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Brain-Computer Interface (BCI) Development for Motor Disabled People Integration in a Water Fountains Company

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Abstract. The motor disability is a limitation for people who suffer to get a job and be integrated into the country's industries. A lot of tools have been developed for rehabilitation or improving their motor skills, but not to be included in the industries. This paper presents a proposal for an application of current techniques for the motor disabled people inclusion through the development of a brain-computer interface (BCI) that, based on a device that captures real-time electroencephalogram (EEG) brainwave, can take decisions or activities without the need of movement. This research was conducted with various people in a water fountains company, obtaining satisfactory results. Experimental data show the accuracy of the device, from the training stage to the testing stage.

Keywords. Brain-computer interfaces (BCI), brain imaging techniques (BIT), electroencephalography (EEG), water fountains company, motor disabled.

1 Introduction

Despite all the efforts made by companies, internally, with the intellectual capital management and then production process control; and externally, with the searching of the society support, one of the most important problem that concern us, is the disability, because this is increasing day by day, and the most vulnerable populations are being attacked in greater proportion [1]. In this sense, in recent years, companies have been turning to one of the most vulnerable groups, the disabled, for their inclusion in the industries and give them the value they deserve, sharing their society support [2].

People with disabilities find a lot of obstacles, including work highlights, like the barrier of being hired. These barriers are caused from childhood, because in the case of disabled children, they have less probability of having access to education than children without disabilities, causing then, they were less qualified to perform some work. Also, there are currently more than one billion people living worldwide with some form of disability, per the global report on disability, conducted by the World Health Organization (WHO), and the World Bank [1], representing 15% of the total population. Because of the aging population and increasing chronic diseases worldwide, the proportion of people with disabilities has been increasing.

Within this perspective, in Mexico, the National Institute of Statistics, Geography and Informatics (INEGI) has made the group of disabilities per their difficulty: walking or moving, seeing, hearing, speaking or communicating, attention and learning, self-care and finally mind [3]. Based on this classification, there are 5’739,217 inhabitants in Mexico with disabilities; difficulty walking or moving leads the percentages with 58.3%, followed by do with 27.2%, listen to 12.1%, mental with 8.5 %, talk or communicate with 8.3%, personal care deal with 5.5% and finally pay attention or learn with 4.4% [3]. The sum is greater than 100%, this is because some people have more than one disability, for example, the deaf has a hearing impairment and a talking one. In the case of these people, they would need to work in an ordinary company, for example, in a standardized working environment, for facilitating their social integration and economic and personal independence [4].

In this perspective, it has been found that people who have disabilities and have a job, have a personal sense of well-being, a good level of self-efficacy and social identity [2].

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Similarly, it has been shown that in an analysis of job satisfaction, for them, this is superior, because their expectations about employment are lower than those of people without disabilities [5]. To help them, there have developed many instruments, such as prosthetics, wheelchairs, walking sticks, touch screens, information and communications technology (ICT), and so on. Unfortunately, few companies have been given the task to innovate, create technology, implementing a department of research and development or make alliances with research centers to develop assistive technologies that can incorporate these people into the workplace and thus, realize the concept or theory of creating shared value [6].

Another technology used for these people is the brain-computer interface (BCI). Most of these applications were developed for the people that need to communicate, to move and to interact with the persons and things that are surrounding them [7]. An example of a movement application with this kind of systems is known as robotic cloth, that is robotic prosthetic or an exoskeleton with brain control. It was intended to develop and implement the first BCI that could restore the mobility of their full body, especially in patients with a severe paralysis. The patient can move easily, simply should adjust, depending on the terrain in which it moves, speed and movement. This is obtained by the interaction of the brain and robotic signals. These results are looking to have the chance to experience in the future the temperature sensation and the land on which we move, despite being using prosthesis [7].

The BCI is also privative for better accessibility for people, an example of this is the adaptation of wheelchairs driven by extracted commands blinking eyes and muscles, or from images scanned by a camera. In this case the user cannot transform his thoughts into movements, but through its power of his brain activity, can move objects through the BCI, as it has full cognitive ability. The BCI also may place users in a virtual environment, being able to have a direct interaction with the mouse, monitor, keyboard or other peripherals without the need for muscle activity [8]. The Freie University of Berlin developed a project to drive a car through an EEG-based BCI. This system uses a computer to control the cursor and a headband with electrodes.

It was used in paraplegics. The development of BCI can contribute significantly in cognitive processing voice generation and decreased pain. It can be used in the treatment of mental disorders such as attention deficit, epilepsy, depression and schizophrenia [9].

It is noteworthy that the future of BCI applications depends on their capacity, functionality and reliability. Users will accept more as they have more competitive advantages than conventional assistive technologies [10]. For the motor disability, the principal purpose of the developments is for helping them for moving, not for working in a company. We identified this need in the companies, the need of having disabled people working in the companies as a person without disabilities. The main idea of this investigation is to develop a system that can help to the motor disabled people to be integrated in the companies, and with this, the companies can have a competitive advantage, create a shared value with the society and increase their credibility with their customers. We decided to develop a brain-computer interface (BCI), for controlling the results of the thoughts of the disabled people. For reading the brain waves we put electrodes with the electroencephalogram method (EEG), and we use the EMOTIV EPOC® system [7]. Thanks to this system they don't have to move themselves, they only should think. We chose this technology because it is a noninvasive technology, it is safe, and it has a fast response and a good accuracy [12]. In the following paragraphs, we are going to explain the brain imaging techniques (BIT), and the process of the BCI, from the brain signal to the final actuator.

