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Departamento de Electrónica, Sistemas e Informática

ESPECIALIDAD EN SISTEMAS EMBEBIDOS



## **WIENER FILTERING FOR MYOELECTRIC SIGNAL**

Tesina para obtener el grado de:

ESPECIALISTA EN SISTEMAS EMBEBIDOS

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## Abstract

*EMG (Electromyography) signals are used to diagnose muscular pathologies and are also employed as inputs for electronic applications. However, a major disadvantage in detecting this signal is the noise that can be derived from power sources, incorrect placement of the electrodes, and the environment. To reduce the noise in the signal a filter must be incorporated in the system. The aim of this work is to reduce the noise generated in the muscular signals through an embedded system, using a Wiener filter with 50 coefficients. A real-time application was implemented using an Olimex SHIELD-EKG-EMG shield and a SAM V71 board. The shield was used to obtain the signal using the ADC of the SAM V71 board and the filter was programmed on the board. Several tests were performed using distinct frequencies and number of samples. With a frequency of 250Hz and 1024 samples, the system was not considered real-time, because the time needed to obtain the samples was 4.096 seconds. In this regard, if the signal reaches a programmed threshold level of the ADC, the actuator of the system would have been activated after 4.096 seconds plus the time needed to compute the filter values in the worst time scenario, making it an undesired configuration. In contrast, by reducing the number of samples to 100, the time needed to obtain the samples considerably decreased to 0.4 seconds, and thus, the system was considered real-time. On the other hand, with a frequency of 3kHz and 4096 samples, the filtered signal was almost the same as the raw signal and a similar result was obtained with 1.5Hz and 2048 samples, so both tests were discarded. Finally, the frequency that provided the best result was at 500Hz and 200 samples due to the acquisition signal time, processing filter time, and reduced number of samples. Therefore, a correct configuration of the frequency and number of samples is crucial to compute a Wiener filter on an embedded application.*



# Resumen

*Las señales de electromiografía son usadas para diagnosticar patologías musculares y también son usadas como entradas para aplicaciones electrónicas. Sin embargo, la mayor desventaja al detectar esta señal es el ruido que puede ser generado por fuentes de alimentación, colocación incorrecta de los electrodos y el medio. Para reducir el ruido en la señal, un filtro debe ser implementado en el sistema. El objetivo de este trabajo es reducir el ruido generado en las señales musculares a través de un sistema embebido, usando un filtro Wiener con 50 coeficientes. Una aplicación de tiempo real fue implementada usando un shield Olimex SHIELD-EKG-EMG y una tarjeta de desarrollo SAM V71. El shield fue utilizado para obtener la señal con el uso del ADC de la tarjeta SAM V71 y el filtro fue programado en la tarjeta. Varias pruebas fueron realizadas usando diferentes frecuencias y número de muestras. Con una frecuencia de 250Hz y 1024 muestras, el sistema no fue considerado de tiempo real porque el tiempo necesario para obtener las muestras fue de 4.096. En este sentido, si la señal alcanza un nivel de umbral programado en el ADC, el actuador del sistema hubiera sido activado después de 4.096 segundos más el tiempo necesario para el cálculo de los valores del filtro en el peor escenario de tiempo, esto lo hace una configuración no deseada. En contraste, al reducir el número de muestras a 100, el tiempo necesario para obtener las muestras se redujo considerablemente a 0.4 segundos y por lo tanto, el sistema puede ser considerado de tiempo real. Por otro lado, con una frecuencia de 3KHz y 4096 muestras, la señal filtrada fue casi la misma que la señal cruda, de manera similar este resultado fue obtenido con 1.5Hz y 2048 muestras, así que ambas pruebas fueron descartadas. Finalmente, la frecuencia que proporcionó el mejor resultado fue a 500Hz y 200 muestras debido al tiempo de adquisición de la señal, tiempo de procesamiento del filtro y el reducido número de muestras. Por lo tanto, una correcta configuración de frecuencia y número de muestras es crucial para el cálculo del filtro Wiener para aplicaciones embebidas.*

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## List of acronyms and abbreviations

EMG	Electromyography
FPU	Floating Point Unit
SAM	SMART ARM-based Flash MCU
ECG	Electrocardiogram
LMS	Lean Mean Square
SNR	Signal to Noise Ratio
PSD	Power Spectral Density
IIR	Infinite Impulse Response
FPGA	Field-Programmable Gate Array
PLI	Power Line Noise
Hz	Hertz
KHz	KiloHertz
MHz	MegaHertz
ECG	Electrocardiogram
MSE	Mean Square Error
MUAP	Motor Unit Action Potential
ANN	Artificial Neural Network
ADC	Analog to Digital Converter



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# Introduction

An EMG signal, also known as myoelectric signal, is the electrical muscular activity generated by muscle contraction. It provides information that can be used as diagnosis for muscular activation and muscular pathologies, such as muscular dystrophy, polymyositis, muscle strains, muscle contusions, and myasthenia gravis. There are two methods to obtain this signal, the non-invasive method that uses surface electrodes that are settled over the skin of the muscle, or the invasive method that uses needle electrodes that are placed within the muscle or in the muscle [1]. Besides, these signals have been used during the last years for robotics and biomedical applications.

Myoelectric signals are commonly used in prostheses as inputs to move fingers, the wrist, or the complete limb of a prosthesis. This is an innovative way to use a system, instead of using a button or an analogical input, a muscle can be used instead. Since the signal can be treated as an input on a system, when it reaches an expected amplitude, the system can generate an output. However, unexpected outputs may occur if the signal is not properly processed, and thus, amplifying, filtering, and digitalizing the signal is a must [1].

The main problem with this kind of signal is that it is very noisy due to its low voltage amplitude. Therefore, an amplifying step must be done and then, an appropriate filter is needed in order to obtain an optimal response. Over the years there have been improvements of the different types of filters used to obtain a better response [2]. However, other factors may cause noisy problems, since each muscle has a different size and length, the electrodes must be placed in the correct position to reduce noise, and otherwise, an incorrect placement may affect the signal acquisition. Furthermore, if the environment is noisy or the system is not properly protected to avoid noise, the signal acquisition will be affected. Therefore, the signal would not be appropriate to analyze.

Another problem to deal with is muscular fatigue. After several times the muscle has been contracted, the signal is not the same as expected, and it will have decreased. Therefore, the muscle will not reach the desired amplitude to activate the output of the system. When the muscle is weary, the signal changes and it is hard to know if the muscle is in a contracted state, relaxed state, or it is just noise. Therefore, the amplitude would not be enough to activate the programmable output, and thus, causing the system to not generate the output.

The purpose of this work is to reduce the noise of the signal using a Wiener filter. This filter is commonly used for signal and image processing. It is a filter that uses a noisy signal to generate a new one with an appearance near to a desired signal making the noise less notorious. The quality of the filter depends on the number of coefficients that are used. The purpose of the Wiener filtering is to generate an estimate as an output of a signal and the desired signal as inputs, by using statistical methods. To achieve this, a SAM V71 board will be used to code the filter, using the FPU for the mathematical operations [3], and the SHIELD-EKG-EMG will be used to obtain the signal [4].

# 1. Background

The filtering of an analogical signal can be performed with different types of digital or analogical filters. Sharma, B. et al. compared the use of the Wiener filter against an Adaptive Least Mean Square (LMS) algorithm on an Electrocardiogram (ECG) signal and found that the Wiener filter was a better option in terms of signal to noise ratio (SNR). Furthermore, the power spectral density (PSD) had a considerable peak in the Wiener filter graph and the LMS remained plain, so by comparing them, the Wiener filter was still the best option. However, this work was done by computer simulation using MATLAB, not in an embedded system, so the processing time was not a variable to deal with [5]. This work serves as a reference for the use of the Wiener filter over EMG signals since the purpose is to reduce the noise of an analogical signal, and the approach is the same.

Development boards are commonly used for EMG signal processing using surface electrodes for robotics and biomedical applications. However, a new way to implement this kind of applications is with the use of a Field-programmable gate array (FPGA). Toledo, D. et al. implemented an IIR filter on a FPGA, but it was not an embedded application due to the use of computer simulation in MATLAB for the calculation of the coefficients [6]. It is important to consider that every person has their own frequency pattern for the acquisition of EMG signals. A sampling frequency of 500Hz was used to obtain the EMG signals and the signal improves when the frequency used is higher than 50Hz.

Malboubi, M. et al. used a Laguerre filter with fuzzy logic for PLI and its harmonics. The advantage of using a Laguerre filter is the low number of parameters for processing. Noise generated by power sources at 50Hz or 60Hz is the first problem to deal with when the signal acquisition hardware is designed, especially for medical equipment. The reduction of this noise is more important than the noise generated by other factors, like the environmental noise. The findings from this study describe how the fuzzy logic helped to increase the SNR level making the signal response better than just with the use of the Laguerre filter [7].

