Design and Development of Surface Based Active EMG Sensor for Biomedical Applications

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Declaration

I certify that this research work titled "*Design and Development of Surface Based Active EMG Sensor for Biomedical Applications"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

Hafiz Umar Aslam

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Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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In the start, I would like to thanks to Allah Subah-O-Tala for giving me a chance to do a slight contribution in the technological phase because without His grace I would not be able to complete this assigned task. This is all due to His grace and ideas that He putted in my Brain.

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Abstract

The muscle in our body plays a vital and pivotal role in performing each minor task of routine activities. The action command is generated by the brain is executed by the human organ systems including Hands, legs etc. The messages are transmitted through motor neurons. The linkage of the muscle is based on the bone along with cords also called tissues. The contraction and relaxation of the muscle also causes tension in the tendons. The contraction of the muscle is possible due to the stimulation process in which exchange of the ions across the fiber of the muscle produces a voltage difference along with current in milliamps range. When the specific area of the muscle is targeted it's called Electromyogram (EMG).

The EMG signal are related to signal generated from the muscle of the human body, this signal is being widely used in clinical testing for the detection of any disorder. The involvement of the EMG signal detection is very common in the rehab centers in which those people they have lost hands/legs. An organ of the body indeed plays a role of backbone in the lives of amputees so that to recover that sense of confidence in the amputee's artificial limbs are being developed to provide an ease in the lives of amputees. The broad classification of the EMG sensors are active and passive sensors. In the active sensor pre-amplification module is incorporated whereas, in the passive sensor only raw signal is obtained using piece of metals.

In this research, the main objective is to design and develop a low cost and better performance sensor to obtain the signal from the muscle for the clinical testing and real time applications. In the developed sensor the EMG signal is extracted using stain less steel electrode. The obtained signal is further passed through the efficient band pass filter with cutoff frequencies as 10Hz to 150Hz. Once the signal is passed through the band pass filter the external noise factor got reduced to clearly visualize the EMG spectrum on a spectrum analyzer. The stage before the band pass filter is differential amplifier in which the signal is subtracted and enhanced using the gain of the amplifier. Once the signal got free from the external noises then notch filter with high Q-factor was applied to reduce the noise factor. The resultant signal contained reduced number of noise harmonics due to the incorporation of the notch filter design.

Key Words: *Electromyogram(EMG),Artifacts, Active sensor, notch filter*

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CHAPTER 1: INTRODUCTION

In the proposed work an active sensor is developed for biomedical applications. The developed sensor is compared with the commercial sensor Z03-002 based on the multiple parameters including signal to noise ratio (SNR), Response time of the sensor (Tr) and Electrode Impedance of the sensor. The comparison of the sensors is discussed in result section of the thesis. In the domain of biomedical various researchers are putting immense efforts to increase the efficiency, signal to noise ratio and electrode impedance of the sensors to make them more comfortable for the amputees because of the long-time usage of the limbs. In this chapter various factors are discussed that impacts the performance of the sensor and related background.

1.1. Message Propagation

A muscle of the human body is the main source of movement and enables the person to perform any kind of task for example picking of glass, exercise etc. In the background of the muscle movement there is complete mechanism in the brain that executes every time when the activity is performed. A message is conveyed to the muscle through the neurons. A neuron picks the message and perform the required action based on the command given by the brain. In the entire cluster of neurons, motor neuron is responsible for the transmission of nerve messages. When muscle contracts or relaxes its length varies in a specific range, for example when muscle contracts its length decreases up to 57% of the actual length of the muscle whereas, when muscle relaxes its length increases up to 70% of the actual length [1]. A neuron, axon and other related fibers are the part of motor unit.

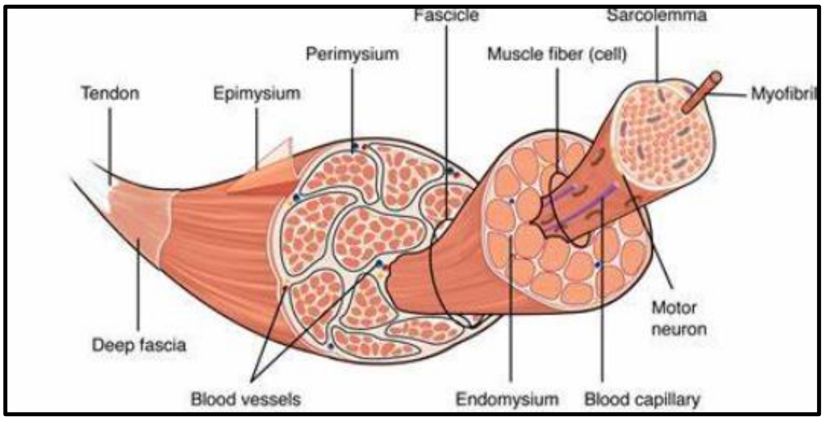

Figure 1: Representation of Fiber [1]

The conduction of the nerve messages is transmitted via motor Neurons. The structure of the entire motor unit consists of fibers through which the messages are sent to the desired muscle. The contraction of the muscle is possible due to the motor neurons that carries messages from the brain. A motor neuron is the combination of the dendrite and axon that relates to the muscle fiber. A message transmitted from the brain is carried by the motor neuron and axon of first neuron is further connected with the dendrite to propagate the message [2], as shown in Figure1.