2 Brain Imaging Techniques (BIT) and Brain-Computer Interfaces (BCI)

For the control of human movement, there are two types of brain activities: hemodynamic and electrophysiological. In the case of hemodynamic brain activity, this is for a greater presence of blood glucose in neurons activated in inactive neurons, can be detected by means of surplus oxyhemoglobin in the veins of the active region, in other words, there is a higher amount of glucose and oxygen, and can be seen in the change in the local ratio of oxyhemoglobin and deoxyhemoglobin [14].

These variations can be quantified by methods such as single-photon emission-computed tomography (SPECT), functional magnetic resonance imaging (fMRI), positron-emission tomography (PET), and near infrared spectroscopy (NIRS), with which you can make a reconstruction of 3D brain activity. Methods for obtaining hemodynamic activity are considered indirect because quantitate the amount of glucose and oxygen, which does not directly represent brain activity [13].

A direct method of measuring the brain activity is the electrophysiological activity of the brain, which is caused by electro-chemical exchange of information between neurons transmission, as well as by the ionic currents which are conducted within the same neurons. This type of measurement can be performed from a single neuron, by an invasive electrical measurement, to measuring a set of neurons, using techniques such as magnetoencephalography (MEG), electrocorticography (ECoG), electroencephalography (EEG), and brain implants such as single-unit activity (SUA), multi-unit activity (MUA), and local field potentials (LFPs) [13].

For measurement of hemodynamic brain activity, one technique used is the Single-photon emission-computed tomography (SPECT), which generates an image based on the path followed by ray image gamma emitted by radionuclides that were injected into the bloodstream [15].

This scan provides 3D information of the area to be assessed. A similar SPECT technique is positron emission tomography (PET), which, when there are radionuclides injected in the person, they emit gamma in opposite colliding with electrons directions [16].

Another technique used is functional magnetic resonance imaging (fMRI), which determines the different variations in localized oxygen levels in the blood that are produced during brain activity. This technique is a non-invasive technique with great accuracy [17]. The non-invasive NIRS technique the differential in hemoglobin concentrations located in areas with higher neuronal activity. Such concentrations are measured by absorption or scattering of infrared light reflected in brain tissue [18].

As for the techniques that analyze electrophysiological activity, one is the MEG, which detects magnetic fields generated by electrical currents in neurons. These magnetic fields are very weak, but their advantage is that they suffer less distortion by the skull and scalp than electric fields [19]. Another technique is the ECoG. In this invasive technique, the electrodes are implanted on the surface of the crust reading electrical activity, obtaining good spatial and temporal resolution [20].

EEG is a similar technique that also reads electrical activity of neurons, caused by induction during the synaptic excitements of the dendrites currents [21]. These measurements are obtained by electrodes, which are placed on the scalp, making a noninvasive technique. The NIRS technique, as mentioned above, and the EEG, are the only non-invasive techniques that are portable [22].

Finally, the technique of brain implants, the intracortical neuron recording (INR), is introduced into the brain gray matter, to measure individually the electrical activity of neurons. There are three types of signals that can be detected by this: the SUA, the MUA and the LFPs [23]. These techniques provide the best spatial and temporal resolution, but may have problems with the viability and long-term biocompatibility [24].

We can see the two-different kind of BIT. The direct techniques, that detects electrical or magnetic activity of the brain: EEG, MEG, ECoG, INR, LFP, MUA and SUA. And the indirect techniques, which detect the metabolic activity of the brain: fMRI, SPECT, PET and NIRS. In Table 1, we can see the BIT sorted by the invasive level, and then, by the portability. In this, we found there are only two techniques that match with our requirements: the EEG and the NIRS, portable techniques that were non-invasive.

Table 2 shows the BIT sorted by the temporal resolution, first by the fastest, and then, by the spatial resolution, firstly the smallest. We can see the fastest technique is the EEG. We chose the EEG brain imaging technique for this investigation because it is portable, non-invasive and it has the fastest response. Once they have been read brainwaves, we need to monitor them on a computer system. For the above, the brain-computer interfaces (BCI) are used.

Table 1. The BIT were sorted by the Invasive Level and then by the Portability

Brain Imaging Technique	Invasive Level	Portability	Activity Type
EEG	No	Yes	Electrical
NIRS	No	Yes	Metabolic
MEG	No	No	Magnetic
fMRI	No	No	Metabolic
SPECT	No	No	Metabolic
PET	No	No	Metabolic
ECoG	Slightly	Yes	Electrical
INR (LFP)	Strongly	Yes	Electrical
INR (MUA)	Strongly	Yes	Electrical
INR (SUA)	Strongly	Yes	Electrical

Table 2. The BIT were sorted by the Temporal Resolution and then by the Spatial Resolution

Brain Imaging Technique	Activity Type	Temporal Resolution	Spatial Resolution
EEG	Electrical	~0.001 s	~10.00 mm
INR (SUA)	Electrical	~0.003 s	~0.05 mm
INR (MUA)	Electrical	~0.003 s	~0.10 mm
INR (LFP)	Electrical	~0.003 s	~0.50 mm
ECoG	Electrical	~0.003 s	~1.00 mm
MEG	Magnetic	~0.050 s	~5.00 mm
PET	Metabolic	~0.200 s	~1.00 mm
fMRI	Metabolic	~1.000 s	~1.00 mm
NIRS	Metabolic	~1.000 s	~20.00 mm
SPECT	Metabolic	~10 s - 30 min	~10.00 mm

These interfaces are also known as brain-machine interface, which allows any user who has suffered some nerve damage of his system by any amputation, trauma or disease, to control a computer, electronic or robotic device, via control signals, generated by their neurophysiological activity [13].