There is another type of noise that the electrodes receive from the human body when EMG signals are obtained, and these are the ECG signals. Due to these signals, without having an appropriate filtering that cancels the ECG signals, it is recommended to not place the electrodes near the heart area. Abbaspour, S. et. al proposed the evaluation of an adaptive filter against a different conventional filtering technique, the use of an artificial neural network (ANN), and found that the estimated noise by the ANN method was better than the adaptive filter [8].

A similar work for canceling ECG signals was proposed by Cheng, K. et. al, using an adaptive filter with the recursive least square lattice structure. The results showed that this filter was effective in an ECG cancellation and the use of a fast Hartley transform reduced time calculation. Therefore, this adaptive filter was useful for real-time applications [9].

The SHIELD-EKG-EMG [4] uses a third-order Butterworth filter with a cut-off frequency of 40hz. This filter is made by placing a first-order and a second-order in cascade. Depending on the filter order, it can have 20dB/decade times the filter order, so a third-order has 60dB/decade [4]. Since the obtained signal is still noisy, another filter is needed in order to improve the signal. This shield has 5 channels for EKG-EMG detection, so 5 of these shields can be coupled over a development board. When more than one channel is used, just one reference electrode is needed instead of 5, this makes the system less susceptible to noise, and having 4 more electrodes would make the system noisier.

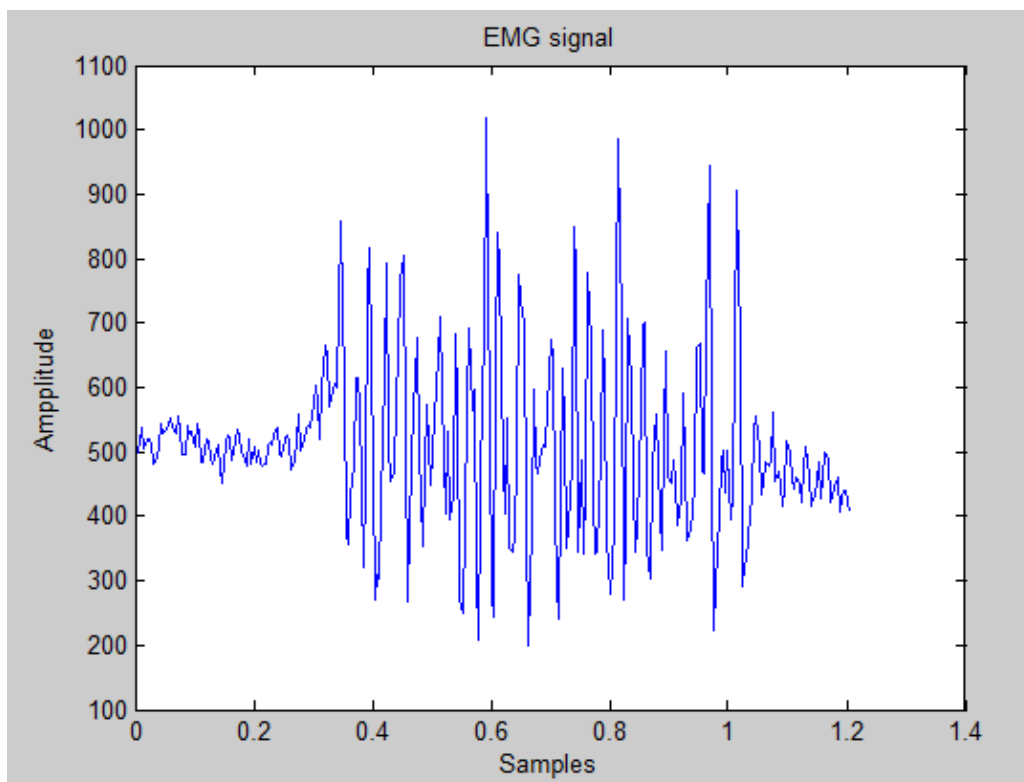


## 2. Theoretical Framework

### 2.1. Electromyography

The technique to obtain, process, and record the electrical contractions generated by the muscles, is known as electromyography. It is focused on the neuromuscular system. With the information provided by the EMG, a medical specialist can use it to diagnose muscular pathologies using an invasive or non-invasive method. However, the first step in order to use EMG is to understand the behavior of muscle contractions. Furthermore, many years of research were necessary to understand how muscles generate an action potential to start any movement within the body.

Figure 2-1 shows a noisy EMG signal obtained in 300 samples from the muscle of the forearm by the superficial method and measured in a frequency of 250Hz.



*Figure 2-1. EMG signal at 250Hz.*

The components of the muscular signal are amplitude, frequency, and phase. There are different approaches in regards to the amplitude that the signal can reach, and most potential actions have an amplitude between  $100\mu\text{V}$  to  $2\text{mV}$  [10]. Garcia Cavalcanti et al. stated that the bandwidth bound varies from 15 to 400Hz in order to detect these signals [11].

The SNR plays an important role in EMG, and it is defined as the ratio of the energy in the EMG signals to the energy in the noise signal. The noise is a component present within in electrical signals that is not part of the desired measured signal [1].

### **2.1.1 EMG History**

The origins of the EMG started around the XVII century, when the Italian biologist Francesco Redi, referred to as "*the founder of experimental biology*", discovered that a muscle of a ray fish was able to generate electricity. This discovery established the relation between muscles and electricity. In 1773, Walsh continued with the discovery made by Francesco Redi and demonstrated that the muscular tissue of the ray fish is able to produce an electrical spark. In 1792, a publication entitled "*De Viribus Electricitatis in Motu Musculari Commentarius*" by Luigi Galvani, demonstrated that the electricity could initiate a muscle contraction [12].

In 1849, Dubois Raymond discovered that it was possible to obtain a log of the electrical activity during the muscular contraction. In 1912, H. Piper researched about EMG, and he is considered to be the first investigator to study EMG signals [13]. In 1922, Gasser and Erlanger used an oscilloscope to show the electrical signals of the muscle [14]. Between 1930 and 1950, scientists started to use enhanced electrodes for muscular studies. The clinical use of EMG for treatment of specific disorders started in the 60s. In 1966, Hardyck, C. D. and his partners were the first to use the EMG technique [15]. At the beginning of the 80s, Cram and Steger developed a clinical method to scan a variety of muscles using a sensible EMG device [16]. In the mid-80s, when the electrode techniques were integrated, these had the enough technical levels to be

adapted in small low weight instruments, which allowed their development in medicine and biomechanical fields.

Nowadays, there is a huge number of amplifiers that are sold in the electronics market. The EMG has been used for the record of superficial muscles in clinical and kinesiology protocols. Furthermore, the needle electrodes are used for the study of deep muscles or to locate their muscular activity. There are EMG applications that are used for the diagnosis of neuronal or neuromuscular problems as well as in the biomechanical field for motor function, neuromuscular physiology, movement disorders, postural control, and physical therapy.

### **2.1.2 Motor Unit Action Potential**

The motor unit action potential (MUAP) by definition is the combination of the muscle fiber action potentials from all muscle fibers. The methods that can be used to obtain MUAP include non-invasive and invasive techniques [1]. The invasive method is preferred if the medical specialist needs to obtain critical information in order to detect muscular pathologies. The non-invasive method is preferred for recreational projects, such as robotic applications.

The neuromuscular system is the part of the body that uses the nervous system and the muscles to generate movement through muscles. The functional element of the neuromuscular system is known as motor unit (MU). The MU is composed of the alpha spinal motorneuron and its inverted set of muscular cells. To obtain the action potential of the muscles and record them, an instrument must serve as a contact medium between the muscle and the observed signal [17].

### **2.1.3 Electrodes**

The instrument needed to transfer information from an environment to another is called a transducer. The transducer that is in contact with the desired muscle to obtain the signal and is connected to the system that processes the signal, is known as an electrode. These electrodes can be different in size and quality. They are used to communicate the information received from the

tissues of the muscle through another electronic device, such as an embedded controller or a computer.

Armored wire is needed to avoid more noise in the system and it is used to establish the communication between electrodes and the electronic device, a good wire will reduce undesired noise.

#### **2.1.4 Needle Electrodes**

The method that uses needle electrodes is invasive, which means an instrument must be inserted in the body of the patient. There are 2 types of electrodes in the market: the concentric needle electrode and the monopolar needle electrode. The monopolar needle is made of stainless steel and is easier to insert due to its small diameter. The concentric needle does not need an extra electrode as reference. However, due to its larger size, the insertion is painful. The signals obtained from both types of needles will not be the same due to differences in the velocity of nerves and muscle fibers and in terms of frequency [18].

People must be careful with this type of electrodes, it is not easy to place them in the exact position to analyze the muscle. Therefore, a medical specialist is required to properly perform the insertion because an incorrect insertion could cause serious injury.

#### **2.1.5 Superficial Electrodes**

The method that uses superficial electrodes is non-invasive, which means an instrument is placed over the body of the patient. Three electrodes are needed to obtain the signal using this method and two electrodes are used to obtain the difference of the action potential generated by the muscle, and the third is used as reference and it must not be located near the other two electrodes.

