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Study and realization of signal acquisition and monitoring system physiological (EMG) for medical applications.

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ملخص :

يهدف هذا العمل إلى تطوير و إنجاز جهاز طبي يقوم بالتقاط الإشارات الكهربائية الموجودة على مستوى العضلة باستعمال القطب السطحي المطبق على جلد العضلة حيث تساعد هذه الإشارات على تقييم الأداء و قياس الجهد العضلي باستخدام حساسات من نوع EMG.

الكلمات المفتاحية : مستشعر Python,I2C,Raspberry Pi,EMG.

Abstract :

This work aims to develop and accomplish a medical device that extracts electrical signals using surface electrode level applied to the skin of the muscle,These human signals used to evaluate and measuring performance and muscle effort using medical sensors of the type EMG.

Keywords : EMG sensor,python,I2C,Raspberry PI.

Résumé :

Ce travail consiste à développer et à réaliser un dispositif médical qui assure la détection des signaux électriques au niveau de l'électrode de surface appliqués sur la peau du muscle, car ces signaux aident à évaluer les performances et à mesurer l'effort musculaire à l'aide de capteurs médicaux du type EMG.

Mots clés : EMG sensor,python,I2C,Raspberry PI.

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Most warm gratitude goes to all teachers of Electronics Department that contributed to our training.

Finally, great thanks go to all who helped us with encouragement and support which have never ceased all along the preparation of our work.

Dedication

Thank you **Allah** who gave me the ability to write, reflect and strength.

The joy of success is never complete unless it is shared with those we love. I dedicate this modest work to:

My very dear parents, for their moral and financial support and for being the light of my life, who have always encouraged me to finish my studies, in their hoping for a long life and may **Allah** keep them.

I dedicate all my family, especially my brothers, sisters and all the teachers.

hichem BETTAOULA

Dedication

Praise be to **Allah** who has given us success in knowledge and in this research.

I dedicate this work To my father and mother, to my grandfather and to my grandmother who helped and motivated me to learn and study . To all my brothers and friends And for all family members.

For all the university staff who watched over us, teachers and workers.

abderrahmane IMAM

Contents

ABSTRACT **i**

List of Figures **viii**

List of Tables **xi**

List of abbreviations and symbols **xii**

INTRODUCTION **1**

1 DATA ACQUISITION SYSTEM **2**

1.1 Introduction 2

1.2 Data acquisition structure 2

1.3 Data acquisition hardware 4

1.4 Signals 4

1.4.1 Analog signals 4

1.4.2 Digital signals 5

1.5 Signal conditioning 5

1.6 Filter requirement 6

1.6.1 Low-Pass filter 6

1.6.2 High-Pass filter 8

1.6.3 Band-Reject filters 9

1.6.4 Band-Pass filters 9

1.6.5 Passive and Active filters 10
1.6.6 Digital filters 10
1.7 Conclusion 13

2 SURFACE ELECTROMYOGRAPHY 14

2.1 Introduction 14
2.2 Skeletal muscle anatomy 14
2.2.1 Actin filaments 15
2.2.2 Myosin filaments 15
2.3 Muscle contraction 15
2.4 Electrical aspect of muscle excitability 15
2.5 Electromyography 17
2.6 Electrical noise on EMG signals 17
2.6.1 Noises in electronics equipment 17
2.6.2 Ambient noise 18
2.6.3 Motion artifact 18
2.7 Relationship of EMG signals with other measures 18
2.8 Types of electromyography 18
2.8.1 Invasive electromyography 18
2.8.2 Non invasive electromyography 19
2.9 Typical advantages of EMG 21
2.10 EMG signal processing 21
2.10.1 Electromyography rectified 21
2.10.2 Electromyography smoothed 21
2.10.3 Average EMG (or integrated) over time interval 21
2.10.4 Root mean square of EMG signal 22
2.11 Signal energy study 22

2.12 Conclusion 23

3 IMPLEMENTATION **24**

3.1 Raspberry Pi 24

3.1.1 The Raspberry Pi's components 25

3.1.2 The Raspberry Pi's ports 26

3.2 EMG Detector 29

3.2.1 Features 30

3.2.2 Interface function 30

3.3 Analog-to-Digital Converter 30

3.3.1 Features 31

3.3.2 Functional block diagram 31

3.4 Electrical components 32

3.5 I2C interface 33

3.6 Python 34

3.7 Typical Connections 34

3.8 Hardwar installation 35

3.9 Implementation experiments and results 35

3.9.1 Implementation 35

3.9.2 Experiments and results 36

3.10 Interpretation 42

3.11 Conclusion 43

CONCLUSION **44**

Bibliography **46**

List of Figures

1.1 Digital measurement chain. 3

1.2 Structures of multi-channel data acquisition systems. 3

1.3 Primary characteristics of an analog signal. 4

1.4 Primary characteristics of a digital signal. 5

1.5 RL Low-Pass circuit. 6

1.6 RC Low-Pass circuit. 7

1.7 The frequency response of a low-pass filter. 7

1.8 RL high-pass filter. 8

1.9 RC high-pass filter. 8

1.10 The frequency response of a high-pass filter. 9

1.11 A Typical frequency response of a band-pass filter. 9

2.1 Skeletal muscle anatomy. 14

2.2 Muscle contraction. 15

2.3 Schematic of depolarization & repolarization cycle in membranes. . . 16

2.4 The Action Potential Adopted & redrawn. 17

2.5 Fine wire electrode. 19

2.6 Insert the fine wires into the muscle tissue. 19

2.7 Anatomical positions of surface electrode sites. 20

2.8 Temporal energy representations of S(t)=t signal 23

3.1 Raspberry Pi 3 B+. 24
3.2 The Raspberry Pi's system-on-chip (SoC). 25
3.3 The Raspberry Pi's random access memory (RAM). 25
3.4 The Raspberry Pi's radio module. 26
3.5 The Raspberry Pi's power management integrated circuit (PMIC). . . 26
3.6 The Raspberry Pi's USB ports. 27
3.7 The Raspberry Pi's Ethernet port. 27
3.8 The Raspberry Pi's AV jack. 27
3.9 The Raspberry Pi's HDMI port. 28
3.10 The Raspberry Pi's micro USB power port. 28
3.11 The Raspberry Pi's GPIO header. 28
3.12 The Raspberry Pi pin numbers and functions. 29
3.13 Grove EMG detector. 29
3.14 EMG interface. 30
3.15 ADC ads1115. 31
3.16 ADS1115 Functional Block Diagram. 32
3.17 A Breadboard with sections for power distribution 32
3.18 The three types of jumper wire. 33
3.19 I2C interface. 34
3.20 Typical Connections of the project. 34
3.21 The hardwar instalation 35
3.22 The project instalation 36
3.23 The signal extracted from experience 1. 37
3.24 Signal treatment 37
3.25 Experience 1 results 38
3.26 The signal extracted from experience 2. 39

3.27 Signal treatment 39
3.28 Experience 2 results. 40
3.29 The signal extracted from experience 3. 41
3.30 Signal treatment. 41
3.31 Experience 3 results. 42

List of Tables

3.1 Experience 1 information. 38

3.2 Experience 2 information. 40

3.3 Experience 3 information. 42

List of abbreviations and symbols

EMG :	Electromyography
PC :	Personal computer
$S\&H$:	Sample-and-hold
ADC :	Analog to digital converter
DAC :	Digital to Analog converter
LPF :	Low-pass filter
RC :	Resistor–capacitor
BRF :	Band-reject filter
BPF :	Band-pass filter
FIR :	Finite-impulse response
SoC :	System on chip
GPU :	Graphics processing unit
RAM :	Random-Access Memory
SD :	Secure Digital
$WIFI$:	Wireless fidelity
USB :	Universal serial bus
$PMIC$:	Power management integrated circuit
AV :	Audio visual
$GPIO$:	General Purpose Input/Output
SDA :	Serial Data Line
SCL :	Serial Clock Line
RPI :	Raspberry Pi
$TRRS$:	tip-ring-ring-sleeve
$HDMI$:	High-Definition Multimedia Interface
LED :	Light Emitting Diode
$M2F$:	Male-to-female
$M2M$:	Male-to-male
$F2F$:	Female-to-female

Introduction

In physical human life, most activities are performed by important elements which are the muscles. Movements and locomotion are initiated by electrophysiological excitation of a group of motor units (MUs) while muscle contracting voluntarily or involuntarily . The electrophysiological signal generated during arousal / contraction can be detected and used to study muscle function.This process is known as electromyography (EMG). Electromyography is the study of muscle functions by analysing the electrical signals generated during muscle contractions [1].

The muscule skeletal system, made up of muscles, bones and joints, the muscule skeletal requires attention and care very special if you didn't care about them than will be, aches, contractures, pain and the inflammations will become the companions of an activity .

To help doctors confirm the existence or not of muscle pain, electromyography is particularly useful in the assessment of certain muscle deficits in order to assess this muscular effort. The objective of our work is to realize a device that allows the detection of the Electromyogram (EMG) signal, for treatment and assess effort muscular.

In this context, this project will be organized in 3 chapters :

The first chapter allows to study the different electronic stages allowing the study and the realization of the EMG signal acquisition card.

The second chapter presents the physiological and anatomical information of human muscles which is very important to understand the source of the EMG signal.

In the last chapter we will present the analog signal and his interface to the PC using the Raspberry Pi. Then display the EMG signal on a computer after extracting the signal with Raspberry Pi using Python language and the processing with Matlab software.

Chapter 1

DATA ACQUISITION SYSTEM

1.1 Introduction

Data acquisition system is the gathering of signals from real-world measurement sources and the digitizing of those signals for storage, analysis and presentation on a personal computer (PC). Light, temperature, pressure, in addition to acquiring data, data acquisition systems also are used to generate electrical signals.

A data acquisition system provides a way to empirically test designs, theories and real-world systems for validation or research. At first, data acquisition devices stood alone and were manually controlled by an operator. When the PC emerged, data acquisition devices and instruments could be connected to the computer through a serial port, parallel port, or some custom interface. A computer program could control the device automatically and retrieve data from the device for storage, analysis, or presentation [2].

1.2 Data acquisition structure

A Sensor converts the physical signal $x_{phys}(t)$ into an electrical signal $x_{el}(t)$. Then is amplified or dampened in order to fit the input range of the successive processing elements. A filter ensures that all signal components above half the sampling frequency are damped below an acceptable level. Next, the filtered signal $x_{filt}(t)$ is sampled by a sample-and-hold (S&H) circuit in addition, its amplitude is quantized by an ADC. After this, the signal $x[n]$ is fully digital and ready for further processing [3].

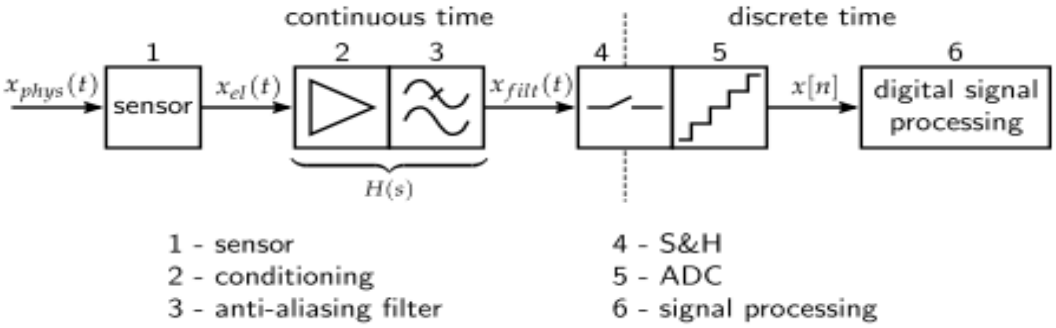


Figure 1.1: Digital measurement chain.

When multiple signals have to be acquired simultaneously, the obvious solution is to let multiple instances of the digital measurement chain sample the signals in parallel and to collect the digital data via a data bus (see figure 1.2(a)). Instead, analog multiplexer are used to sample all channels sequentially with the same ADC and S&H circuit. Instead, analog multiplexer are used to sample all channels sequentially with the same ADC and S&H circuit (see figure 1.2(b)).

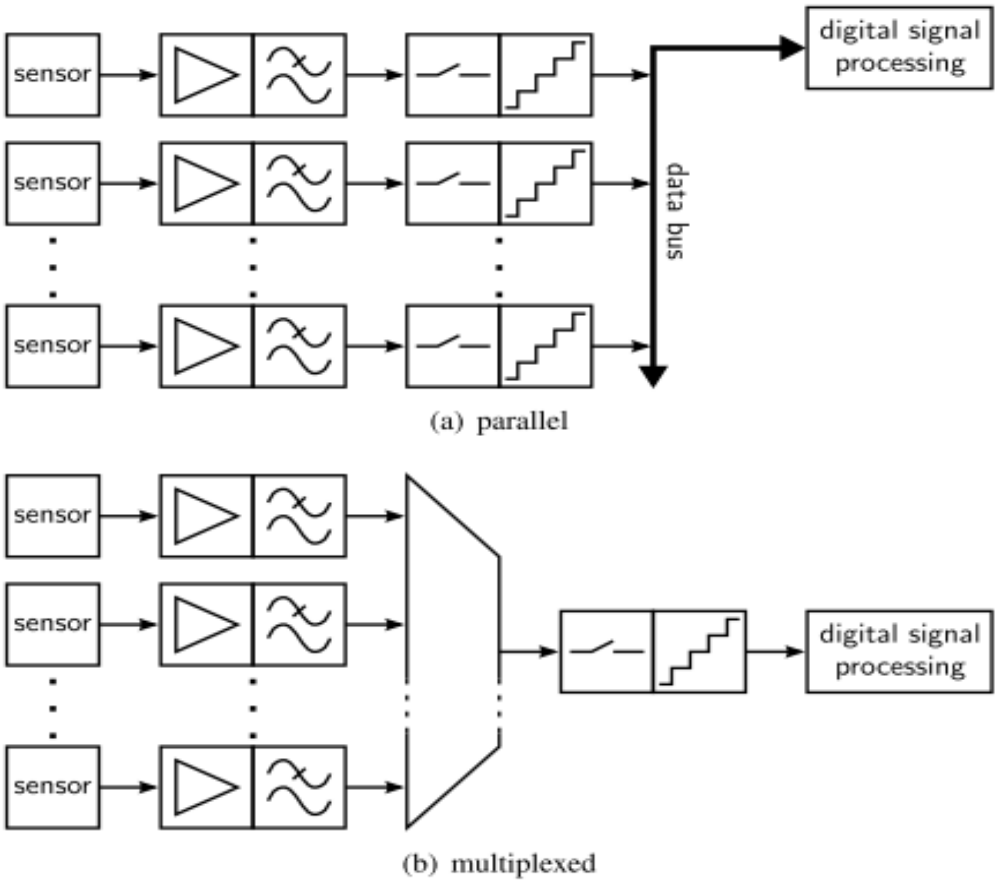


Figure 1.2: Structures of multi-channel data acquisition systems.

