Universidad Autónoma de Querétaro

Facultad de Ingeniería

Ingeniería en Automatización con Línea Terminal en Mecatrónica

Diseño e implementación de un sistema BCI para el análisis de EEG

TESIS

Que como parte de los requisitos para obtener el grado de Ingeniera en Automatización con Línea Terminal en Mecatrónica

Presenta:

Luz María Sánchez Reyes

Dirigido por:

Dr. Juvenal Rodríguez Reséndiz

SINODALES

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Resumen

El propósito de esta investigación es implementar un sistema BCI (Brain Computer Interface) con arquitectura abierta para el análisis de potenciales. Específicamente, el proyecto consiste en lograr que la interfaz para mostrar las señales EEG (electroencefalograma) pueda ser modificable, así como la programación del procesador embebido (DSP, Digital Signal Processor), es decir, tener un sistema de adquisición de señales EEG capaz de ser modificado a como mejor convenga al usuario. Se presentan algunos datos históricos sobre el desarrollo de los sistemas BCI en las últimas décadas y la importancia del dispositivo en el área de la medicina y más específicamente en la rehabilitación de personas con discapacidades motrices. Además, se muestran resultados de pruebas EEG a diferentes personas, verificando que los niveles de interferencia y ruido estén dentro de los límites permitidos de acuerdo a otros estudios similares.

Palabras clave: *BCI, DSP, EEG, LabView, arquitectura abierta.*

Abstract

The purpose of this research is to implement a BCI (Brain Computer Interface) system with an open architecture for the analysis of potentials. Specifically, the project consists of making the interface to show the EEG (electroencephalogram) signals be modifiable, as well as the programming of the embedded processor (DSP, Digital Signal Processor), that is to say, to have an EEG signal acquisition system capable of being modified to best suit the user. Some historical data on the development of BCI systems in the last decades and the importance of the device in the area of medicine and more specifically in the rehabilitation of people with motor disabilities are presented. Also, results of EEG tests to different people are shown, verifying that the levels of interference and noise are within the allowed limits according to other similar studies.

Key words: *BCI, DSP, EEG, LabView, open architecture.*

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I thank God for accompanying and guiding me through life, for being my strength in times of weakness and for giving me a life full of learning, experiences and above all happiness.

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CHAPTER 1

Introduction

The present investigation refers to the design and implementation of a system for the acquisition of EEG signals applied to the analysis of the brain, i.e., the electroencephalogram. The electroencephalogram (EEG) is the record of the electrical activity of brain neurons, in Figure 1.1 is shows the basic operation of a BCI (Brain Computer Interface) system for analysis of EEG signals. This register has very complex forms that vary greatly with the location of the electrodes and between individuals. This is due to a large number of interconnections presented by neurons and by the non-uniform structure of the brain.

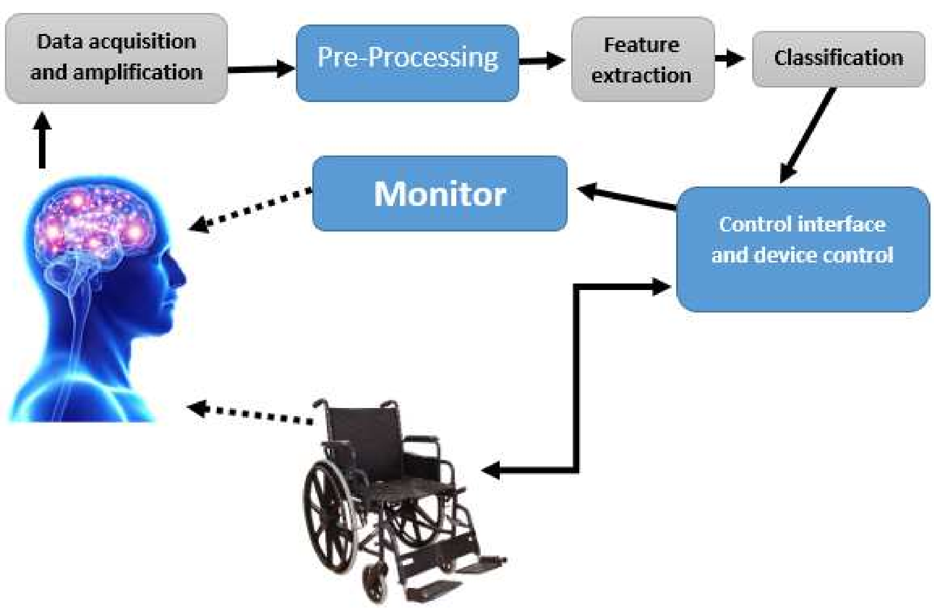


Figure 1.1: Block diagram of the basic operation of a BCI system.

A BCI is an interface that attempts to provide the brain with multiple, non-muscular channels of communication and control to transmit messages and commands to the outside world. In recent years, the development of portable and low-cost BCI systems has led to an increase in the development of BCI systems, from the simplest device of an electrode to portable 64-channel systems. For the BCI project development, we used an 8-channel EEG with 24-bit ADC resolution.

1.1 Motivation

By 2014, there were 32.5 million households in the country, of which 6.1 million reports that there is at least one person with a neuro-motor disability; i.e., in 19 out of 100 households a person with a neuro-motor disability lives. In Figure 1.2 is shown the percentage of people in Mexico who suffer some disability.

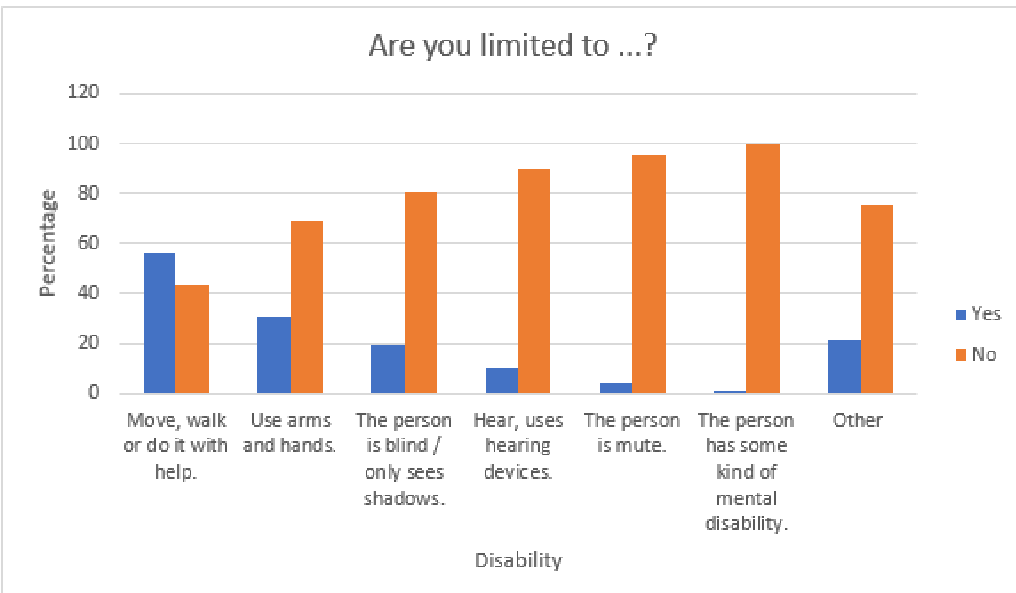


Figure 1.2: Characteristics of persons with disabilities.

BCI systems are very important in the field of medicine and more specifically in rehabilitation. They contribute to establish a communication channel and control for those individuals with deficiencies in their motor functions, therefore with the design and implementation of a BCI system is sought using signal acquisition, pre-processing, feature extraction, sorting, and feedback.

With the research of BCI systems, it is possible to achieve in future research the development of an efficient, effective and easy-to-use BCI system; it would be possible for people of limited resources to acquire and be able to use BCI system, and with the increased resolution of the system, a better analysis of brain signals can be achieved.

1.2 Problem Formulation

A brain computer interface is mainly based on the analysis of electroencephalographic signals recorded during certain mental activity to control an external component. EEG activity includes a variety of different rhythms identified by their frequency, location and other aspects of brain function that cause the EEG signal be extremely complex, however, the development of new and improved BCI systems will allow us to analyze the EEG signal more efficiently, quickly and is affordable for many people.

The number of people with motor disabilities increases each year considerably. Currently, most research centers concentrate their efforts to achieve the improvement of BCI systems since this will allow us to develop biofeedback techniques that help us to generate a reliable form to the same electroencephalographic pattern in function of interest.

Also, most devices in the market for monitoring electroencephalographic signals have a resolution of 8 to 16 bits, with the improvement of this parameter can achieve better signal analysis. With the improvement in the design and adaptation of the device, it is hoped that future research will achieve a BCI system that is more accessible to people with limited resources.

1.3 Hypothesis

A BCI platform developed at the UAQ enables advanced processing research tools to be generated through EEG signal analysis techniques.

1.4 Objective

Implement an EEG signal acquisition system with an open architecture.

1.4.1 Specific Objectives

- Implement a programming code on an embedded processor for an EEG signal acquisition system.

- Use a noise-filter for the processing of electroencephalographic signals.
- Implement a modifiable graphical interface for EEG signal analysis.
- Generate EEG signals database.

1.5 Thesis Structure

The thesis is organized as follows:

- Chapter 1 is about the general panorama of the problem addressed in this project.
- Chapter 2 is about the state of the art of the BCI systems applied for EEG signal analysis.
- Chapter 3 is about the development of the project, describes the steps taken to achieve the goal.
- Chapter 4 shows the results obtained according to the objectives set.
- Chapter 5 is about the analysis of the results obtained.

CHAPTER 2

Literature Survey

The electroencephalogram (EEG) is a record of spontaneous potential differences or brain waves measured on the surface of the individual's human brain through metal electrodes (lead, zinc, silver, platinum, aluminum, steel, etc.) scalp (Barea, 2012), (Seijas et al., 2009). Brain waves are classified into four groups or bands depending on the frequency range and are identified by the Greek letters α, β, θ and δ as shown below. In Table 2.1 is shown the states of the brain and the Figure 2.1 shows the brainwave pattern occurring when a person is in different states of arousal (P & B., 2008),(W. et al., 2010).

Type of brainwave	Frequency(Hz)	State of consciousness	Normal amplitude(uV)
Beta β	13-30	A person in awake or alert condition.	<20
Alpha α	9-12	A person wakes up and truly relaxed.	20-60
Theta θ	5-8	A person feels depressed and tired.	<100
Delta δ	2-4	A person is in deep sleep.	<100

Table 2.1: Brain states

Current medical science has tools to monitor brain activity through the electroencephalography (EEG) technique. The development of this technology has allowed the appearance of devices that allow the communication of the brain with a machine (BCI), which fields of application are diverse and are increasing (P. & Karayiannis, 1997), (W. et al., 2010), (P & B., 2008).

The EEG was invented by Hans Berger in 1924 although his study started before that year. The earliest descriptions of the existence of electrical brain activity were made by the English physiologist Richard Caton, professor of physiology at Liverpool's Royal School of Medicine. The English scientist hypothesized that peripheral stimuli could provoke focal electrical brain responses. This hypothesis allowed him to obtain in 1874 funding from the British Association of Medicine to be able to confirm it. In his historical publication on brain electrical activity in the British Medical Journal in 1875, he compared his work to that of an English neurosurgeon, David Ferrier, some years earlier. In Figure 2.2 is shown a

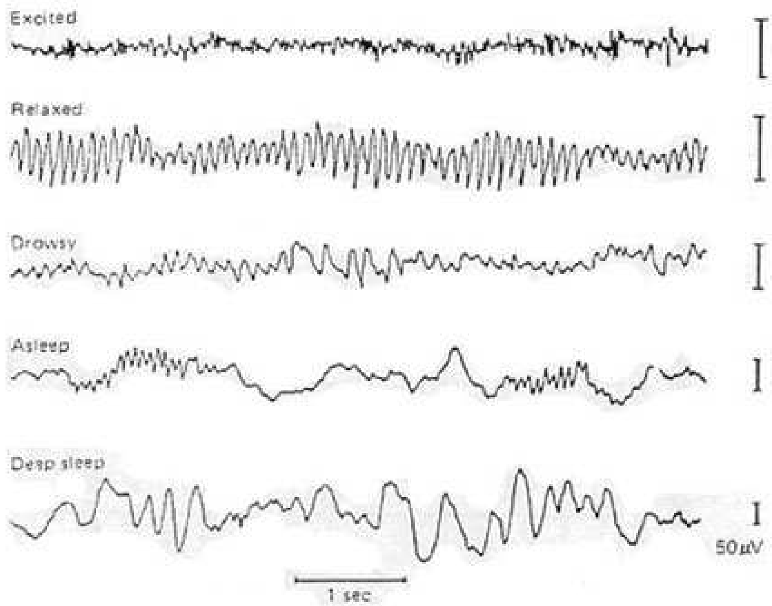
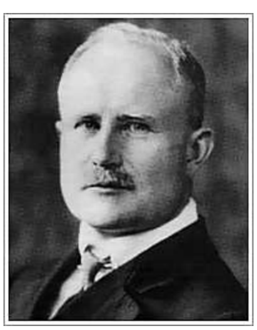


Figure 2.1: Types de EEG or Brainwaves (P & B., 2008).

photograph by Hans Berger and Richard Caton, investigators of EEG signal analysis (Savage, 2015),(Audette, 2015).

Approximately 15 years after the discoveries of Caton, Adolf Beck, medical students, and Professor Cybulsky, their mentor at the University of Krakow in Poland, inspired by the works of Hitzig and Fritsch, made new proposals to try other methods of functional localization in brain. It is important to mention that neither of them knew the works of Caton. Beck's thesis describes the observation of visual evoked potentials (F. & N., 2015), (H. R. & R., 2016), (N. et al., 2014), (V. R. et al., 2004).



(a)

(b)

Figure 2.2: (a) Hans Berger 1; (b) Richard Caton 2.

Russians Pavel Kaufman (1912) and Pradvich Neminski (1913) were the first to establish that cerebral electrical potentials can be collected through the intact skull. Kaufman described the existence of two bio-electrical periods during anesthesia: the first to increase potentials (excitation phase) and the second to decrease potentials (depression stage). Neminski, using a string galvanometer, first described the different brain rhythms captured in dog brains according to their frequency (10 to 15, 20 to 32 cycles per second), baptizing these oscillations with the term "electroencephalogram".

Despite the innumerable studies on brain activity and EEG performed by different researchers, the father of the human EEG was Hans Berger, Head of Psychiatry Unit at the University of Jena (Germany). He after a long series of studies on July 6 of 1924 recorded the first of the rhythmic oscillations of the brain of a young man of 17 years. For electroencephalographic recording in humans, he used needle electrodes and a cord galvanometer with a mirror that reflected light which in turn allowed the exposure of silver bromide photographic paper that moved at 3 cm per second (the same speed that we use today).

In 1929, he published his discovery: spontaneous brain electrical activity in humans. As a careful investigator, he described in his publication the works of Caton, like those of Beck and Cybulsky. In his publication, he mentions: "'Consequently, I believe that I have discovered the Electroencephalogram of man and that I reveal it here for the first time." In 1930, he made 1,133 records in 76 people and prepared a second report. He designated with letters of the Greek alphabet the two types of waves that he had observed from the beginning in the tracings performed to human beings. The higher voltage and lower frequency were called alpha waves, the lower voltage and higher frequency, beta waves.

In 1931 we studied the frequency with which abnormal electroencephalography activity was observed in patients with epilepsy and recorded for the first time tip-wave activity.

Efforts to simultaneously record electroencephalography of signals EEG and intact events began in 1938 when at a meeting of the American Psychiatric Association Schwab showed moving images synchronized with an electroencephalographic tracing. Jasper and Hunter were able to perform a simultaneous recording of EEG and patient activity with a single camera with an ingenious system of mirrors placed on the patient and the electroencephalographic tracing. In the 1950's, television made the process less complicated. In 1960 the transistors that had been invented in 1947 replaced the amplifiers with vacuum tubes in the electroencephalogram obtaining a better graphic record. The same transistors made possible the computerized management of all aspects of electroencephalography (Barea, 2012), (Seijas et al., 2009),(Palacios, 2002).

Table 2.2 shows some technical characteristics of different BCI's for EEG signal analysis, implemented in the last decades V. R. et al. (2004), Putz et al. (2006), (Lin et al., 2008), (Ferree et al., 2001), (Lin et al., n.d.), (Chi & Cauwenberghs, 2010), (Martins et al., 1998), (Liao et al., 2012), (N. et al., 2014):

Year	Type	Channel	Samples/s	Num.Bits	Bandwidth	Gain	Transmission
2004	Implantable	Multichannel	40	12	450-5000	–	Cable
2006	No-invasivo	3	200	–	0.5-30	8	Cable
2008	No-invasivo	32	500	16	0.5-100	–	Bluetooth
2001	No-invasivo	128	250	16	0.1-100	–	–
2002	No-invasivo	8	512	12	1-50	6000	Bluetooth
2010	No-invasivo	4	–	16	0.7-159	–	Bluetooth
1998	–	16	–	–	0.3-150	500	–
2009	Implantable	32	15.7	10	0.1-50000	–	RF
2010	Implantable	32	30	12	0.5-50	–	RF
2012	No-invasivo	3	256	12	<100	5500	Bluetooth
2009	Implantable	64	62.5	8	390-2500	–	RF
2007	Front-end	–	–	–	0.5-100	–	–
2014	No-invasivo	16	1000	12	>0-15.5	–	–
2014	Implantable	16	–	10	450-5000	–	Wireless

Table 2.2: Technical characteristics of EEG systems

2.1 Background

2.1.1 The human brain

The brain is an electrochemical organ, in Figure 2.3 shows the basic parts of the brain. When brain works, different regions of the brain emit different frequencies called brain waves (Ormrod, 2005). The human brain is made up of specialized cells called neurons. Neurons are composed of a cell body, a nucleus, dendrites and an axon.