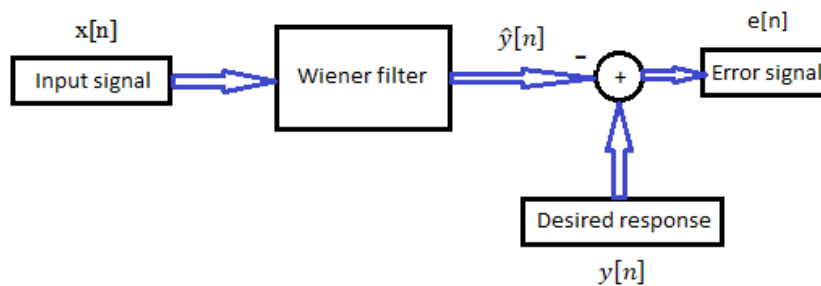
For recreational applications, this type of electrodes are mostly used because a medical specialist is not needed to examine the correct placement of the electrodes. An incorrect

placement could cause more noise in the signal acquisition, but without the risk of injuries in the muscle.

To begin an EMG measurement, the muscle that is going to be analyzed needs to be cleaned first. However, it is recommended to remove any hair present in the area of the skin to obtain a better EMG signal.

## 2.2. Wiener Filter

The Wiener filter is a process designed to reduce the MSE (Mean Square Error) between a desired outcome and an estimate formed by a linear combination of samples from another related process [19]. It is important to state that the MSE is minimized but not eliminated. The filter is used for signal and image processing, echo cancellation, linear prediction, and estimation. Figure 2-1 shows the representation of the Wiener filter.



*Figure 2-2. Representation of the Wiener filter.*

The input signal  $x[n]$  has two components: the desired response that must be obtained plus the noise component. This can be represented as:

$$x[n] = y[n] + v[n] \quad (2-1)$$

To estimate the value of an unknown variable  $y$  related to a set of unknown variables  $x_1, x_2, \dots, x_p$ , using a linear estimator is shown in the equation below [19]

$$\hat{y}[n] = \sum_{k=1}^P h_k x_k = h^T x \quad (2-2)$$

The error between the true and estimated values is given by

$$e \triangleq y - \hat{y} = y - \sum_{k=1}^P h_k x_k = y - h^T x \quad (2-3)$$

It is necessary to determine the coefficients  $h_1, h_2, \dots, h_p$  that minimize the MSE  $E(e^2)$ . Using (2-2) the equation results

$$e^2 = \left( y - \sum_{k=1}^P h_k x_k \right) \left( y - \sum_{m=1}^P h_m x_m \right) = y^2 - 2 \sum_{k=1}^P h_k x_k y + \sum_{k=1}^P \sum_{m=1}^P h_k h_m x_k x_m \quad (2-4)$$

Taking the expectation of both sides of 2-4 yields, the following equation is obtained

$$E(e^2) = E(y^2) - 2 \sum_{k=1}^P h_k E(x_k y) + \sum_{k=1}^P \sum_{m=1}^P h_k h_m E(x_k x_m) \quad (2-5)$$

The correlation matrix  $R_x$  is defined by the random vector  $x$  and the cross-correlation vector  $g$  between  $x$  and  $y$  by,

$$R_x \triangleq \begin{bmatrix} E(x_1 x_1) & E(x_1 x_2) & \cdots & E(x_1 x_p) \\ E(x_2 x_1) & E(x_2 x_2) & \cdots & E(x_2 x_p) \\ \vdots & \vdots & \ddots & \vdots \\ E(x_p x_1) & E(x_p x_2) & \cdots & E(x_p x_p) \end{bmatrix} \text{ and } g \triangleq \begin{bmatrix} E(x_1 y) \\ E(x_2 y) \\ \vdots \\ E(x_p y) \end{bmatrix} \quad (2-6)$$

(2-4) can be expressed in a matrix form as follows:

$$J(h) \triangleq E(e^2) = E(y^2) - 2h^T g + h^T R_x h \quad (2-7)$$

From  $E(Y_2) = a^T R_x a \geq 0$ , and (2-2) is the same as having  $E(\hat{y}^2) = h^T R_x h$ . Since  $E(\hat{y}^2) \geq 0$ , it is concluded that  $h^T R_x h \geq 0$ , and the correlation matrix is always nonnegative definite. Setting the partial derivatives of  $E(e^2)$  with respect to each coefficient  $h_1, h_2, \dots, h_p$  equal to zero, the following equation is obtained

$$\frac{\partial E(e^2)}{\partial h_i} = E\left(\frac{\partial e^2}{\partial h_i}\right) = E\left(2e \frac{\partial e}{\partial h_i}\right) = -2E(e x_i) = 0, 1 \leq i \leq p \quad (2-8)$$

This yields a set of simultaneous equations that specify the optimum value for each coefficient. (2-3) and (2-8) are used to obtain the so-called normal equations

$$\begin{aligned} E(x_1 x_1)h_1 + E(x_1 x_2)h_2 + \dots + E(x_1 x_p)h_p &= E(x_1 y) \\ E(x_2 x_1)h_1 + E(x_2 x_2)h_2 + \dots + E(x_2 x_p)h_p &= E(x_2 y) \\ \vdots & \\ E(x_p x_1)h_1 + E(x_p x_2)h_2 + \dots + E(x_p x_p)h_p &= E(x_p y) \end{aligned} \quad (2-9)$$

which can be written in matrix form as follows:

$$R_x h = g \quad (2-10)$$

As shown in (2-1),  $x[n]$  is the input signal and  $y[n]$  is the desired response, and  $v[n]$  is the noise component that represents the input signal. The following expression is used to estimate the desired signal:

$$\hat{y}[n] = \sum_{k=1}^P h_k x[n+1-k] \quad (2-11)$$

The MSE can be expressed as  $E(e^2[n])$ , assuming that the processes  $x[n]$  and  $y[n]$  are jointly wide-sense stationary, and  $E(x_k x_m) = E(x[n+1-k]x[n+1-m]) = r_x[|m-k|]$  and  $E(x_k y) = E(x[n+1-k]y[n]) = r_{xy}[1-k] = r_{yx}[k-1]$ . Therefore, the normal equations take the form:

$$\begin{bmatrix} r_x[0] & r_x[1] & \cdots & r_x[p-1] \\ r_x[1] & r_x[0] & \cdots & r_x[p-2] \\ \vdots & \vdots & \ddots & \vdots \\ r_x[p-1] & r_x[p-1] & \cdots & r_x[0] \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_p \end{bmatrix} = \begin{bmatrix} r_{yx}[0] \\ r_{yx}[1] \\ \vdots \\ r_{yx}[p-1] \end{bmatrix} \quad (2-12)$$

or  $R_x h_o = g$ , where the matrix  $R_x$  is symmetric Toeplitz. Since  $R_x$  and  $g$  do not depend on the time index  $n$ , the optimum filter coefficients  $h_o$  do not depend on  $n$  as well. Therefore, for stationary processes the optimum filter is time-invariant. If it is set to  $h_o[k-1] = h_k, 1 \leq k \leq p$ , the normal equations can be written as:

$$\sum_{k=0}^{p-1} h_o[k] r_x[m-k] = r_{yx}[m], \quad 0 \leq m \leq p-1 \quad (2-13)$$

The minimum value of  $MSE E(e^2[n])$ , where  $e[n] = y[n] - \hat{y}[n]$ , is given by,

$$J_o = r_y[0] - h_o^T g = r_y[0] - \sum_{k=0}^{p-1} h_o[k] r_{yx}[k] \quad (2-14)$$

The filter defined by (2-12) is known as a Wiener filter because it is the discrete-time equivalent of the continuous-time optimum filter introduced by Norbert Wiener. The design of the Wiener filter does not depend upon the particular realizations  $x[n]$  and  $y[n]$  of the input and desired response stochastic processes, but upon the first  $p$  values of the correlation sequences



$r_x[m]$  and  $r_{yx}[m]$ . Therefore, the same Wiener filter can be used for all random signals with the same second-order moments [19].

### 2.2.1 Correlation

The correlation is a statistic technique that is used to compare the relationship between 2 processes. In signal processing, two signals are used to produce a third signal. This third signal is called the cross-correlation of the two input signals. If a signal is correlated with itself, the resulting signal is called autocorrelation [20]. The correlation of a signal  $x[n]$  and the signal  $y[n]$  is defined by,

$$r_{xy}[l] \triangleq \sum_{n=-\infty}^{\infty} x[n]y[n-l], \quad -\infty < l < \infty \quad (2-15)$$

Considering the 2 signals  $x[n]$  and  $y[n-l]$ , the signal  $y[n-l]$  differs in the x-axis compared to  $x[n]$ . This is necessary to see how much the signal  $y[n]$  needs to be shifted in the a-axis to make  $y[n]$  identical to  $x[n]$ .

