



## Portable dynamic electromyography for human gait Electromiógrafo dinámico portátil para la marcha humana

Esperanza Camargo Casallas<sup>1</sup>  
Stephanie Lizeth Puentes Pérez<sup>2</sup>  
Sergio Enrique Pulido Morales<sup>3</sup>

Fecha de envío: 14 de enero de 2015  
Fecha de recepción: 25 de abril de 2015  
Fecha de aceptación: 12 de agosto de 2015

**Abstract:** A significant percentage of the Colombian population has pathology in their lower extremities. The lack of objective analysis and laboratories has resulted in undiagnosed diseases in studies of patients. The portable electromyography serves to acquire the electrical signals from different motor units of muscles of the lower extremities involved in walking, then process and save them to a remote storage device (microSD™) to be observed on a computer via a java app, with the possibility that these studies be imported into a PDF and printed. The device has two channels of study, a marker of passage, and an item of electrical insulation to protect the patient which is powered by rechargeable batteries. By contributing in conjunction with graduate specialists in physical medicine and rehabilitation at the Universidad Nacional de Colombia, covering more demand for a fully portable device which studies show will be more realistic solving the problem that people change the gait pattern to be observed.

**Keywords:** Electromyography, microSD™ memory, walking laboratory, micro-controller.

- 1 BSc. In Electronic Control and Instrumentation, Universidad Distrital Francisco José De Caldas, Colombia; PhD(c) In Engineering, Pontificia Universidad Javeriana, Colombia. Current position: Professor Universidad Distrital Francisco José de Caldas, Colombia. Director Research Group DIGITI, Universidad Distrital Francisco José De Caldas, Colombia. E-mail: ecamargoc@udistrital.edu.co
- 2 BSc. In Electrical, Universidad Nacional de Colombia, Colombia. Current position: Electricity Eng. Universidad Nacional de Colombia, Colombia. E-mail: lizzy1\_59@hotmail.com
- 3 BSc. In Mechatronics, Universidad Nacional de Colombia, Colombia. Current position: Electronic Eng. Universidad Nacional de Colombia, Colombia. E-mail: sepulidom@unal.edu.co

**Resumen:** Un significativo porcentaje de la población Colombiana presenta patología en sus extremidades inferiores; sin embargo, la falta de laboratorios con análisis objetivos hace que no se diagnostiquen en los estudios de los pacientes. En el presente artículo, se describe la investigación que condujo a un electro-miógrafo portátil con la función de adquirir señales eléctricas provenientes de las diferentes unidades motoras de los músculos de las extremidades inferiores -implicados en la marcha-; procesarlas y guardarlas en un dispositivo de almacenamiento remoto (microSD™) para luego visualizarlas en un computador con una aplicación de java, teniendo la posibilidad de que estos estudios sean importados a un PDF para que sean imprimibles. El dispositivo cuenta con dos canales de estudio, un marcador de paso, un elemento de aislamiento eléctrico, para la protección del paciente y es alimentado con pilas recargables. Se contribuye de este modo con un módulo del laboratorio de Marcha humana -en conjunto con especialistas de postgrado en medicina física y rehabilitación de la Universidad Nacional de Colombia- para abarcar más demanda, ofreciendo alta calidad, comodidad y eficiencia, a través de un dispositivo totalmente portátil y cuyos estudios serán de mayor realismo al desarrollarse en la cotidianidad del paciente, resolviendo el problema de que las personas cambian el patrón de marcha al ser observadas.

**Palabras clave:** comunicación encubierta, imagen a color, imagen a escala de grises, medición de calidad, transparencia.

## 1. Introduction

To solve the problem of high demand for studies of electromyography during the gait<sup>1</sup> vs the few specialized centers<sup>2</sup>, a portable electromyography powered by rechargeable batteries has been implemented, giving the patient comfort and freedom at the time of the study, also, it decreases the change pattern's gait when the patient feels observed.

For an electrophysiological study of the neuromuscular system (EMG), MEDITRACE®

electrodes were used. An amplifier of bio-instrumentation measured the difference of electrical potential between two electrodes placed strategically on the skin was used. To improve the output signal, it was filtered and amplified.

This signal has a conversion into digital data through a PIC18f4550 microcontroller, also, a sensor in the sole of the foot was placed to indicate when the patient makes a step during the gait, so that the PIC captures the data and it is saved instantly to a microSD memory™

- 1 The percentage of the Colombian population has pathology in his lower extremities was captured for DANE information [1].
- 2 This affirmation was done due to the specialized centers are located in the principal capitals of Colombia, and a lot of people that have any pathology were located at another places far away from these cities.

in a text file, using a communication protocol SPI.

Finally, you can display the text file data stored on the microSD™, you can print these images and save the data in the computer, using a software designed in programming software called Netbeans JAVA language-based allowing a very friendly and simple interface.