Neurons are electrically excitable cells, process and transmit information via chemical and electrical signals, in Figure 2.4 shows the basic parts and interactions of neurons. The electrical signals are generated by changes in the electrical charge of the neuron membrane that covers the whole cell. Neurons have an electrical potential at rest, which is the potential difference between the inside of the cell and the extracellular space. The resting potential fluctuates as a result of impulses coming from other neurons through the synapses. The synapse is a specialized inter-cellular functional junction between neurons, where the transmission of the nerve impulse is carried out, which begins with a chemical discharge that causes an electric current in the cell membrane. The cell membrane contains ion channels where ions of sodium (Na+), potassium (K+), and chloride (Cl-) and calcium (Ca-) are concentrated during chemical processes in the cell. The concentration of ions creates potential differences in the membrane. Changes in membrane tension generate post-synaptic

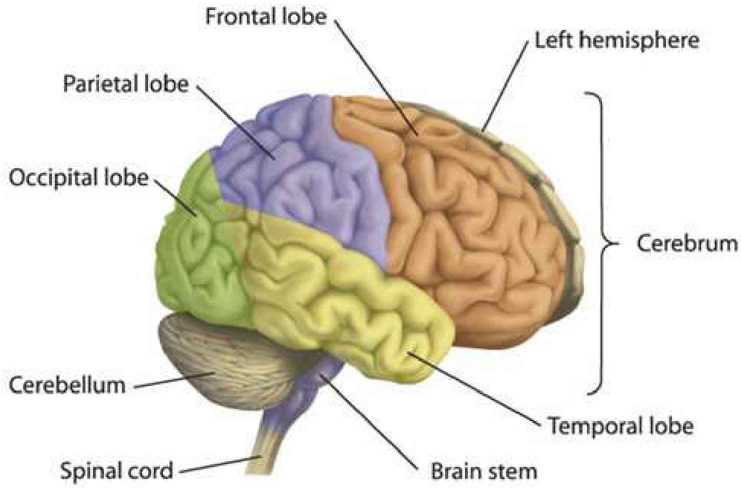


Figure 2.3: Parts of the brain.

potentials which cause electrical flux along the membrane and dendrites (Prieto et al., 2013), (P. & Karayiannis, 1997), (W. et al., 2010).

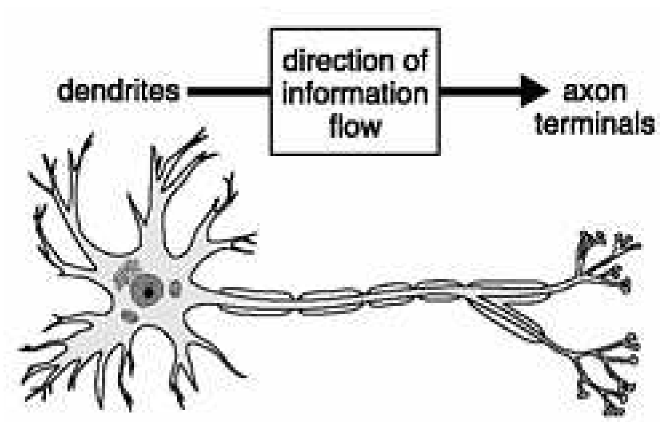


Figure 2.4: Neurons and their interactions.

When the potential difference is summed in the activation zone of the axon reaches the range of -43mV, the axon is triggered by generating an action potential at the +30mV that goes along the axon to release the axons. Transmitters at the end of it. When the potential difference is summed, and below this threshold, the axon rests (Ormrod, 2005), (Prieto et al., 2013).

Despite the fact that most electrical currents remain inside the cerebral cortex, a small fraction penetrates the scalp, causing different parts of the scalp to have different electrical potentials. These differences vary in amplitudes of 10-100uV which are detected by electrodes. There are different methods for recording brain activity based on state conditions (wakefulness, sleep, etc.) (Ormrod, 2005), (Prieto et al., 2013):

1. Electroencephalogram (EEG).
2. Magnetoencephalography (MEG).
3. Near infrared spectroscopy (NIRS).
4. Positron emission tomography (PET).
5. Functional Magnetic resonance imaging (FMRI).

Electrocorticography is an invasive technique, i.e.; it requires an intervention for the placement of electrodes on the cortical surface ($2.2m\Omega$). For their part, techniques 3, 5, 6 and 7 require higher cost facilities and equipment.

Electromyography is related to muscle contraction and single wave patterns. EEG is a simple, non-invasive, portable and inexpensive technique; Therefore, the most widely used method for recording brain activity in BCI systems. The present work will focus on the use of EEG technology (Prieto et al., 2013).

The electroencephalogram is an analysis that is used to detect abnormalities related to the electrical activity of the brain. This procedure keeps track of brain waves and records them. Small metal discs with thin wires (electrodes) are placed on the scalp and signals are then sent to a computer to record the results. The normal electrical activity of the brain forms a recognizable pattern. Through an EEG, doctors may look for abnormal patterns that indicate seizures or other problems.

2.1.2 EEG capture

Electrical signals are fundamental to the function of the nervous system, so it is important to determine the electrical properties that propagate along the excitable cells. However, despite the great diversity of recording techniques and experimental protocols, there are some common elements in all of them (P & B., 2008). The steps for the acquisition of EEG signals are shown in Figure 2.5.

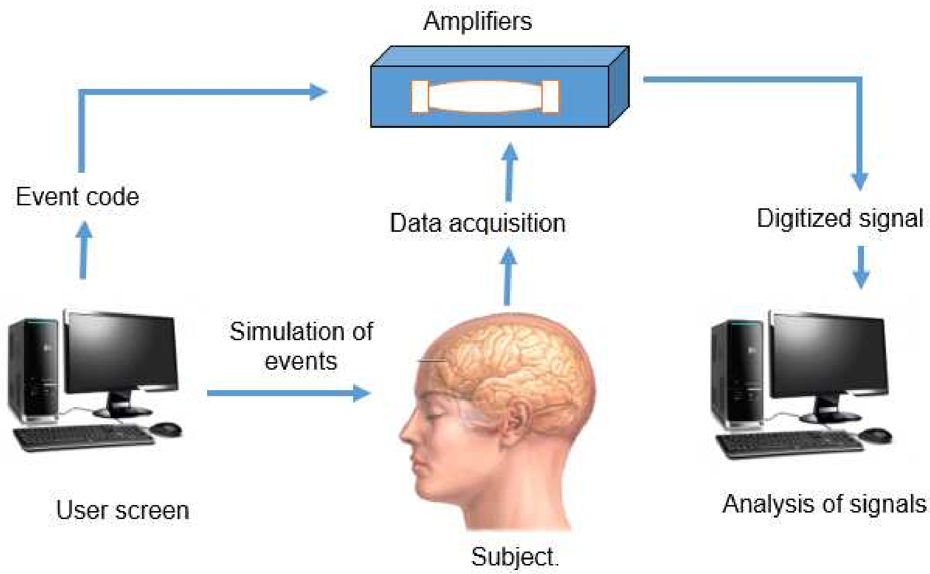


Figure 2.5: Acquisition of EEG signals.

Several procedures can capture brain bio-electrical activity:

- On the scalp.
- At the base of the skull.
- In exposed brain.
- In deep brain locations.

Different types of electrodes are used to capture the signal:

- Surface electrodes: Apply on the scalp.
- Basal Electrodes: Apply to the base of the skull without the need for a surgical procedure.
- Surgical electrodes: The surgery is precise and can be cortical or intracerebral.

The register of the brain bio-electrical activity receives different names according to the form of capture:

- EEG: When surface or basal electrodes are used.
- ECOG: If surgical electrodes are used on the surface of the cortex.
- E-EEG: When deep-operating surgical electrodes are used.

2.1.3 Electrodes for recording biopotentials

To record biopotentials you need an element that interfaces between the body and the measuring equipment, this element is the electrode, i.e., an electrode is a transducer. Most bioelectrical signals are acquired from one of the following three forms of electrodes: surface macroelectrodes, internal macroelectrodes, and microelectrodes. The electrodes can be classified into two types:

- Polarizable: In this type of electrodes there is no charge exchange at the electrode-electrolyte interface when a current is applied, in other words, the electrode behaves like a capacitor, and for this reason, there will be small scattering currents.
- Not polarizable: In this case, there is an exchange of charges at the electrode-electrolyte interface when we apply a current, in these will not require energy for the transition of charges so they will not exist on potentials.

The above is theoretically because in reality there are no materials for an electrode to behave in a theoretical way, then in practice are used materials that resemble a behavior as required in theory. For the polarizable electrodes, noble materials such as platinum are used, while silver-silver chloride electrodes are used for non-polarizable electrodes.

Classification of surface electrodes:

- Adhered. They are small metal disks of 5 mm in diameter. They are adhered with conductive paste and are fixed with collodion that is insulating, in Figure 2.6 (A) is shown an example of adhered electrodes. Correctly applied give very low contact resistances (1-2kΩ).
- Contact. These consist of small tubes of chlorinated silver threaded to plastic supports, in Figure 2.6 (B) is shown an example of contact electrodes. A pad is placed at its contact end which is moistened with conductive solution. They are fastened to the skull with elastic bands and connected with crocodile clips. They are very easy to place but uncomfortable for the patient. It is why they do not allow long-term registrations.
- In mesh helmet. The electrodes are included in a kind of elastic hull. There are helmets of different sizes, depending on the size of the patient. They are fastened with ribbons to a thoracic band. The most important features are the convenience of placement, patient comfort in long-term records, their immunity to artifacts and the accuracy of

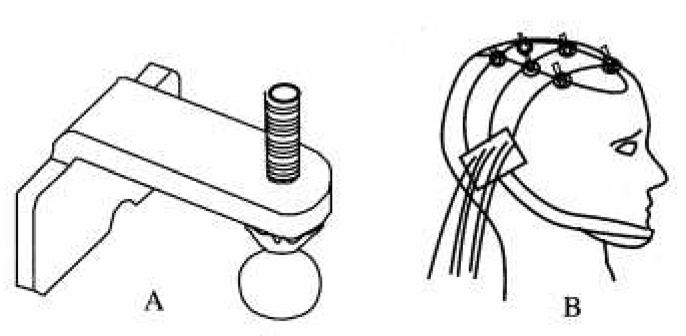


Figure 2.6: A. Adhered electrodes, B. Contact electrodes.

their placement, which makes them very useful in comparative studies, although to take advantage of this Characteristic is a very refined technique

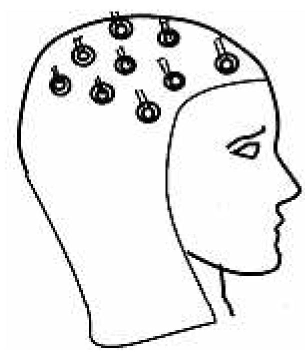


Figure 2.7: Principle of placement of electrodes in mesh helmet.

- Needle. Its use is very limited; It is only used in newborns and ICU. They can be disposable (single use) or multipurpose. In this case, their sterilization and handling must be very careful. All electrodes described so far only record the superior convexity of the bark. Special electrodes such as pharyngeal, sphenoidal, and tympanic are used to study the basal face of the brain.

- Surgical. They are used during the surgery and are handled exclusively by the neurosurgeon. They can be dural, cortical or intracerebral.

2.1.4 Ten-twenty electrode system of the International Federation

The "Ten-Twenty" International System is the most used today, however, with the EEG signal acquisition card that has only eight channels. Therefore the most important positions of the "Ten-Twenty" system will be chosen. To locate the electrodes according to the system "Ten-Twenty" proceed as follows:

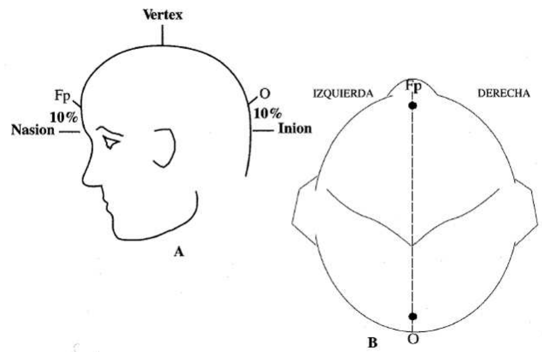
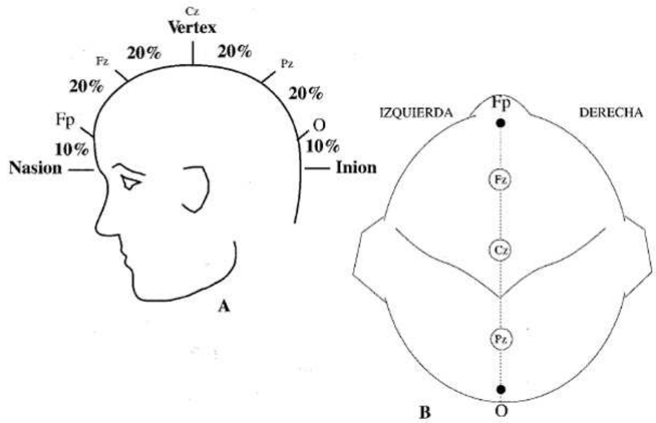
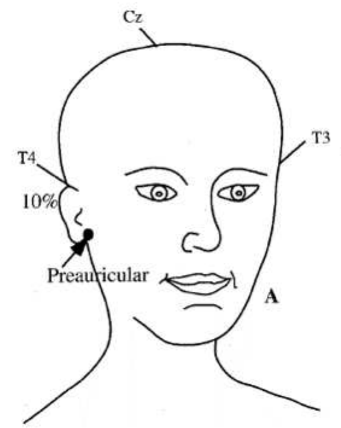


Figure 2.8: Position of the inion, nasion, Fp and O.

- The distance between the nasion and the inion is measured through the vertex. 10% of this distance on the nasion points to the point Fp (Polar Frontal). 10% of this distance on the inion points to point O (Occipital). Figure 2.8 shows the position of the inion and nasion, as well as Fp and O.
- As a general rule, the electrodes on the left side are numbered odd while those on the right side are numbered even. Also, the midline electrodes are given the subscript "z"'.
- Between the points FP and O are placed three other points spaced at equal intervals (between each two the 20% of the nasion-inion distance). These three points are, from front to back, Fz (Frontal) Cz (Central or Vertex) and Pz (Parietal). Do not confuse Fz, Cz or Pz whose subscripts mean "zero" (zero) with the letter "O" referring to the occipital electrodes. In Figure 2.9 (a) is shown the position of Fz, Cz, and Pz.
- The distance between the preauricular points (located in front of the auditory pavilion) and the vertex (Cz) is measured. The 10% of this distance marks the position of the medial temporal points, T3 (left) and T4 (right). In Figure 2.9 (b) is shown the position of T3, T4, and previous ones.



(a)



(b)

Figure 2.9: (a)Position of Fz, Cz and Pz ; (b) Position of C3 and C4.

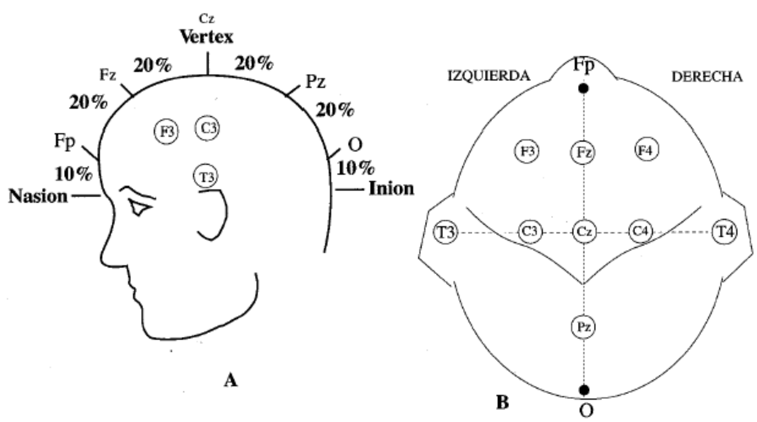


Figure 2.10: Position of C3 and C4.

- About 20% of the measurement above the mid-point are electrodes C3 (left) and C4 (right). The vertex is now the point of intersection between the anteroposterior line and the lateral coronal line. T3 (left) and T4 (right). In Figure 2.10 (B) is show the position of C3 and C4.

- The electrodes F3 and F4 (Left and Right, respectively) are located equally between the front mind point (Fz) and the line of temporary electrodes.

2.1.5 Recommendations for the use of electrodes

- When polarizable electrodes are used in contact with an electrolyte, a double layer of charges is formed at the interface.
- If the electrode is moved, a charge displacement is generated that produces a variation of the half-cell potential until equilibrium is restored.
- If a potential difference between two electrodes is being measured and one is moving, the noise appears in the measured signal.
- Noise is known as a motion artifact and can be a serious interference in the measurement of biopotentials.
- The motion artifact is minimal on non-polarizable electrodes.
- The motion artifact has a greater influence on low frequencies.

The behavior of an electrode depends on:

- The model.
- The characteristics of currents passing through the electrode.
- The behavior of high and low currents.
- Waveform.
- The frequency

2.1.6 EEG waves

- They have amplitudes ranging from 10uV in registers on the cortex, to 100uV on the surface of the scalp.
- Its frequencies are between 0.5Hz and 100Hz.
- They depend on the degree of activity of the cerebral cortex.
- Most of the time they do not have any specific shape.
- Normal rhythms are often categorized as alpha, beta, theta and delta:

- Alpha waves (α) have frequencies between 9Hz and 12Hz. They are recorded in normal subjects with no activity and eyes closed, especially in the occipital area; its amplitude is between 20uV and 200uV.
- Beta waves (β) have frequencies between 13Hz and 30Hz, but can reach up to 50Hz; are mainly found in the parietal and frontal regions. They are divided into two fundamental types, of very different behavior, beta1 and beta2. The beta1 waves have a double frequency to the beta waves 2 and behave in a similar way to them. Beta2 waves appear when the CNS is intensely activated or when the subject is under stress.
- Theta waves (θ) have frequencies between 5Hz and 8Hz and occur in childhood, but adults can also present them in periods of emotional stress and frustration. They are located in the parietal and temporal zones.
- Delta waves (δ) have frequencies lower than 4Hz and occur during deep sleep, in childhood, and severe brain organ diseases.