1.3 Data acquisition hardware

The heart of a data acquisition device is a digital-to-analog converter (DAC), an analog-to-digital converter (ADC) or some combinations of the two and the sensors.

An ADC has a list of binary values that represent analog voltage ranges. The ADC's purpose is to select a value from this list that is closest to an actual voltage at a specified time. The value is then transferred in binary format to a computer.

A sensor is a device that converts a physical phenomenon into a measurable electrical signal.

The accuracy of a data acquisition system can change with temperature, time and usage. Data acquisition hardware can store on board correction constants for offset and gain errors. An offset error is a constant difference between the measured and actual voltage, regardless of the voltage level. A gain error increases linearly as the measured voltage increases. Some data acquisition hardware also includes an accurate voltage source on board that can be periodically used as a reference to correct the gain and offset error parameters [2].

1.4 Signals

1.4.1 Analog signals

The three primary characteristics of an analog signal are level, shape and frequency.

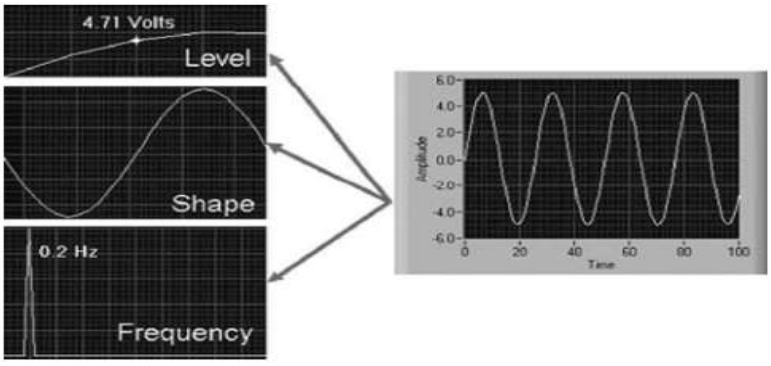


Figure 1.3: Primary characteristics of an analog signal.

Level

An analog signals can take on any value, the level gives vital information about the measured analog signal.

Shape

The shape of an analog signal is too important as the level, because measuring the shape of an analog signal allows further analysis of the signal, like the analysis of heartbeats, vibration and sound. A shape can be sine, cosine and triangle, square and saw tooth.

Frequency

When frequency is the most important piece of information, it is important to consider both accuracy and acquisition speed. Although the acquisition speed for acquiring the frequency of a signal is less than the speed required for obtaining the shape of a signal, the signal must still be acquired fast enough so that the pertinent information is not lost while the analog signal is being acquired [2].

1.4.2 Digital signals

A digital signal has two possible levels, high and low, and hase two major characteristics, State and Rate.

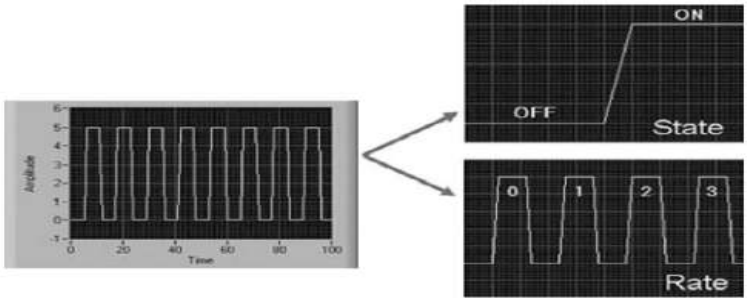


Figure 1.4: Primary characteristics of a digital signal.

State

The state of a digital signal is essentially the level of the signal, on or off, high or low.

Rate

The rate of a digital signal measures how often a portion of the signal occurs.

1.5 Signal conditioning

No real situation will have perfect signals, be completely free of noise, or be guaranteed to be electrically safe. Most real signals require some sort of preparation (conditioning) before being gathered by a data acquisition system. Signal

conditioning hardware provides a method to remove as much as possible unwanted components of a digital or analog signal [2].

1.6 Filter requirement

1.6.1 Low-Pass filter

A LPF is designed to pass all frequencies below the cutoff frequency. It ideally has amplitude of 100% (of input appear in the output). However, in reality, the amplitude starts to drop before the cutoff frequency. In this case, the cutoff frequency is identified when the transfer function gain drops 3 dB or the output signal amplitude reaches 70.7% of the input signal [4].

$H_(jw)$ is the transfer function of the filter or simply the ratio of the output voltage over the input voltage :

$$\mid H(jw) \mid_{w=wc}= \frac{1}{\sqrt{2}} H_{max} \tag{1.1}$$

Maximum output can reach 1 :

$$\mid H(jw) \mid_{w=wc}= \frac{V_{out}(jw)}{V_{in}(jw)} = \frac{1}{\sqrt{2}} \tag{1.2}$$

The exact frequency response of the filter depends on the filter design.

RL Low-Pass Filter

To pass low-frequency signals to the output of a filter, an inductor may be used to bridge the input to output ports [4].

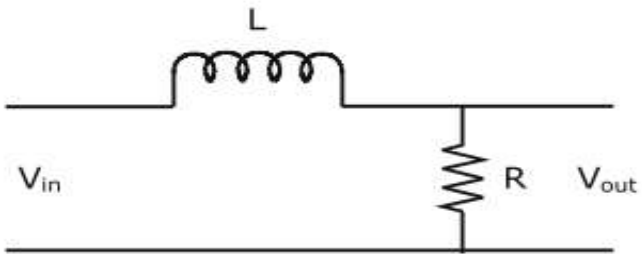


Figure 1.5: RL Low-Pass circuit.

The transfer function of the filter :

$$\mid H(jw) \mid_{w=wc}= \frac{V_{out}(jw)}{V_{in}(jw)} =\mid \frac{\frac{R}{L}}{jw_c + \frac{R}{L}} \mid= \frac{1}{\sqrt{2}} \tag{1.3}$$

$$\frac{\frac{R}{L}}{\sqrt{w_c^2 + (\frac{R}{L})^2}} = \frac{1}{\sqrt{2}} \tag{1.4}$$

Solving for w_c results in :

$$w_c = \frac{R}{L} \tag{1.5}$$

RC Low-Pass filter

Capacitors conduct high frequencies. If a capacitor is connected then only low frequencies reach the output as shown in the figure(1.6).

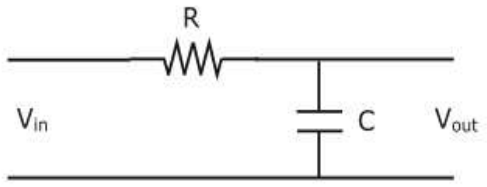


Figure 1.6: RC Low-Pass circuit.

The transfer function of the filter :

$$\mid H(jw) \mid_{w=wc} = \frac{V_{out}(jw)}{V_{in}(jw)} = \mid \frac{\frac{1}{RC}}{jw_c + \frac{1}{RC}} \mid = \frac{1}{\sqrt{2}} \tag{1.6}$$

$$\frac{\frac{1}{RC}}{\sqrt{w_c^2 + (\frac{1}{RC})^2}} = \frac{1}{\sqrt{2}} \tag{1.7}$$

Solving for w_c results in :

$$w_c = \frac{1}{RC} \tag{1.8}$$

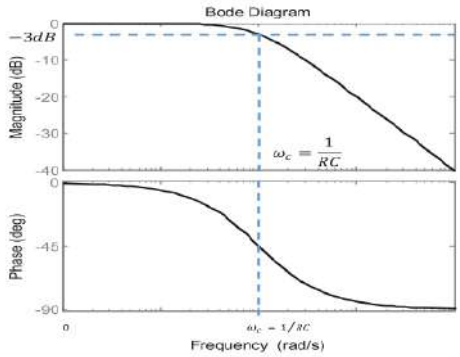


Figure 1.7: The frequency response of a low-pass filter.

1.6.2 High-Pass filter

A HPF is a circuit that eliminates frequencies below the cutoff frequency and allows to pass signals of higher frequency than the cutoff frequency. This characteristic can be obtained using an inductor or a capacitor based circuit [4].

RL HPF

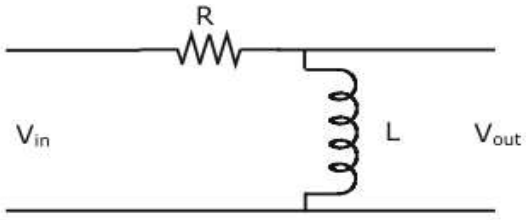


Figure 1.8: RL high-pass filter.

The transfer function of the filter :

$$\mid H(jw) \mid_{w=wc} = \frac{V_{out}(jw)}{V_{in}(jw)} = \mid \frac{jw_c}{jw_c + \frac{R}{L}} \mid = \frac{1}{\sqrt{2}} \tag{1.9}$$

$$\frac{w_c}{\sqrt{w_c^2 + (\frac{R}{L})^2}} = \frac{1}{\sqrt{2}} \tag{1.10}$$

Solving for w_c results in :

$$w_c = \frac{R}{L} \tag{1.11}$$

RC HPF

Capacitors pass high-frequency signals and block low frequencies. Using a capacitor to bridge the input to the output of a resistive load provides path for high frequency signals to pass and low frequency signals to be rejected.

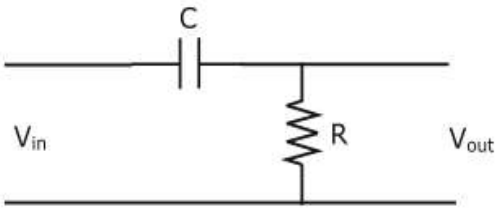


Figure 1.9: RC high-pass filter.

The transfer function of the filter :

$$\mid H(jw) \mid_{w=wc} = \frac{V_{out}(jw)}{V_{in}(jw)} = \mid \frac{jw_c}{jw_c + \frac{1}{RC}} \mid = \frac{1}{\sqrt{2}} \tag{1.12}$$

$$\frac{w_c}{\sqrt{w_c^2 + (\frac{1}{RC})^2}} = \frac{1}{\sqrt{2}} \tag{1.13}$$

Solving for w_c results in :

$$w_c = \frac{1}{RC} \tag{1.14}$$

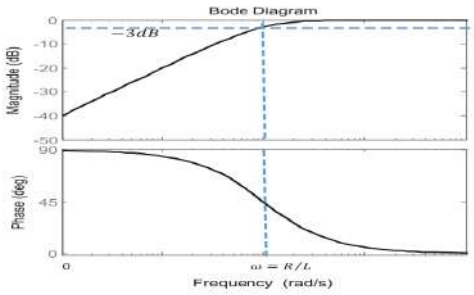


Figure 1.10: The frequency response of a high-pass filter.

1.6.3 Band-Reject filters

A band-reject filter is a circuit that passes signals outside a specific range and blocks the signals in the range, also known as bandwidths [4].

1.6.4 Band-Pass filters

A band-pass filter is designed to pass signals of frequencies in a specific range (bandwidth) and block the rest. A BPF reaches its highest amplitude at a frequency in the bandwidth BW known as resonant frequency w_0 . There are two cutoff frequencies w_{c1} , w_{c2} to form the passband and determine the bandwidth as :

$$BW = wc2 - wc1 \tag{1.15}$$

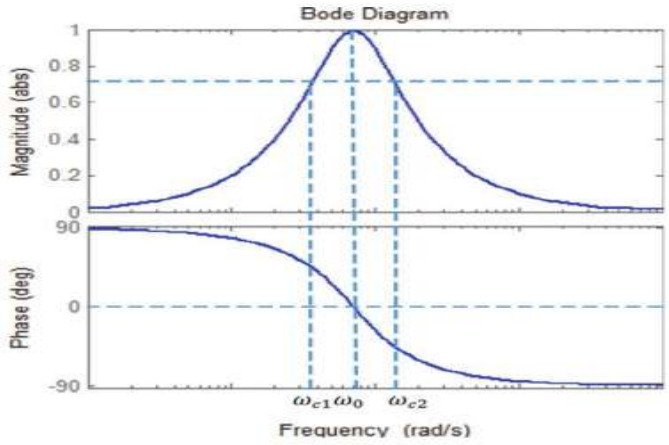


Figure 1.11: A Typical frequency response of a band-pass filter.

1.6.5 Passive and Active filters

When a signal is passed through a filter, its amplitude may drop a small percentage because the circuit elements are not ideal and the signal may lose some power. Therefore, the filters are categorized into passive (with no amplification) or active (with amplification) [4].