This article provides an introduction to the important concepts to have a minimal path through the electromyography, after making a description about the project including how it was designed and implemented, and finally, the results acquired with this will be known.

## 2. Electromyography during walking

Currently in the market there are high quality and precise electromyography such as MEB-9400K Laptop [2], SIERRA II WEDGE [3], however, its communication to computer is cabling, for this reason, the patient must carry a laptop if the person wants an exam with quotidian parameters. The Italian Electromyography BTS POCKET EMG [4] has the facility to be portable, but its commercial value adds the import cost, making it a very expensive device.

Nationally an investigation development into DIGITI group<sup>3</sup>, is found however, its study object is the arm and its communication was performed via USB, [5] generating the same problem that two first devices presented. About portable electromyography, one development at the Universidad de Los Andes [6] was found, but its study object was a spine.

### 2.1 Stages of the human gait

The human gait normal and pathological is described as "a series of alternating, rhythmic movements, extremities and the trunk that determine a displacement forward of the Centre of gravity"

In this sense, dynamic electromyography has played a fundamental role. Electromyography detects, amplifies, and graphically shows the electrical activity of muscle contractions. When a muscle contracts, the constituent fibers of the motor unit suffering a depolarization that causes an electrical disturbance, which can be collected through electrodes (surface or thin wire). This signal is amplified and filtered; it is then reflected in a graphical representation. Dynamic electromyography is the only valid method to determine when a muscle is active during the gait cycle [7].

The Gait cycle begins when a foot makes contact with the ground and ends with the following contact with the same foot; It is called the distance between these two contacts full step.

The Gait cycle is divided into a) Phase of support, b). Swing phase. Figure 1.

One leg is in the phase of support when you have contact with the ground, and it is otherwise in its phase of rolling.

#### 2.1.1. Support phase

The stance phase can be divided into 5 moments: heel contact, support planting, support, elevation of the heel, and foot takeoff [9–11].

Heel contact is the moment in which the reference leg heel touches the ground. Support

3 Research Group DIGITI, Universidad Distrital Francisco José De Caldas (Colombia).

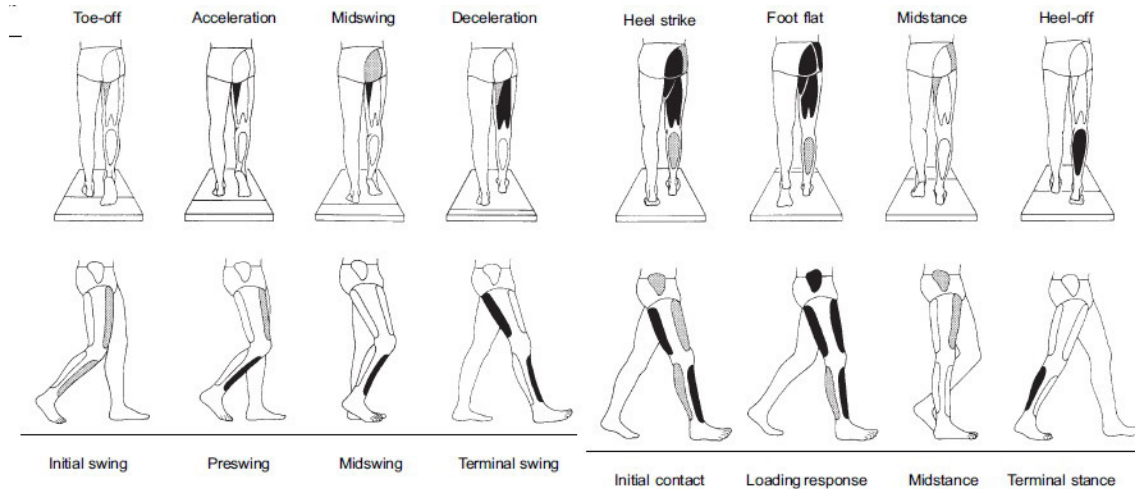


Figure 1. Stage of human walking. Source: [8].

plant refers to the front of the foot making contact with the ground.

The average support occurs when the greater trochanter is vertically aligned with the center of the foot, seen from a sagittal plane.

The elevation of the heel occurs when the heel rises from the ground. The DT foot occurs when fingers rise from the ground.

### 2.1.2. Swing phase

The swing phase can be divided into three intervals: acceleration, average rolling, and deceleration [9–11].

The period of acceleration is characterized by the rapid acceleration of the end of the leg as soon as the fingers leave the ground.

Rolling average, balanced leg interval passes to the other leg, moving forward, since it is in the support phase.

And the last interval, the deceleration of the leg that moves rapidly when it nears the end of the interval.