Recently a fifth band called gamma (γ) between 22Hz and 40Hz has been found, related to the result of the attention or sensorial stimulation; which has a very low amplitude of 2uV "peak to peak" (P & B., 2008), (Chen & Hsieh, 2008), (F. & N., 2015).

2.1.7 Considerations for mounting an EEG

- Long Distance Mounts are used when registering between non-contiguous electrodes.
- On the contrary, in the Mounts at Short Distances records are made between neighboring electrodes. On the other hand, the assemblies have also been classified by the International Federation of EEG and Neurophysiology in Longitudinal and Transverse.
- In the Longitudinal Assemblies the activity of pairs of electrodes arranged in the anteroposterior direction of each half of the skull is recorded.
- Transverse Mounts record pairs of electrodes arranged transversely according to the anterior, middle or posterior sagittal planes.
- It is also recommended to follow the following guidelines in the design of EEG recording assemblies.
- Register at least eight channels.
- Use the ten-twenty system for electrode placement.
- Each routine EEG recording session should include at least one assembly of the three main types: referential, longitudinal bipolar and transverse bipolar.

Patient Preparation

- The patient should be alert and well rested.
- The patient will need to take his glasses.
- The patient will take his regular medications.
- Exam time: 30 minutes

2.1.8 EEG Applications

EEG studies can be used for the development of biofeedback techniques that help us to generate a reliable form to the same electroencephalographic pattern in function of an interest. Also, it can aid in the diagnosis of pathological conditions such as (Putz et al., 2006), (N. et al., 2014), (Barea, 2012), (Duong et al., 2001):

- Brain Death: Brain death, better called brain death, is defined as the complete and irreversible cessation of brain or brain activity.
- Brain tumors: A brain tumor is a growth of abnormal cells in the brain tissue. Tumors can be benign (without cancer cells) or malignant (with cancer cells growing very fast). Some are primary, that is, they begin in the brain. Others are metastatic, that is, they started somewhere else in the body and reached the brain.
- Epilepsy: A disease of the nervous system, due to the appearance of abnormal electrical activity in the cerebral cortex, which causes sudden attacks characterized by violent convulsions and loss of consciousness.
- Multiple sclerosis: Pathological hardening of a tissue or organism that is due to the abnormal and progressive increase of connective tissue cells that form its structure; mainly applies to the blood vessels and the nervous system.
- Sleep disorders: Sleep disorders or sleep disorders (also known as sleeping sickness or even sleeping disorders, depending on the Spanish-speaking country in question) are a large group of conditions that affect the normal development of the sleep-wake cycle. Some sleep disorders can be very serious and interfere with the individual's physical, mental and emotional functioning.

2.1.9 Discrete Fourier transform (DFT)

The DFT is one of the techniques applied for the processing of EEG signals. The DFT is not the same as the Discrete Time Fourier Transform (DTFT). Both start with a discrete-time signal, but the DFT produces a discrete frequency domain representation while the DTFT is continuous in the frequency domain. These two transformations have much in common, so it is useful to have a basic understanding of the properties of the DTFT, these properties are described in equations 2, 3 y 4.

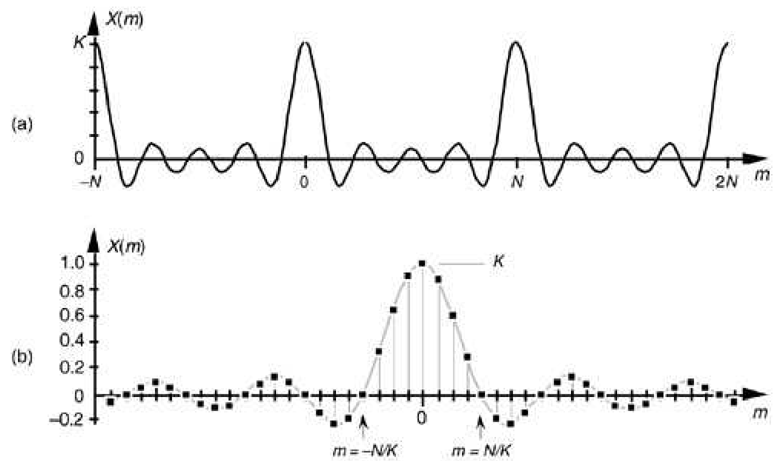


Figure 2.11: DFT symmetry.

Periodicity: The DTFT $X = e^{jw}$, is periodic. One period extends from $f = 0$ to fs, where fs is the sampling frequency. Taking advantage of this redundancy, the DFT is only defined in the region between 0 and fs.

Symmetry: When the region between 0 and fs is examined, it can be seen that there is even symmetry around the central poin, $0.5fs$, the Nyquist frequency. This symmetry adds redundant information.

Figure 2.11 shows the DFT (implemented with the Matlab FFT function) of a cosine with a frequency tenth the sampling frequency. Note that the data between $0.5fs$ y fs is a mirror image of the data between 0 y $0.5fs$.

2.1.10 Fast Fourier Transform (FFT)

The FFT is one of the techniques applied for the processing of EEG signals. A periodic signal that repeats over time as an EEG can be represented as the sum of sine waves. The functions to be added may be very different, those that will be of particular interest to us, and on that basis, Fourier analysis have certain frequencies. The advantage of choosing these functions, which are called harmonics, is that analyzing any signal to see its components is simple. Discrete Fourier Transformation (DFT) is used to obtain the components of a continuous signal, and there are many ways of calculating it. The most efficient is the Fast Fourier Transform, the FFT.

The FFT is a faster version of the Discrete Fourier Transform. The FFT uses some clever algorithms to do the same thing as DTF, but in much less time. While the order of complexity of the DFT algorithms is N^2 , that of the FFT is $Nlog(N)$, where N is the number of data to be processed.

The DFT is extremely important in the area of frequency (spectrum) analysis, as it takes a discrete signal in the time domain and transforms the signal into its discrete frequency domain representation. Without a discrete time to discrete frequency transform, we would not be able to calculate the Fourier transform with a microprocessor or DSP based system. It is the speed and discrete nature of the FFT that allows us to analyze the signal spectrum with some software like Matlab.

The Laplace transform described in equation 1 is used to find a pole / zero, the representation of a signal or a continuous system over time, $x(t)$, in the s-plane. Similarly, the z-transform is used to find a pole / zero, the representation of a signal or system continues over time, $x(t)$, in the s-planes, $x[n]$, in the z-plane.

The continuous-time Fourier transform can be found by evaluating the Laplace transform in $s = jw$. The time of the discrete Fourier transform can be found by evaluating the z-transformed into $z = e^{j\Omega}$, equation 1.

For the analysis of EEG signals, it is not enough to do it with the Fourier Transform, because the signals change concerning time as well, so a Time-Frequency analysis is required that can be performed with the Short Window Fourier Transform (STFT) or with the Continuous Wavelet Transform (CWT).

2.1.11 BCI Systems

BCI systems can be classified into two groups according to the nature of the input signal:

- Endogenous BCI systems.
- Exogenous BCI systems.

Endogenous BCI systems depend on the user's ability to control their electrophysiological activity, such as the amplitude of the EEG in a specific frequency band over a particular area of the cerebral cortex. BCI systems based on motor imaging (sensorimotor rhythms) or slow cortical potentials (SCP) are endogenous systems and require an intensive training period. The following two systems are described:

- BCI based on slow cortical potentials. SCPs are slow changes of the voltage generated in the cerebral cortex, with a variable duration between 0.5 and 10 seconds. Negative SCPs are typically associated with movement and other functions involving cortical activation. It has been shown that people can learn to control these potentials.
- BCI based on motor images or sensorimotor rhythms (P & B., 2008). It is based on a paradigm of two or more kinds of motor images (movement of the right or left hand, of the feet, of the tongue, etc.) or other mental tasks (rotation of a cube, accomplishment of arithmetical calculations, etc.). These types of mental tasks produce changes in the amplitude of the sensorimotor rhythms (8-12Hz) and (16-24Hz) recorded on the somatosensory and motor zones of the cerebral cortex. These rhythms exhibit variations both for the execution of a real movement and for the imagination of a movement or the preparation thereof (E. et al., 1989), (Zhiqiang, 2006).

Exogenous BCI systems depend on the electrophysiological activity evoked by external stimuli and do not require an intensive training phase.

The processing of the signal in BCI systems is usually divided into four stages. First, an initial stage of preprocessing is performed in which the EEG signals are filtered and some of the possible artifacts overlapping the signal of interest (blinking, eye movement, electrocardiogram, muscular movements, etc.). After that, a second step is performed which involves the extraction of certain specific characteristics of the EEG signal. Next, we apply characteristic selection methods that choose the most significant within the extracted set, which encode the intention of the user. Finally, the classification algorithms translate the set of characteristics selected in a specific command, related to the intention of the user (W. et al., 2010) (Duong et al., 2001)(E. et al., 1989; Zhiqiang, 2006) (Instruments, n.d.), (Zhiqiang, 2006).

CHAPTER 3

Methodology

This chapter describes the procedures that were performed in the development of the work, including the material and equipment used, the DSP programming codes, the interface components in LabView, and some other required theoretical justifications.

The methodology is divided into three stages; the first stage was the bibliographic search that allowed to know the state of the art of BCI systems and the techniques for EEG signal processing. The second stage consists of the selection of a device with the characteristics required for the acquisition of EEG signals. The third stage is to ensure that the closed architecture of the device can be modified to achieve an open architecture, applied to both the electronic board and the BCI system. The general structure of the work is shown in Figure 3.1.

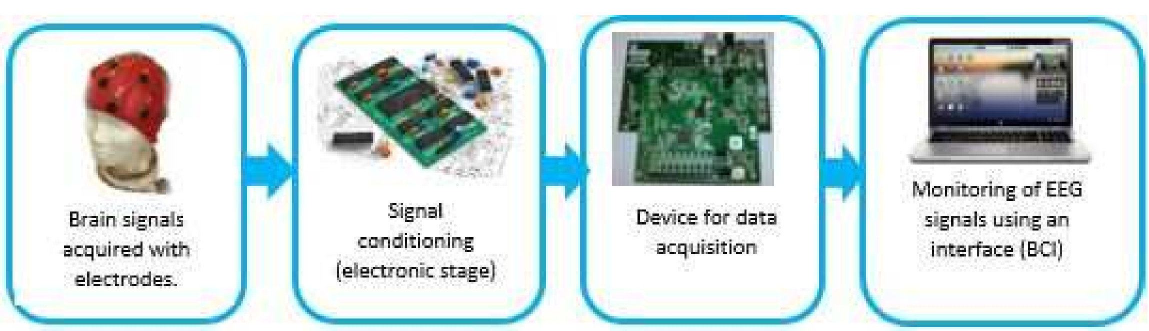


Figure 3.1: Stages of the project.

3.1 Specification

During the development of the project some physical devices were used, however, the most important are the electrodes and the ADS1299EEG-FE kit.

3.1.1 Electrodes for EEG signals

The electrodes perform the interface function between the body and the measuring devices, allowing the conduction of electric current from the human body to the electronic circuit.

The potential measurement is performed between the active electrode (collecting the signal) and a reference electrode (ground), minimizing interference. In EEG systems, reference and common mode electrodes are located on the head to minimize noise. The localization of these elements in the scalp is standardized following the international electrode location system 10-20. However, it is important to mention that only eight electrodes were used at the main points of the 10-20 system.

Figure 3.2: Electrodes.

3.1.2 Kit ADS1299EEG-FE

The kit consists of two parts, the EVM and the ADS1299 of eight-channel and 24-bit resolution. The ADS1299EEG-FE card is designed for simultaneous sampling of eight channels. EVM is a low-power module designed for electroencephalography (EEG)applications. In Figure 3.3 the ADS1299EEG-FE kit is observed.

Figure 3.3: ADS1299-FE-Kit.

The motherboard allows the MMB0 ADS1299EEG-FE to be connected to the computer via an available USB port. The features supported by the hardware are as follows:

- Configurable for bipolar or unipolar supply operation
- Configurable for internal and external clock and reference via jumper settings
- Configurable for dc-coupled inputs
- External bias electrode drive
- Option to provide a common reference to all channels negative terminals.
- Option to select any electrode as reference electrode
- Option to choose any electrode as bias electrode
- External shield drive amplifier

The analog signals received with the help of the electrodes are converted to digital signals using the ADS1299EEG, before the second part of the kit, the DSP (EVM), performs the functions of reception, processing, and representation of the results, in Figure 3.4 is shown the main parts of the process.

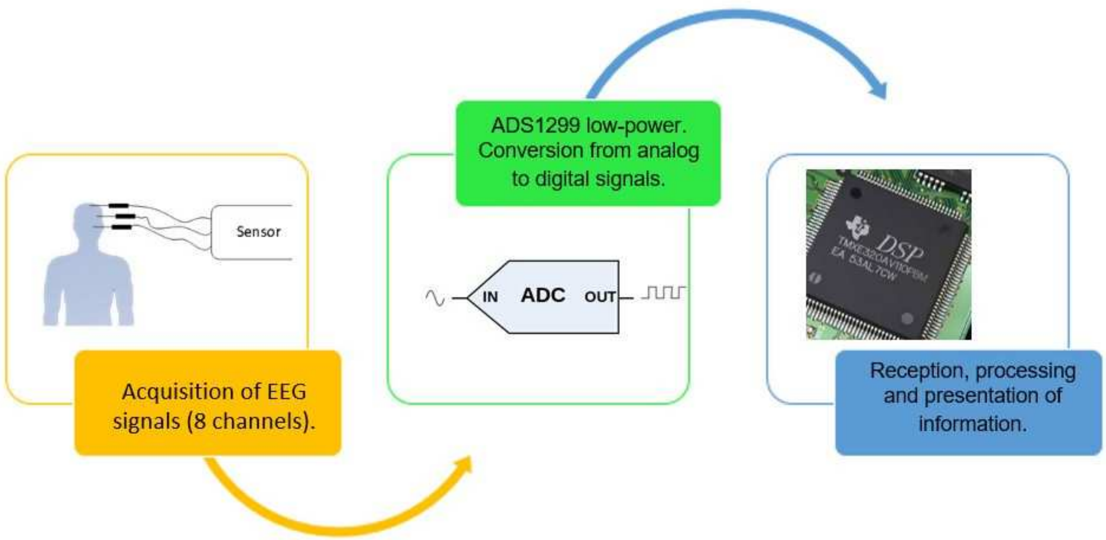


Figure 3.4: Tasks of kit ADS1299EEG-FE.

The acquisition card used during the research is the kit ADS1299EEG. It was chosen because it meets the minimum number of channels allowed to perform an EEG study, has a good resolution adc (analog-to-digital conversion) since it is 24-bit, has a very low consumption of power, it is easy to adapt to a portable device, among other features that are mentioned in the appendix and that make the card very useful for the desired applications.

3.2 Design

The second stage of the project consisted of the selection of a device that meets the requirements that our case is the acquisition of EEG signals. The device selected was the ADS1299EEG-FE Kit, this kit includes two cards, the first is the ADC and the second includes the DSP also includes an interface made in LabView. Both the interface and the DSP code initially have a closed architecture, so the goal was to make this architecture open, which is the third stage of the project.

3.2.1 BCI (Brain Computer Interface)

LabView is a language and, at the same time, a graphical programming environment in which applications can be created quickly and easily. The components made in LabView are called files (VI Virtual Instrument), in many cases, the file (VI) can contain another one or others so that the following will be subVI of the first: the concept is equivalent to the functions or procedure of a traditional language. To group several VIs you can use a library. Also, a library can contain other libraries.

The interface that was used as BCI is composed of the main library that includes 6 secondary libraries. The main library is called lib1299 and contains some components for advanced mathematical operations, reading, writing and data storage, configurations to establish communication between the electronic card and the computer, components to present the information graphically, etc. Components and libraries contain both public and private components. The libraries that integrate the interface are the following:

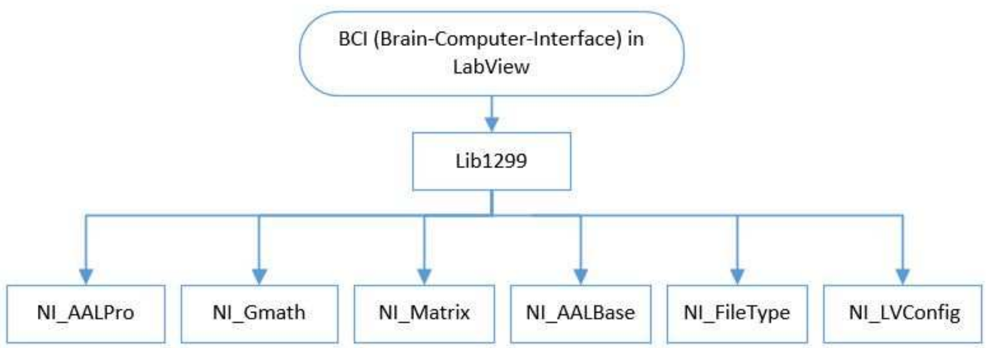


Figure 3.5: Hierarchy of libraries in LabView.

- This library contains related components for performing complex number matrix operations, calculating the Fast Fourier Transform and its derivatives. Also included are components for probabilistic calculations, linear interpolations, coordinate transformation, normalizations, calculation of integrals and derivatives, mean values, etc. This library helps the interface in the analysis section, since this section makes use of the FFT, DFT, among others.
- Gmath: As its name implies, this library has components related to mathematical operations. Its main area of work are operations with polynomials which is very important for the part of applications of numerical methods. It also has components to calculate the STFT and Laplace Transform.