1.6.6 Digital filters

FIR filters

The finite-impulse response (FIR) filter is characterized by a unit sample response that has a finite duration. One of the advantages of FIR filters compared to their infinite-impulse response (IIR) counterparts is that FIR filters can be designed with exactly linear phase. Linear phase response is important for applications where phase distortion due to n onlinear phase can degrade performance, such as in data transmission and television applications [5].

A FIR causal filter can be characterized by the transfer function :

$$H(z) = \sum_{n=0}^{N-1} h(nT)z^{-n} \tag{1.16}$$

where :

h(nT) is the impulse response of the filter.

N is the filter length.

T is the sampling interval.

Frequency response of linear phase FIR filters

The frequency response of a causal linear phase FIR filter can be simplified to some simple forms :

(1) Symmetric impulse response and N=odd. In this case :

$$H(z) = \sum_{n=0}^{\frac{N-3}{2}} h(nT)e^{-jwnt} + h[\frac{(N-1)T}{2}]e^{-jw(N-1)\frac{T}{2}} + \sum_{n=\frac{N+1}{2}}^{N-1} h(nT)e^{-jwnT} \tag{1.17}$$

The equation can be simplfied further to :

$$H(e^{jwT}) = e^{-jw(N-1)\frac{T}{2}}[\sum_{K=1}^{(N-1)/2} a(k)cos(wkT)] \tag{1.18}$$

where:

$a(k) = 2h[((N-1)/2 - k)T]$

$a(0) = h[(N-1)T/2]$

(2) Symmetric impulse response and N=even. For this case, the frequency response takes the form :

$$H(e^{jwT}) = e^{-jw(N-1)T/2}\{\sum_{k=0}^{N/2-1} 2h(kT)cos[w(\frac{N}{2} - k - \frac{1}{2})T]\} \tag{1.19}$$

Equation can be simplified to the form :

$$H(e^{jwT}) = e^{-jw(N-1)T/2}\{\sum_{k=0}^{N/2} b(k)cos[w(k - \frac{1}{2})T]\} \tag{1.20}$$

where :

$b(k) = 2h[(N/2 - k)T]$,k=1,2,...,N/2.

(3) Antisymmetric impulse response and N=odd, the frequency response is given by :

$$H(e^{jwt}) = je^{-jw(N-1)T/2}\{\sum_{k=1}^{(N-1)/2} 2h[(\frac{N-1}{2} - k)T]sin(wkT) + h[\frac{(N-1)T}{2}] \tag{1.21}$$

Equation can be simplified to the form :

$$H(e^{jwT}) = je^{-jw(N-1)T/2}\{\sum_{k=1}^{(N-1)/2} c(k)sin(wkT)\} \tag{1.22}$$

where :

$c(k) = 2h[((N-1)/2 - k)T, k = 1, 2, ..., (N-1)/2.]$

(4) Antisymmetric impulse response and N=even :

$$H(e^{jwT}) = e^{-jw(N-1)T/2}\{\sum_{k=0}^{N/2-1} 2h(kT)sin[w(\frac{N}{2} - k - \frac{1}{2})T]\} \tag{1.23}$$

Equation can be simplified to the form :

$$H(e^{jwT}) = e^{-jw(N-1)\frac{T}{2}}\{\sum_{K=1}^{N/2} d(k)sin(w(k - \frac{1}{2})T)\} \tag{1.24}$$

where :

$d(k) = 2h[N/2 - k)T], k = 1, 2, ..., N/2.$

In this case, the frequency response is zero at w=0, independent of d(k).

IIR Filters

A digital filter with impulse response having infinite length is termed infinite impulse response (IIR) filter. The most important class of IIR filters can be described by the difference equation [5].

$$y(n) = b_0x(n)+b_1x(n-1)+...+b_Mx(n-M)-a_1y(n-1)-a_2y(n-2)-...-a_Ny(n-N) \tag{1.25}$$

where :

x(n) is the input.

y(n) is the output of the filter.

$[a_1,a_2,...,a_N][b_0,b_1,...,b_M]$are constant coefficients.

Frequency response

The frequency response of the IIR filter is the due of the system function evaluated on the unit circle on the complex plane, with $z = e^{j2\pi f}$, where f varies from 0 to 1 or from -1/2 to 1/2. The variable f represents the digital frequency, we write$H(f)$ for $H(z) \mid_{exp(j2\pi f)}$ [5].

$$H(f) = b_0e^{j2\pi(M-N)f}\frac{(e^{j2\pi f}-q_1)(e^{j2\pi f}-q_2)...(e^{j2\pi f}-q_M)}{(e^{j2\pi f}-p_1)(e^{j2\pi f}-p_2)...(e^{j2\pi f}-p_N)} \tag{1.26}$$

$H(f)$ is generally a complex function of f, consisting of the real part $H_R(f)$ and the imaginary part$H_I(f)$.It can also be expressed in terms of the magnitude$|H(f)|$ and the phase $\theta(f)$.

$$H(f) = H_R(f) + jH_I(f) =\mid H(f) \mid e^{j\theta(f)} \tag{1.27}$$

The magnitude square can be written as :

$$\mid H(f) \mid^2= H(f)H^*(f) = [H_R(f)]^2 + [H_I(f)]^2 \tag{1.28}$$

Since :

$$H^*(f) = H^*(1/z) \mid_{z=exp(j2\pi f)} \tag{1.29}$$

And :

$$H^*(1/z^*) = H(z^{-1}) \tag{1.30}$$

when all the coefficients of H(z) are real, we have :

$$\mid H(f)^2 = H(z)H(z^{-1}) \mid_{z=exp(j2\pi f)} \tag{1.31}$$

The magnitude square can be put in the form :

$$\mid H(f) \mid^2= \frac{\sum_{k=0}^{M} b_kcos(2\pi kf)}{\sum_{k=0}^{N} a_kcos((2\pi kf)} \tag{1.32}$$

where the coefficients are given by :

$$b_0 = \sum_{j=0}^{M} b_j^2$$

$$b_k = 2 \sum_{j=k}^{M} b_j b_{j-4}$$

$$k = 1, ..., M \tag{1.33}$$

By factoring the numerators and denominators into second-order factors :

$$H(z) = \frac{b_N}{a_N} + \sum_{i=1}^{k} \frac{b_{i0} + b_{i1} z^{-1}}{1 + a_{i1} z^{-1} + a_{i2} z^{-2}} \tag{1.34}$$

IIR filters are typically implemented using second order sections to reduce error due to rounding, speed up the processing, and improve stability.

1.7 Conclusion

Nowadays, data acquisition system play a critical role in all life fields such as science research, smart homes and cities, industrial maintenance. The data acquisition systems are used to improve efficiency, ensure reliability and to identify problems.

Chapter 2

SURFACE ELECTROMYOGRAPHY

2.1 Introduction

The human body includes over 650 muscles attached to the skeleton, which constitute about 40% of the total body weight. Their contractions allow the body to come alive, each end of the muscle is attached by a point called origin or insertion and has a fleshy contractile portion called the muscular body [6].

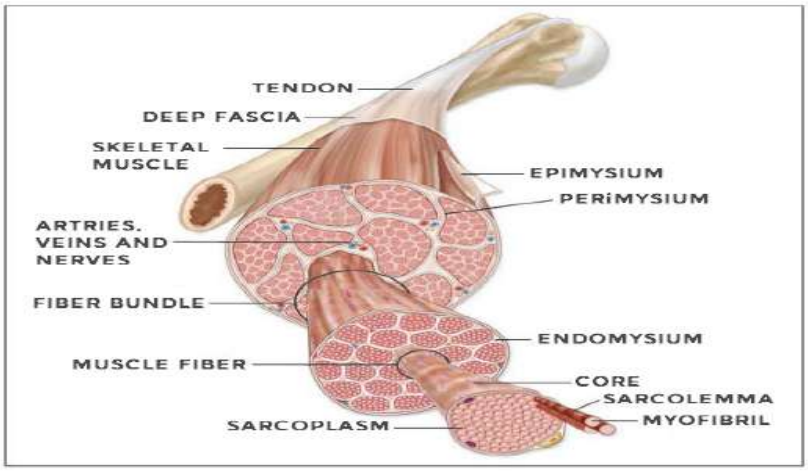


Figure 2.1: Skeletal muscle anatomy.

2.2 Skeletal muscle anatomy

Muscle mass contain several bundles of fibers, these fibers made up by two types of filaments, actin filaments and myosin filaments [7].

2.2.1 Actin filaments

The actin filament is a thin fiber, this fiber countains two negatively charged molecules that spiral around each other[7].

2.2.2 Myosin filaments

The myosin filament is larger then actin filament with “globular heads” on it, These filaments are also negatively charged [7].

2.3 Muscle contraction

According to the theory of Huxley which is based on Hansel and Huxley model, this model explains how muscles create internal tension.

It states that, during muscle contraction, the actin filaments slip between the filaments of myosin.

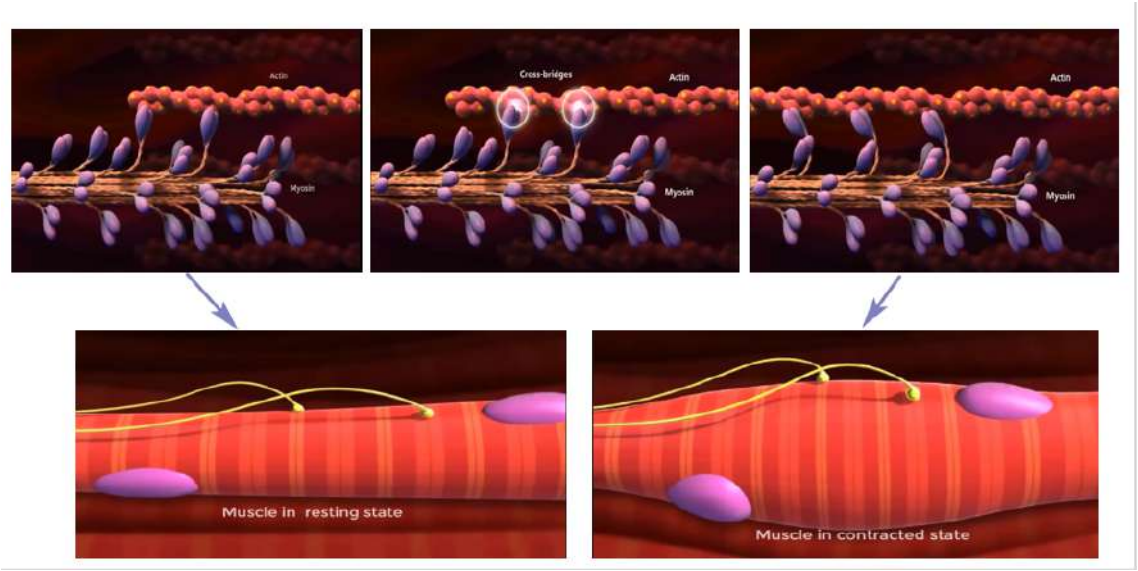


Figure 2.2: Muscle contraction.

When a myosin head attaches to an actin filament, forming an actin-myosin bridge and move, the two filaments slide one on top of the other. Myosin heads and bridges thus formed undergo a change in spatial configuration, from the moment the heads of myosin become attached at the active sites of actin filaments [8].

2.4 Electrical aspect of muscle excitability

The excitability of muscle fibers through neuronal control is factor important in muscle physiology . This phenomenon explained by the semi-permeability that characterizes the membrane of sarcolemma describing the electrical properties of the

muscle contraction. An ionic equilibrium between the interior and exterior spaces of the muscle cells constitutes a resting potential of the membrane (approximately -80 m V to -90 m V when it is not contracted).This difference in potential which is maintained by physiological processes (ion pump) results in a negative intracellular charge compared to the external surface.

During the contraction, the diffusion characteristics of the membrane of each excited fiber are briefly modified by a flow of Na + ions towards the interior of the muscle cell, if a certain threshold is exceeded, this causes quickly change (depolarization) of the membrane (from - 80 mV to 30 mV maximum). Therefore, it is an electrical impulse which will be restored immediately by a reverse diffusion (repolarization) of the Na + ions towards the outside of the cell and the repolarization phase and followed by a period of hyperpolarization, see figure (1.2).

The action potential consists of a succession of depolarization-repolarization which one could assimilate to a wave at the level of the motor plates, which extends along the muscle fiber in both directions, as well as at the interior see figure (1.3) [9].

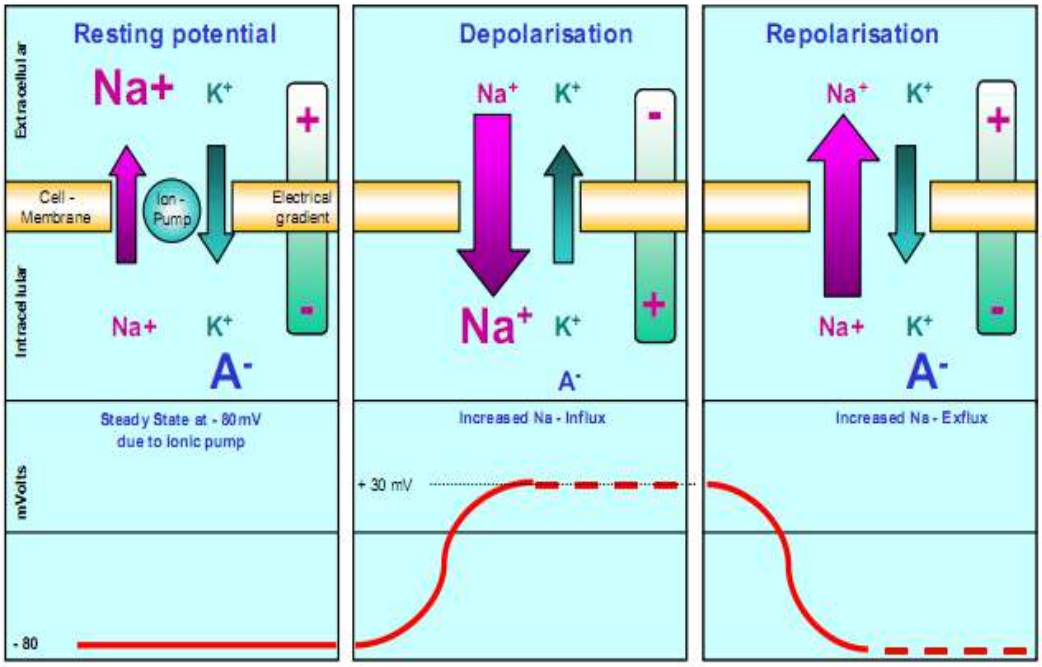


Figure 2.3: Schematic of depolarization & repolarization cycle in membranes.