### 2.3. Analog To Digital Converter

An Analog to Digital Converter (ADC) is a feature that receives an analogical signal and converts the voltage received after a certain time to its digital binary representation that stands for the voltage of the analogical signal. A disadvantage of the ADC is that it consumes more processing time than a digital to analog converter (DAC) [21].

The main characteristic of these controllers is the resolution. It states the number of values the controller can generate over the analogical values. There are controllers of 8, 10, and 12 bits in the market. The formula to obtain the resolution is the following:

$$Resolution = \frac{V_i}{2^n - 1} \quad (2-16)$$

Where  $V_i$  is the input voltage in the controller and  $n$  is the number of bits of the controller.

## 2.4. Microcontroller

A microcontroller is an integrated system that contains peripherals, memory, and a processor, all in one chip. A microcontroller is used for embedded applications due to the low number of resources within it. However, these small resources are a problem for some developers when the embedded application demands more memory. A program is uploaded in the memory and the microcontroller performs a defined number of tasks depending on the inputs of the peripherals.

The advantages of microcontrollers are the low cost, small size and fast time of development due to the low number of resources of each element (memories and peripherals) in one single chip. On the other hand, the disadvantages are limited memory size and low operation speed.

There are different microcontroller architectures: 8 bits, 16 bits, and 32 bits. The developer needs to decide which architecture is the best, depending on the type of application, cost, and performance.

### 2.4.1 Development Board SAM V71

The SAM V71 board is a Flash MCU designed for automotive applications. The board uses an ARM Cortex-M7 processor with an architecture of 32-bits and it can work up to 300MHz. This processor has a FPU integrated for single and double floating point operations. The SAM V71 has three software-selectable low-power modes: sleep, wait, and backup. When the board is in sleep mode, functions can still run while the processor has stopped. When the

board is in wait mode, functions are stopped and some peripherals can still work if they are programmed by the developer. When the board is in backup mode, the real-time timer and the real-time clock are still running [22].

Features:

- ARM Cortex-M7
- Up to 2048 Kbytes embedded Flash
- One reset button
- Two user push buttons
- Two yellow LEDs
- Super capacitor backup
- Arduino Compatible Shields
- 32.768 kHz crystal oscillator
- Ethernet MAC
- Four Three-Channel 16-bit Timer/Counters
- Two Analog Front-End Controllers
- Two master Controller Area Networks
- Two 4-channel 16-bit PWMs

## **2.5. Board Shields**

A board shield is a plug-in electronic device that can be inserted in the pins of an electronic board. The main purpose of these devices is to provide the developer the necessary components located on an electric board to perform common outputs like the control of an electrical motor, including a LED matrix, a set of relays, and analogical sensors, among others. The demand of these devices increased when the Arduino platform became popular in the market.

### 2.5.1 SHIELD-EKG-EMG

The SHIELD-EKG-EMG was designed to obtain bio-signals, such as ECG and EMG signals. These signals can be used as inputs for any application. This shield is open hardware, so every user can have access to the shield schematics [23].

Up to 6 shields can be stacked in a single board, the channel pin must be changed if one stacked shield is using the same channel. When more than one shield is stacked, there must be just one reference electrode. The shield has a potentiometer for controlling the gain and the manufacturer does not recommend moving it. The shield can operate at 3.3V or 5V and a jumper is used to select the desired voltage.

Features:

- Shield made for Arduino
- Calibration signal generation by D4/D9 digital output
- Precise trimmer potentiometer for calibration
- Input connector for standard or active electrode

## 3. Methodology

### 3.1. Scope of the project

This work aimed to reduce the noise from EMG signals using an embedded system. In order to achieve this, the SAMV71 board [3] was used to code the Wiener filter and to process the EMG signal received by the SHIELD-EKG-EMG [4]. The system will aim to reduce a percentage of the noise but will not completely eliminate the noise.

### 3.2. Development tools

The IDE (Integrated Development Environment)  $\mu$ Vision version 5.24.2.0 developed by the Keil company, was used to code the program of the SAM V71 using the MDK of the board [24]. Figure 3-2 shows the  $\mu$ Vision interface.

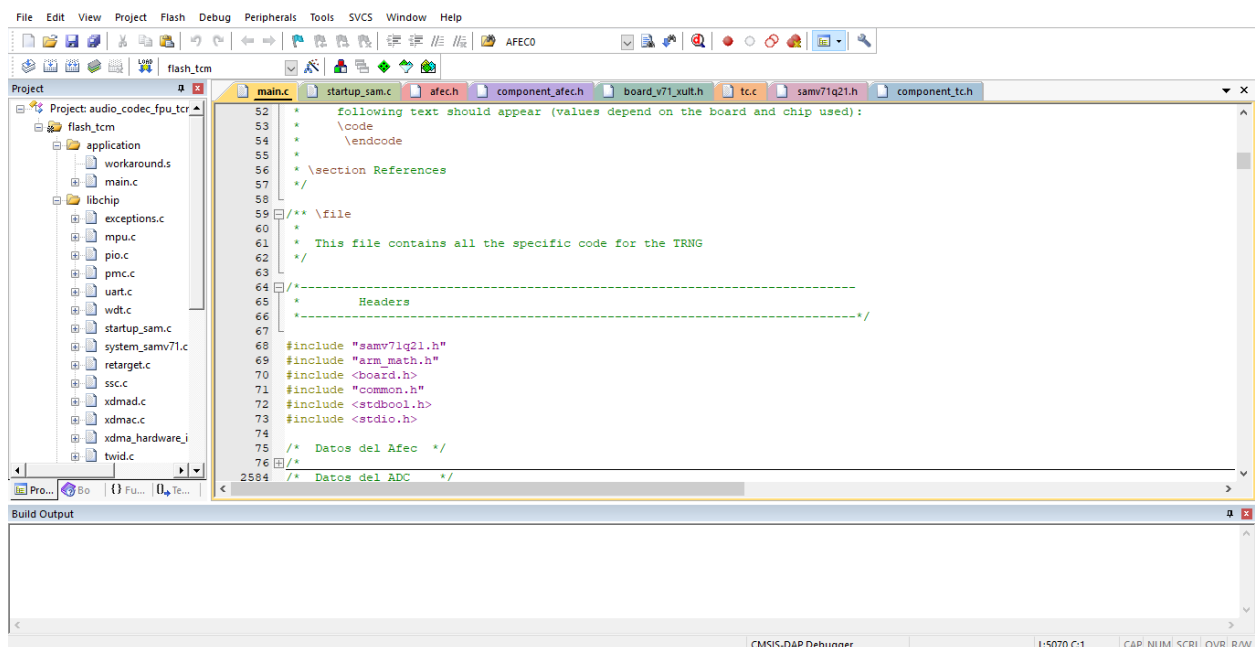


Figure 3-1. uVision interface.

TeraTerm is an open source terminal emulator that supports serial port connections. The tool was used to test the output of the EMG signal received by the board[25]. Figure 3-3 shows the Tera Term interface.

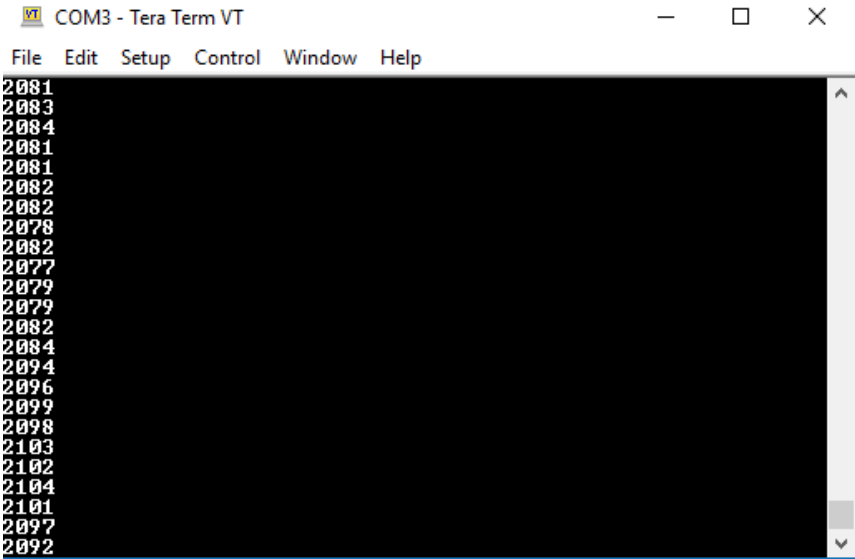


Figure 3-2. TeraTerm Interface.

Processing version 3.0.2 was used to see the output of the Wiener filter through a graph. The information is received from the output of the serial communication[26]. Since the board sends the samples information by serial communication, these values could be printed in a graph. Figure 3-3 shows the interface.