In other words, the BCI allow interaction between users and their environment [7]. The advances in knowledge of neurophysiology and movement systems in the past 4 decades have led to major improvements in the BCI.

At first, researchers tested monkeys with them to analyze the behavior of their brain waves.

As they were advancing their research, these began to be implemented in humans, using intracranial sensors for reading the BCI [25].

The focus of the BCI is to help patients to communicate with their environment, improve their mobility, assist in their recovery, or treat disease. A BCI can be used to restore, supplement, replace or upgrade the Central Neural System (CNS), of natural outlets [26].

Nowadays, the BCI are geared more to improve communication, mobility, rehabilitation and treatment of diseases, for its foray into the industry. Similarly, besides being developed BCI for people with disabilities, they are doing for the great video game market.

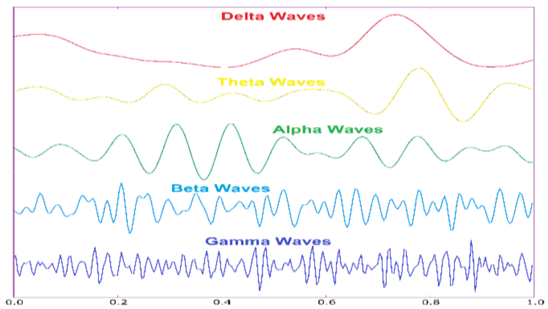

Fig. 1. Brain waves

Table 3. Frequency ranges of the brain waves

Band	Frequency (Hz)
Delta	< 4
Theta	≥ 4 and < 8
Alpha	≥ 8 and < 16
Beta	≥16 and < 32
Gamma	>32 and < 100

In addition to video games, other applications of BCI for these people are focused on being able to communicate, control computers, manipulate robotic systems, or move simple prosthesis [27], without the need to move some muscle, using only his brain.

We can see that the BCI technologies are not only limited to control simple electrical devices but to control more complex systems. This is achieved by sending the BCI high level control command for the system, which is translated into low-level commands for controlling the entire system [28]. These commands are the result of the brain activity patterns detection.

These patterns are obtained by processing the obtained signals acquired by the sensors, in this case, the electrodes, reflect the intention of the user to perform an activity, and are translated into an outlet, such as control of an external device or the movement of a cursor [29]. The electrodes of BCI systems detect the five major brain waves read of most EEG devices and shown in Fig. **1**. The frequency bands are divided per their frequency and are: Alpha (α), Theta (θ), Beta (β), Delta (δ) and Gamma (γ) [30]. Delta waves (δ) are the slowest and with greater amplitude brain waves, range from 1 to 3 Hz, are detected in the thalamus or cortex, associated with the phase 3 of NREM sleep (Non-rapid eye movement sleep), known as slow-wave sleep (SWS), and represents the deep sleep.

Theta waves (θ), are located on the scalp, are low frequency waves, range between 4 and 8 Hz. There are 2 types of Theta waves. Theta cortical, associated with meditative states, sleep period, or during sleep, but not sleep; and Theta hypothalamus, when there is any motor activity, such walking or during the REM sleep (rapid eye movement sleep).

Alpha waves (α), can be detected by EEG or MEG, are originated mainly in the occipital lobe, can be detected with closed eyes, drowsiness open eyes or when sleep decreases, are the strongest EEG brain waves, show greater amplitude on the dominant side, oscillate between 8 and 16 Hertz, have a connection with the mental states of relaxation and are useful to have training through biofeedback.

Beta waves (β), are in the motor cortex, related to muscle contractions, associated with the waking, have low amplitude waves, with multiple variable frequencies, ranging from 16 to 32 Hz, and associated with active concentration, active thinking, busy thinking and anxiety. Their main activity is detected by sensors when the brain is in a quiescent state, and decreases when there is a change in its movement.

Finally, Gamma waves (γ), oscillate between 32 and 100 Hertz, being mainly 40. They are related to cognitive processes and the use of short-term memory for recognizing objects. Table 3 shows the frequency ranges of the brain waves.

There are three types of BCI, shown in Fig. 2, per the acquisition of neurophysiological signals obtained from brain activity. The direct or invasive BCI, SUA, which implies an invasive procedure to implant the electrodes in the brain, that is, directly into the gray matter. The partially invasive BCI, ECoG, in which electrodes are implanted inside the skull but without reaching the brain. And the non-invasive BCI, based on analysis EEG, which uses scalp electrodes [31].