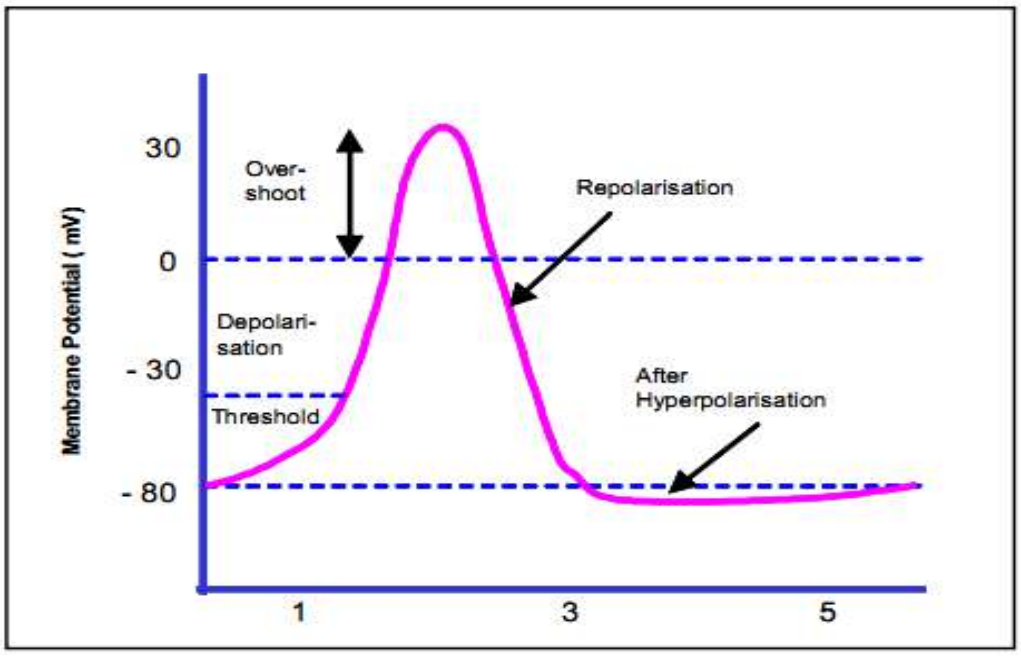


Figure 2.4: The Action Potential Adopted & redrawn.

2.5 Electromyography

The EMG signal is a biomedical signal that means collective electrical signal acquired from any organ that represents a physical variable of interest. This signal is normally function of time and describable in terms of amplitude, frequency and phase.

The EMG signal measures electrical currents generated in muscles during its contraction thats represente the neuromuscular activities .

EMG signal is complicated signal, wich is the nervous system always controls the muscle activity (contraction/relaxation) and is dependent on the anatomical and physiological properties of muscles [10].

2.6 Electrical noise on EMG signals

The amplitude range of EMG signal is from 0 to 10mv (+5 to -5) without amplification, since the traveling of EMG signals through different tissue acquire a lot of noises It is important to understand the characteristics of the electrical noise which will affect EMG signals, may be classified into the following types [10] :

2.6.1 Noises in electronics equipment

This kinds of noise cannot be eliminated, just using high quality electronic components can only reduce it [10].

2.6.2 Ambient noise

Electromagnetic radiation is the source of Ambient noise, the surfaces of human bodies are constantly inundated with electromagnetic radiation and it is impossible to avoid exposure to it on the earth [10].

2.6.3 Motion artifact

When this type of noise enters to the system, the information is skewed thats make irregularities in the data . There are two sources of motion artifact :

- Electrode interface.
- Electrode cable .

The motion artifact can be reduced by good electronics design circuits [10].

2.7 Relationship of EMG signals with other measures

The relationship between EMG signals to other forms of clinical information should be related, such as pain, manual muscle testing, range of motion, isolated joint control and other indexes of function. If the patient is taking medications that might interact with the treatment, these should be noted. These medications, include but are not limited to, muscle relaxants, tranquilizers, some analgesics, central nervous system depressants and antispasticity agents [7].

2.8 Types of electromyography

EMG signals can be captured directly from muscles with two methods, needle (invasive) and surface electrodes (non invasive). The EMG signals recorded by surface electrodes are reliable and simple methods for utilization of muscle energy, this reasons make this method the preferred one [11].

2.8.1 Invasive electromyography

It is a procedure that involves the insertion of an EMG electrode as a needle in muscle mass to explore muscles when they contract and relax . The EMG signal acquired from Invasive operation gives more precise results than that acquired from the surface EMG, because it is less contaminated by the EMG artifact emitted by other muscles, but it constitutes a bad choice for studies related to low back pain and movement analysis [6].

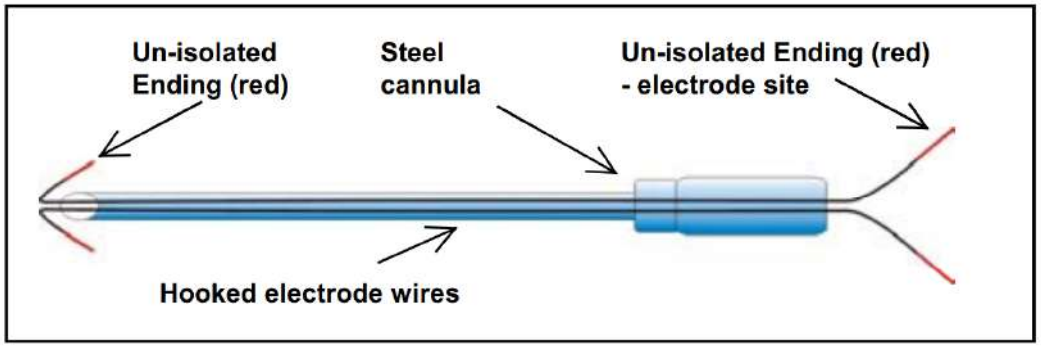


Figure 2.5: Fine wire electrode.

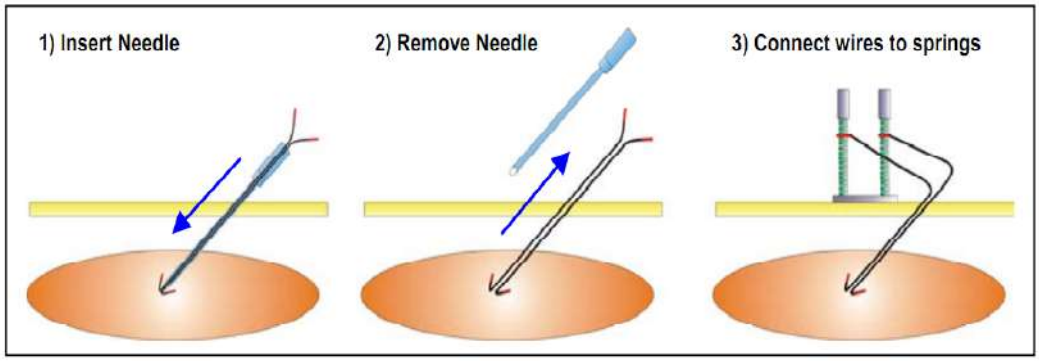


Figure 2.6: Insert the fine wires into the muscle tissue.

2.8.2 Non invasive electromyography

The most methods used is surface electromyography (EMG), used to quantify the activity level of a muscle, by measuring the action potentials of the responsible motor units on contractions muscles.

This kind of electrode has two categories, passive and active. The passive electrode has a conductive (commonly metal) detection surface touching with the skin, while the active electrode has a differential amplifier with a passive electrode in order to reduce the effects of capacitance coupling and provide very low output impedance, rather than transmitting the signal to the amplifier through long lead wires [12].

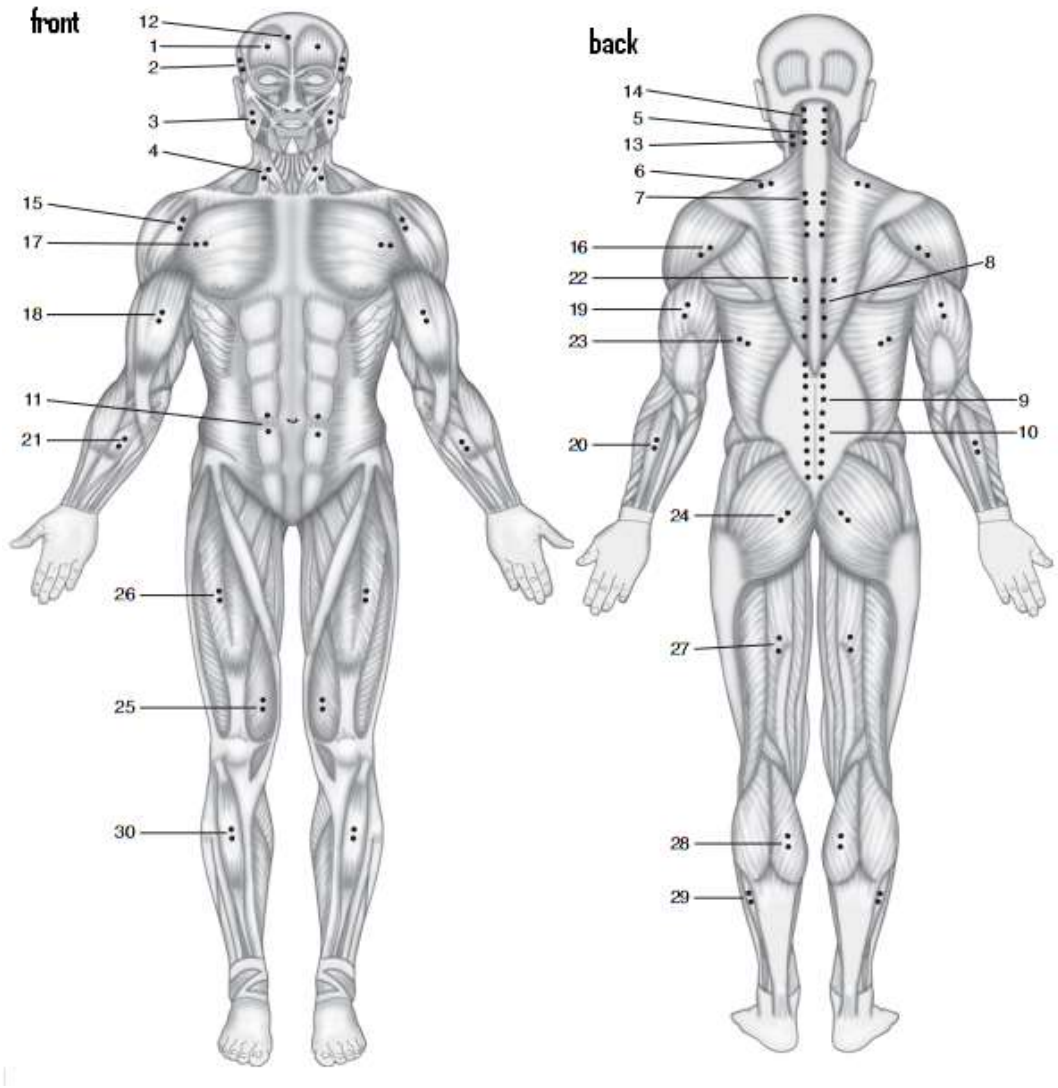


Figure 2.7: Anatomical positions of surface electrode sites.

1. Low frontalis	11. Abdominals	21. Wrist flexors
2. Temporalis	12. High frontalis	22. Lower trapezius
3. Masseter	13. Lateral neck	23. Latissimus dorsi
4. Sternocleidomastoid	14. Capitis	24. Gluteus maximus
5. Cervical paraspinals	15. Anterior deltoid	25. Vastus medialis
6. Upper trapezius	16. Posterior deltoid	26. Quadriceps femoris
7. T-1 paraspinals	17. Pectoralis major	27. Medial hamstrings
8. T-6 paraspinals	18. Biceps	28. Gastrocnemius
9. T-10 paraspinals	19. Triceps	29. Soleus
10. L-3 paraspinals	20. Wrist extensors	30. Tibialis anterior

2.9 Typical advantages of EMG

The Italian Francesco Redi (1626-1698) was the first in 1666 showed the muscle can generate electricity. Since then, many researchers have studied the possibility of generation current. It was French Dubois Reymond who in 1849 produced the first EMG signal recording , There are many advantages of the EMG signal, the most importants is [9] :

- Very helpful to measurement of muscular performance .
- EMG allows to "look" directly into the muscle .
- Helping to make decision both, before/after surgery .
- Helps patients improve and train their muscles .
- Help to analysis to improve sports activities.
- It very important to use EMG for Detecting muscle response in ergonomic studies.

2.10 EMG signal processing

Some techniques used for medical electromyogram signal processing are:

2.10.1 Electromyography rectified

The values of EMG signal are positive or negative, it is difficult to judge if the action potential approaches or moves away from the electrode. To make good quantification for all positive and negative phases, the EMG signal is rectified by taking its absolute value [6].