- Matrix: The Matrix library includes all mathematical operations applied to matrices with real numbers and elements imaginaries. This library helps indirectly to the main interface.
- AALBase: The AALBase library contains components related to probability and statistics. Most of its components are related to the elimination of noise, that is, with filters of order n. Its components are designed to achieve a wide variety of filter types.
- FileType: It is the library that has fewer components, but not least that the others. Its components are directly related to the handling of files.
- LVConfig: In this library, there are very useful components for the interface as it integrates components related to the necessary configurations for communication, data types, reading, and writing, etc. It allows us to establish a communication channel between the card and the computer.
- Lib1299: It is the main library of the interface, it contains specific components to establish the information link between the electronic card and the computer, as well as the necessary components for graphics and information processing.

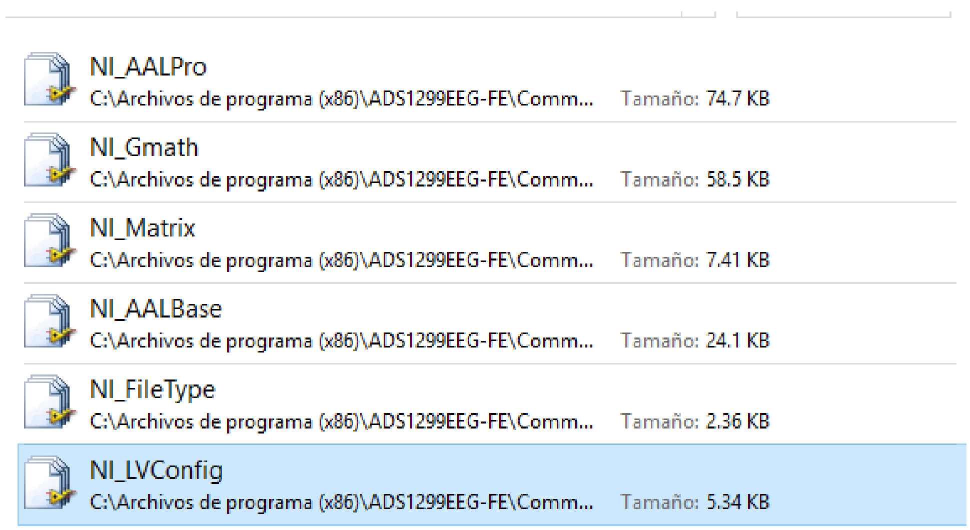


Figure 3.6: Libraries

In a closed architecture, it is not allowed to add, modernize and change its components. By converting to an open architecture allows us to see its interior without any restriction, as well as modify its structure to suit the user. To be able to modify the main library, they first explored the properties of the components, their function and hierarchy, and the LabView work environment was studied in detail. In Figure 3.7 is shown some of the disadvantages of modifying the components without changing the type of architecture.

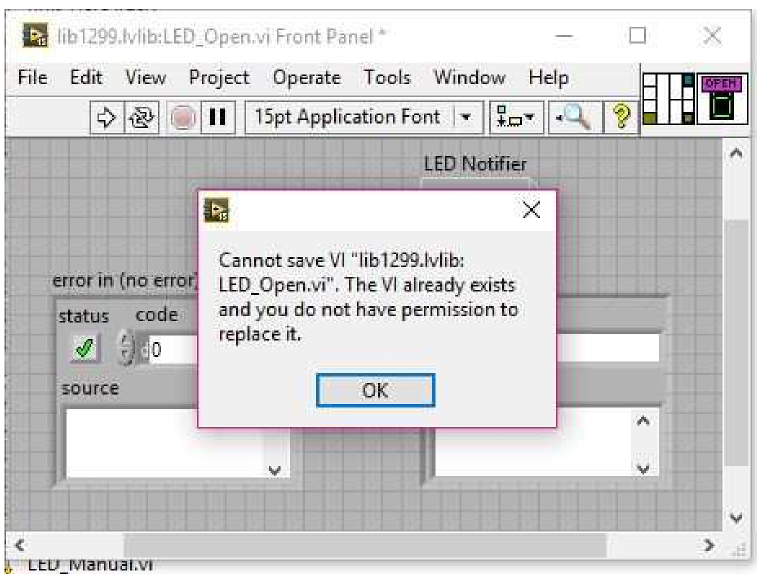


Figure 3.7: Non-modifiable component.

3.2.2 Code for DSP

The code of the DSP, just like the interface makes use of libraries. In Figure 3.8 are shown the main components contained in the code. The main library is called ads1299evm.h, this library contains the settings for setting the communication channel between adc and DSP.

- The usb.h library contains the settings for communicating to the DSP with the LabView interface.
- The mmb0.h library is used to process the received information.
- The portconf.h library is also used in the port configuration for communication between the LabView interface and the DSP.
- The library mmb0ui.h just like the library mmb0.h contains tasks that help the processing of information that is received from the adc.

The initial code had been made in a very old code composer version, so the goal was to migrate and understand this code. Adding code for the first time to the new software version

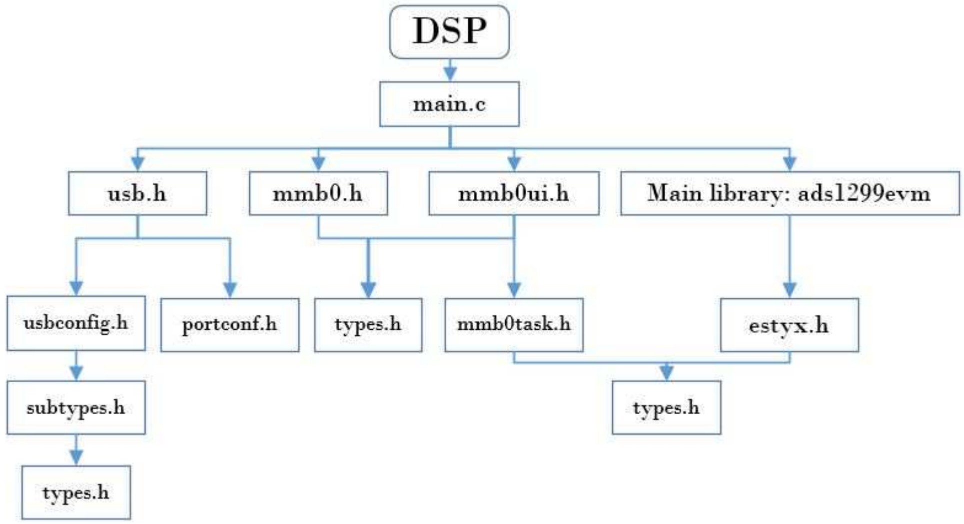


Figure 3.8: DSP code components.

contained a little more than 120 errors, after the first modifications the number of errors dropped to 31 and then continued to fall. The errors were of different types, so to solve each error we investigated the characteristics of the error and its possible causes. Figure 3.9 shows some of the errors that it had.

3.3 Implementation

3.3.1 BCI components

The objective for the part of the interface was to be able to modify the components that integrate the main interface. After exploring the properties of the components, their function and hierarchy; some properties of the software were studied in detail with emphasis on concepts that are used in the main libraries.

Two ways were found that would allow us to modify the components; the first way is to make a copy of the components to be modified. The copy is directly linked to the main library, in Figure 3.12 is shown the modified component added to the list of the main library components is observed. Making a copy allows us to modify the components and to be able to add elements that help for specific tasks that we want to do and also maintains the original functions of the main interface. The second way to modify the components is to disintegrate the library, modify the components and then reintegrate the library. However, the disadvantage of this form is that once the library is integrated, you can not modify

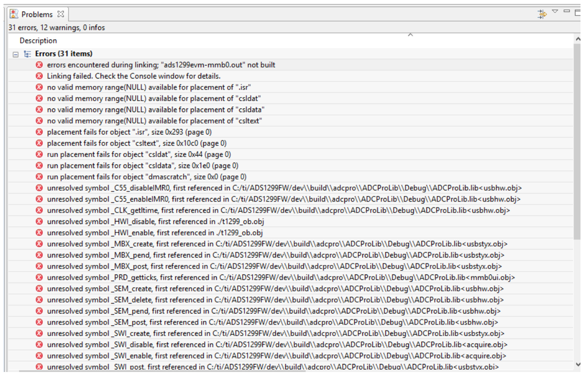


Figure 3.9: Errors for migrating the code.

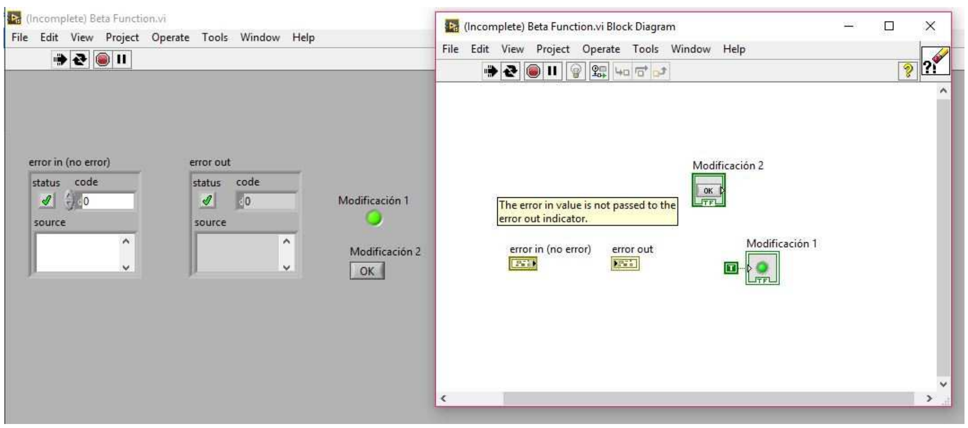


Figure 3.10: Modification 1 of components.

the components until they are again to disintegrate and to disintegrate the library we must know in detail the hierarchy of the components that in our case are a little more than three hundred components. Figure 3.11 shows a component that was modified by adding a led and a button.

3.3.2 Programming Codes

The errors that initially had to migrate the code were of address, modified several paths, new addresses were added. Other errors were memory spaces, some others of code ambiguities, etc. Each error was investigated specifically, and its possible causes and from this solution actions were determined. Some other errors were due to the BIOS version and xdc tools required for the project since these two elements are required to be fully compatible with the project.

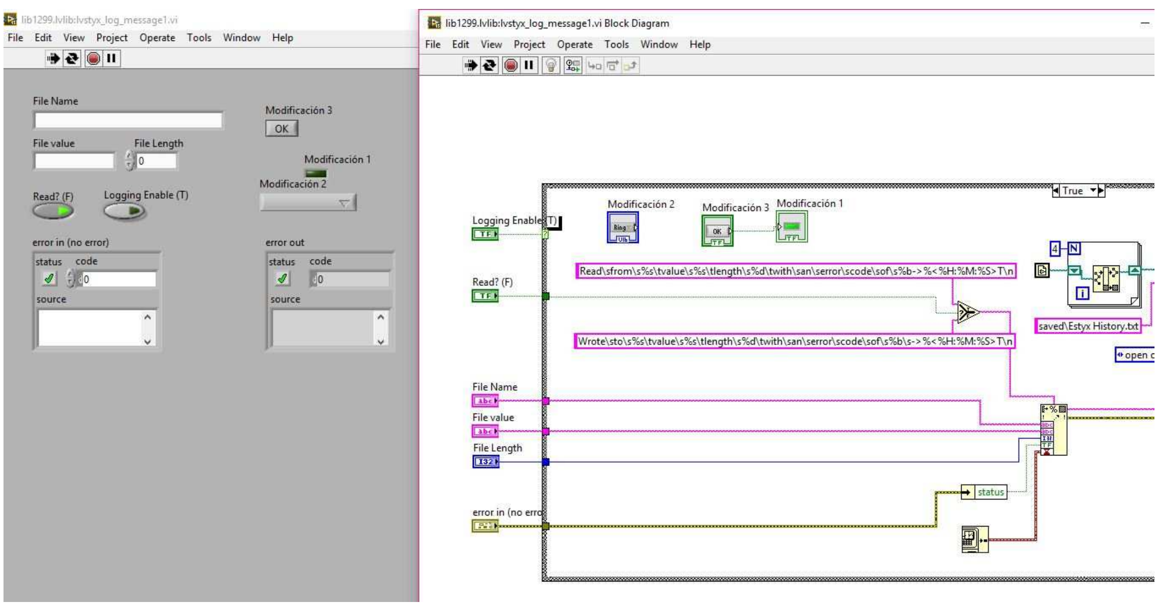


Figure 3.11: Modification 3 of components.

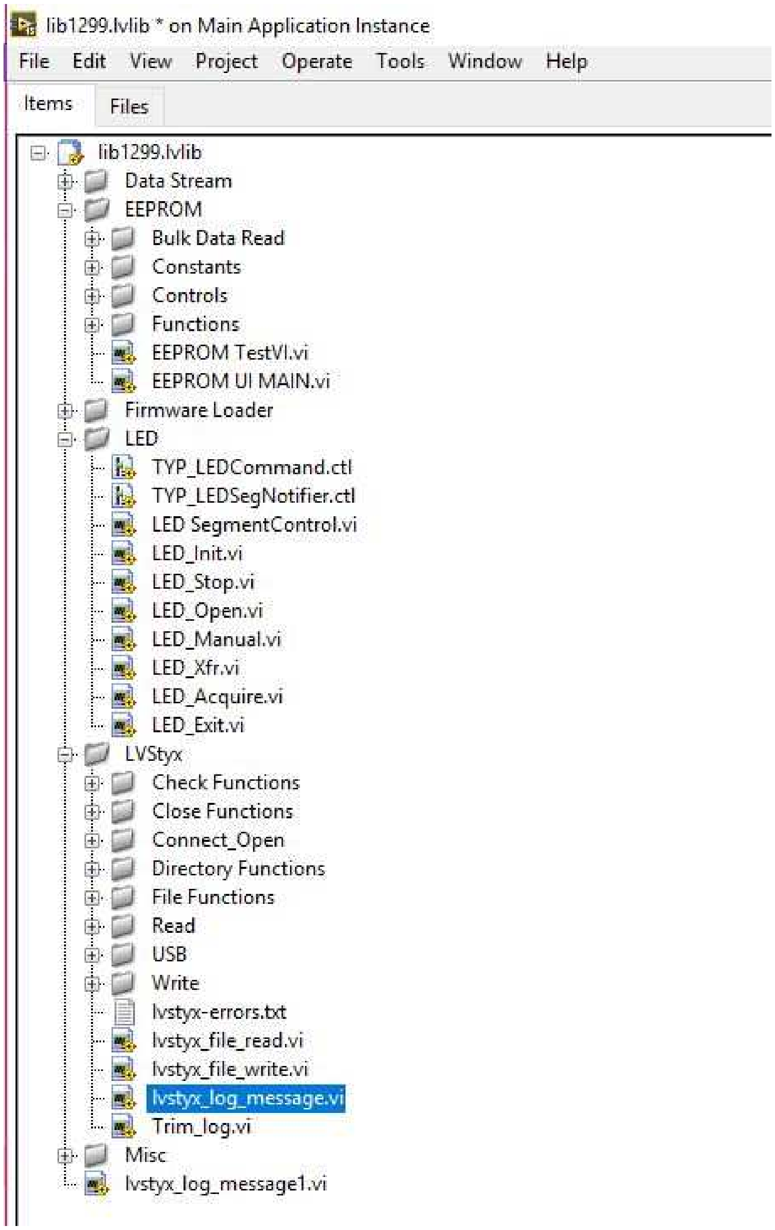


Figure 3.12: Modification 2 of components.

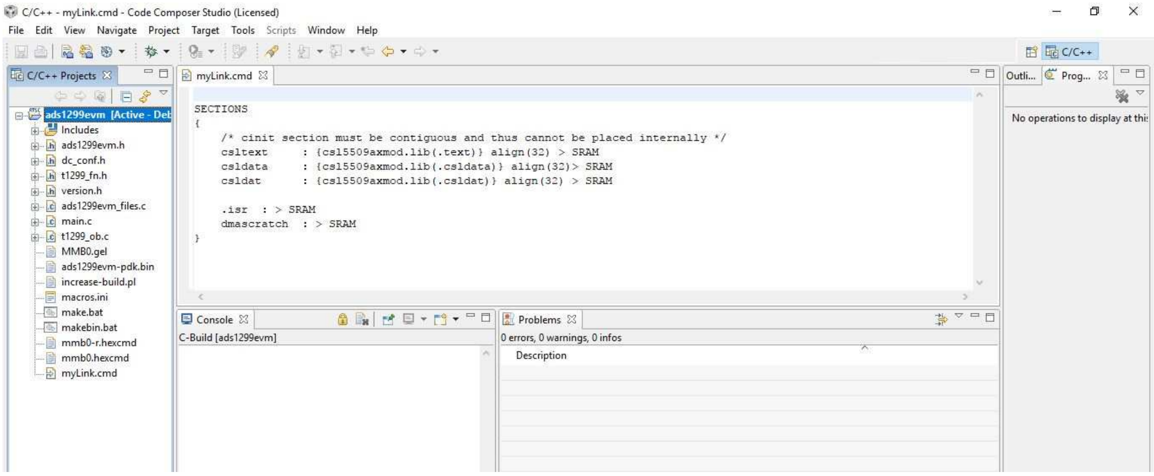


Figure 3.13: DSP Code.