Once the user has an intention, it is detected from brain activity using electrodes placed on the scalp, cortical surface or within the brain.

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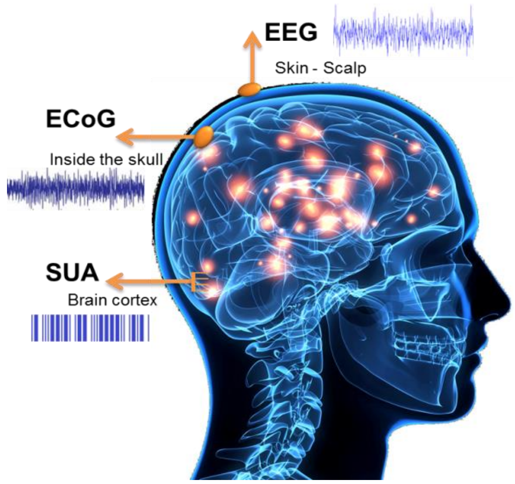

Fig. 2. Types of acquisition of neurophysiological signals of BCI: SUA, ECoG and EEG

Fig. 3. Device used for acquiring the EEG signals

As neural electronic signals, they need to be acquired, amplified and digitized.

Once digitized, they are sent to a computer. For a better sensor reading, it is necessary to remove all external devices that could generate some interference [32].

Having eliminated external devices, the main acquired signals are filtered to remove any electrical noise and other unwanted signals.

As it has been removed unwanted electrical noise, the brain signals are converted into functions or commands to an output device, directly related to the user's intention.

Finally, the device provides a feedback signal to observe its efficiency [33].

3 Development of Non-Invasive Brain-Computer Interfaces Dedicated to Rehabilitation Systems

Based on the above, it was decided to develop a BCI, that detect brainwaves from an EEG, because this is the fastest of BIT, besides being a non-invasive portable system. The device that was used is the EMOTIV EPOC ®, which has a high resolution, is a portable system and has been designed specifically for research.

THE EMOTIV system measures the electrical activity associated with the brain and facial muscles [11].

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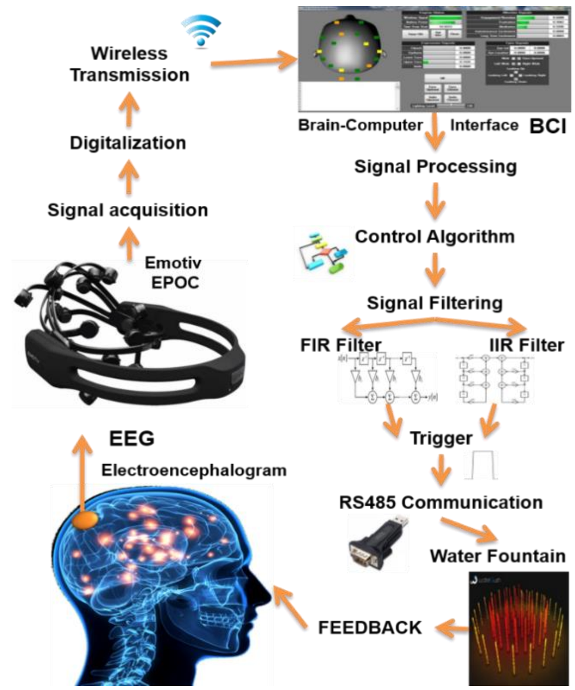

Fig. 4. General diagram of the complete operation of the EEG-BCI integrated system

It has 14 electrodes, 1 gyroscope, sensors, lithium-poly and a transceiver radio frequency to connect wirelessly with the computer or embedded system. In Fig. 3, we can see the location of the gyroscope, battery and sensors, where the electrodes are. The system can have a range with its lithium-poly battery up to 12 hours. It has a 16 bits resolution, with the least significant bit (LSB), equal to 0.51μV [11].

Having defined the EEG system that was to be used, we joined with the BCI. The integrated complete EEG-BCI system (Fig. 4), has the following functionality: the user performs an intention, i.e., a specified mental task, with the aim of producing an electronic signal in your brain. Once generated this intention, the analog brain signal is acquired via EEG system, amplified for processing, digitized and transmitted wirelessly via radio frequency (RF), in a 2.4 GHz band. This signal is received by the computer, processed using a pattern recognition for getting events and commands related to intention.

To reduce noise and hysteresis, a finite impulse response filter (FIR), or an infinite impulse response filter (IIR), are applied to the processed events. After this, new events and commands are obtained and sent via the RS485 serial transmission protocol to the output device. From these commands, you can control the movement of a device, the environment, and many other applications. Finally, a visual mental process feedback is performed by the user, to verify that the instruction he thought was effectively send to the output device.

Per the motor disability of each person, and its specific task, we should configure the system in the relationship for the inputs we get, and the outputs we want. For example, if we wanted to program a line of waterjets moving one behind other, we would to get the “Push” activity and match it with the lineal waterjet movement of the water fountain configuration software.

Once we had defined the system, we worked in conjunction with BCI tests that were performed by various persons to verify the reliability of the system. These tests were divided into 3 stages: the testing, the training and the performance stage. Each person was asked to conduct mental activities for seeing the operation and response between the desired activity and the result

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obtained. All tests were recorded for later analysis. The mental activities that were asked to people were to imagine that an object is pushed by him, pulled, levitated, rotated or disappeared.