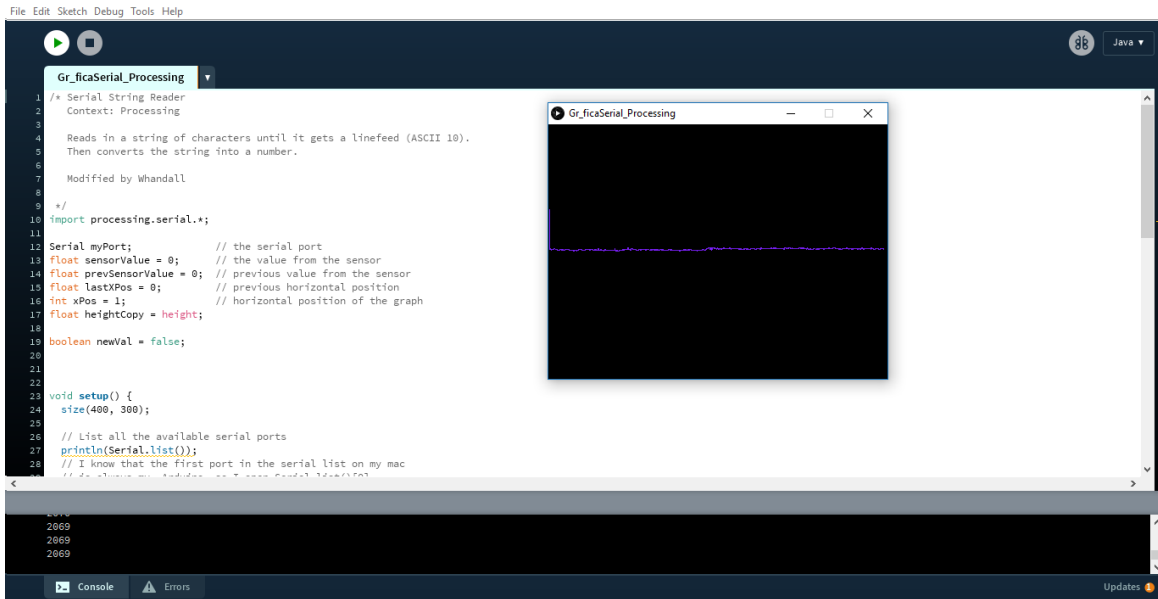


Figure 3-3. Processing interface.

MATLAB was used to print raw, filtered graphs, and to obtain the spectrum density of the signals [27]. Figure 3-4 shows the MATLAB editor interface used to code scripts.

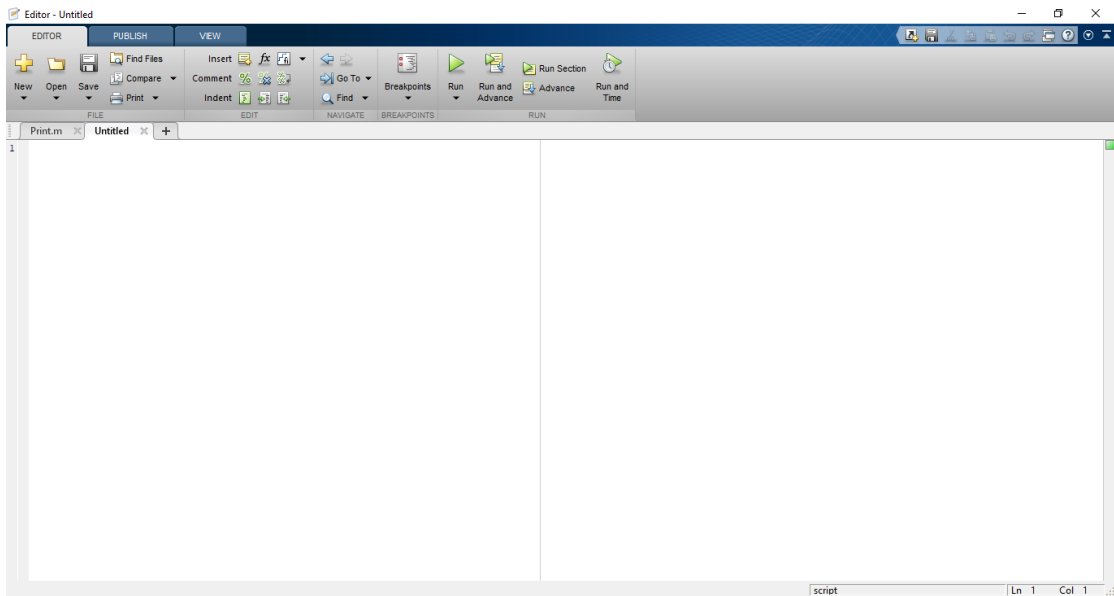


Figure 3-4. MATLAB editor interface.

### 3.3. Implementation

Before starting to code the filter, the first step was to obtain the EMG signal through the ADC of the board. Figure 3-5 shows the surface electrodes used to obtain the samples of the signal. In order to test that the signals were received, the values of the signals were printed by code and the Tera Term terminal was used to see if the values of the signals were printed. After verifying that the values were correctly printed, processing was used to confirm the values shown in the graph.



*Figure 3-5. Superficial EMG electrodes.*

After the input was ready, 2048 samples were printed in Tera Term and used in  $\mu$ Vision as an array to avoid placing the electrodes on the muscles every time new samples were needed to process the output of the Wiener filter. The next step was to enable the FPU of the board and then code the Wiener filter. The final output (filtered EMG signal) is shown in processing.

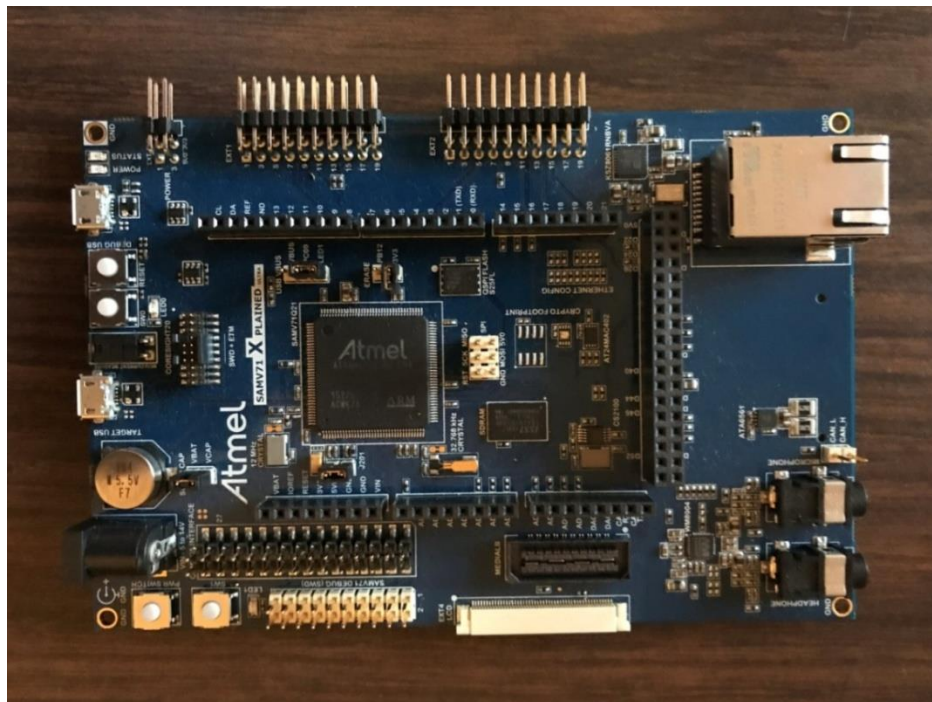
The wire is the physical medium between the electrodes and the electronic device. It has an audio jack to connect it to the Shield-EKG-EMG. Figure 3-6 shows the wire.





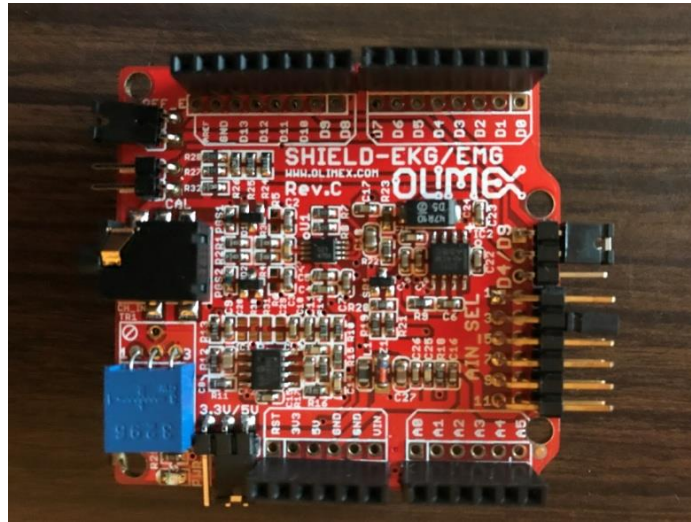
*Figure 3-6. Wire for superficial electrodes.*

The SAM V71 board used to compute the Wiener filter is shown in Figure 3-7.