2.10.2 Electromyography smoothed

The best way to decrease the variance and high frequency noise of the rectified EMG signal (digitalization, sampling, intrinsic), The signal can be smoothed by a low pass filter or a moving average. This tool can allow for example better detection of the beginning and end of a puff [6].

2.10.3 Average EMG (or integrated) over time interval

Generally two parameters used to quantify the average level of excitation on fixed time interval, average or integration of the rectified EMG signal . These two parameters can decrease the variability due to instant excitation of muscle fibers [6].

2.10.4 Root mean square of EMG signal

The EMG signal is quantified in the time domain using root mean square (RMS), which represents the amplitude of EMG signal over time interval, root mean square equation is [6] :

$$RMS = \sqrt{\frac{1}{T} * \int_{(1+T)/2}^{(1-T)/2} X(t)\,\mathrm{d}t} \tag{2.1}$$

Where :

X(t) = EMG signal.

T = Time interval.

2.11 Signal energy study

Calculating the square of signal or the absolute value are methods to extract the envelope.

The absolute value gives the same weight to all the samples regardless of their value or intensity, but the energy (square) changes the measurement by the accentuation of the high intensities compared to the low intensities.

There are other methods for extracting the envelope as Shannon's entropy and Shannon energy .

This two methods give the biggest weight to the intensities signal averages, therefore low intensity noise and high disturbances intensities will be attenuated [13].

- Square energy :

$$EN = S(t)^2 \tag{2.2}$$

- Absolute value :

$$V = \mid S(t) \mid \tag{2.3}$$

- Shannon's Entropy :

$$EP = - \mid S(t) \mid * log \mid S(t) \mid \tag{2.4}$$

- Shannon energy :

$$Es = -S(t)^2 * logS(t)^2 \tag{2.5}$$

The figure below displays comparison between these different methods .

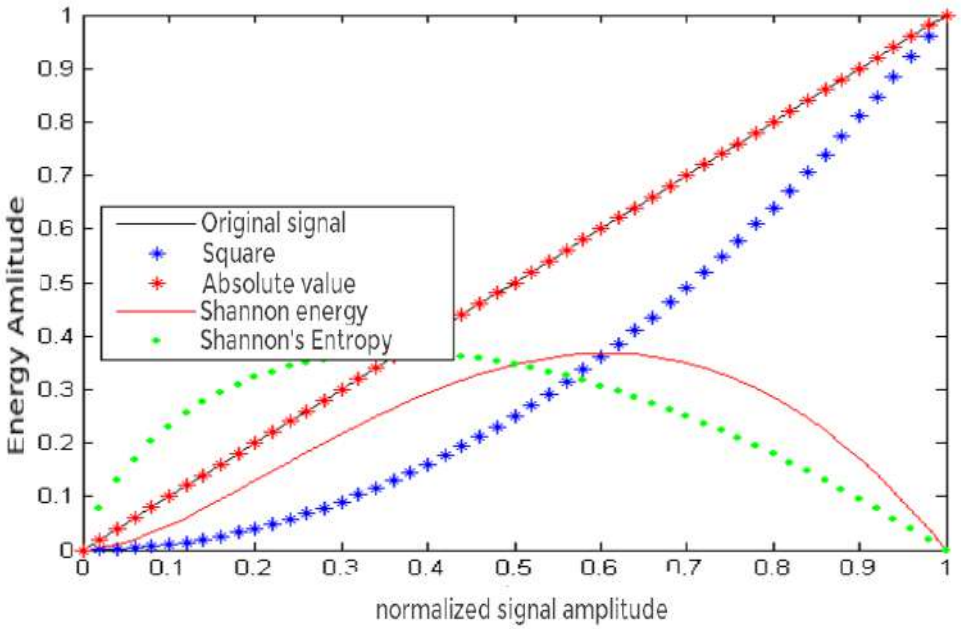


Figure 2.8: Temporal energy representations of S(t)=t signal .

2.12 Conclusion

In this chapter we presented the anatomy and physiology of human muscle and we have understood the source of Electromyography (EMG) signal and we also described how this signal can be detected by two ways, surface electrodes or needle electrodes. In the Next chapter we will describe the device that will allow the detection of surface EMG and its analysis.

Chapter 3

IMPLEMENTATION

Introduction

The EMG signals are highly sensitive signals that can only be studied through a precise mechanism such as motion sensors, these sensors cannot be used without a computer due to data processing.

3.1 Raspberry Pi

The Raspberry Pi is a remarkable device, a fully functional computer in a tiny and low-cost package. Whether you're looking for a device you can use to browse the web or play games, are interested in learning how to write your own programs, or are looking to create your own circuits and physical devices [14].



Figure 3.1: Raspberry Pi 3 B+.

3.1.1 The Raspberry Pi's components

Like any computer, the Pi is made up of various different components, each of which has a role to play in making it work. The first, and arguably most important, of these , the system-on-chip (SoC) [14].



Figure 3.2: The Raspberry Pi's system-on-chip (SoC).

The system-on-chip, known as an integrated circuit, which contains the bulk of the Raspberry Pi's system. This includes the central processing unit (CPU), commonly thought of as the brain of a computer, and the graphics processing unit (GPU), which handles the visual side of things.

When you're working on the Pi, it's the RAM that holds what you're doing, only when you save your work will it be written to the microSD card. Together, these components form the Pi's volatile and non-volatile memories. The volatile RAM loses its contents whenever the Pi is powered off, while the non-volatile microSD card keeps its contents [14].



Figure 3.3: The Raspberry Pi's random access memory (RAM).

The radio is the component which gives the Raspberry Pi the ability to communicate with devices wirelessly. The radio itself acts as two main components in fact, a WiFi radio for connecting to computer networks and a Bluetooth radio, for connecting to peripherals like mice and for sending data to or receiving data from nearby smart devices like sensors or smartphones [14].

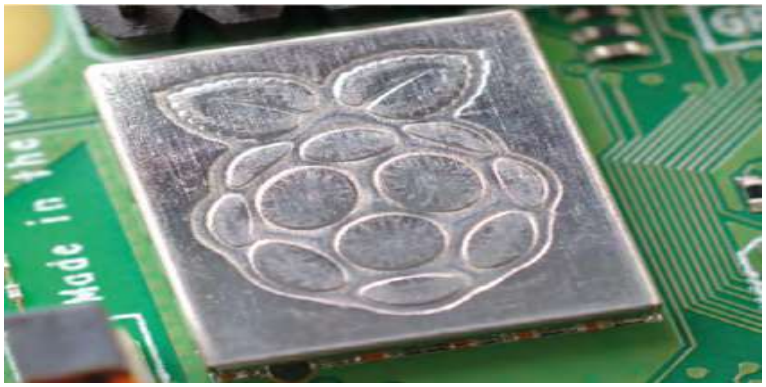


Figure 3.4: The Raspberry Pi's radio module.

The network and USB controller is responsible for running the Ethernet port and the four USB ports [14].

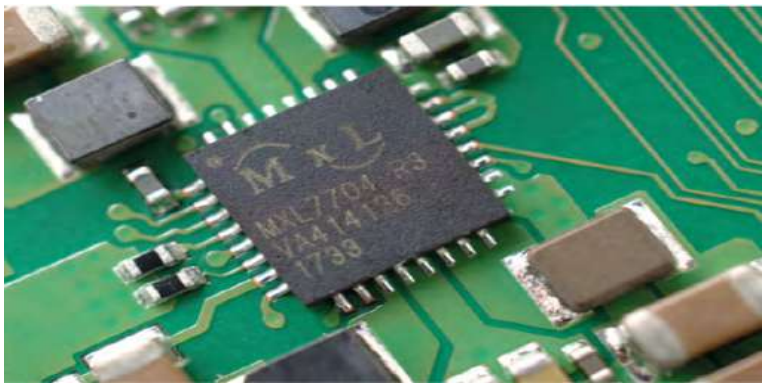


Figure 3.5: The Raspberry Pi's power management integrated circuit (PMIC).

3.1.2 The Raspberry Pi's ports

The Raspberry Pi has four Universal Serial Bus (USB) ports . These ports let you connect any USB-compatible peripheral, from keyboards and mice to digital cameras and flash drives to the Pi. Speaking technically, these are known as USB 2.0 ports [14].



Figure 3.6: The Raspberry Pi's USB ports.

The Ethernet port, also known as a network port, we can use this port to connect the Raspberry Pi to a wired computer network using a cable with what is known as an RJ45 connector.

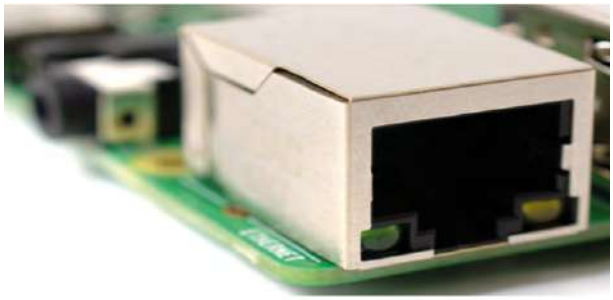


Figure 3.7: The Raspberry Pi's Ethernet port.

The audio-visual (AV) jack. This is also known as the headphone jack. The AV jack carries a video signal which can be connected to TVs, projectors and other displays that support a composite video signal using a special cable known as a tip-ring-ring-sleeve (TRRS) adapter.



Figure 3.8: The Raspberry Pi's AV jack.

The High-Definition Multimedia Interface (HDMI) port.We'll use

this to connect the Raspberry Pi to our display device, whether that's a computer monitor, TV or projector.



Figure 3.9: The Raspberry Pi's HDMI port.

Above the HDMI port is a micro USB power port, which you'll use to connect the Raspberry Pi to a power source.



Figure 3.10: The Raspberry Pi's micro USB power port.

At the right-hand edge of the board you'll find 40 metal pins, split into two rows of 20 pins. This is the GPIO (general-purpose input/output) header, a feature of the Raspberry Pi used to talk to additional hardware from LEDs and buttons all the way to temperature sensors, joysticks and pulse-rate monitors. Just below and to the left of this header is another, smaller header with four pins, this is used to connect the Power over Ethernet (PoE) HAT, an optional add-on which lets the Raspberry Pi receive power from a network connection rather than the micro USB socket [14].

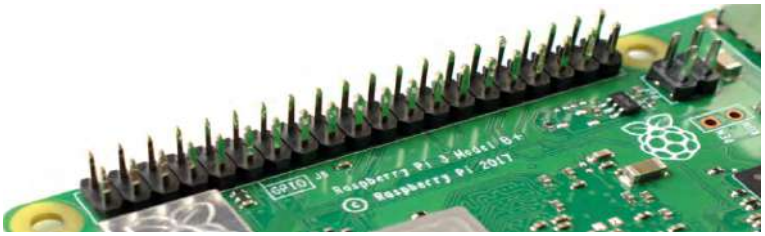


Figure 3.11: The Raspberry Pi's GPIO header.

The Raspberry Pi GPIO header is made up of 40 male pins. Some pins are available to use in our physical computing projects, some pins provide power, while other pins are reserved for communicating with add-on hardware. There are several categories of pin types, each of which has a particular function.

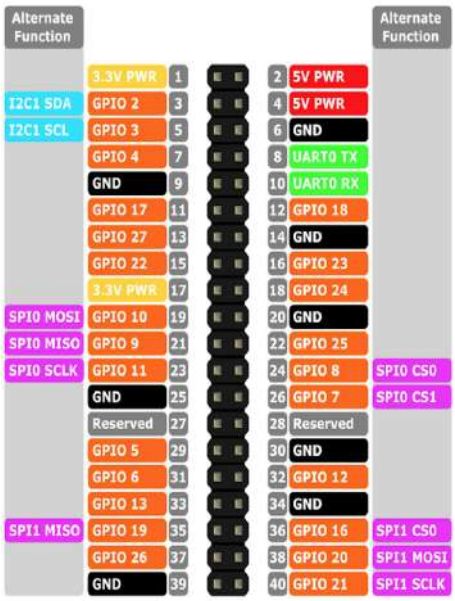


Figure 3.12: The Raspberry Pi pin numbers and functions.

3.2 EMG Detector

EMG detector is a bridge connects human body and electrical devices, the sensor gathers small muscle signal then process with two amplifers and filters. You can add this signal into your control system. In standby mode, the output voltage is 1.5V. When detect muscle active, the output signal rise up, the maximum voltage is 3.3V. You can use this sensor in 3.3V or 5V system.

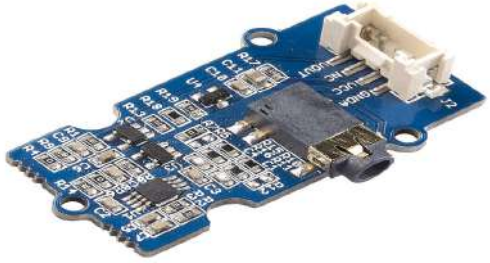


Figure 3.13: Grove EMG detector.

3.2.1 Features

- Grove Compatible.
- 3.5mm Connector.
- 6 Disposable Surface Electrodes.
- Power supply voltage : 3.3V-5V .
- 1000mm Cable Leads.
- No additional power supply .

3.2.2 Interface function

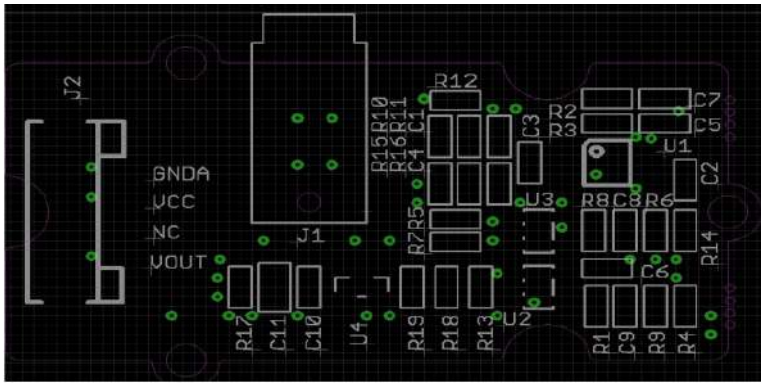


Figure 3.14: EMG interface.