From every thought of each person was a binary result recorded, i.e., if the system had responded satisfactorily, it was recorded a high logic value ("1"), otherwise a low logic value ("0"). For each type of thinking test, they performed a test for each stage. They performed 20 tests in testing, 40 in training and 40 in performance.

The testing consisted in asking people to use the system without prior training, and undertake the requested thoughts. In training, they were trained in using the system to improve its performance. The training was that each person had to practice for each event, had to observe the thought made and the response obtained, so the system could identify him. The performance was if they were already using it at industry.

Prior to the implementation of the system in the industry, it was found that there was hysteresis in the processed signal, so it was decided to implement a filter to remove unwanted sporadic events. It was necessary to implement a filter to analyze the historical events, besides its latest logical responses. If the system was in a high logic value ("1") and reached a sporadic event of a low logic value ("0"), the latter was despised.

To change its status, we need several events with a low value ("0"). Similarly, going from "0" to "1" was the same. The concept of two types of filters was used for this filtered signal:

Finite Impulse Response (FIR) and Infinite Impulse Response (IIR). In the FIR, N past samples are used for analysis and required to observe and analyze the behavior of the signal [34]. Its general formula is:

$$y(n) = b_0 x(n) + b_1 x(n-1) + \cdots + b_N x(n-N)\,, \tag{1}$$

briefly:

$$y(n) = \sum_{i=0}^{N} b_i \cdot x(n-i)\,. \tag{2}$$

where:

- $x(n)$ is the input signal,
- $y(n)$ is the output signal,
- N is the order of the filter, a filter of order N is (N + 1) terms on the right side,
- b_i are the filter coefficients.

In IIR filter, besides using N past samples, N-1 samples of the latest system outputs are used [35]. Its general formula is:

$$y(n) = \frac{1}{a_0} \cdot [b_0 x(n) + b_1 x(n-1) + \cdots + b_N x(n-N) - a_1 y(n-1) - a_2 y(n-2) - \cdots - a_M y(n - M)], \tag{3}$$

briefly:

$$y(n) = \frac{1}{a_0} \cdot \left(\sum_{i=0}^{N} b_i \cdot x(n-i) - \sum_{j=0}^{M} a_j \cdot y(n-j) \right), \tag{4}$$

where:

- $x(n)$ is the input signal,
- $y(n)$ is the output signal,
- N is the feedforward filter order,
- b_i are the feedforward filter coefficients,
- M is the feedback filter order,
- a_i are the feedback filter coefficients.

From the above concepts, we decided to use both filters to see what the filter was, that gave us a better performance according to our binary samples.

As it was increasing the filter order, i.e., the number of samples (N), the signal was softening. Also for greater filter precision, binary signals were transformed in analog values, thus obtaining greater range activation. Once applied the filter, it was necessary to return to a binary signal, so a comparison signal or "trigger" was implemented. With this, we increase or decrease the events duration with only alters its comparison value.

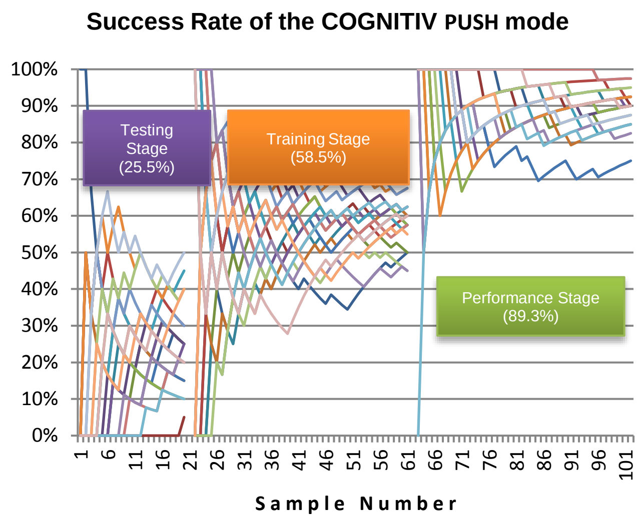

Fig. 5. COGNITIV results of PUSH mode

The first test was performed based on the FIR filter order 2 to 16, in which it was observed how the signal was acquired gradually softened. The larger was the order of the filter, the center stabilized was the signal tended, so it was concluded that it could not use a very high order. From the above, it was decided instead of using a high order filter, analyze the signal by two filters not so high order, obtaining very satisfactory results, illustrated in the following chapter.

The second test was carried out by the IIR filter, in the same way as above, from order 2 to 16., and, there were analyzed inputs and outputs. IIR filter was more efficient than FIR, reconstructing the acquired signal in fewer samples.

Per the results, it was decided to use the concept of IIR filter to implement two filters of 3rd order each. To return to the binary events signal, it was used a 50% "trigger". This “trigger” works as the following way: all signal greater or equal than 50%, would be taken as a high logic value (“1"), whereas any value less than 50% would be taken as a low logic (“0"). Once the filter was implemented, it was decided to test the system in a company dedicated to the manufacture of dancing water fountains that coordinates water and light with the rhythm of music.