## 2.2 Electromyography

It is a technological means for the study of human movement, this technique indicates when a muscle is active or inactive, electromyography detects, amplifies, and shows graphically the electrical activity of the muscle contraction when a muscle contracts the constituent fibers of the motor unit suffers a depolarization that causes an electrical disturbance, which can be collected through some electrode [12], [13].

The electromyography (EMG) and nerve conduction tests are most useful electro diagnostic methods in the study of the motor function.

## 3. Methodology

### 3.1 Models musculoskeletal

Dynamic electromyography has yielded a set of patterns that identify the sequence of muscle activation and deactivation during gait cycles. Based on this information and some biomechanical relationships of motion, different representations of the human gait have

been proposed, using muscle and joint models that approximate the complex interaction of the musculoskeletal system. According to the complexity introduced by these models to represent musculoskeletal interaction, the musculoskeletal system can be divided into models based on mechanical systems and computational models [14].

### 3.2 Acquisition and signal processing

The electrodes pick up the electrical activity of the muscle, either by inclusion within it or through the overlying skin, or prior coupling through conductive paste to reduce contact resistance [15–17].

These electrical signals are taken primarily in the muscles of the lower extremities, especially in the gastrocnemius muscle, by placing the electrodes as shown in Figure 2.

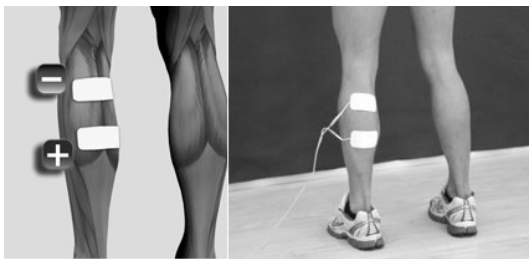


Figure 2. Electrode location. Source: [17].

To perform the difference of potential of the electrode bio-instrumentation AD620 amplifier; this amplifier was used as its name says, that is, especially used for medical applications since they can conveniently increase so small voltage levels without altering the shape of the signal [8]; It is also used due to its low cost and power consumption.

With this integrated circuit, AD620493 times the signal with the use of a resistance of  $100\Omega$  calculated with the relationship that exposes the manufacturer is amplified.

It is a filtering of noise that presence by movement of the wiring, for this filter, a high Butterword 20 Hz is used, plus a filtering to remove the harmonics generated by the signal was implemented making a pass filter Butterword of 500 Hz.

Filters and filters equations were used with an operational amplifier, these are implemented with the op-amp TL074, since this integrated circuit is ideal for working with low frequencies.

Continuing, with a 3.3 amplification made times with C.I. TL074, to obtain a signal 1620 times amplified.

### 3.3 Scanning of the electromyography signal

Using a microcontroller from Microchip, due to Harvard architecture that it has, also it has two separate memories which are connected via two separate bus groups. Both busses are totally independent and can be of different widths, so that CPU access is independent and simultaneous to the memory of data and instructions, getting that instructions be carried out in less clock cycles. Due to the speed, a PIC of high range was used. The difference in ranges of microcontrollers refer to the greater amount of records to work speed, RAM and ROM memory.

The signal amplified and filtered is made with a conditioning amplifier TL074, configured as Adder to make an offset, i.e., placing the negative signal on positive values to take the values with the PIC Microcontroller 18f4550.

In addition, it is the signal of a sensor that detects when the heel makes contact with the floor to indicate the beginning and end of a step of the Gait.

These signals are taken in the PIC with the ADC (analog digital converter) using the process shown in figure 3, resulting in the digitalization of electromyography signals, keeping data in the buffer of 512 to supplement its capacity to be then stored on the microSD™ in a text file named EMG\_SS.

```
set_adc_channel(0);
delay_ms(1);
muestra1=read_adc(); //digital value first chanel ( 1° sample EMG)
delay_ms(1);
set_adc_channel(1);
delay_ms(1);
muestra2=read_adc(); //digital value second chanel (2° sample EMG)
delay_ms(1);
set_adc_channel(2);
delay_ms(1);
muestra3=read_adc(); //digital value of sensor step
delay_ms(1);
```

Figure 3. Analog digital converter code. Source: own.

Both busses are totally independent and can be of different widths, so that CPU access independent and simultaneous to the memory of data and instructions can compute that instructions be carried out in less clock cycles.

Due to the speed it was decided to work with a PIC of high range. The difference in ranges of microcontrollers, refer to the greater amount of records to work speed, RAM and ROM memory.

The signal amplified and filtered is made with a conditioning amplifier TL074, configured as Adder to make an offset, i.e., placing the negative signal on positive values to take the values with the PIC Microcontroller 18f4550.

In addition the signal of a sensor that detects when the heel makes contact with the floor to indicate the beginning and end of a step of the Gait.

