module acquisition system and BCI2000 platform. The electrodes were positioned using the EMOTIV® system electrode distribution (see figure 2 above).

The experiment was conducted using the following paradigm. Subject was seated in a comfortably chair, facing a screen and was instructed to relax, watch the screen and avoid blinking and swallowing. EEG recordings consisted in 20 minutes sessions approximately, divided in 4 runs with rest intervals between 1- 2 minutes long.

Each run included 3 different tasks which involved the imagined movement of right hand, left hand or both hands in response to a visual stimulus in the middle of the screen. Every task was repeated 10 times randomly during each run, separated by a random inter-trial interval of 5 to 6 seconds of duration. During the inter-trial intervals, the screen was blank, and subjects were asked to relax. The experiment included 5 sessions.

The EEG recording signals between 8 and 30 Hz were processed. Using the "Offline Analysis" tool available in BCI2000 platform®, spectrums analysis were computed for each task versus rest. Then, the topographic maps for the selected frequencies were performed. In these maps, each electrode position is properly marked and spatial distribution of values encoded in colors was plotted [9].

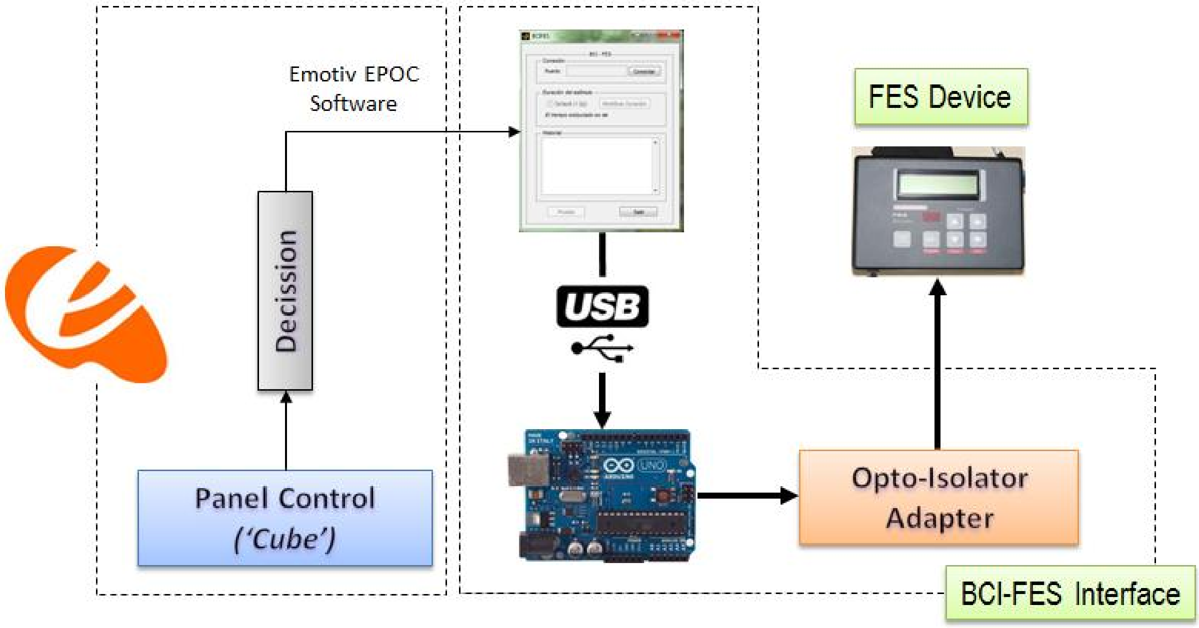

Figure 4. Information pathways through the BCI-FES system.

3. Results

3.1. BCI-FES System
In figure 5, photographic picture of the BCI-FES system is shown. It was able to sense the EEG, to detect the motor-related cerebral activity and to command the FES device. In figure 6, a photography of stroke patient using the system can be observed.

3.2. Topographic maps
Figure 7 presents the topographic maps of the analysed frequencies for the subject for each task. The results correspond to activities related to motor imagination of left/right and both hands. It can be observed that Event-Related Desynchronization (ERD) patterns associated to hand´s motor imagery are visualized for all tasks. Furthermore, it is observed that the localization of ERD patterns appears in different cortical regions, due to the special EMOTIV® system electrode distribution (see figure 2 above). Also it can be observed that the ERD frequencies for only one hand were located on *beta* rhythm range, while for both hands was located in *mu* rhythm one. Besides, during the imagination of right hand, cortical regions associated with other mental activities were also activated.