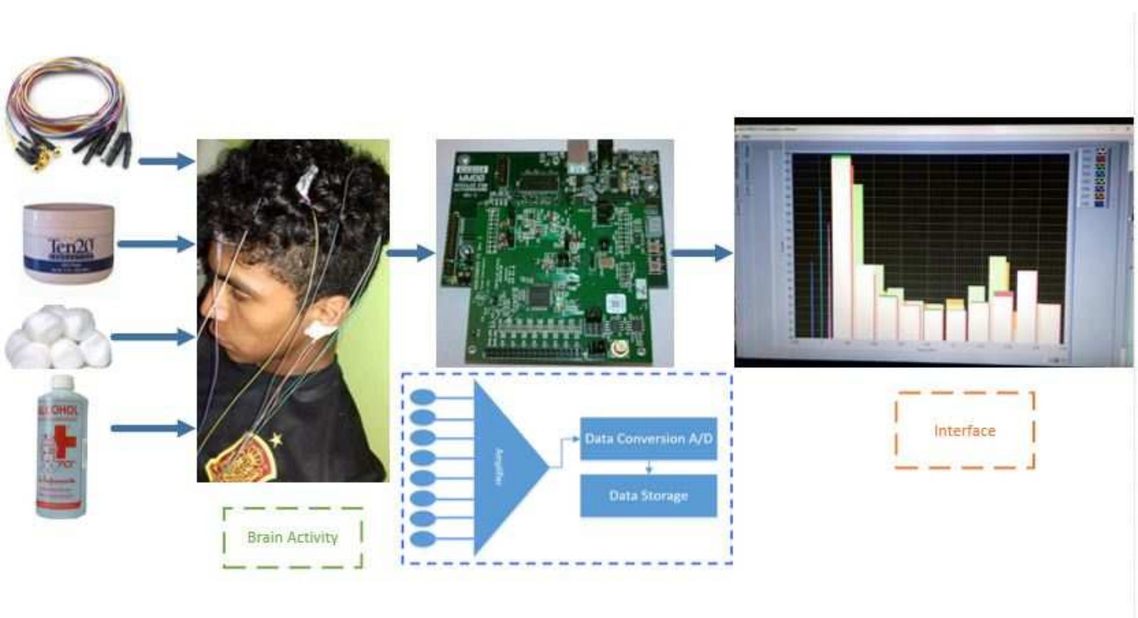


Figure 3.14: EEG signal acquisition system

CHAPTER 4

Results and Discussion

4.1 Results

Biopotentials are those electrical signals emitted by the human body. In nature there are many types of biopotentials, several of them mentioned before. In the experimental part, mainly EEG tests were performed, but also some EMG (electromyography).

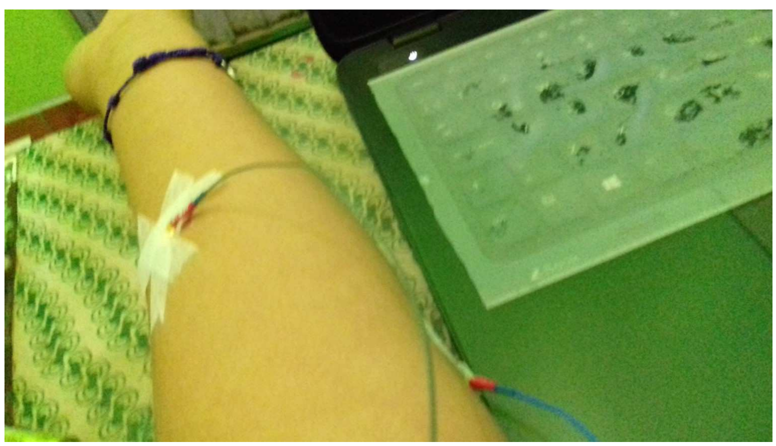
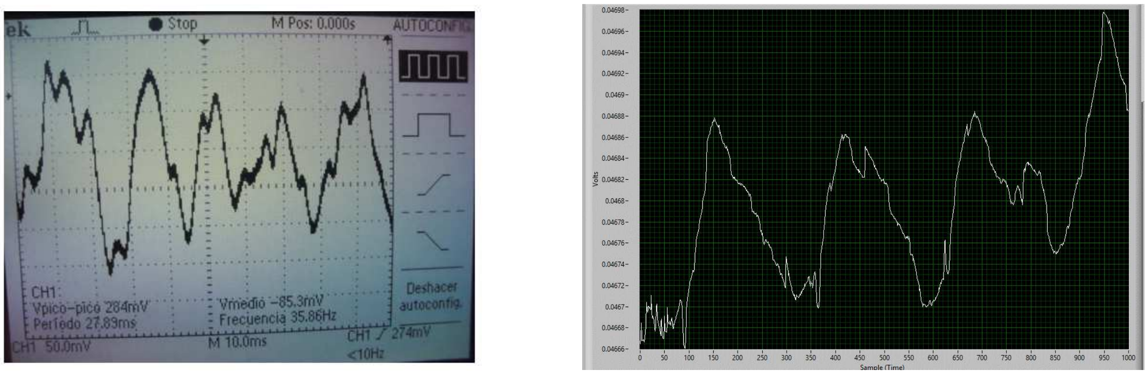


Figure 4.1: Accommodation of the electrodes in the forearm.

- EMG tests: Tests were performed on the left arm, and this consisted of analyzing the shape of the signals in time when the arm is tensioned and without tension in the same environment. In Figure 4.1 is shown the arrangement of the electrodes. The test was applied once to 5 different people and 20 times to the same person.

  The results were compared with data obtained from several sources of information. In Figure 4.2 is shown the comparison between the results obtained and base data, it can be observed that the results are very similar in time.



(a) (b)

Figure 4.2: Response in time of the tensioned arm (a) base data ; (b) test data.

- EEG tests: According to the "Ten-Twenty" system the eight positions were selected to place the electrodes, the positions were as follows: FP1, FZ, F4, C3, Cz, C4, Pz, 01 and T4. In Figure 4.3 is shown the selected positions.

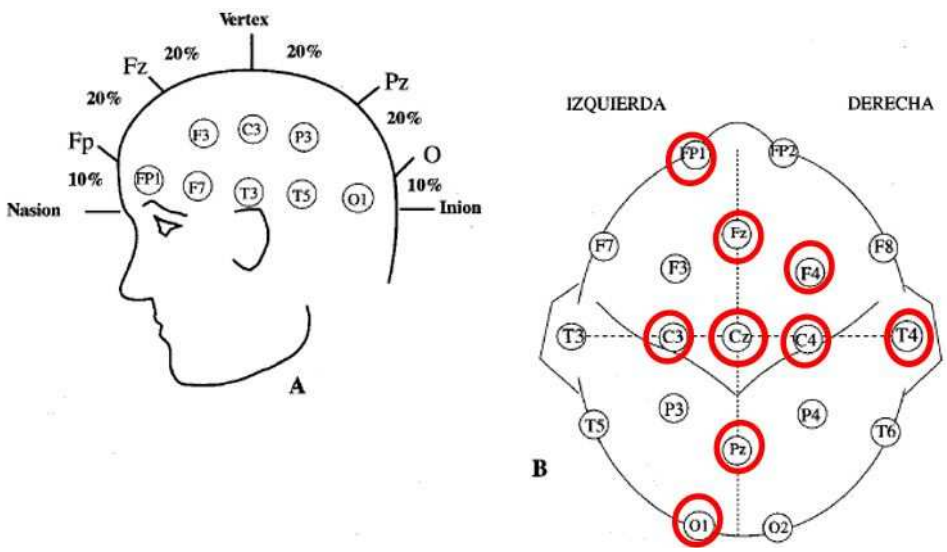


Figure 4.3: Accompaniment of the electrodes.

The test was applied twice to 3 people. In Figure 4.4 is shown the materials used for the application of the EEG test: conductive paste, electrodes, conditioning card and signal processing, medical cloth tape, four rechargeable batteries and a computer.

In Figure 4.5 is shown the position of the electrode used as reference (ground), placed in

Figure 4.4: Materials of test EEG.

the lower part of the left ear. The primary purpose of the ground is to prevent power line noise from interfering with the small biopotential signals of interest.

In Figure 4.6 is shown the electrode placed in the position FP1, and in Figure 4.7 b is observed that the eight electrodes were stained, some of them being fastened with the help of the medical cloth strap.

In Figure 4.8 is shown the arrangement of the electrodes. In Figure 4.9 is shown the connection of electrodes to the acquisition board and the card the power supply and to the computer (graphical interface). The connection of the electrodes can be simple or differential, and in our case it was simple. In Figure 4.7 is shown the connection of interface, card, electrodes, and patient.

In the results obtained from the EEG tests, no specific pattern was verified, only the signals were checked for amplitude. Also it was verified that the levels of interferences and noise were within the allowed limits. EEG tests are more complicated than myoelectric tests since the amplitude of an EEG signal is much smaller than a myoelectric signal, so they are more easily affected by external factors.

The tests were applied while the person was asleep, the people were of average age (18-25), and each test lasted between half an one hour. In Figure 4.11 is shown acquired EEG signals while the person was asleep.

In the experimental part, I attended on several occasions to the Neurodevelopment Research Unit of the UNAM to observe the techniques and the necessary conditions for the application of an EEG study. In Unit EEG studies are applied to premature babies to check

Figure 4.5: Accompaniment of the electrode GND (ground).

that they do not suffer any illness or mental retardation caused by being preterm babies. In Research Unit electrodes are used in the helmet mode and the electrodes are arranged following the "Ten-Twenty" system.

4.2 Discussion

This research aimed to achieve an open architecture for a BCI system applied to EEG signals from people with some motor disabilities. Also, myoelectric tests were performed and some patterns such as that of a tensioned forearm were identified. The EEG and myoelectric tests were applied several times to different people to verify the good functioning of the device; in Figure 5.14 in shown the acquisition of EEG signals.

From the results obtained in this project, it can be deduced that it is possible to achieve an open architecture in both the electronic board and the LabView interface, and also to apply the BCI system for the analysis of EEG or biopotential signals. By turning to an open architecture allows us to see its interior without any restriction, as well as modify its structure to suit the user. From the data obtained from the EEG and myoelectric tests, it can be concluded that the interference and noise effects are within the limits of other similar studies.

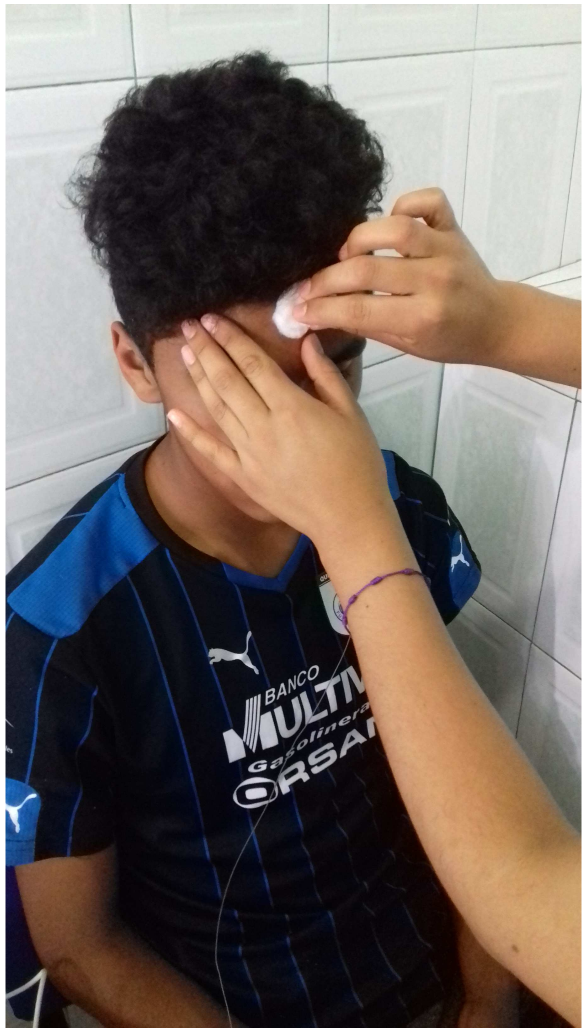


Figure 4.6: Arrangement of electrodes and EEG test connections: electrode FP1.

4.3 Significance/Impact

4.3.1 Social Impact

- In recent years the number of people with a neuro-motor disability has increased. It is estimated that there are 32.5 million households in the country, of which 6.1 million reports at least one person with a disability; that is, in 19 of every 100 hours lives a person who suffers from a disability.

  BCI systems are very important in the field of medicine and more specifically in rehabilitation since they contribute to establish a channel of communication and control for those individuals with a deficiency in their motor functions.

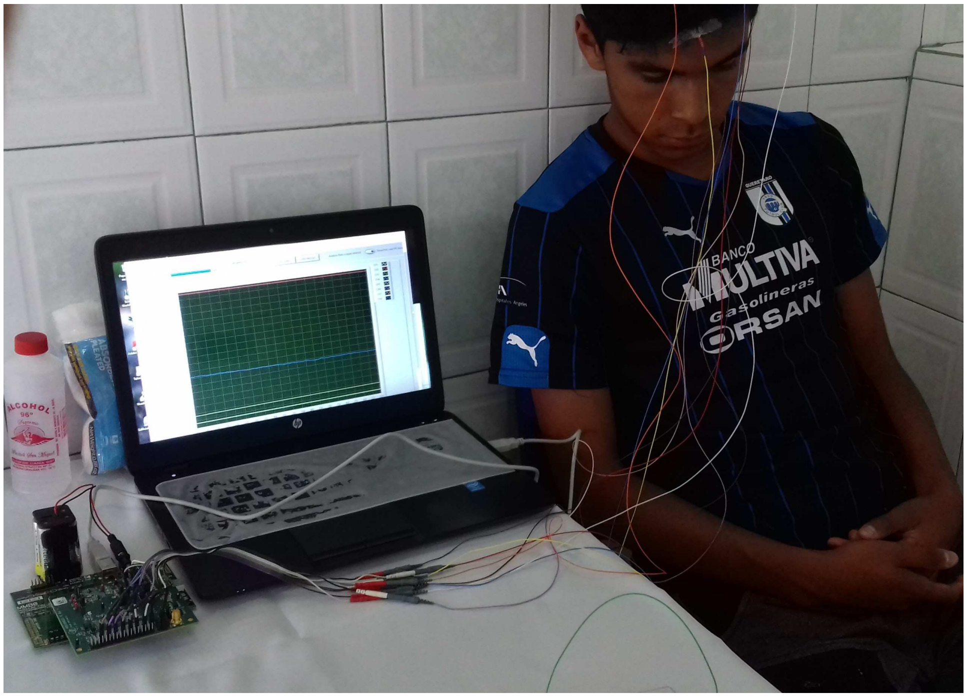


Figure 4.7: Arrangement of electrodes and EEG test connections: EEG test connections.

With the implementation of modifications and improvements applied to BCI systems, more user-friendly devices can be achieved. Describe user-friendly and easy-to-understand hardware and software interfaces for any user. Having an easy-to-use device makes it easy to use with a wide variety of people.

4.3.2 Environmental Impact

- In the market, there are different types of electrodes, one of the classifications are disposable and non-disposable. With the implementation of new techniques for the analysis of signals can be achieved the reduction of waste since during the selection of materials was sought that the materials to be used were non-disposable to avoid generating large impacts to the environment.

  Also, the device used is low power consumption. Therefore, it takes maximum advantage of the electric power, and the batteries are rechargeable because if disposable batteries are used, it will contaminate the environment in large quantities.

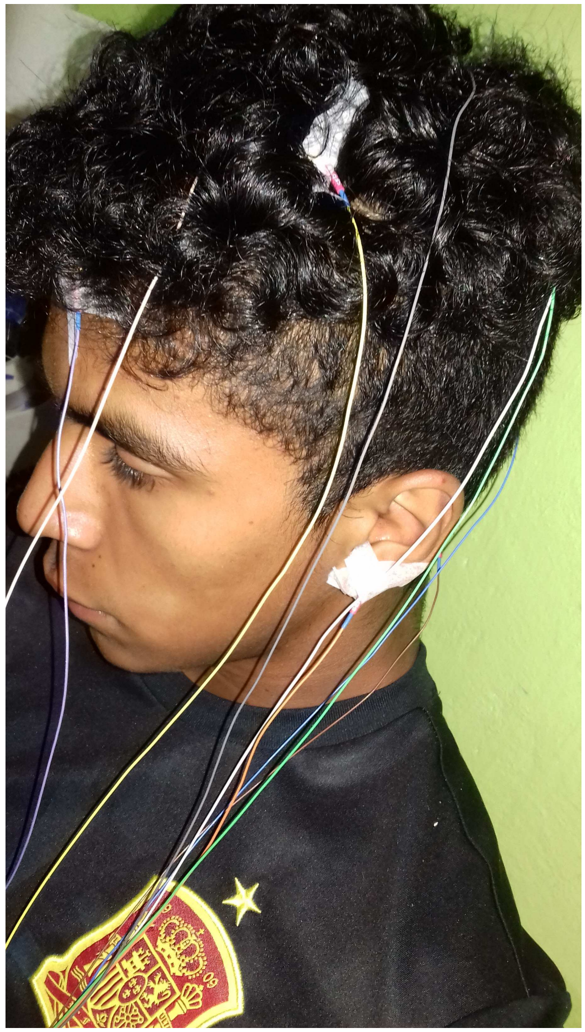


Figure 4.8: Person with electrodes.

4.3.3 Economic Impact

- By designing and implementing enhancements to a BCI system, it is possible that in future investigations the device will be made more accessible to the people with limited resources, as most devices on the market are costly and increase significantly whit the number of channels and the type of communication it contains.

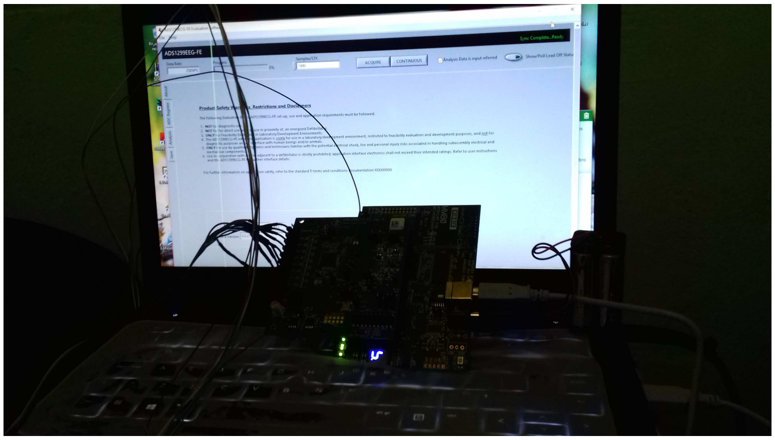


Figure 4.9: Connection of electrodes to the acquisition board.