These signals are taken in the PIC with the ADC (analog digital converter) using the process shown in Figure 4, resulting in the digitalization of electromyograph signals, keeping data in the buffer of 512 to supplement its capacity to be then stored on the microSD™ in a text file named EMG\_SS.

### 3.4 MicroSD™ Implementation

For communication with the micro SD™ memory the SPI protocol is used where a 4-pin of microcontroller PIC18F4550 was needed: 1 for clock, 1 for enabling sent, 1 of command sent, and one for a receipt of the response.

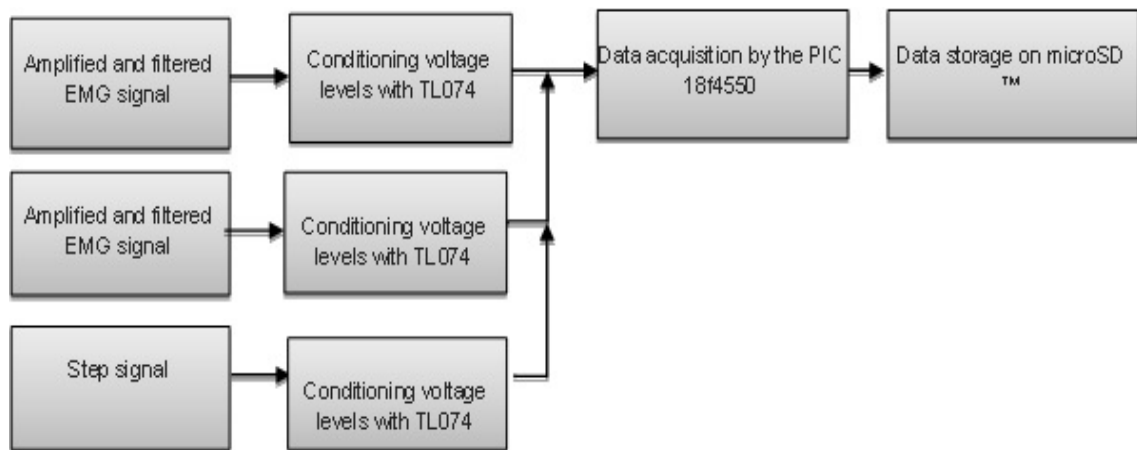


Figure 4. Electromyography Signals Digitalization. Source: own.

The SPI (Serial Peripheral Interface) is a three-line bus on which packets of information of 8 bits are transmitted. Each of these three lines carries the information between different devices connected to the bus. They transfer these two data lines (one in each direction) and the third line is the clock. [18]

Due to this, this protocol has a clock that is essential for both devices to be synchronized, one good methodology is maintaining the same voltage, limiting the current with a resistor, and sending many data chains with some packaging.

Using a memory microSD™ due to the speed in which you work for the compatibility that has with the vast majority of electronic devices and for its size. For the implementation of this memory, the DM3AT is used. (Card connector microSD™).

The routine of the PIC was carried out in the PIC-C compiler, which created a main program that calls two libraries according to the need:

SDcard\_hard: this library is responsible for the part of communication hardware-level, i.e. enabling pin and the sent command to accomplish this.

The commands used in this communication can be seen in Figure 5.

After sending, a command response of memory is expected to follow the process.

Fat16\_SDcard: this library is responsible for handling it, referred to with the FAT, i.e. the reading and/or writing of memory.

Communication pin, is enabled to start communication with the memory is reset memory (CMD0), memory (CMD1) initialization process is activated, fixed block read / write of 512 (CMD16); i.e. the communication buffer is configured to work; and finally disable the pin of communication; If the successful process is achieved by initializing the microSD™ memory.

Then the Fat16 Bookstore is initialized, this is to make writing and reading files or folders within the microSD™.

When using this library, you can only reach write or read microSD™ up to 2 GB memory since superior memories should already handle fat32.

Create the file in memory called EMG\_SS.txt through the routine of Figure 6.

```
#define CMD0 0 //reset SD Card
#define CMD1 1 //initialization process of SD Card
#define CMD9 9 //read register CSD
#define CMD10 10 // read register CID
#define CMD16 16 //choose long of block for read/write (1 to512)
#define CMD17 17 //reading of one only block
#define CMD24 24 //Writing of one only block
#define CMD59 59 //ON/OFF CRC
#define CMD32 32 //reset direction of first block to erase
#define CDM33 33 //reset direction of last block in a continued rank to erase
#define CMD38 38 //Erase all sectors within directions established
```

Figure 5. Commands used in communication with MicroSD™. Source: own.

```
#define DirectorioRaiz 0
char NombreArchivo[13]="EMG_SS.txt"; // Short name of text file
char Texto[40]="\n*****datos agregados*****\r\n"; // initial message within text file
crea_file=FAT_CreateFile( FileName,FileName,RootDirectory,Text );
```

Figure 6. Code snippet to create text file. Source: own.