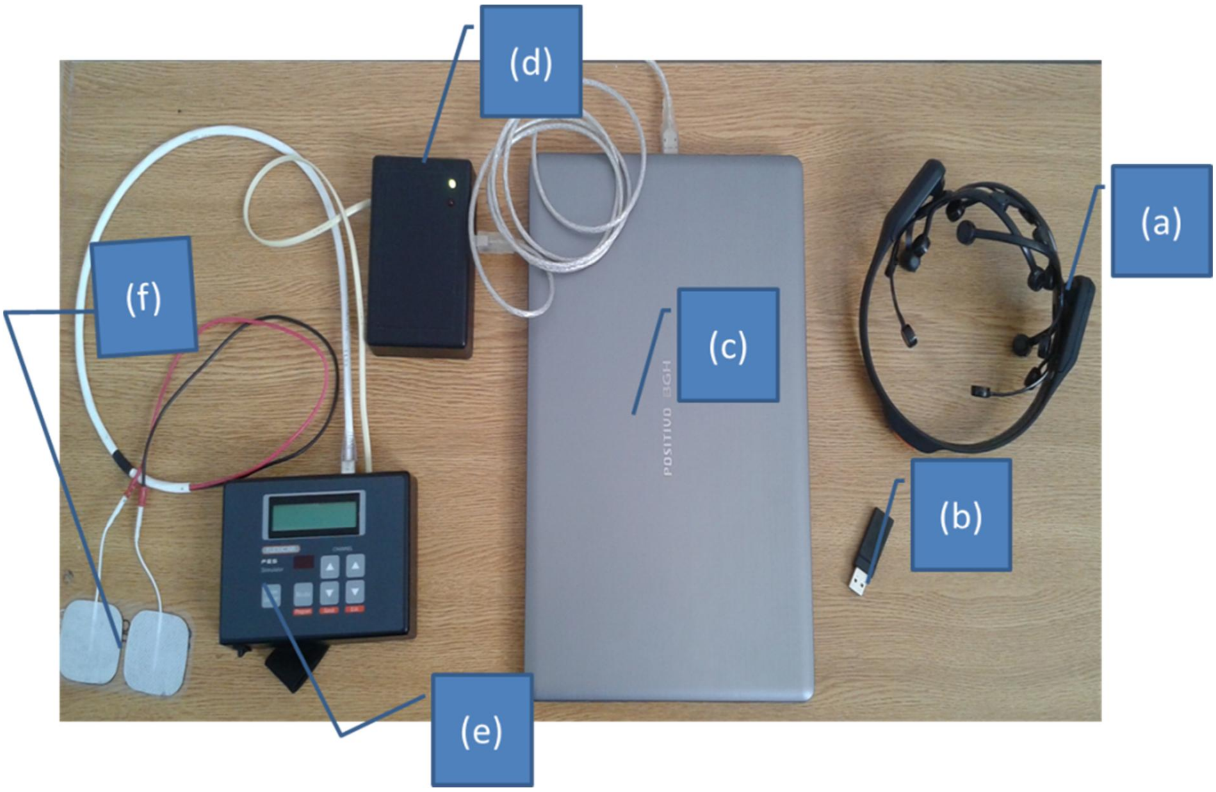

Figure 5. Photography of BCI-FES system: (a) Emotiv EEG headset®; (b) Bluetooth transmitter; (c): portable computer; (d): BCI-FES interface; (e): FES Stimulator®; (f): FES electrodes

Figure 6. Photography of a stroke patient using the BCI-FES system during its treatment.

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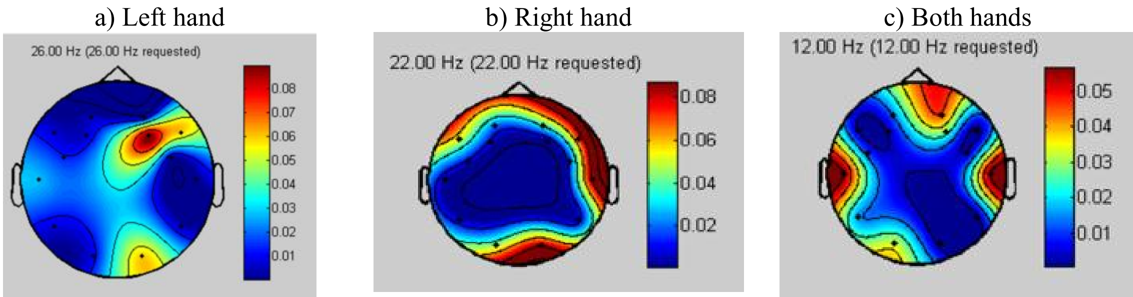

Figure 7. Topographic maps obtained by the processing of signals from Emotiv EEG headset® during related to the imagination of hands' motor activity.

4. Conclusion

The developed BCI-FES system reached the proposed aims. It is able to sense the brain activities related to motor tasks, to process it and to control a FES device. It is portable and easy to set up and use during daily clinical practice. Therefore at this moment, it is being used and evaluated in a new rehabilitation program, with post stroke patients. It is relevant to mention that EMOTIV® system's electrodes location is not the best suitable for recording EEG from motor cortex. This issue brings the need to design a headset with appropriate electrode location to detect more specifically motor ERD.

5. Acknowledgments

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6. Disclosures

No conflicts of interest, financial or otherwise, are declared by the authors.

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