- J2: Grove interface, connect to analog I/O.
- J1: EMG Disposable Surface Electrodes connector.
- U1: INA331IDGKT, difference amplifier.
- U2, U3: OPA333, Zero drift amplifier.

3.3 Analog-to-Digital Converter

The ADC, ADS1115 provides 16-bit precision at 860 samples/second over I2C interface. The chip can be configured as 4 single-ended input channels or two differential channels. As a nice bonus, it even includes a programmable gain amplifier, up to x16, to help boost up smaller single/differential signals to the full range. This ADC can run from

2V to 5V power/logic, can measure a large range of signals and its super easy to use. It is a great general purpose 16 bit converter.



Figure 3.15: ADC ads1115.

3.3.1 Features

The ADS1115 are very small, low-power, 16-bit,delta-sigma $\Delta\Sigma$ analog-to-digital converters (ADCs). The ADS1115 are extremely easy to configure and design into a wide variety of applications, and allow precise measurements to be obtained with very little effort. The ADS1115 consist of a $\Delta\Sigma$ analog-to-digital core with adjustable gain, an internal voltage reference, a clock oscillator and an I2C interface. An additional feature available on the ADS1115 is a programmable digital comparator that provides an alert on a dedicated pin. All of these features are intended to reduce required external circuitry and improve performance.

3.3.2 Functional block diagram

The ADS1115 core measures a differential signal,V_{IN} , that is the difference of AIN_P and AIN_N . A MUX is available on the ADS1115. This architecture results in a very strong attenuation in any common-mode signals. The converter core consists of a differential, switched-capacitor $\Delta\Sigma$ modulator followed by a digital filter. Input signals are compared to the internal voltage reference. The digital filter receives a high-speed bitstream from the modulator and outputs a code proportional to the input voltage.

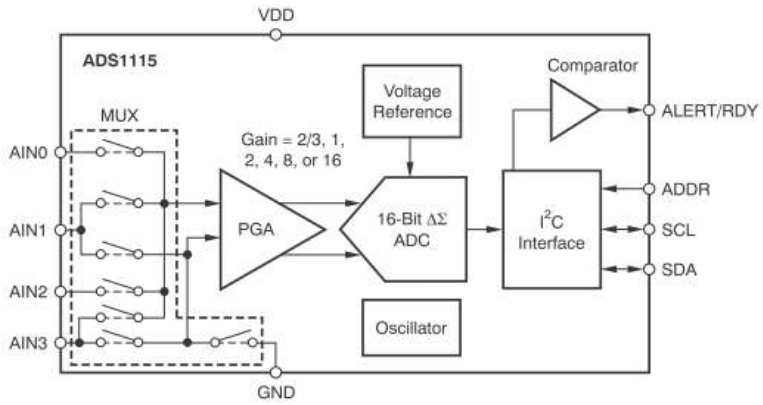


Figure 3.16: ADS1115 Functional Block Diagram.

3.4 Electrical components

The GPIO header is only part of what we'll need to begin working with physical computing; The other half is made up of electrical components, the devices we'll control from the GPIO header. There are millions upon millions of different components available, but most GPIO projects are made using the following common parts.

- Breadboard, also known as a Solderless Breadboard, can make physical computing projects considerably easier. Rather than having a bunch of separate components which need to be connected with wires, a Breadboard lets you insert components and have them connected through metal tracks which are hidden beneath its surface. Many Breadboards also include sections for power distribution, making it easier to build your circuits.

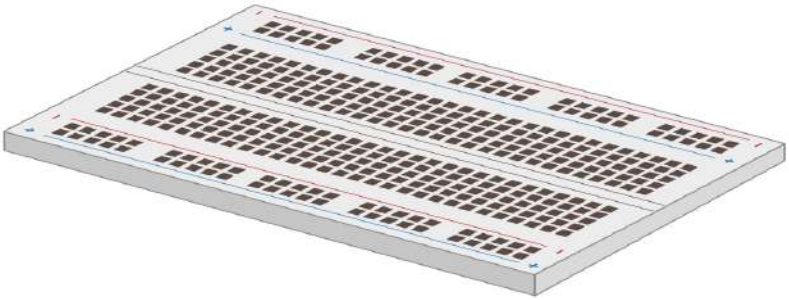


Figure 3.17: A Breadboard with sections for power distribution .

- Jumper wires, also known as Jumper leads, connect components to the Raspberry Pi and if you're not using a Breadboard, to

each other. They are available in three versions : male-to-female (M2F), which you'll need to connect a Breadboard to the GPIO pins; female-to-female (F2F), which can be used to connect individual components together if you're not using a Breadboard and male-to-male (M2M), which is used to make connections from one part of a Breadboard to another.

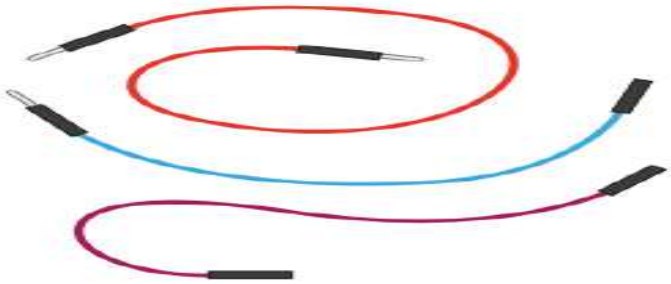


Figure 3.18: The three types of jumper wire.

3.5 I2C interface

I2C or Inter-integrated Circuit protocol is a hardware protocol designed to allow multiple slave integrated circuits to communicate with one or more master. It uses two bidirectional open-drain lines, Serial Data Line (SDA) and Serial Clock Line (SCL). Each slave device has a unique address. Transfer from and to master device is serial and it is split into 8-bit packets.

The initial I2C specifications defined maximum clock frequency of 100 kHz. This was later increased to 400 kHz as Fast mode. There is also a High speed mode which can go up to 3.4 MHz and there is also a 5 MHz ultra-fast mode.

Data on the I2C bus is transferred in 8-bit packets, that means you can address up to 127 slaves, each I2C slave device has a 7-bit address that needs to be unique on the bus followed by an Acknowledge bit. Some devices have fixed I2C address while others have few address lines which determine lower bits of the I2C address.

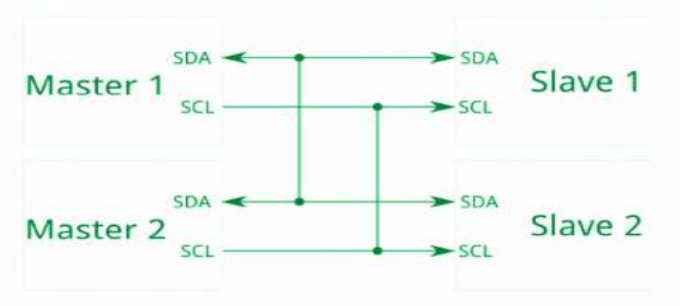


Figure 3.19: I2C interface.

3.6 Python

Python is a general-purpose programming language. That means it was designed and developed to write software for a wide variety of disciplines. Python has been used to write applications to solve problems in biology, chemistry, financial analysis, numerical analysis, robotics and many other fields. It is also widely used as a scripting language for use by computer administrators, who use it to capture and replay sequences of computer commands [15].

3.7 Typical Connections

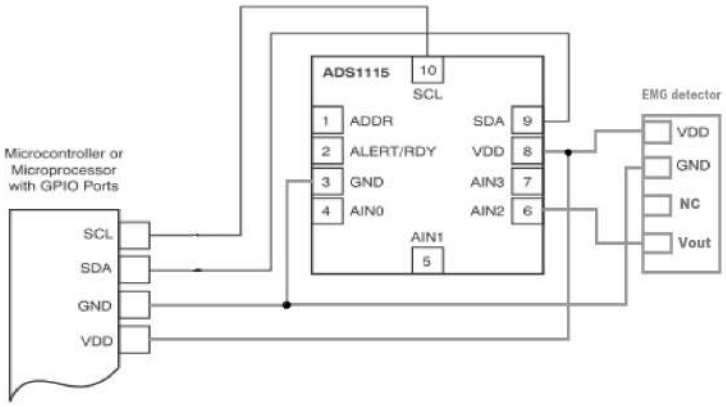


Figure 3.20: Typical Connections of the project.

Project description: The system includes an EMG control connected to the ADC ADS1115 and the last is connected to the RPI

with the I2C interface throw SCL and SDA. The RPI doesn't have an analogue inpute so we use the ADC ADS1115 that receive the analogue signal from the EMG detector and transform it to a 16 bit digital signal and send it to the RPI.

3.8 Hardwar installation

The RPI is connected to the ADC ADS1115 throw Jumper wire on the Breadbord and the EMG sensor is connected to the ADC at A0 .

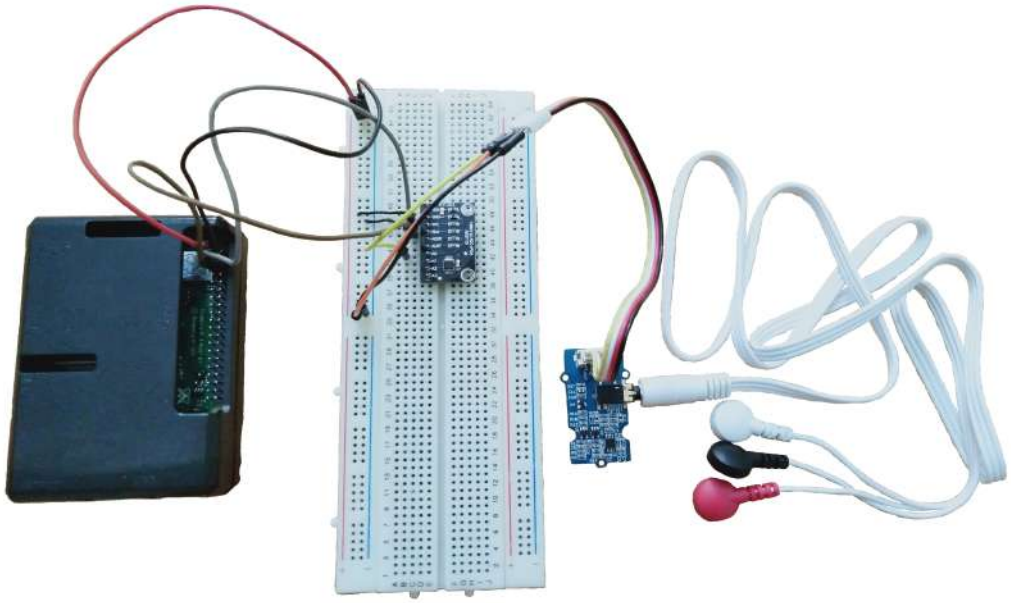


Figure 3.21: The hardwar instalation .

3.9 Implementation experiments and results

3.9.1 Implementation

The EMG signals are extracted by the sensor and sent to the Raspberry Pi, so that the latter processes them and save them . Then the file is sent to the computer where it is processed at the Matlab level.

The extracted signals could not be read because of the distortions, so they had to be filtered. For more accuracy, two filters were used to extract the information alone without any distortions.

The signals extracted from the same muscle(foream muscle) for comparison and audit, but it can be used on all external muscles.

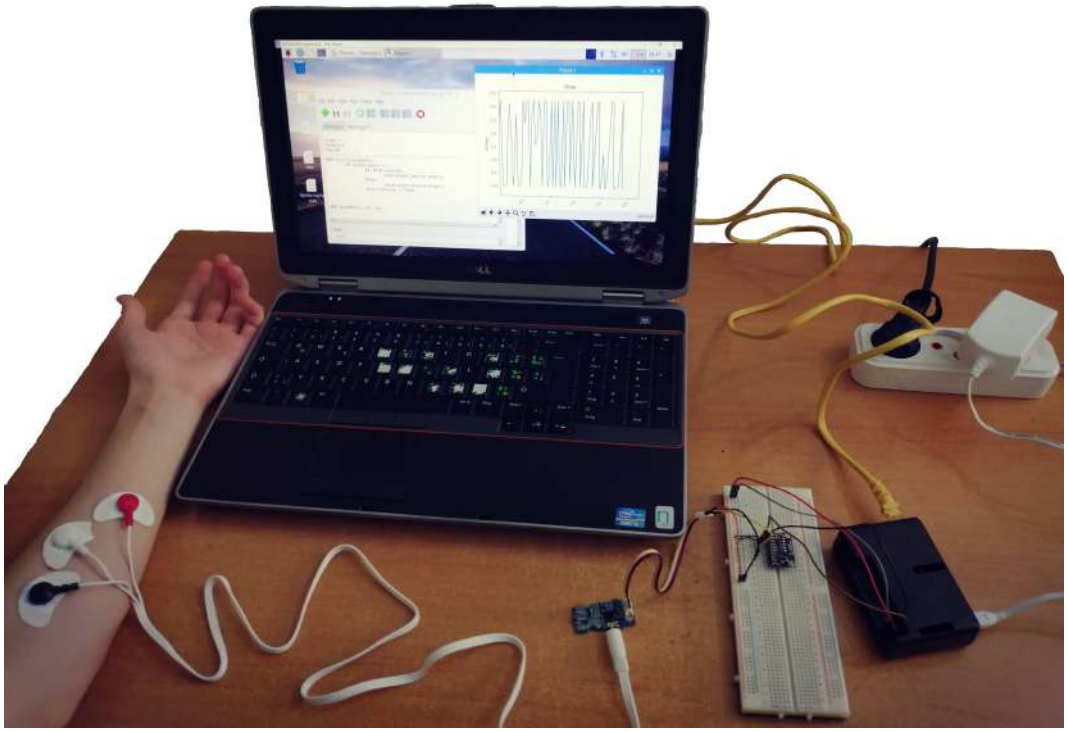


Figure 3.22: The project instalation .