	Home	End
Channel 1	#	S
Channel 2	/	&
Sensor step	<	>

Table 1. Packaging of data symbols. Source: own.

Since the used buffer is 512 so much data are saved as you can in this, getting them with the ADC, performing a stage of packaging, where the 2 channels and sensor data have different symbols for this, as shown in table 1.

Having the full buffer he is the search for the text file and continues writing in the microSD™. Repeating this process until needed by the user or this cycle is shorter for 3 minutes.

### 3.5 User interface

Software developed in Java in the environment of Netbeans. Software is recommended to be used with superior to 1768 x 768 screen resolutions, and it is designed to infer the resolution of the computer where fence to run, and warn if it is not recommended.

The user interface called "MyOgRaPhY v1.2", is a simple application (see Figure 7) where you can view data stored on the microSD™ in the text file, after plotted may be zoomed, create a pdf with the graphics to be printed, and save the text file on the computer with the date, patient name and remarks of the specialist.

All functions are detailed in the user manual.

The software prompts the user to load or open the text file where the data stored on the microSD™; These data are stored in a vector for each channel.

Whenever the user tries to upload a file that does not correspond to the software needs, a warning appears via a message that the correct file must be loaded.

To begin to graph is activated timers that began every 1ms to draw lines connecting each of the data that is in these vectors in a Canvas, graphing the channel data that is selected; either one or both.

Also, the display shows the marker step (blue line. Figure 7). You will finish drawing until the saved data runs out generating pages of charts that can be displayed by moving the Scrollbar that is located at the bottom of the Canvas.

Then you can either zoom on the image to see it in more detail as the data on a page, this also has a Scrollbar to view all data.



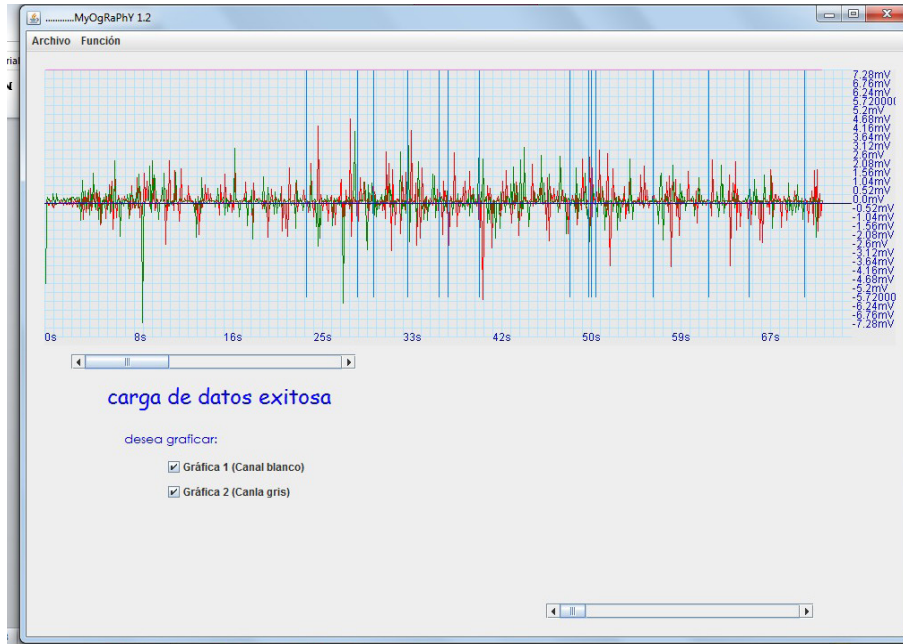


Figure 7. User interface. Source: own.