For the water-light-sound coordination, this company performs a manual programming, i.e., all events and sequences should be generated as they play the song. This kind of programming is time-consuming, tedious and tiring, because they should listen to the song at least 50 times.

Based on the above, it was decided to implement the system in this company in a person with motor disabilities, which would make the programming of songs using the EEG-BCI system.

The system will generate the events and sequences to be executed by the fountains per the thoughts generated by the person and his rhythm and harmony feeling of the song that he was listening.

4 Results

The efficiency of the system was analyzed during its three stages tested. For the tests, people were asked to carry out some thoughts. From these, if the system detected his thought, it was registered a logic high ("1"), otherwise a low logic ("0") was captured. The first time, system efficiency was low, ranging from 5% to 50% of efficiency, and having a 26% average. While was conducting more tests, we could see that their performance was gradually improving. This can be seen in Fig. 4, where there are the results displayed of the 20-people performance that imagined they were

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Table 4. Effectiveness percentage of each person during the Push activity

	Person #	Stage 1	Stage 2	Stage 3
Activity - Push	1	25%	50%	90%
	2	5%	58%	90%
	3	25%	50%	88%
	4	25%	63%	90%
	5	20%	60%	93%
	6	15%	60%	85%
	7	15%	58%	75%
	8	30%	60%	93%
	9	10%	58%	90%
	10	25%	63%	90%
	11	45%	58%	85%
	12	40%	68%	93%
	13	30%	68%	98%
	14	20%	58%	98%
	15	40%	45%	95%
	16	20%	45%	83%
	17	10%	63%	85%
	18	40%	55%	90%
	19	50%	75%	88%
	20	20%	60%	90%
	Average	**25.50%**	**58.50%**	**89.30%**

Stage 1: Testing Stage
Stage 2: Training Stage
Stage 3: Performance Stage

pushing an object. During the testing stage, it had 25.5% effectiveness. Once practiced in training stage, they doubled to 58.5% of effectiveness. Finally, in performance, they increased to 89.3%.

Similarly, we can observe Table 4, in which the effectiveness percentage that had each person during each stage is shown, and its average. Fig. 5 shows the average of all people during all the sampling time of the PUSH activity and the substantial progress between the stages.

Besides the pushing thinking, they were also tested to imagine that the object was pulled, levitated, rotated or disappeared, obtaining similar results.

In Fig. 6 we can see the average per stage of all persons in each of the activities or thoughts that they were asked. Despite having obtained effectiveness in all activities nearly 90%, it was necessary to apply a digital filter to obtain a better sampled signal quality. This was necessary because of the hysteresis detected in the system. It was asked to the users to perform during fixed time periods they were doing the mental activities. In other words, the user would perform the mental activity for 1 or 2 seconds, and then stop it for 1 second.

The system had a sampling rate of 10 Hertz, i.e., it takes 10 samples per second. At the top of Fig. 7, we observe a 10 second sampling period, in which the duration of the desired events is clearly visible. Once they processed the information, the data was stored.

The graphical representation of this data can be seen at the bottom of this figure. We also can see in it that the obtained data by the system, is not a truly representation of the desired events. This was caused by the hysteresis of the system. Because of this, it was decided to implement, based on the concepts of FIR and IIR filters, a filter that could reconstruct the original image as real as could be. In this sense was implemented a FIR filter to the acquired signal for eliminating hysteresis. It was implemented from 2nd to 16th filter order for observing the response. In other words, there were taken from the last 2 to the last 16 received input signals.

While it was increasing the filter order, the signal was softening and tended increasingly to be a line. At the following images, there will be a code like this: *XXX#_Y_Z*, where:

– *XXX* is the filter type, it can be FIR or IIR,
– # is the filter order,
– *Y* is the filter turn, A is 1st time, B is 2nd time,
– *Z* indicates if the signal has been triggered (T).

From this filtered signal, a 50% trigger signal, was applied. If the value was higher or equal than the 50% trigger signal, it would be modified to a “1", and if this value was lower than the 50%, it would be modified to “0".

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Table 5. Average of each activity during all stages

Activity	Stage		
	1	2	3
Push	25.5%	58.5%	89.3%
Pull	24.3%	58.9%	90.0%
Levitate	24.8%	60.4%	90.6%
Rotate	23.0%	60.0%	90.4%
Disappear	22.8%	59.1%	90.8%
AVEGAGE	**24.1%**	**59.4%**	**90.2%**