*Figure 3-7. SAM V71 board.*

The SHIELD-EKG-EMG used to obtain the EMG signal is shown in Figure 3-8.



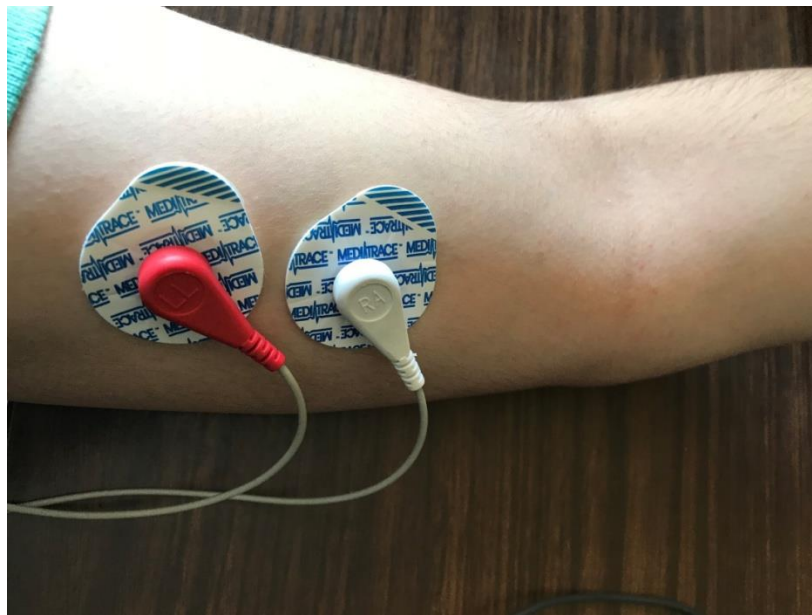
*Figure 3-8. SHIELD-EKG-EMG*

## 4. Results

Several tests were performed with different frequencies and number of samples, 50 coefficients were computed for each test. Using a low frequency at 60Hz and 1024 samples, the system needed to wait 17 seconds to fill the array variable of 1024 samples, with that frequency the system cannot be considered a real-time system. If someone used these parameters and the action potential is enough to activate an output, the system would have responded after 17 seconds.

The processing of the Wiener filter lasted for 64ms using 2048 samples to fully filter the samples received by the ADC of the SAM V71. The time will decrease if less samples are used in the filter. This processing time fits the deadline to be considered a real-time system. The problem at this point is the time needed to obtain the 2048 samples.

The incorrect placement of the electrodes is a considerable variable that generates noise so the better the placement was set the better the response was obtained. Figure 4-1 shows the placement of the electrodes on the bicep of the left arm of a patient.



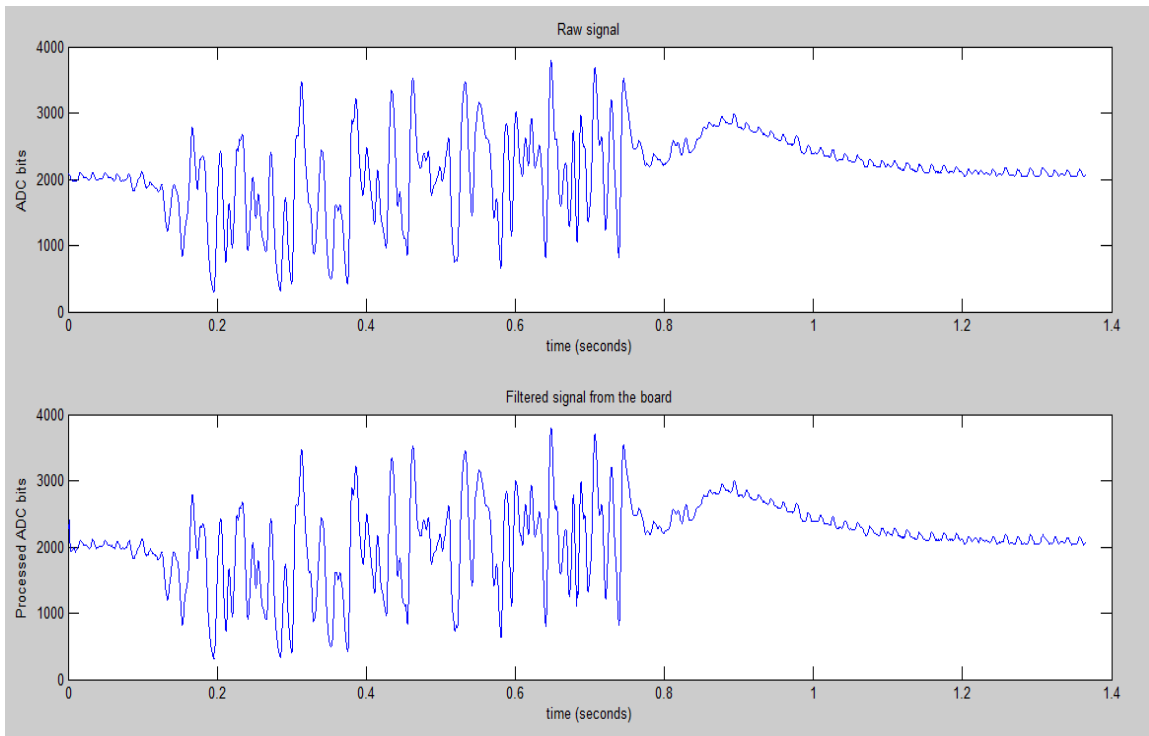
*Figure 4-1. Placement of electrodes on the skin.*

The reference electrode was placed distant from the other two electrodes, since a better measurement is obtained when the reference electrode is not near the electrodes that receive the action potential. Figure 4-2 shows the placement of the reference in the bone of the wrist of the right arm of the patient.



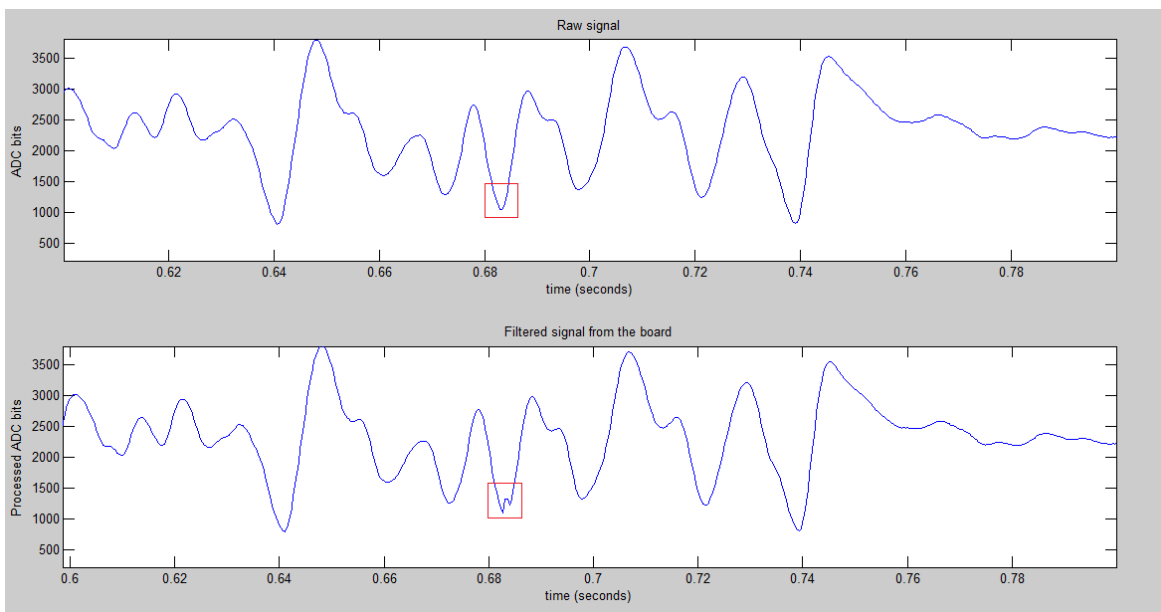
*Figure 4-2. Reference electrode placement on the wrist of a patient.*

To get started with the acquisition of the signal, a test was performed in Processing tool to observe the plot of the graph, then the samples were obtained from Tera Term and the values were used in MATLAB to plot graphs. A test was performed with a frequency of 3KHz in 2048 samples. When the raw values of the signal and the filtered values were compared, they were almost exactly the same. Figure 4-3 shows the result.



*Figure 4-3. Raw signal and filtered signal at 3KHz and 2048 samples.*

At the beginning of the filtered samples, a noise was generated by the filter (Figure 4-4).



*Figure 4-4. Noise at the beginning of the filtered signal.*



Figure 4-5 shows the spectral density of the raw and filtered signals of 3KHz. The graph shows no appreciable differences.