3.9.2 Experiments and results

To operate our medical system to detect and extract EMG signals, we proposed a healthy patient with 25 years old. The obtained results are presente below :

Experience 1 :

The user performed two movements for four seconds in the range of a thousand samples. In the first movement, the user pressed the hand firmly, in the second movement, he made a medium pressure and this is clearly visible.

The extracted signal is not completely clear, but after processing the information clearly shows, the number of movements and the force

applied in the experiment is equal to the number of movements and the applied force in the graph.

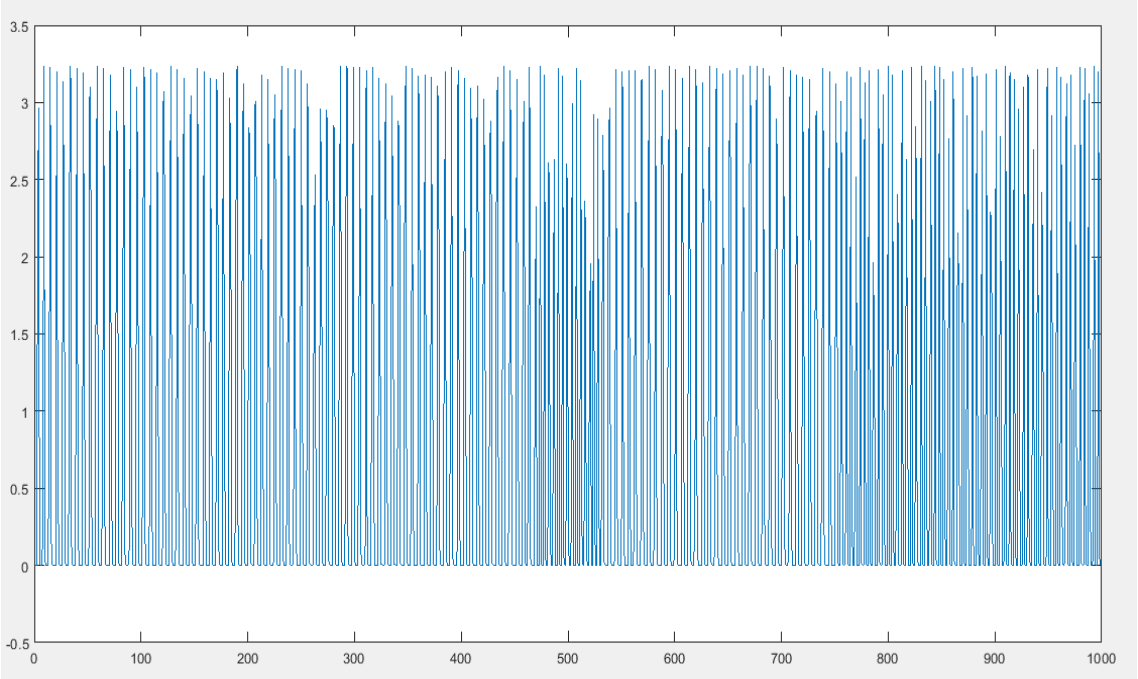


Figure 3.23: The signal extracted from experience 1.

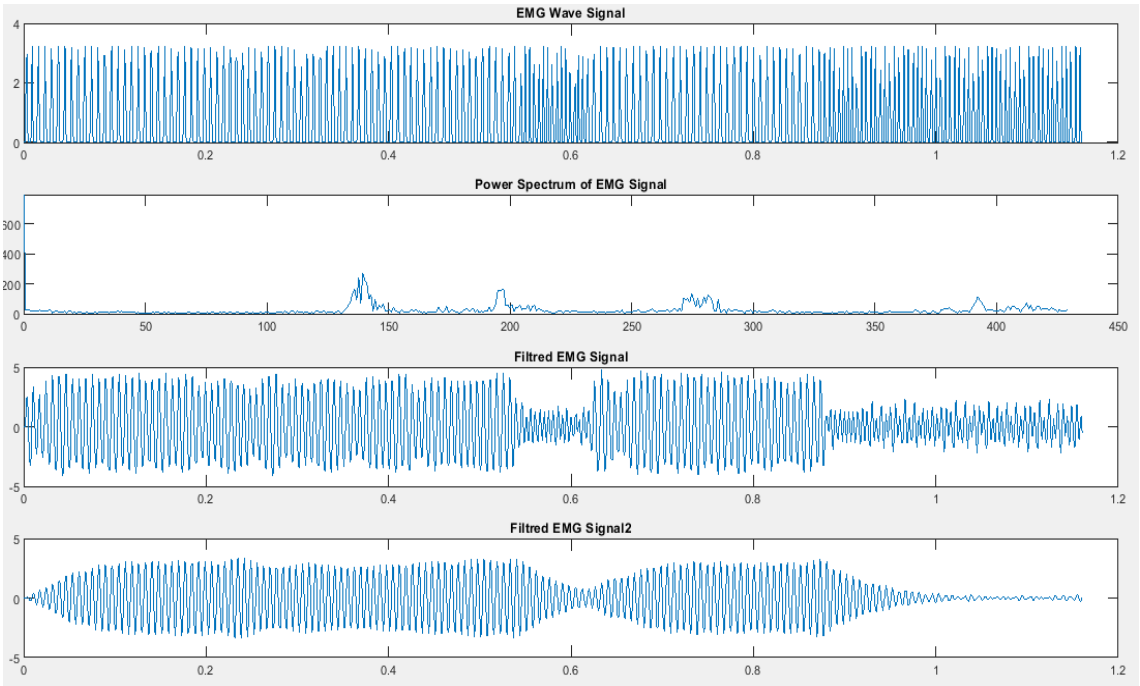


Figure 3.24: Signal treatment .

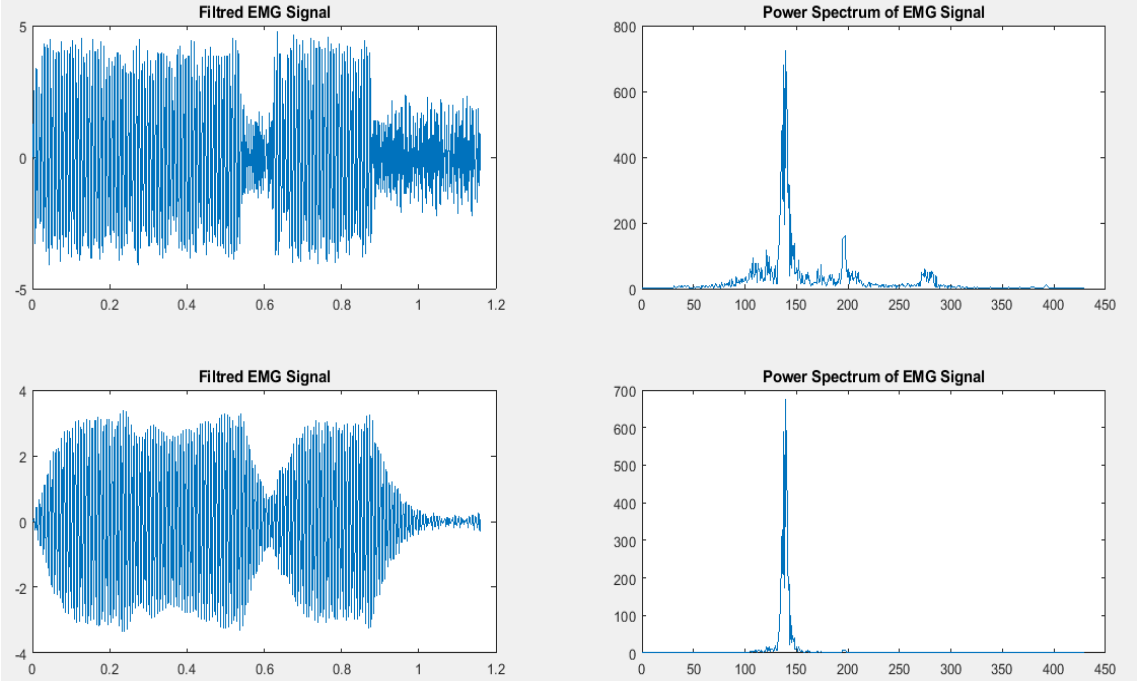


Figure 3.25: Experience 1 results .

Table 3.1: Experience 1 information.

signal	samples	time(s)	amplitude(v)	energy(kj)	entropy	RMS
test 1	1000	4	3.3836	5.2973	3.2304	1.7489

Experience 2 :

The user performed three movements for eight seconds in the range of a two thousand samples. In the first movement, the user made a slight movement, then a fairly strong movement, then a medium-strength movement as shown below.

There is a perfect match between the experience and the shown statement, even the flickering motions can be seen.

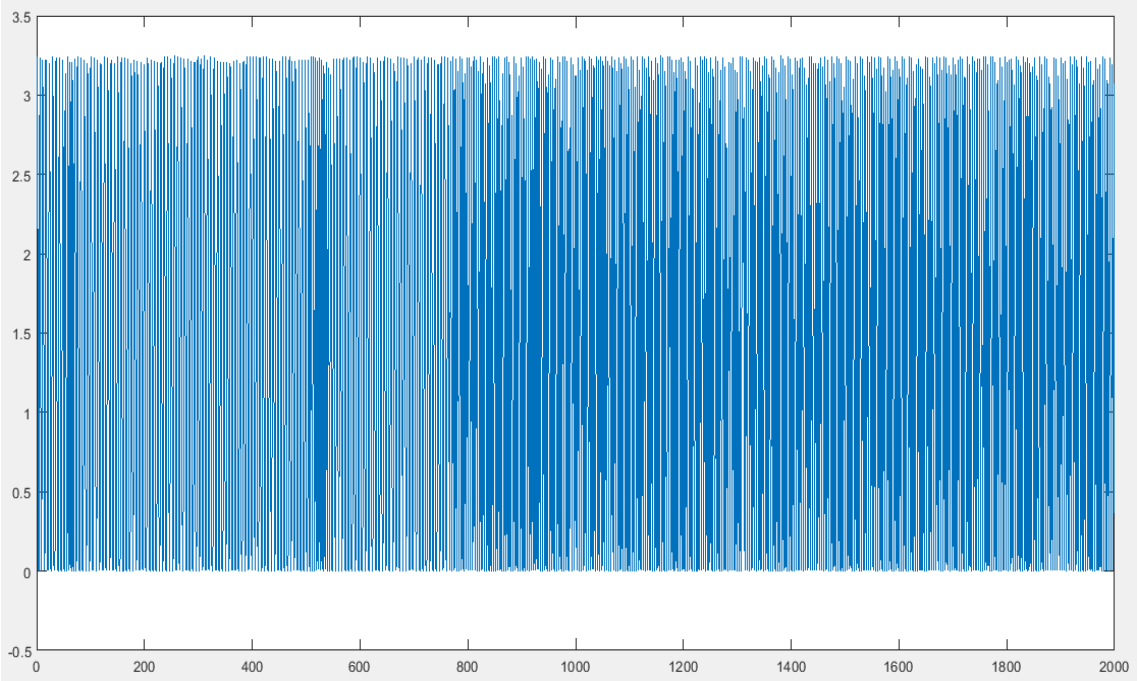


Figure 3.26: The signal extracted from experience 2.

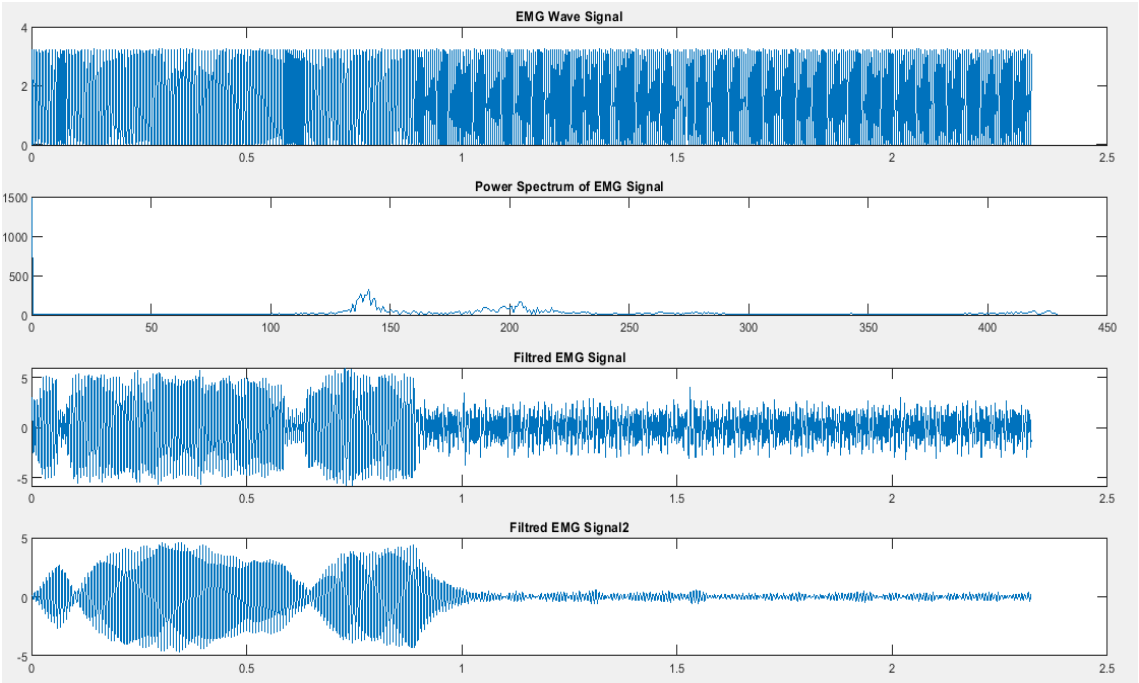


Figure 3.27: Signal treatment .