4.4 Future Work

The project carried out is a small part to achieve the application of the device for rehabilitation and communication with external devices. Therefore, it is hoped that future research will achieve the application of techniques that require statistical techniques and digital processing so that in the future not very distant can be achieved a complete device with applications in people with neuro-motor disability problems or communication with external devices.

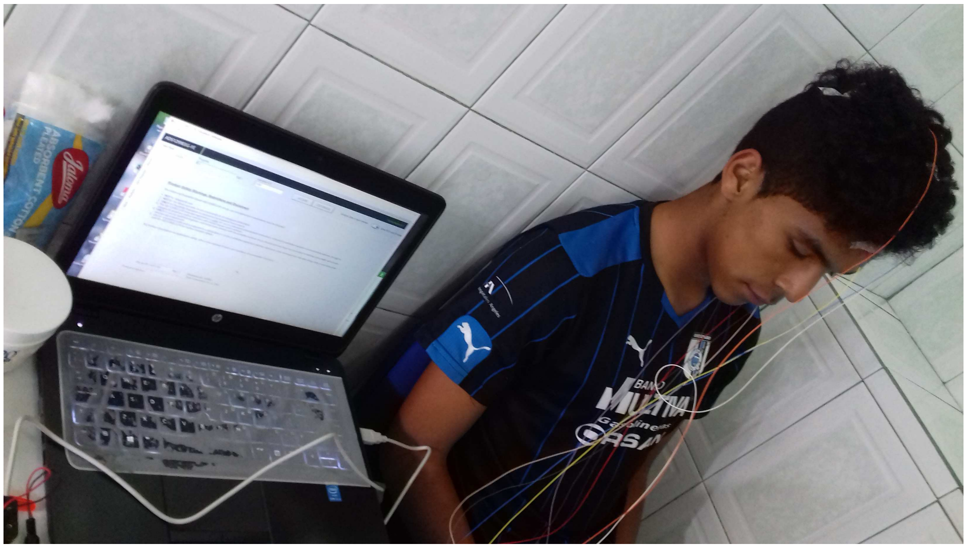


Figure 4.10: Test EEG.

Figure 4.11: Monitoring of EEG signals.

CHAPTER 5

Conclusion

The results obtained from the EEG and myoelectric tests were compared with the results obtained in other investigations; it was observed that the signals in both amplitude and frequency are very similar and that the levels of noise and interference were within limits.

During the development of the project, I learned several things from LabView. LabView is a software capable of solving a great variety of easy and fast engineering problems. In LabView, it is a type of intuitive graphical programming since by the same name of the component it is understood that it does and in which cases to use it. Also, it has an interactive debugging tool, has high performance, can use a multimeter to verify the status of the signals, among other advantages.

Code composer is another of the software used in the project; this was used to program the DSP. When using this software had several disadvantages because the software is very heavy and uses a lot of computer resources to operate, when I used the software on my computer it was very slow and I could only be using this program. Also, for part of making the BIOS compatible (Basic Input / Output System) was very complicated because the software version where the code was made was discontinued and the existing ones were not fully compatible, I had to make several modifications to make them compatible.

BCI systems play a very important role in rehabilitation, so with the improvement of these devices it is possible to help in future research to establish a channel of communication and control for those with neuro-motor problems. Therefore, by having an open architecture for the acquisition and processing of electroencephalogram signals, it is possible to conduct research related to BCI systems, both for diagnosis, rehabilitation and communication with external devices. However, these signals present complex behaviors and noises of different nature, requiring statistical techniques and digital processing.

This research collaborates for future research since this work is part of a first stage and complements research that is currently carried out to achieve the implementation of a complete BCI system.

Within the personal knowledge, In this project I learned to use many LabView tools I did not know existed, I remembered how to use code composer, and I learned to do EEG studies and even a little about how to interpret the results. Also, from the visits made to the UNAM I learned a little to interpret the results of an MRI study since the teacher I visited knew to perform both EEG studies and magnetic resonance imaging studies

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.1 Equations

Equation 1 Laplace Transform: $x(t) <-> X(s)$ where

$$X(s) = \int_{-\infty}^{\infty} x(t)e^{-st} \cdot dx \tag{1}$$

Equation 2 Laplace Transform: $x(t) <-> X(jw)$ where

$$X(jw) = \int_{-\infty}^{\infty} x(t)e^{-jwt} \cdot dx \tag{2}$$

Equation 3 Laplace Transform: $x[n] <-> X(z)$ where

$$X(z) = \sum_{n=-\infty}^{\infty} x[n]z^{-n} \cdot \tag{3}$$

Equation 4 Laplace Transform: $x[n] <-> X(j\Omega)$ where

$$X(e^{j\Omega}) = \sum_{n=-\infty}^{\infty} x[n]e^{-j\Omega n} \tag{4}$$

.2 Table

Table 1 shows the characteristics of biopotentials:

Signal Type	Typical amplitude	Bandwidth	Measure
ECG	0.1-1mV	0.1-100Hz	Superficial
EMG	10uV-1mV	10-5000Hz	Intramuscular
EEG	10-100uV	0.1-100Hz	Superficial
EOG	0.1-1mV	0.1-20Hz	Superficial
Intracellular Potential	1-100mV	200-10KHz	Microelectrode
Galvanic response of the skin	1-500KΩ	0.1-5	Superficial
Basal skin response	10KΩ-1MΩ	cc-0.5Hz	Superficial
Variations of electrical impedance of the tissue	10mΩ-1Ω	cc-20Hz	Superficial

Table 1: Biopotentials.

5.2.1 Test EEG

In Figure 5.1 is shown the arrangement of the electrodes on the scalp and the graphical interface. In Figure 5.2 is shown the connection of the electrodes to the data acquisition target and its connection to the computer. In Figure 5.3 is shown the connection of the electrodes to the acquisition card and the card connected to their power source and the computer, also its shows the interface and some materials used for the application of electrodes such as conductive cream, alcohol, cotton and battery charger. Figures 5.4, 5.5, 5.6 and 5.7 are like the Figure A5, but taken from another angle.

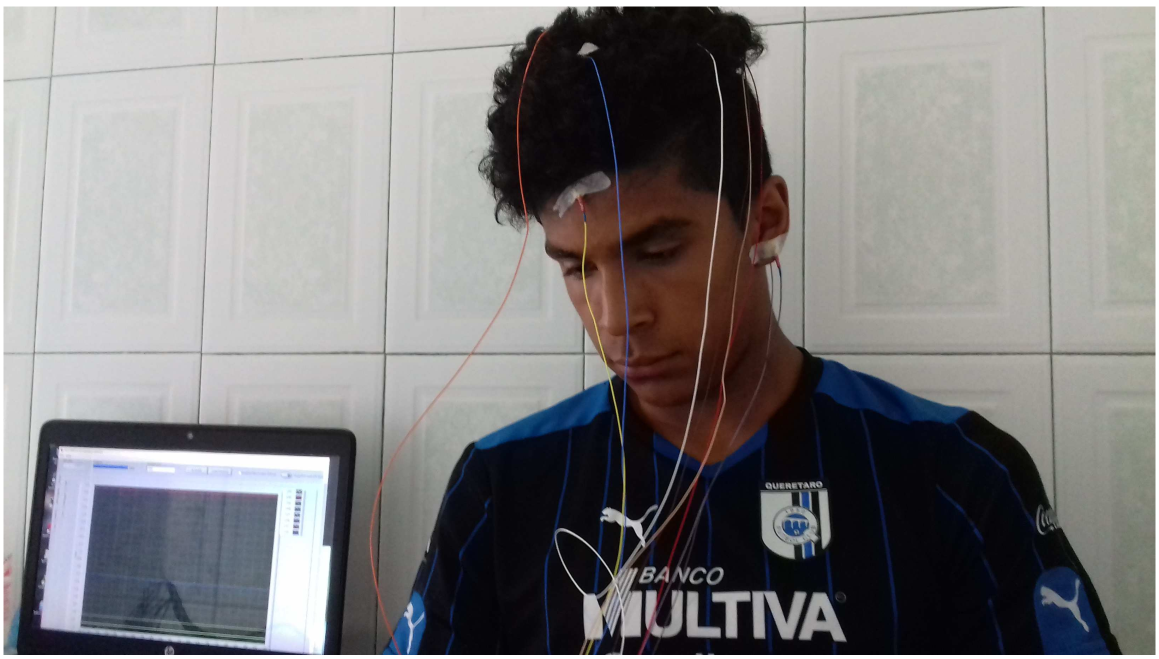

Figure 5.1: System BCI.

5.3 Technical information of materials

5.3.1 EEG Front-End Performance Demonstration Kit

The key features of the ADS1299 system on a chip (SOC) are:

- Eight integrated INAs and eight 24-bit high-resolution ADCs
- Low channel noise of 1uVpp for 65Hz bandwidth
- Low power consumption (5mW/channel)
- Data rates of 250SPS to 16kSPS
- 5V unipolar or bipolar analog supply, 1.8V to 3.6V digital supply.
- DC /AC Lead off detection
- On-chip oscillator
- On-chip bias amplifier
- Versatile MUX to enable programmable reference and bias electrode
- SPI data interface

In Figure 5.11 is shown the architecture of the ADS1299 card.

The ADS1299EEG-FE is designed so that it can be used as a eight channel data acquisition board. In Figure 5.12 is shown the input configurations that are available in the EVM.

5.3.2 Electrodes

- Reusable gold-plated cup electrode with 10mm cup diameter and 1.2m
- One electrode per package. Super-flexible PVC insulated leadwire terminates in a standard Touchproof connector.

5.3.3 Published articles

SISTEMA DE MONITOREO NEURONAL PARA EL ANÁLISIS DE POTENCIALES ENFOCADOS A PERSONAS CON PROBLEMAS MOTRICES

Magazine: CONCYTEQ

Autores: Luz María Sánchez Reyes*

Asesor: Dr. Juvenal Rodríguez Reséndiz

Institución: Universidad Autónoma de Querétaro

I. RESUMEN

La investigación se realizó en la Universidad Autónoma de Querétaro desde hace un año hasta la fecha. El presente trabajo tiene como objetivo implementar una Interfaz Cerebro Computadora BCI (Brain Computer Interface) con arquitectura abierta para el análisis de potenciales, enfocados a personas con problemas motrices. Específicamente, el trabajo consistió en lograr que la interfaz gráfica realizada en LabView sea modificable, así como la programación del procesador embebido DSP (Digital Signal Processor) del sistema de adquisición de señales. Además, se realizaron pruebas EEG (electroencefalograma) a diferentes individuos, verificando que los niveles de interferencia y ruido estén dentro de los límites permitidos de acuerdo a otros estudios similares.

Palabras clave: *BCI, DSP, EEG, LabView, arquitectura abierta.*

II. INTRODUCCIÓN

La presente investigación se refiere al diseño e implementación de una plataforma BCI, basada en la adquisición de señales EEG. Históricamente, las señales EEG fueron registradas por primera vez, por Hans Berger en 1924 aunque su estudio se inicia desde años anteriores. El EEG es un registro de ondas cerebrales o diferencias de potencial espontáneas medidas en la superficie del cerebro humano del individuo a través de electrodos metálicos (Bandara, Jumpei & Kazuo, 2016). Las ondas cerebrales se clasifican en cuatro grupos o bandas principales dependiendo del rango de frecuencias y, se identifican con letras griegas como se muestra a continuación (Colin, King, Wang, Cramer, Zoran & Do, 2014):

- α, alfa (8-13 Hz)
- β, beta (¿13 Hz)

- θ, theta (4-8 Hz)
- δ, delta (0.5-4 Hz)

Con el posterior avance de la computación y de las técnicas de procesamiento de señales, se hizo posible el desarrollo e implementación de Interfaces Cerebro Computadora (BCI), las cuales permiten interactuar con dispositivos electrónicos y entornos virtuales de comunicación, así como controlar sistemas electromecánicos a partir del pre-procesamiento, extracción de características, clasificación y retroalimentación de las señales EEG previamente adquiridas (Xu, Busze, Kim, Makinwa, Van & Firat, 2014). Estos sistemas están permitiendo cada vez más la comunicación y recuperación de personas con discapacidades en sus funciones motoras (Jianjun, Taylor, Kaitlin, Nicholas, Jeffrey & Bin, 2017), (Fares, Tong & Masahi, 2017).

La Organización Mundial de la Salud (OMS) define a las personas con discapacidad como aquellas que tienen dificultad grave o severa para realizar actividades cotidianas básicas tales como: movilidad y desplazamiento, cuidado personal, responsabilidades laborales o escolares, cognición y comunicación. Al año 2014, en el país existen 32.5 millones de hogares, de ellos 6.1 millones reportan que existe al menos una persona con discapacidad; es decir, en 19 de cada 100 hogares viven personas que presenta discapacidades. De estas personas, el 54.9% no cuenta con los ingresos necesario para cubrir sus necesidades, por lo tanto, es muy complicado que ellos tengan acceso a equipos médicos muy sofisticados (Encuesta Nacional sobre Discriminación en México [Enadis], 2014).

Por lo tanto, la investigación en sistemas BCI, es muy importante en el área de la medicina y específicamente en la rehabilitación, ya que contribuyen a constituir un canal de comunicación y control para las personas con deficiencias en sus funciones motoras. El objetivo del presente trabajo es obtener el diseño e implementación de un sistema BCI que busca la mejora de la calidad de vida de personas en condiciones de discapacidad.

III. MATERIALES Y MÉTODOS

La investigación se hizo en las instalaciones de la Universidad Autónoma de Querétaro, en la Facultad de Ingeniería desde el año pasado hasta el año en curso.

Los principales materiales fueron los siguientes: electrodos de montaje superficial con discos de oro y cable blindado, tarjeta electrónica para la adquisición de señales EEG con DSP, materiales para aplicación de electrodos (pasta conductora, algodón, alcohol y pinzas) y una computadora hp (procesador Intel Celeron N3050, memoria de 4 GB y disco duro de 1 MB) para la interfaz gráfica.

La metodología estuvo dividida en tres etapas, la primera etapa fue la búsqueda bibliográfica que permitió conocer el estado del arte de los sistemas BCI y las técnicas para el procesamiento de señales EEG.

La segunda etapa consistió en la selección de un dispositivo con las características requeridas para la adquisición de señales. En la tercera etapa se logró abrir la arquitectura tanto para la tarjeta electrónica como a la interfaz, lo cual constituye un aporte significativo para investigaciones posteriores relacionadas con sistemas BCI. En la Figura 5.13 se ilustran las etapas de la investigación.

a. DISEÑO DE INTERFAZ Y SISTEMA DE ADQUISICIÓN DE SEÑALES

Interfaz: LabView es un lenguaje y, a la vez, un entorno de programación gráfica en el que se pueden crear aplicaciones de una forma rápida y sencilla. Los componentes realizados en LabView se denominan ficheros (VI Virtual Instrument), en múltiples ocasiones el fichero (VI) puede contener a otro u otros de forma que los siguientes serán subVI del primero: el concepto es equivalente a las funciones o procedimiento de un lenguaje tradicional. Para agrupar varios VI se puede emplear una librería, además una librería puede contener a otras librerías.

La interfaz que se utilizó para el sistema BCI está compuesta de una librería principal que incluye 6 librerías secundarías. La librería principal se llama lib1299 y contiene componentes para operaciones matemáticas avanzadas, configuraciones, lectura, escritura y almacenamiento de datos.

Código del DSP: El código del procesador embebido, al igual que la interfaz hace uso de librerías y la librería principal se llama ads1299evm.h. El código original fue realizado en una versión de Code Composer descontinuada, lo cual es una limitante para modificaciones del código de programación. El objetivo principal en esta etapa consistió en migrar a una versión del software vigente.

b. IMPLEMENTACIÓN: MODIFICACIONES DEL SISTEMA PARA LOGRAR UNA ARQUITECTURA ABIERTA

Interfaz gráfica: Después de explorar las propiedades de los componentes, se estudió a detalle algunas propiedades del software poniendo énfasis en conceptos que se usan en las principales librerías. Se encontraron diferentes formas para modificar los elementos, una de ellas consiste en hacer una copia de los elementos a modificar, lo cual además permite mantener las funciones originales de la interfaz principal.

Código de programación del DSP: Inicialmente, el código tenía errores de direccionamiento (paths), espacios de memoria y ambigüedades en la sintaxis. Para solucionar los errores, se investigó específicamente cada error, sus posibles causas y a partir de esto se determinaron las acciones de solución.

IV. RESULTADOS Y DISCUSIÓN

Esta investigación tuvo como propósito principal lograr una arquitectura abierta para un sistema BCI aplicado a señales EEG provenientes de personas con alguna discapacidad motriz. Se realizaron pruebas de biopotenciales y se identificaron algunos patrones como el de un antebrazo tensionado. Las pruebas se aplicaron varias veces a diferentes personas para verificar el buen funcionamiento del dispositivo. En la Figura 5.14 se observa la interfaz gráfica con la adquisición de señales EEG. En la interfaz gráfica se puede modificar el tiempo de muestreo, amplificar las señales, aplicar diferentes tipos de filtros, modificar la formar de adquisición (singular o diferencial), almacenar los datos, desplazar las señales en el tiempo, modificar la escala de la gráfica, entre otras herramientas.