The movement of the individual muscle depends upon the contribution of multiple motor units. A muscle fiber is linked with the all types of motor units but that is same for all the motor units. The activation of the motor unit causes the activation of the fibers, when motor units gets activated it activates the corresponding muscle units that leads to the activation of muscle fibers. There is another very important point that is called innervation. The purpose of the innervations is a point at which organ gets connected with the nerves [3].

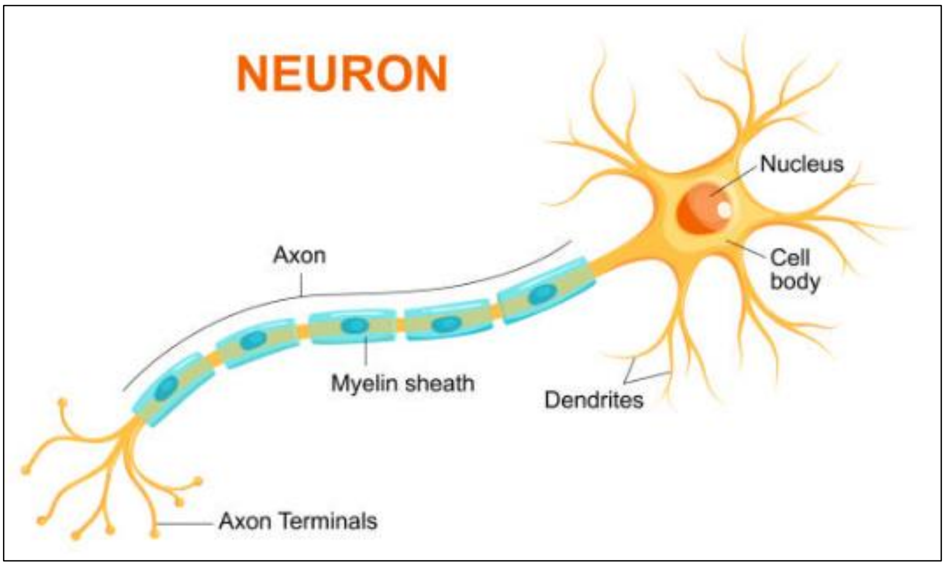

Figure 2 : Representation of Axon [3]

1.2. Signal Generation in Muscle

The exchange of the ions across the muscle fiber is the main cause of signal production because when ions gets exchange a small amount of the current gets produced. The developed potential across the ions is the main cause of action potential for a specific motor unit, it is also called as motor unit action potential [3]. In the previous section, this thing is observed that when an action potential is generated due to the contraction of the muscle it links with the specific motor unit. In the motor unit motor neurons are responsible for the addressing of specific muscle. These messages are received by the brain to produce the desired EMG signal. In the Figure 3 its clear that the raw impulses generated by each motor unit is the sum of EMG signal that is called as Electromyogram [4].

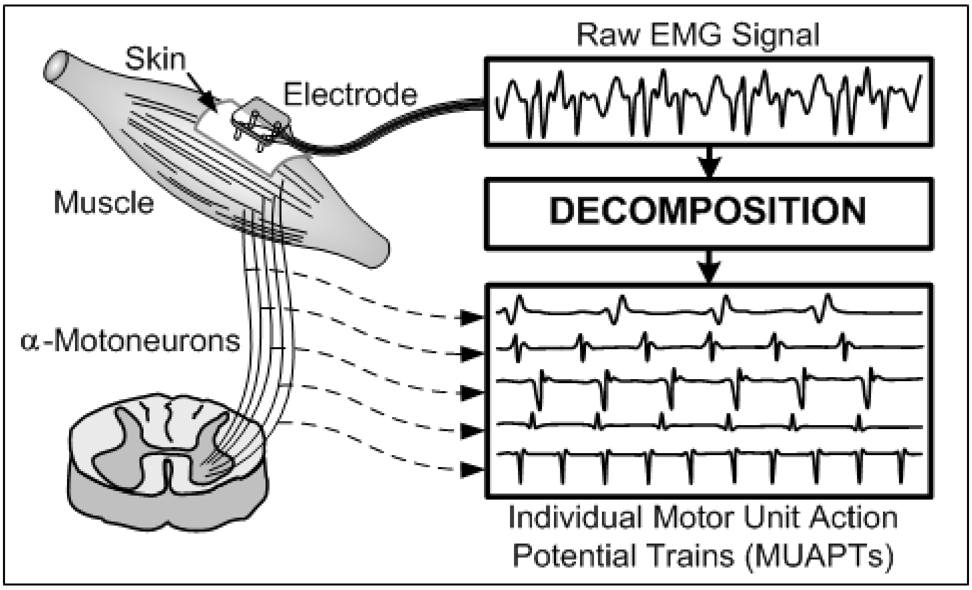

Figure 3: Individual Motor Units [4]

1.3. Functionality of Cells

When the contraction is applied on the muscle a minor magnitude of the current flows in the body that reflects that neuromuscular process is applied. The produced signal is called as the biomedical signal that can be obtained through the activity of any muscle for instance heart muscles or Biceps etc. The human body consist of the various types of the issues to support muscle system of the body.