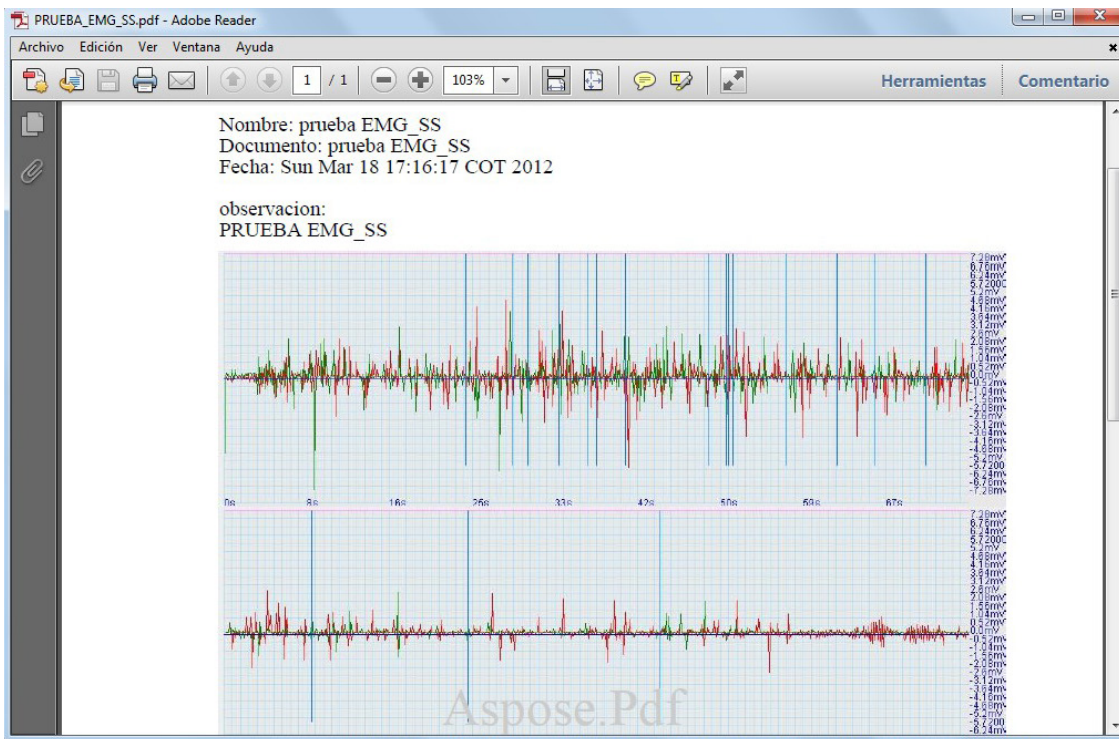


Figure 8. Pdf generated by MyOgRaPhY v1.2. Source: own.

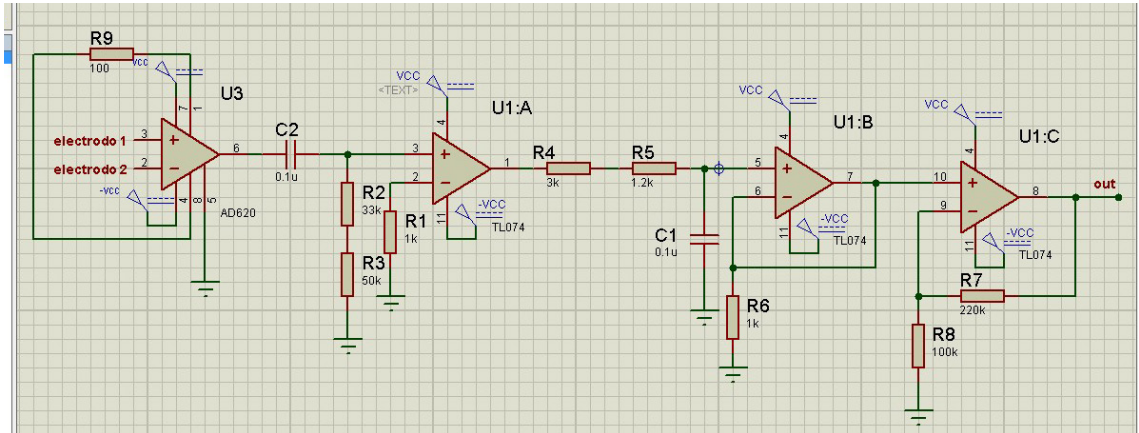


Figure9. Design of Pre-amplification, filtering, and amplification per channel. Source: own.

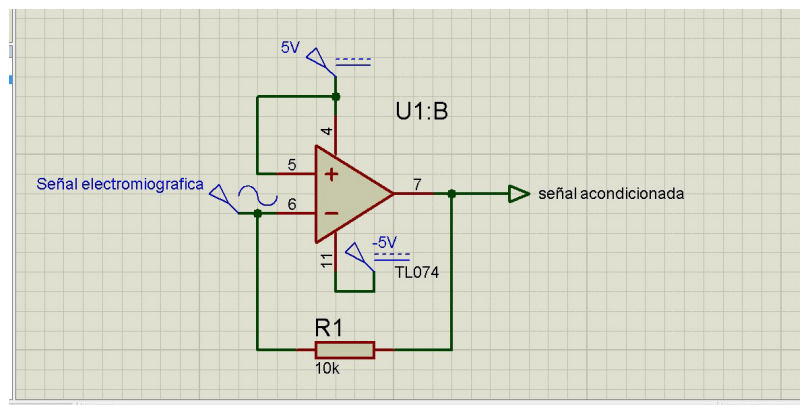


Figure 10. Implemented offset. Source: own.