De los resultados obtenidos en esta investigación, se puede deducir que es posible lograr una arquitectura abierta tanto en el sistema de adquisición como en la interfaz gráfica de LabView, permitiendo la adquisición de señales de EEG y la implementación de sistemas BCI. Al convertir a una arquitectura abierta, permite ver su interior sin ninguna restricción, así como modificar su estructura de acuerdo a la finalidad y necesidades particulares de la investigación. De los datos obtenidos de las pruebas EEG, se puede concluir que las afectaciones por interferencias y ruido están dentro de los límites permitidos de acuerdo a otros estudios similares. Además, del análisis de los resultados se puede afirmar que es posible la identificación de patrones mediante el uso de sistema BCI de arquitectura abierta y que puede oscilar entre un 95% a un 88.9% para el total de la muestra. Los resultados obtenidos se compararon con bases de datos, se verificó la similitud de los mismos y se obtuvieron resultados favorables.

V. CONCLUSIONES

Los sistemas BCI desempeñan un papel muy importante en el área de la medicina, entonces con la mejora de estos dispositivos es posible ayudar para que en investigaciones futuras se logre establecer un canal de comunicación y control para aquellos individuos con problemas neuromotores. Por lo tanto, al tener una arquitectura abierta para la adquisición y procesamiento de señales de electroencefalograma, es posible realizar investigación relacionada con sistemas BCI, tanto para diagnóstico, como para rehabilitación y comunicación con dispositivos externos.

VI. IMPLICACIONES O IMPACTO

Este trabajo constituye un aporte significativo en investigaciones relacionadas con procesamiento de señales y análisis de biopotenciales. Además, la mejora de los sistemas BCI contribuye para el desarrollo de técnicas de biorretroalimentación que ayudan a generar una forma confiable a un mismo patrón electroencefalográfico enfocado a personas con problemas motrices de escasos recursos.

VII. REFERENCIAS BIBLIOGRÁFICAS

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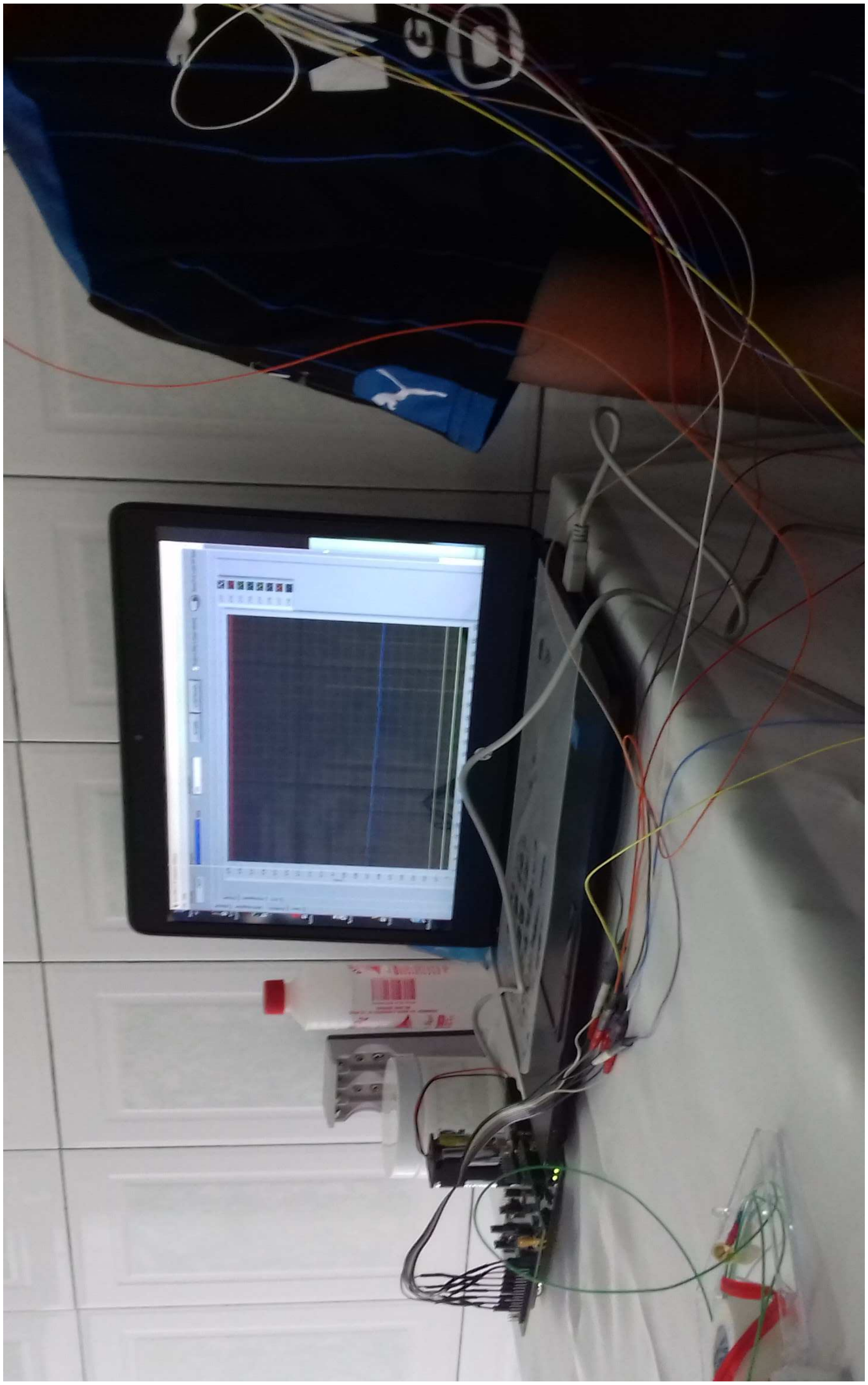

Figure 5.2: Test EEG (A).

Figure 5.3: Test EEG (B).

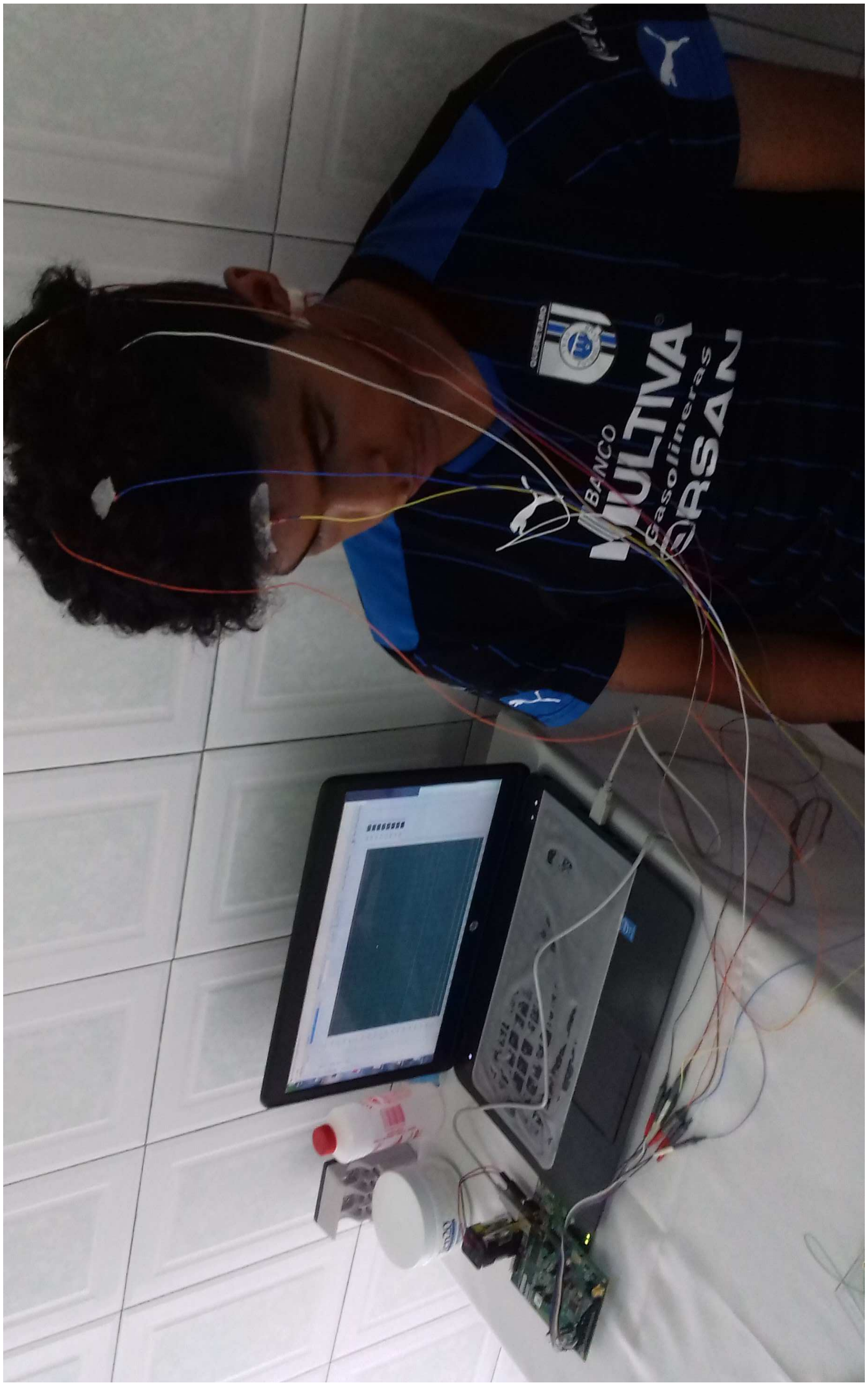

Figure 5.4: Test EEG (C).

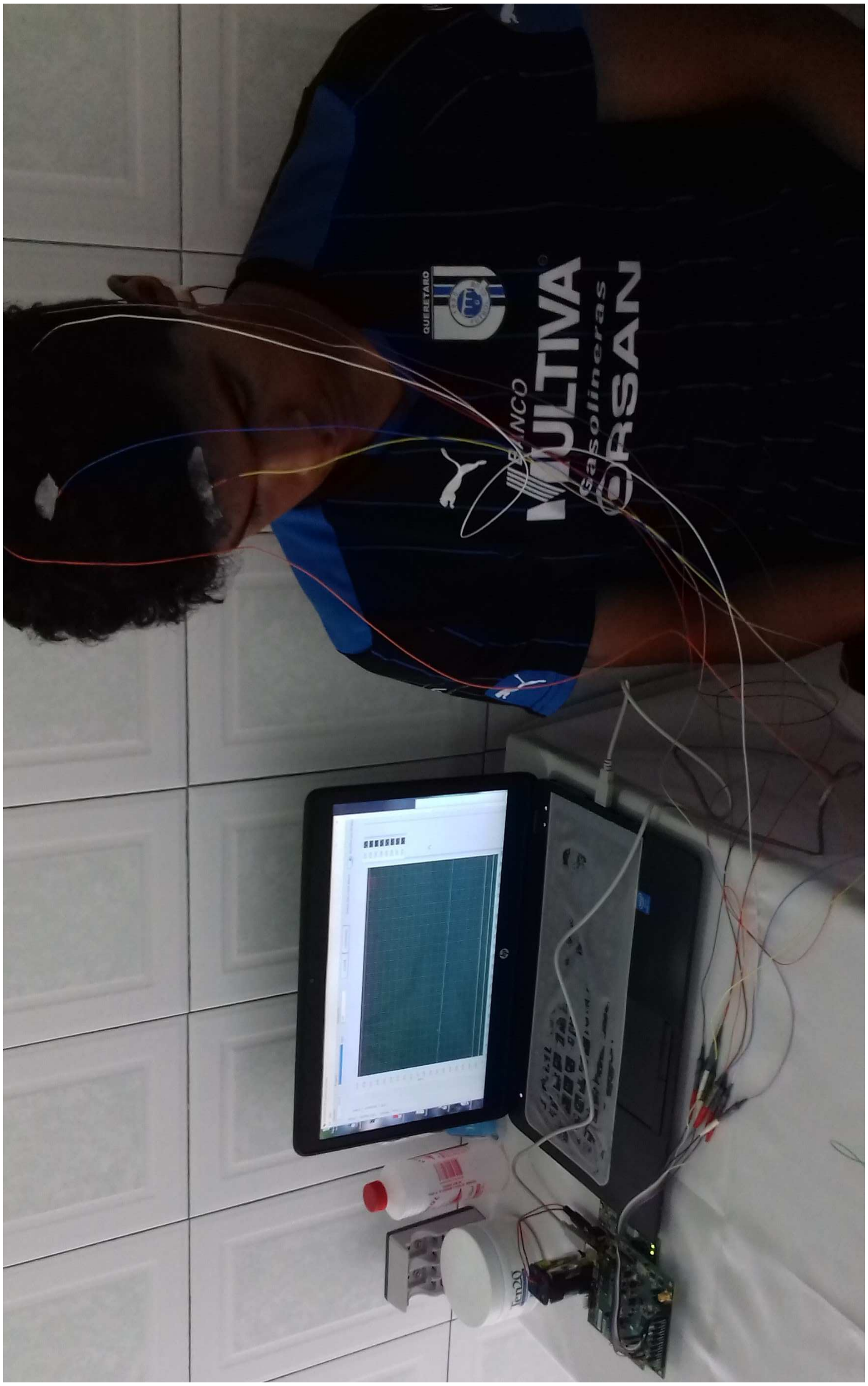

Figure 5.5: Test EEG (D).

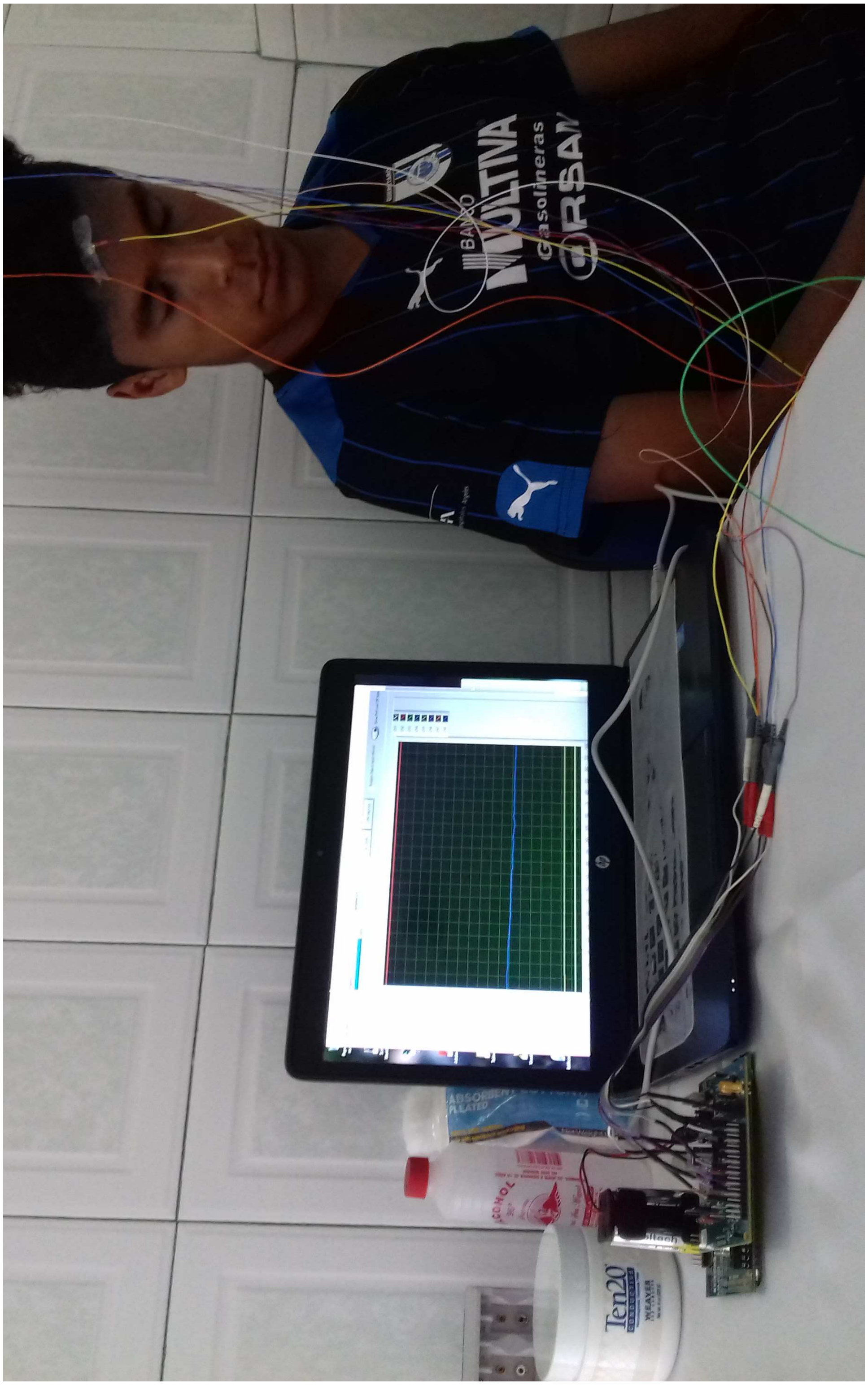

Figure 5.6: Test EEG (E).

Figure 5.7: Test EEG (F).