Stage 1: Testing Stage
Stage 2: Training Stage
Stage 3: Performance Stage

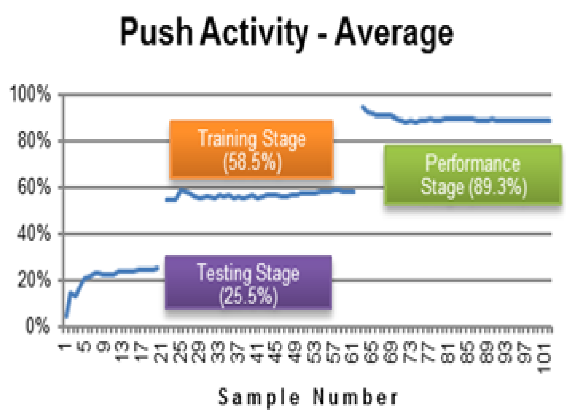

Fig. 6. Average of each stage in the Push activity

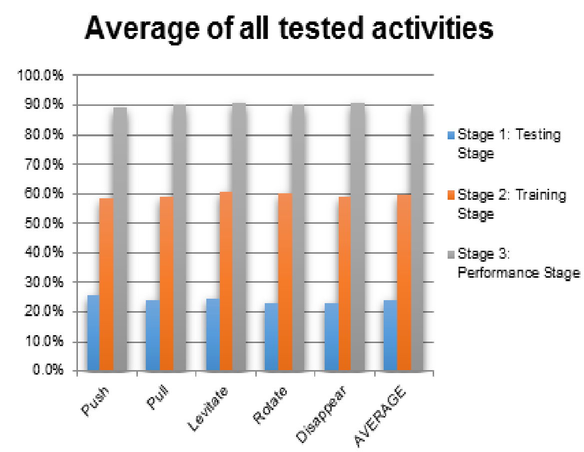

Fig. 7. Average activity during all stages

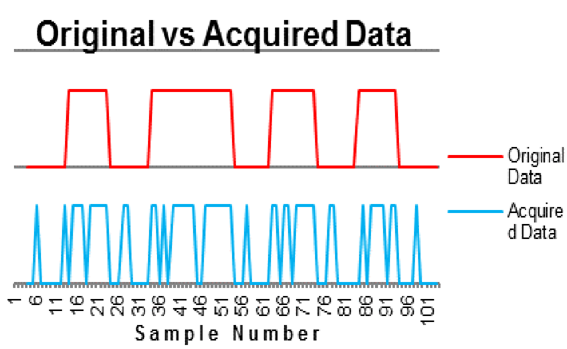

Fig. 8. Comparative between the original data desired and the real acquired data

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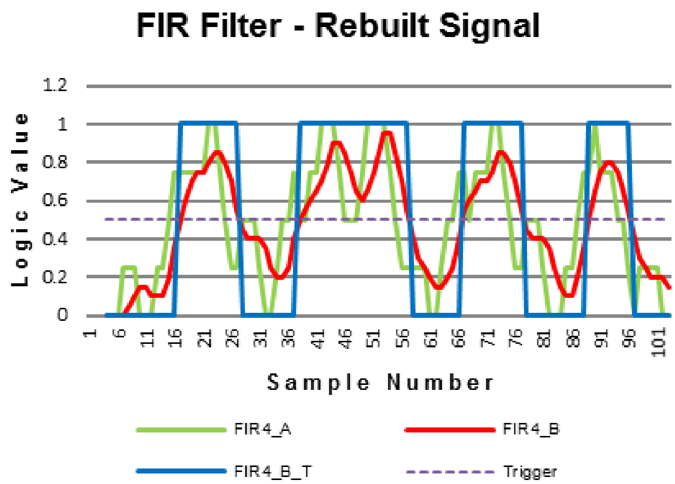

Fig. 9. Rebuilt signal using the FIR filter twice

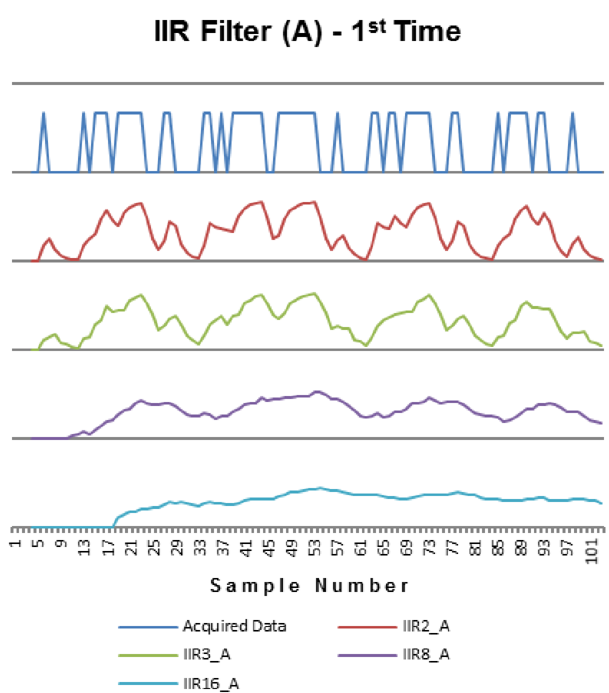

Fig. 10. Filtered signals using the IIR filter by 1st time

The purpose of applying this trigger signal was to recover the digital signal that was originally received.