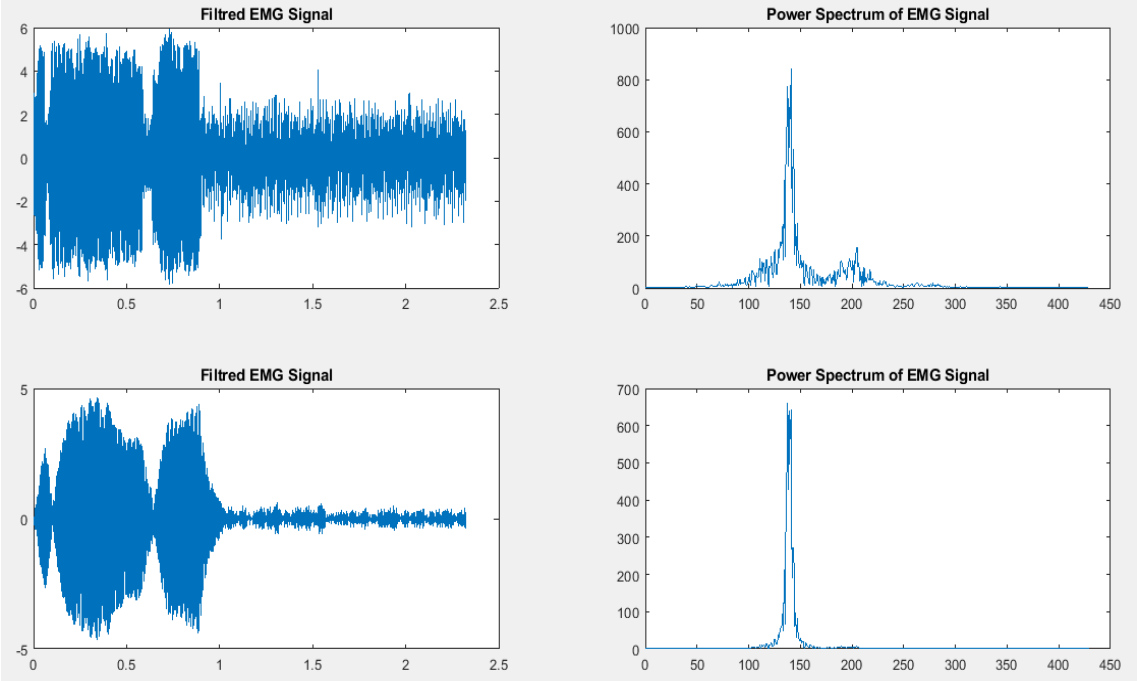


Figure 3.28: Experience 2 results.

Table 3.2: Experience 2 information.

signal	samples	time(s)	amplitude(v)	energy(kj)	entropy	RMS
test 2	2000	8	4.6374	10.437	2.4904	1.5437

Experience 3 :

The user performed six movements for sixteen seconds in the range of a three thousand seven hundred and therty(3730) samples. The user made several different movements, between strong and weak.

The number of movements and their variable strength do not affect the results of the experiment and can be observed quite simply.

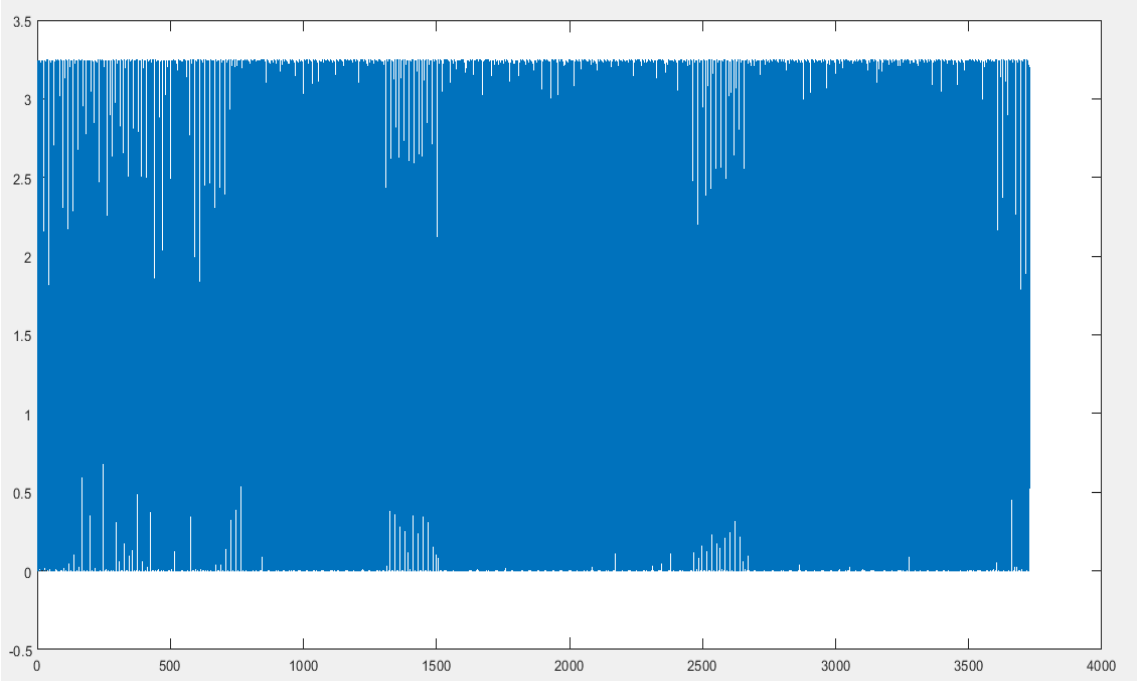


Figure 3.29: The signal extracted from experience 3.

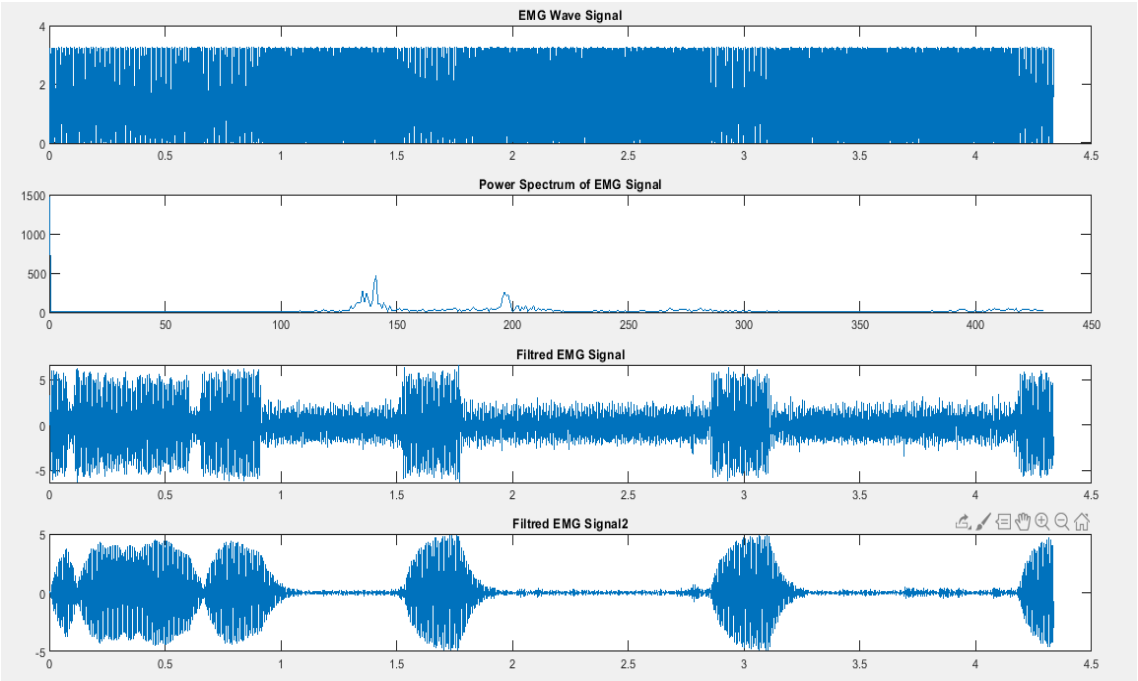


Figure 3.30: Signal treatment.

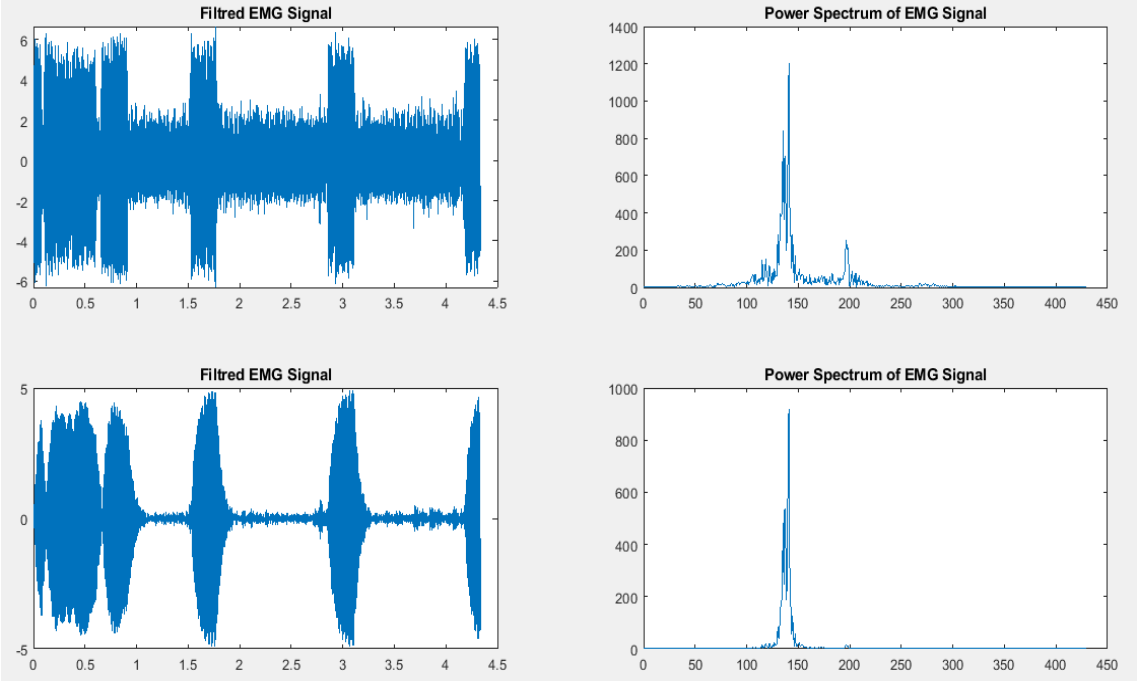


Figure 3.31: Experience 3 results.

Table 3.3: Experience 3 information.

signal	samples	time(s)	amplitude(v)	energy(kj)	entropy	RMS
test 2	3730	16	4.9009	24.321	2.5137	1.6668

3.10 Interpretation

We have done several experiments in which we took into account the number of movements and their strength. The total number of movements and their type were completely identical to what we found in the signals captured from the sensor and all this was completely clear.

The extracted signals are completely distorted and cannot be studied or any information extracted from them, so we placed signals through two digital filters to give the greatest possible accuracy.

While moving, a signal between 3 and 5 volts is recorded, while at rest, a signal is recorded from 0.2 to 0.5 volts. The recorded signals are based on muscle tone, strength and duration of movement.

We note that the more movements the greater energy extracted from the muscle.

The recording is done according to the pulse rate, and this is to give accurate results and the comparison of results is done in a smooth manner .

After processing the extracted signals, the doctor can see the patient's condition quite easily, because of the clarity of the extracted signals.

3.11 Conclusion

An automatic device has been successfully developed that can extract EMG signals from the human body using Raspberry Pi and an EMG sensor, and this is highly efficient in the lowest possible energy and cost. This system can be used easily and can extract all important information in a short period of time and with high accuracy.

CONCLUSION

The objective of this research was to create a system allowing to detect the raw signals EMG in order to ensure a better identification of the parameters which define the nature of neuromuscular pathology.

Through this system, the signal Electromyography has been detected from the muscle through the skin surface after the appearance from the source at the cellular level .

Our system contains electronic component like the sensor, analog to digital converter, Raspberry Pi and a computer to process and display the results and also this system contains theoretical concepts, among them instrumentation amplifier, filtering and acquisition.

A contribution has been added in a medical applications as a realisation of a device allowing the evaluation of muscular effort through the EMG, the device produced allows the detection of the EMG signal without any problem.

The shaping and acquisition of our system by a Raspberry Pi B+ to a PC, then digital processing to assess the effort muscular.

The first step: In this step, the signals present at the polar surface are collected, where these signals are analog and are amplified at the same step.

The second step, which is the most important step, in which the analog signals are converted into digital signals, where the Raspberry Pi can understand the nature of this signals and study it in the next step.

The third step: At this step, the signals are transferred to Raspberry Pi, this machine allows to visualize the signals in real time with the possibility of storing them in files.

In the last step we are going to transfer the file stored on the Raspberry Pi to a computer for processing and displaying with the characteristics of muscle via a graphical interface to assess muscle effort.

Our project can benefit from several improvements such as re-

duction in the number and size of equipment, using artificial neural network (ANN), with all this shortcomings our project gives a very positive result compared to the old model, so the work that we have done has been very rewarding.

Finally we wish to improve this project in the coming months since it is very necessary to help several people in this country.

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