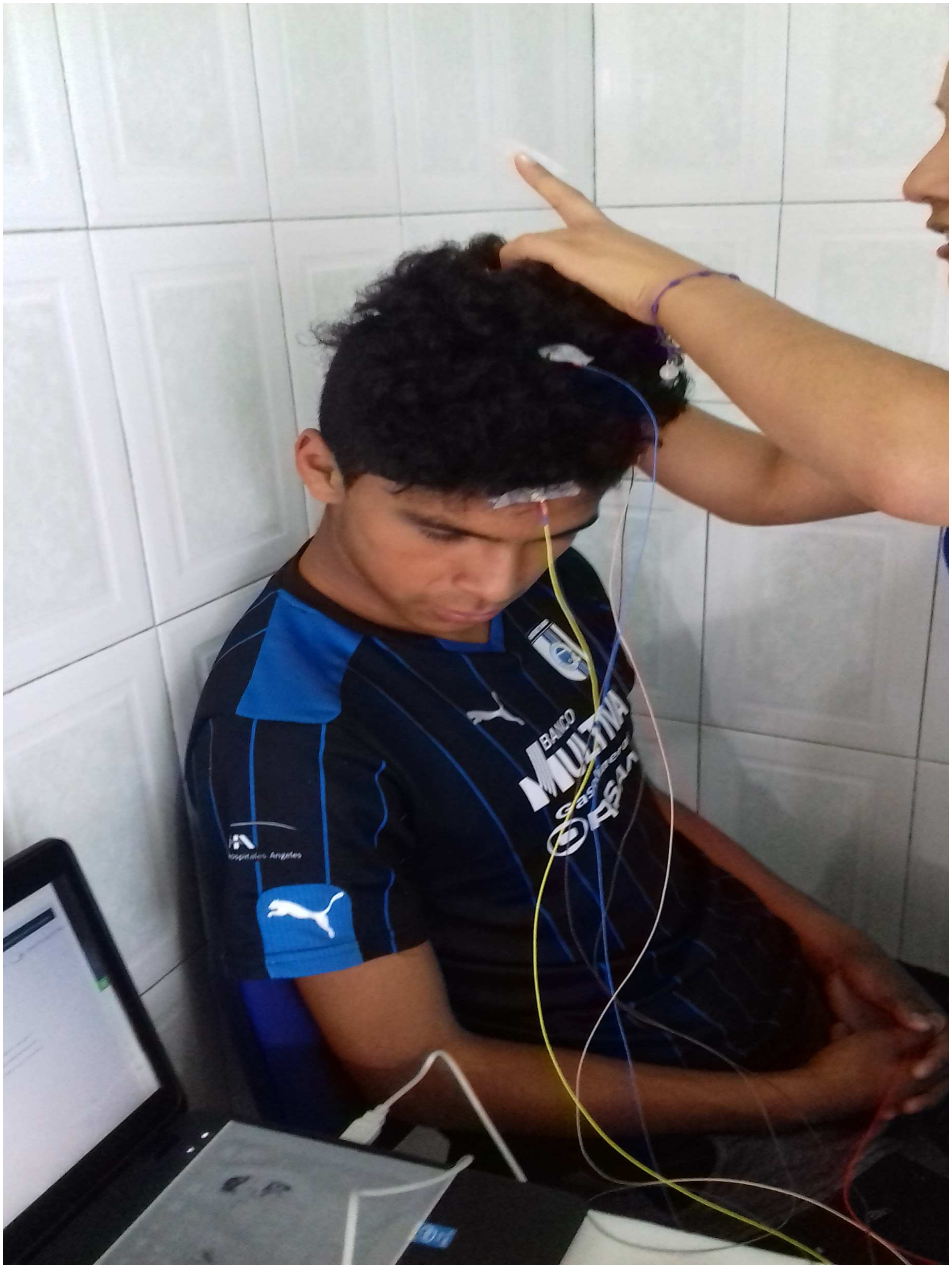

Figure 5.8: Test EEG (G).

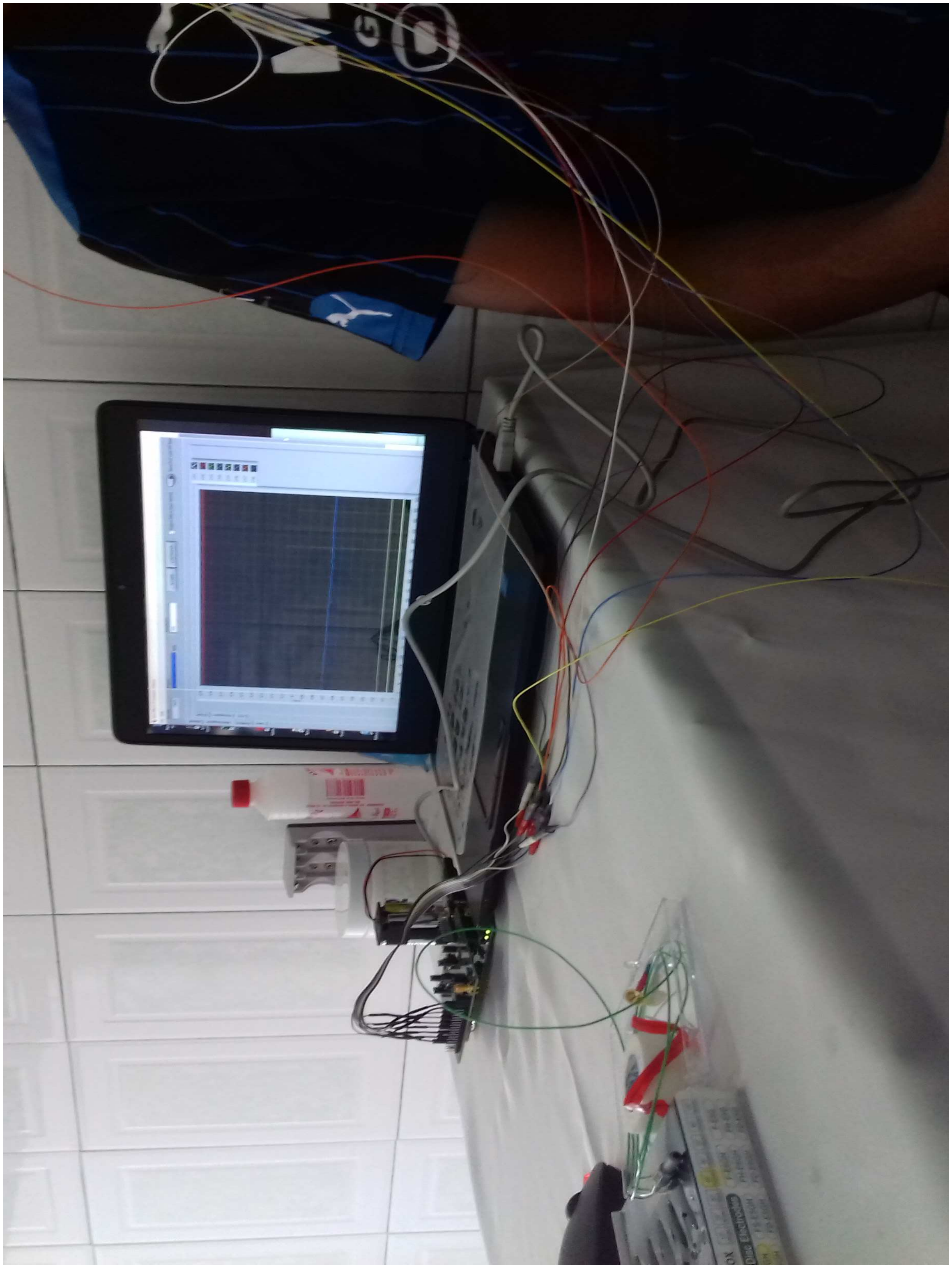

Figure 5.9: Test EEG (H).

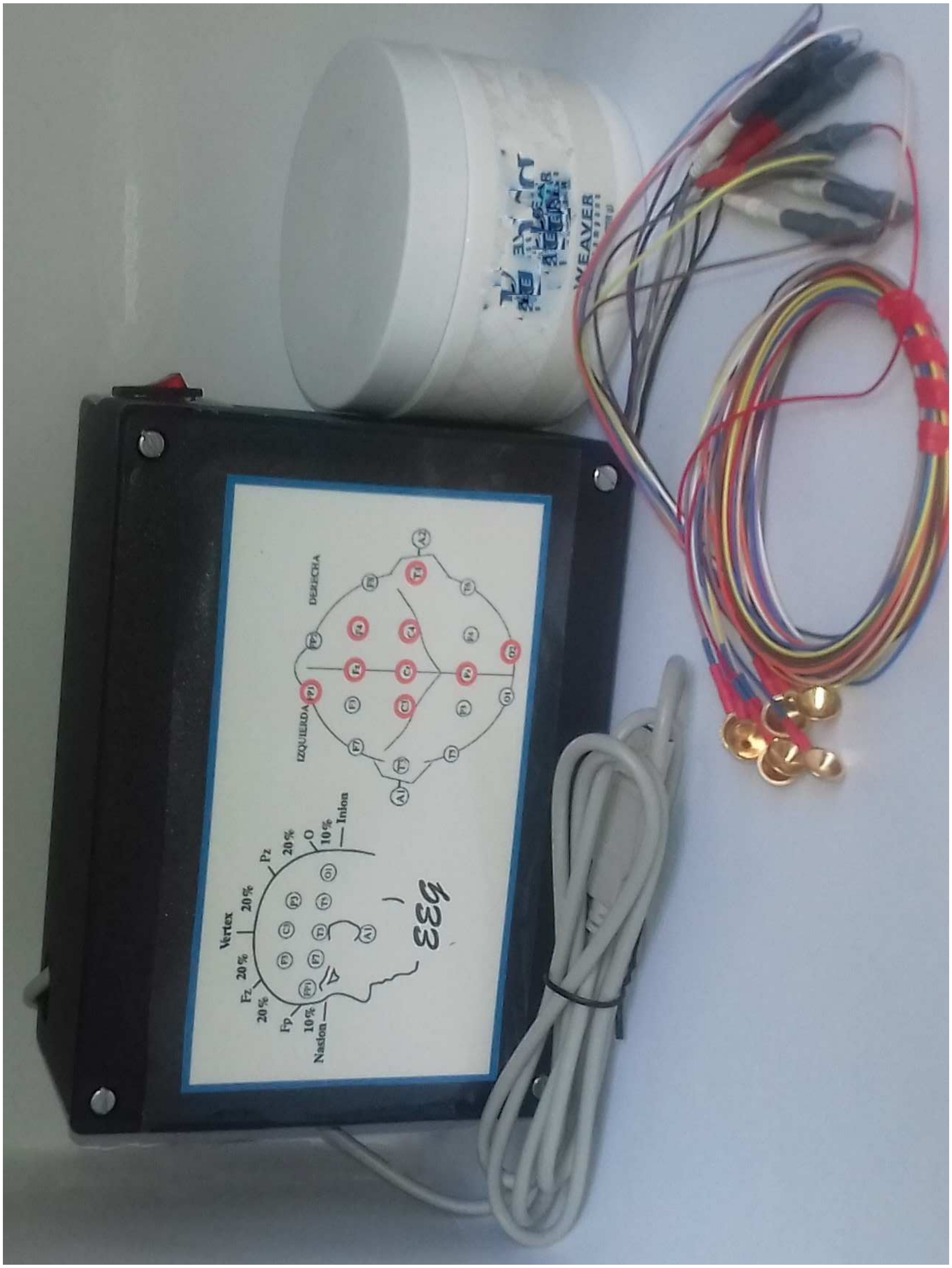

Figure 5.10: Signal acquisition system.

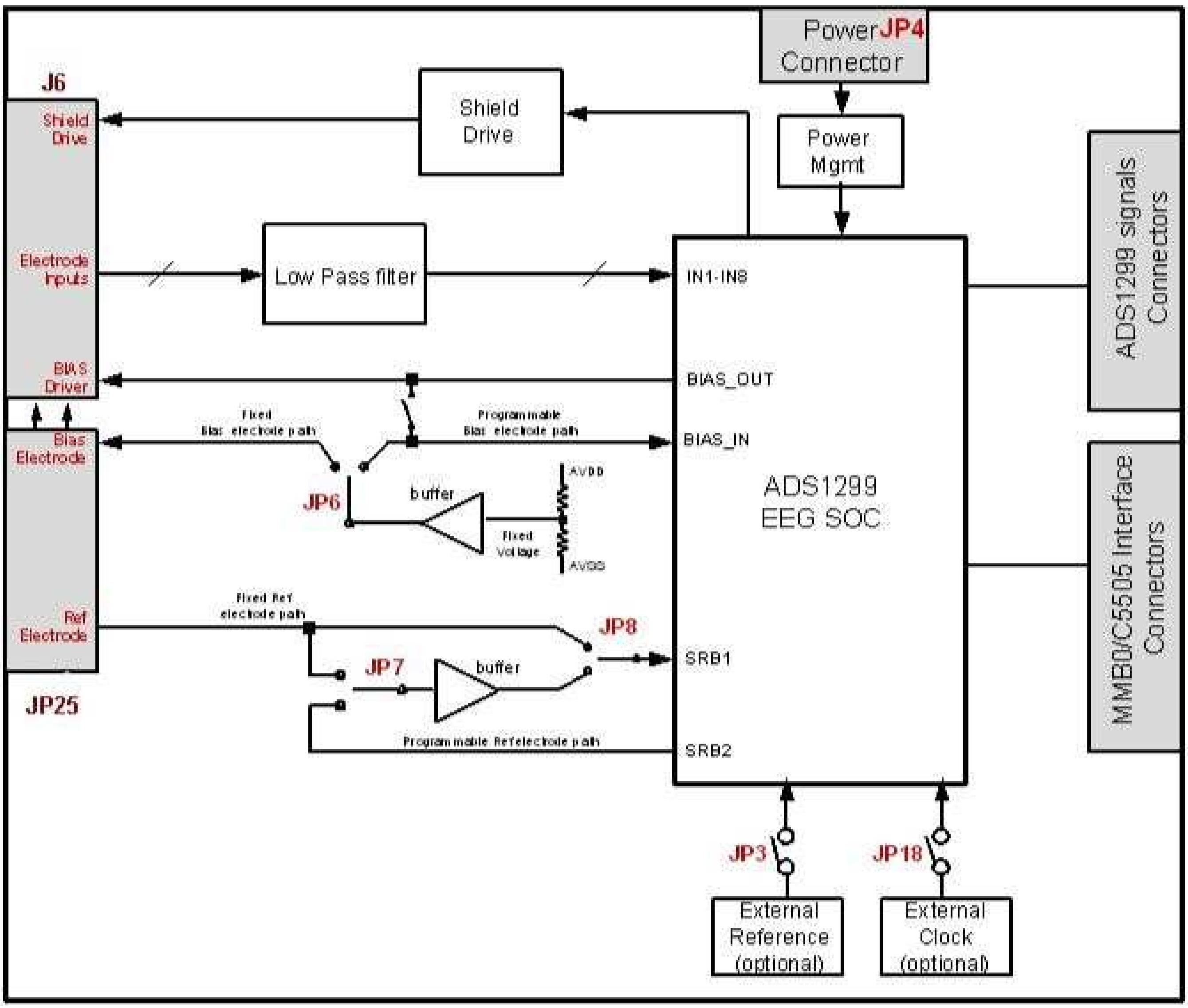

Figure 5.11: Architecture of the ADS1299 card.

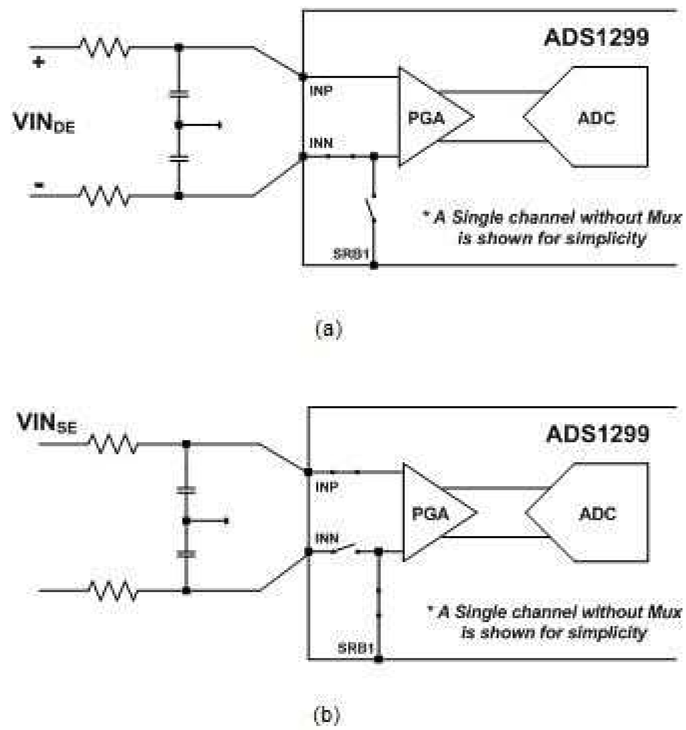

Figure 5.12: ADS1299EEG-FE front end block diagram.

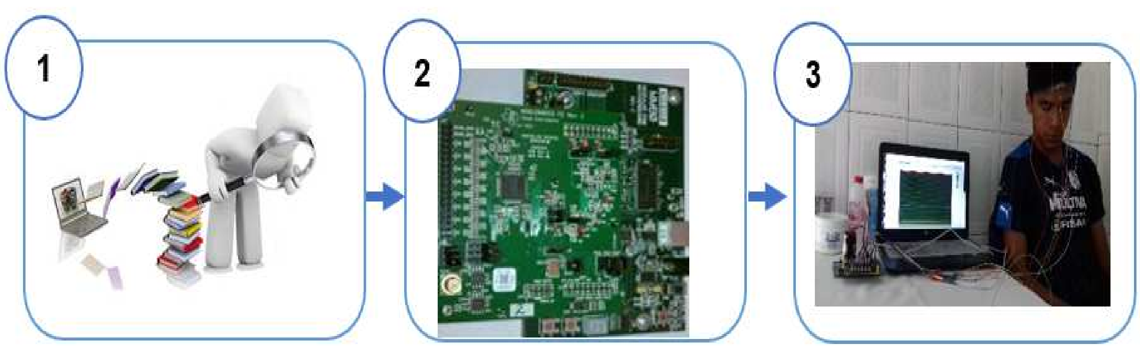

Figure 5.13: Etapas del proyecto de investigación.

Figure 5.14: Interfaz gráfica propuesta en LabView para el análisis de señales EEG.