The signal could be reconstructed with an FIR filter of 8th order, i.e., we have a delay of 8 samples before they can start detecting an event. Due to the

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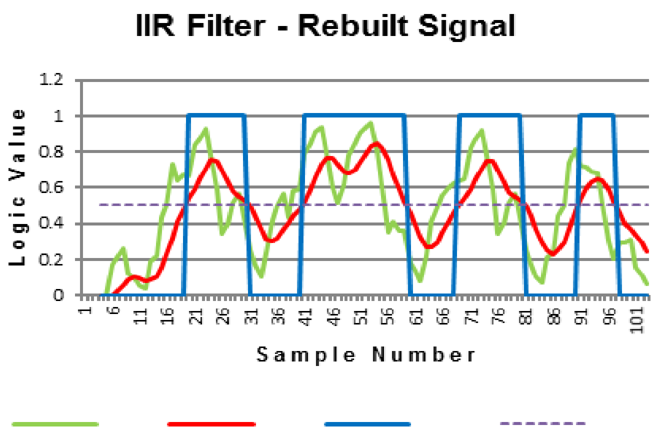

Fig.11. Rebuilt signal using the IIR filter twice

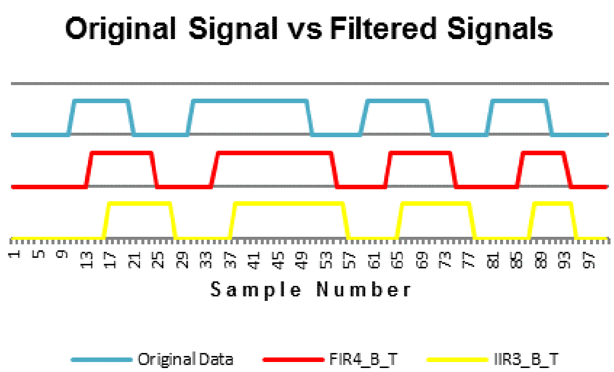

Fig. 12. Comparative between the original desired signal and the filtered signals

foregoing, it was decided to apply the FIR filter again, but this time it would be applied to the filtered signal (A), for the first time. From this information, the 50% trigger signal was applied again, to return it to a binary signal.

The twice filtering showed us that now the starting signal recovered from the filter of 4th order, instead of 8th order which threw us a single filter. This is beneficial for us, because we only should wait 4 samples instead of 8. Then, we got the reconstructed binary signal, obtained from a FIR filter of 4th order.

The first filter (A) signal, the second filter (B), signal, and the binarized signal by the trigger signal are shown in Fig. 8.

Similarly, to the FIR filter, an IIR filter was implemented too. This was implemented also to reduce the system hysteresis. In the IIR filter the output obtained signals are used in addition to the input signals. It was tested from 2nd to 16th order. In Fig. 9 we can see when it was increasing its filter order, the signal was getting smooth and tended increasingly to be a line.

It can be seen in Fig. 10 that the signal is smoother than the FIR filtered. We also applied a 50% trigger signal to the filtered signal. This was for recovering the digital signal that was originally received. The signal could be reconstructed with an 8th IIR filter order, i.e., similarly to the FIR filter, we have 8 samples delay before they can start detecting an event. It was also decided to apply the IIR filter again, but this time it would be applied to the filtered signal (A), for the first time. From this information, the 50% trigger signal was applied

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again, to return it to a binary signal. In contrast to the FIR filter, the 2nd IIR filter (B), recovered the original signal in the 3rd filter order instead of the 8th order tilter. This is beneficial for us because we only should wait 3 samples instead of 8. Then, we got the reconstructed binary signal, obtained from a IIR filter of 3rd order. The first filter (A) signal, the second filter (B) signal, and the binarized signal by the trigger signal are shown in Fig. 11.

Finally, we can see in Fig. 12 the comparison between the desired original signal and the obtained signals after have been analyzed by the FIR and the IIR filter. Here we can see that the FIR filtered signal, despite using more samples, its signal has a faster response than the one analyzed by the IIR filter.

For the kind of application where the system is being applied, this time delay is negligible, because it does not affect, because most of the events have a long duration. Once solved the problem of system hysteresis, it was tested in a company dedicated to making water fountains that dance according the music. Its main application within this company was to program songs for dancing fountains through the system, i.e. using only the thoughts that are read by an EEG and translated by the BCI. By using this technology within the company engaged in the manufacture of water fountains, it was possible to reduce programming time to less than half, which will eventually be reflected in higher profits.

5 Conclusions

Using a system to read an electroencephalogram (EEG), of the brain in real time, in conjunction with a brain-computer interface (BCI), developed, it can be very useful for companies wishing to innovate and incorporate people who suffer any motor disability. The above was because the system would help them to get a better perform at their work without the need of moving, using only their thoughts.

We decided to use this system and apply it to a water fountain company, because this kind of technology is used in most people for rehabilitation and not for use within the industry approach. The brain imaging technique (BIT) for reading the brainwaves was the electroencephalogram (EEG), because it was the system that had a shorter response time, besides of being a non-invasive system.

To reduce the system hysteresis, it can be used the proposed filters: Finite Impulse Response (FIR), filter or Infinite Impulse Response (IIR) filter. Both run with a similar number of samples and have approximately the same delay and reaction time.

After making the proper training of people who was going to use the system, and as well as implementing the appropriate filters to reduce hysteresis, it was observed that the whole system had a high rate of effectiveness and reliability. In addition of the water fountain company, this system has the capability and versatility of been used for any company, it is only necessary adapt it to the company we want to use it for. We configure the inputs we that get. for the outputs, that we want.

Also, this system can significantly improve the life quality of people suffering any physical disability, because it improves their self-esteem, as they are considered to develop a job as anyone else and thus generate a profit also to the company that hired them, creating a shared value between the company and the society in which it is established. From this system and this platform can generate future research, such as automobile control, thinking-only writing, people communication without speaking, rehabilitation, among others.

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