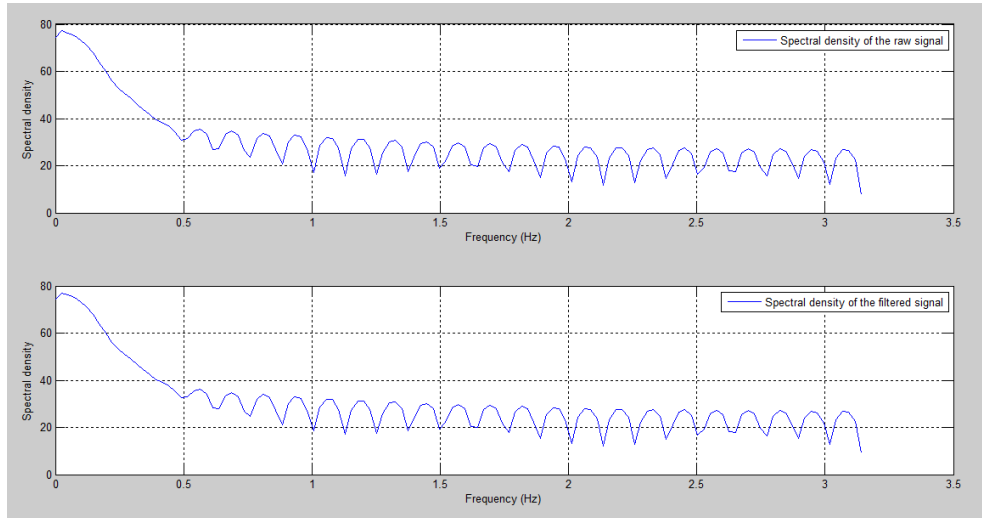


Figure 4-5. Spectral density of the raw and filtered signals at 3KHz and 2048 samples.

A distinct test was performed twice using 250hz in 1024 samples. Figure 4-5 shows a considerable filtered level in these samples. However, the waiting time for receiving the samples lasted 4.816 seconds. The system cannot be considered real-time if the waiting time lasts for more than one second.

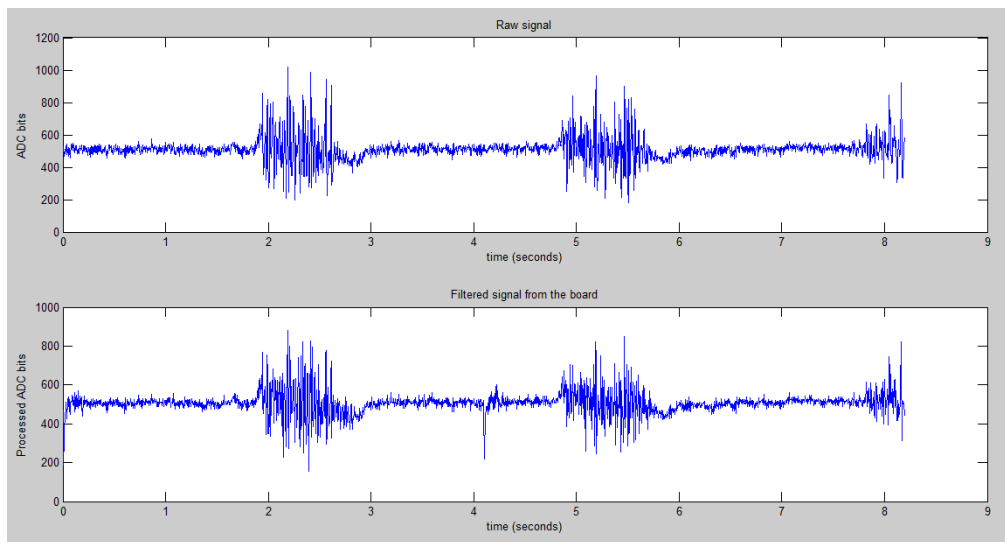
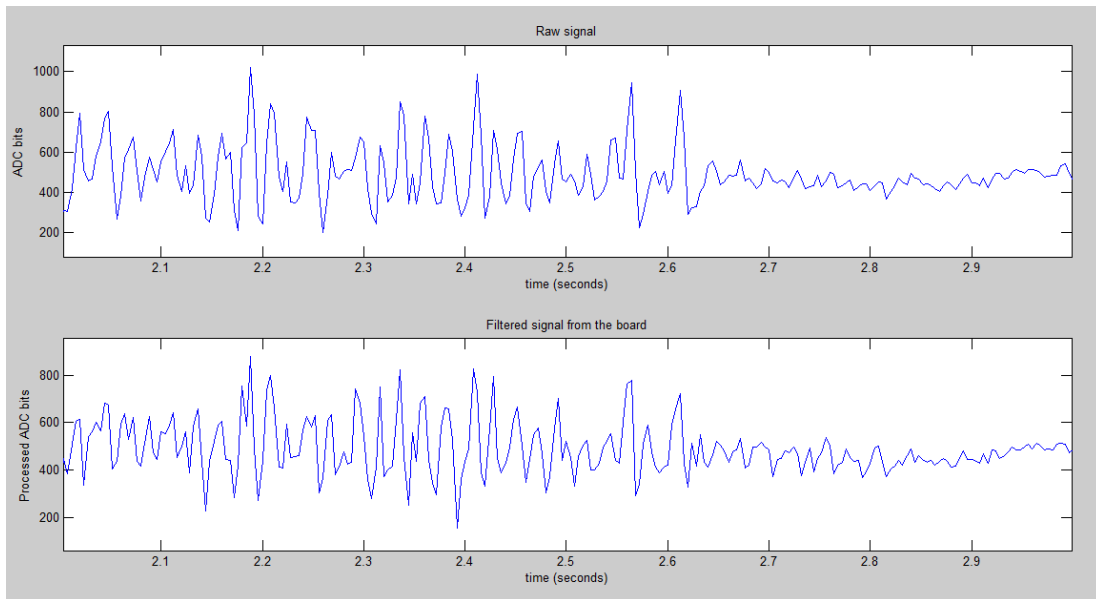


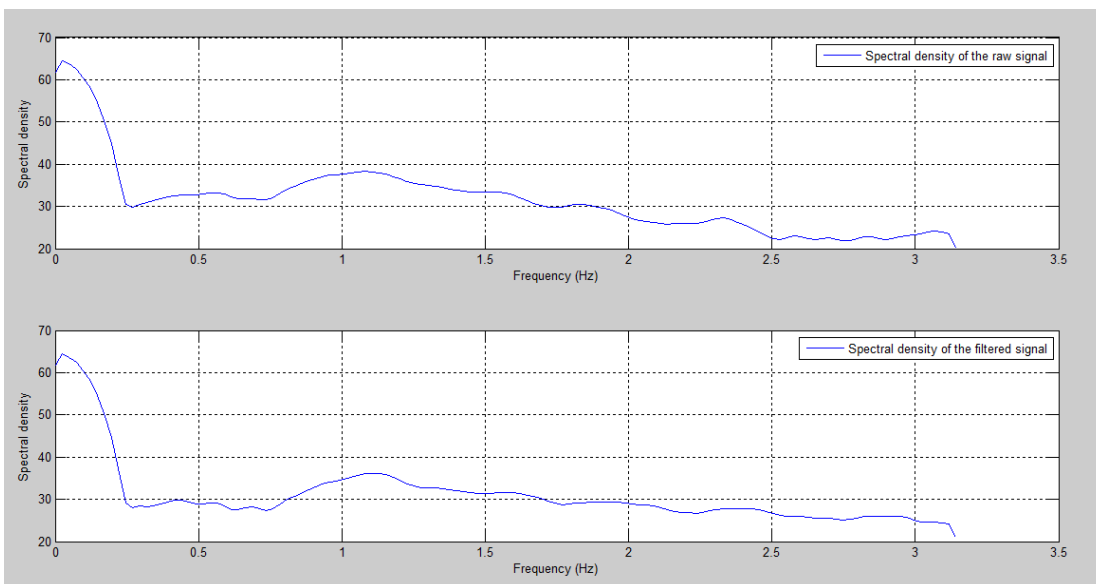
Figure 4-6. Graph of raw and filtered signals at 250hz and 1024 samples.

Figure 4-6 shows a zoom-in image of seconds 2 to 3 from the raw and the filtered signal.