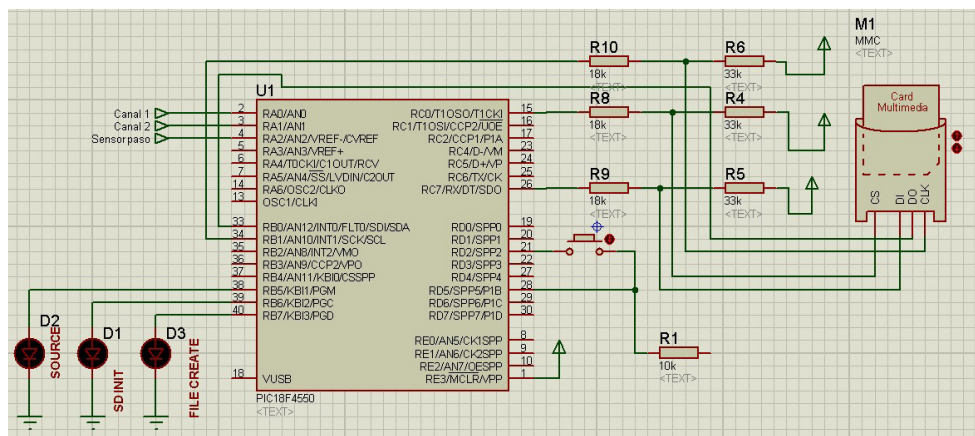


Figure 11. Implemented circuit of pic18f4550. Source: own.

The data can be saved in a text file created from the software to save it where and with the name that the user prefers, for further analysis of these data.

It has the function of creating a pdf (as you can see in Figure 8) to print the graphs of the Studio, where the name, document of the patient, time of creation of pdf, and the remarks of the specialist will be displayed followed by the graphics.

### 3.6 Hardware

The device circuits can be displayed in figures 9, 10 and 11, showing the elements used corresponding to the order of the acquisition and processing of the signal electromyograph (9), (10) voltage conditioning, and digitizing data and storage on microSD™ (12).

## 4. Results.

A portable Electromyography was developed (see Figure 12), powered with 2 9V batteries,

where the data between 90  $\mu$ V and 6mV was amplified, filtered, and taken to a level offset, for signals indicated to be digitized by a microcontroller, additionally also will receive the signal from a sensor of passage (sensor to detect the contact of the heel of the patient with the soil to determine the start and end of Gait), and will keep this data in a text file called EMG\_SS.txt, using the SPI protocol in a microSD™ memory, over the course of two minutes.

This data can be visualized in a software designed by Java where the user will have the option to zoom onto the graph, analyze progress either in a single leg or at the time the two, with the flow indicator to make the study easier and better.

In this research, some studies were done in a daily environment of the person, where developed normal activities for them, generated a real proof, where the observations that could make in this regard. These studies are shown in figure 13, 14 and 15.



Figure 12. Portable electromyography. Source: own.



Figure 13. Fragment EMG study of a 7 year old girl. Source: own.

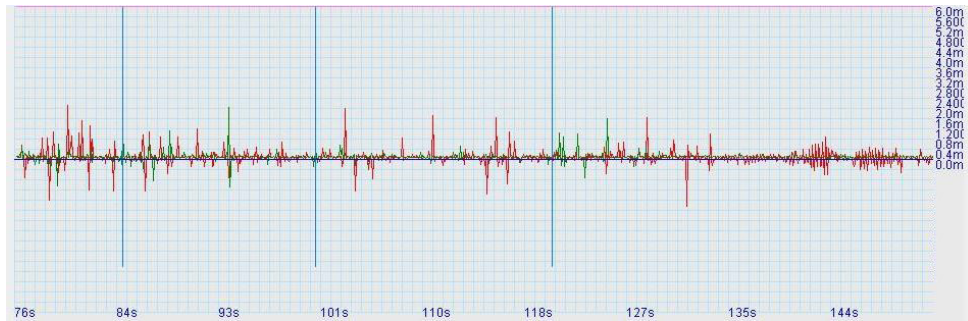


Figure 14. Fragment EMG study of a 18 year old girl. Source: own.



Figure 15. Fragment EMG study of a 30 year old women. Source: own.

The results were available by graduate specialists in physical medicine and rehabilitation at the National University of Colombia.

The procedure applied the gastrocnemius muscle proof on three different people of diverse ages, and observed the development of the Device.

- First it makes the proof in a seven-year-old girl, the study pre-sent a normal signal and tensions were in a terminal swing not superior to 2 mv, besides, its frequency of Gait shows a normal dates between 100 Hz and 200 Hz.
- The second person was an 18-year-old woman, whose study shows normal results with a poor activity, generated high frequency, however, its tension levels are normal (less 2 mV)

- Finally, a study was conducted on a 30-year-old woman with a problem in her left leg, which was witnessed in the signal amplitude generated tension levels higher than 1.5 mv, range not permissible, it frequency of gait was major in the left leg than in the right leg.