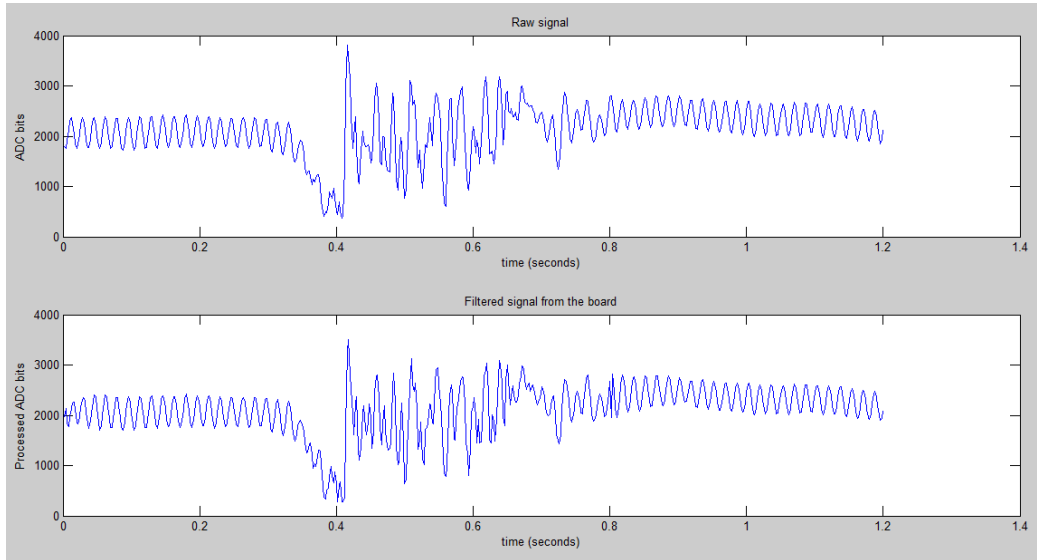
*Figure 4-7. Zoom-in image of the raw and filtered signal at 250hz.*

Figure 4-8 shows the spectral density of the raw and filtered signal of 250Hz and 1024 samples.



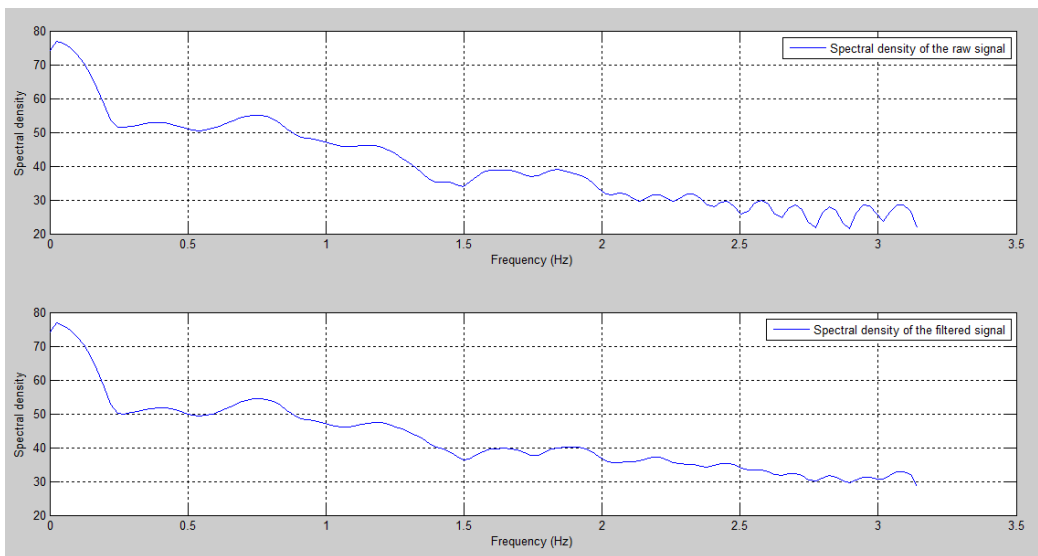
*Figure 4-8. Spectral density of the raw and filtered signal at 250Hz and 1024 samples.*

A distinct test was performed using 500Hz with 200 samples and the sampling was performed three times to get 1.2 sampling seconds. This number of samples was chosen to have 0.4 seconds for the waiting time of the signal acquisition. Figure 4-9 shows the raw and filtered signals graph.



*Figure 4-9. Raw and filtered signal at 500hz and 200 samples.*

The spectral density of the raw and filtered signal at 500 Hz and 200 samples is shown in Figure 4-10.



*Figure 4-10. Spectral density of the raw and filtered signal at 500Hz and 200 samples.*



A distinct test was performed using 250Hz with 100 samples. Figure 4-11 shows the raw and filtered signals graph.

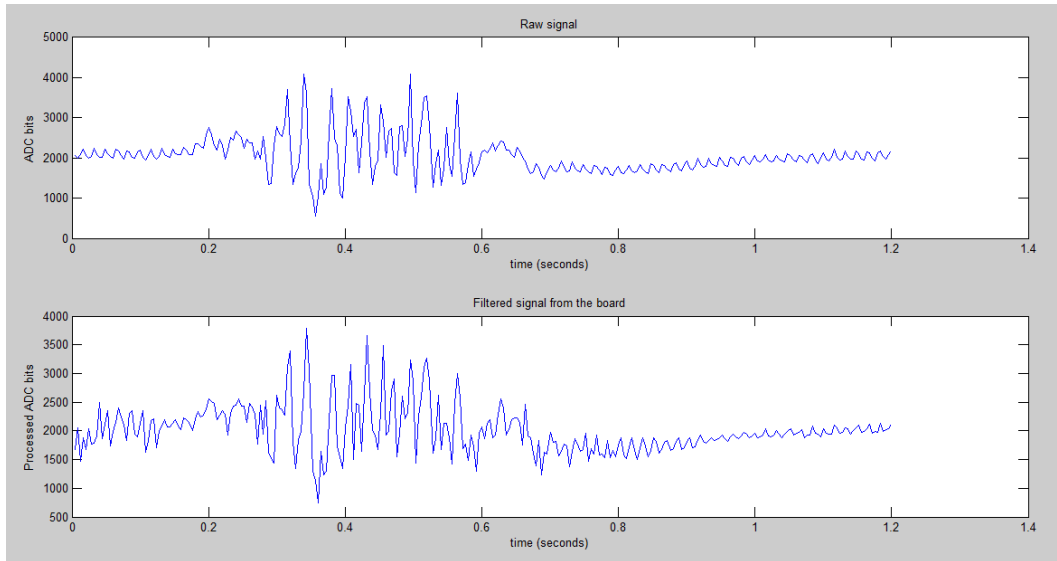


Figure 4-11. Raw and filtered signals at 250hz and 100 samples.

The spectral density of the raw and filtered signals at 250 Hz and 100 samples is shown in Figure 4-12.

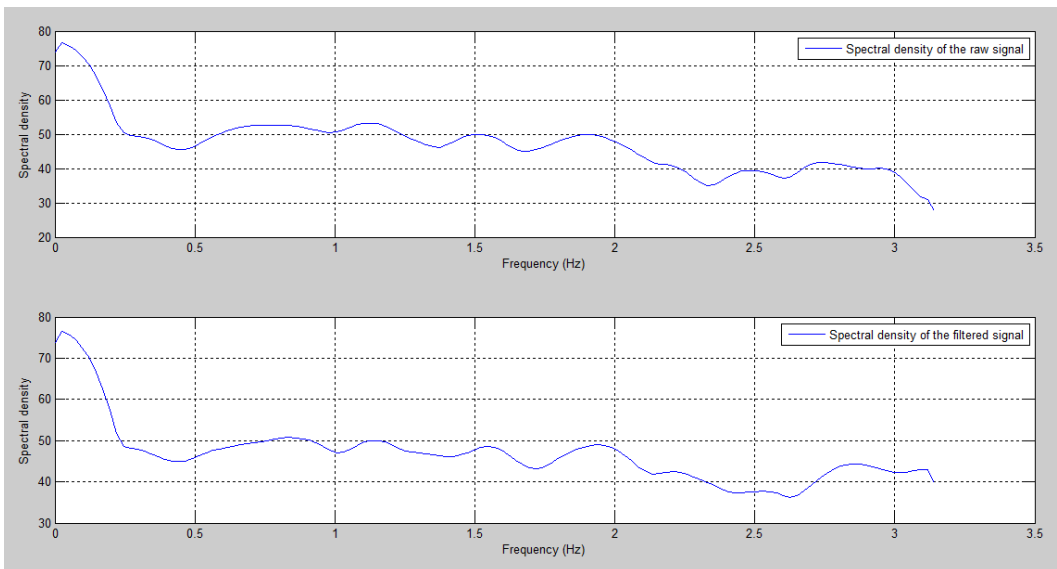


Figure 4-12. Spectral density of the raw and filtered signal at 250Hz and 100 samples.

## 5. Conclusion

The results showed that at frequencies above 1.5KHz using 2048 samples, the filtered signal remains almost the same as the raw signal. Besides, the acquisition time of the signal lasted for 1.365333 seconds, and this waiting time is not appropriate if the signal will be treated as an input to activate an output of the system, this. For frequencies below 500Hz using 300 samples or less, appreciable changes were observed between the raw and filtered signals.

Since the processing time of the Wiener filter implementation in the SAM V71 board lasted for 64ms using 2048 samples, this time is not considered to affect the system and since the samples were reduced to 200 to work with a frequency of 500Hz this time was reduced to 10ms. The critical variables were the number of samples if the working frequency was low, by comparing the results using a frequency of 250Hz with 100 samples against 500Hz with 200 samples, the configuration with 500Hz was still better.

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