## 5. Conclusions

The use of electromyography helps to improve the study of the human body in the neuromuscular part, giving the ability to diagnose problems in the long run with a correction in time.

Thanks to the assistance of specialists in the area of Orthopedics of the Universidad Nacional de Colombia, he could observe and ensure the optimal results of imagery in different

tests in Gait, proving that the device is suitable for the study of electromyography.

When performing different tests, it was observed that the result varied if the individual which is being studied manipulates some conductive element or is close to any electromagnetic radiation, to avoid this, an anti-static handle was implemented.

To have good communication using the Protocol SPI, data synchronization should be checked well, since this is one of the biggest drawbacks for communication with the microSD™.

Speed greater than 100 ms data collection is needed for the graphics and optimal analysis.

## Bibliography

- [1] Grupo de Registros Demográficos, "Información estadística de la discapacidad", DANE, Colombia, 2004
- [2] IVENS S.A. Chile. "MEB-9400K" noviembre 2012. [Online] Available: [http://www.ivals.cl/index.php?option=com\\_open-cart&Itemid=250&route=product/product&path=122\\_166&product\\_id=107](http://www.ivals.cl/index.php?option=com_open-cart&Itemid=250&route=product/product&path=122_166&product_id=107)
- [3] CADWELL LABORATORIES. INC. "Sierra wave" noviembre 2012. [Online] Available: <http://www.cadwell.com/products/emg/> <http://www.cadwell.com/products/emg/wave/>
- [4] BTS BIOENGINEERING S.p.A. "surface EMG" noviembre 2012. [Online] Available: <http://www.btsbioengineering.com/products/surface-emg/>
- [5] W. F. Urbina and F. Martínez. "Implementación de un electromiógrafo con interfaz USB". Facultad Tecnológica. Universidad Francisco José de Caldas. Bogotá D.C. Colombia. 2011. [Online] Available: <http://www.dialnet.unirioja.es/descarga/articulo/4033984.pdf>
- [6] A. García. Et al., "Diseño ergonómico de un sistema de electromiografía portátil" noviembre 2012. [Online] Available: <http://www.iberchip.net/IX/Articles/PAP-022.pdf>
- [7] J. K. Aggarwal and Q. Cai, "Human motion analysis: a review", Computer Vision and Image Understanding, Vol. 73, no. 3, pp. 428–440, 1999.
- [8] T. F. Inman and V. Ralston, "Human Walking," Ergonomics, volume 24, issue 12, 1981.
- [9] W. Robert, "Engineering Biomechanics of Human Motion," Ohio: Leonardo. p. 80, 2010.
- [10] J. Perry, "Normal Gait," J. Sports Sci Med, volume 9, issue 2, 2010.
- [11] M. Nordin, "Biomechanica Basica del Sistema Muscoesqueletico", Madrid, España: Mc Graw Hill, p. 345, 2004
- [12] S. Huang and D. P. Ferris, "Muscle activation patterns in the transtibial amputee." J. Neuroenq Rehabil, volume 9, issue 55, 2012, DOI: 10.1186/1743-0003-9-55
- [13] N. Wiereszen, "Análisis de la Actividad Muscular en Posición Bípeda y durante la Marcha," [Online] Available: <https://es.scribd.com/document/135864951/Marcha-y-Bipedestacion>.
- [14] C. Cifuentes "análisis teórico y computacional de la marcha normal y patológica".

Revista de la Sociedad Española de Rehabilitación y Medicina, Vol 18 no. 2 pp. 182–196. 2010.

- [15] A. V. Moreno, “Consideraciones para el analisis de la marcha humana. Técnicas de videogrametría electromiografía y dinamometría,” Revista Ingeniería Biomédica, Vol. 2, no. 3, pp. 16–26, january-june 2008.
- [16] D. F. Stegeman and H. J. Hermens, “Standards for surface electromyography : the European project ‘ Surface EMG for non-invasive assessment of muscles ( SENIAM )’,” pp. 108–112, 1999.
- [17] D. A. Garz, “Análisis de sensibilidad por la colocación de los electrodos en la electromiografía de superficie Sensitivity analysis for the positioning of electrodes in surface electromiography ( semg ),” Rev. Fac. Ing. Univ Antioquia, no. 46 pp. 70–79, 2008.
- [18] E. López. "Ingeniería en microcontroladores/Protocolo SPI (serial peripheral interface)". octubre 2011. [Online] Available: <http://www.i-micro.com/pdf/articulos/spi.pdf>