In the produced biomedical signal, the amount of the force determines the activation of the motor units. The entire composition of the muscle can now be expressed based on muscle to tissues linkages and then tissues to the cell linkage in which the entire tissue is composed of the multiple cells. There are three common types of the cells containing Na+, k+ and Ca+ and Cl-, in these cells the important factor is the concentration of the cells that means no of the different cells in each tissue because the unbalancing of the cell causes other impacts. When the muscle is at rest or in other words when no contraction is performed the magnitude of the potassium inside the cell is higher than the magnitude of the sodium ions outside the cell. The exchange of the ions inside the cells causes the polarization curve. The entire structure of the cell is based on the ions that moves inside and outside the cell. There are protein channels inside the cell through which the ions move inside and outside the cell. The reason for these channels is to generate voltage difference across the membrane.

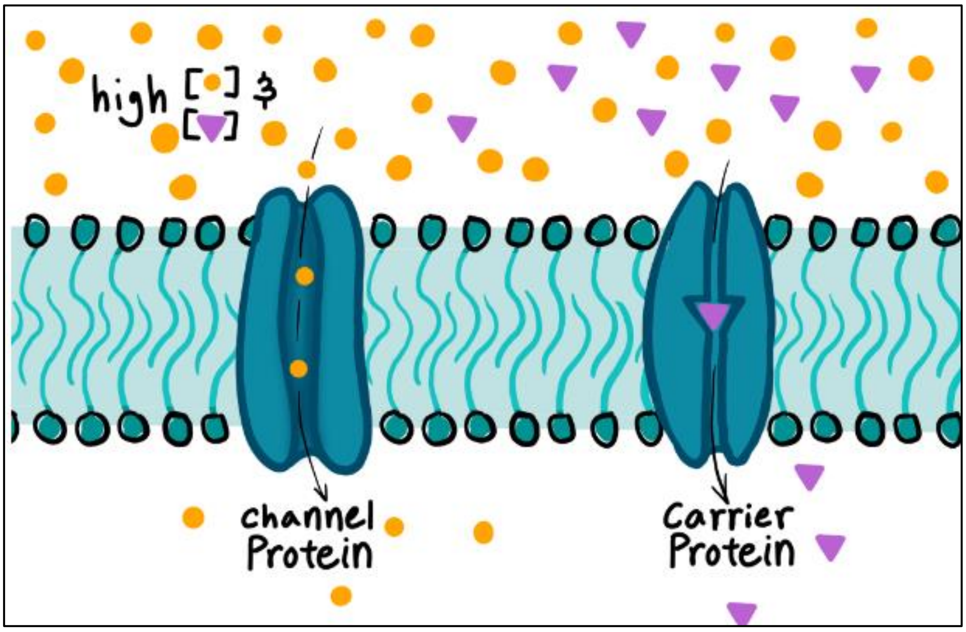

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Figure 4: Structure of Cell [4]

The flow of the sodium ions inside the cells is the main source of the production of the electric current inside the muscle. There are two main types of the transports named as active transport and passive transport.

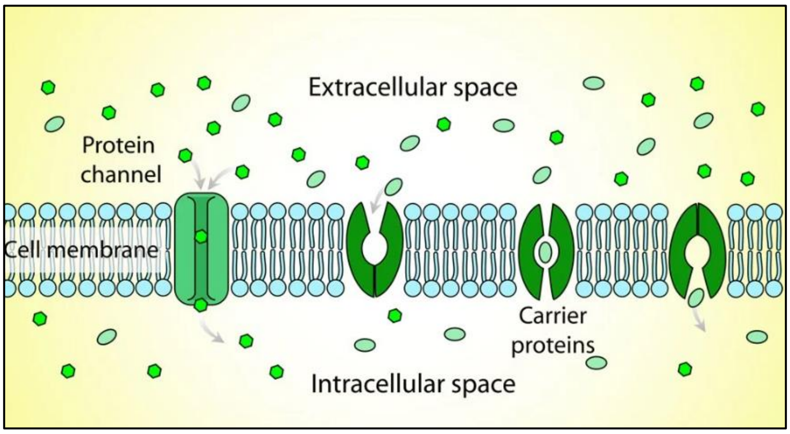

Figure 5 : Active Transport [5]

In this passive transport the movement of the molecules from higher concentration to the lower concentration happens across the cell membrane that is best example of the diffusion whereas in the active transport an opposite process occurs that is movement of the molecules from low to high concentration, but it required some amount of the energy.

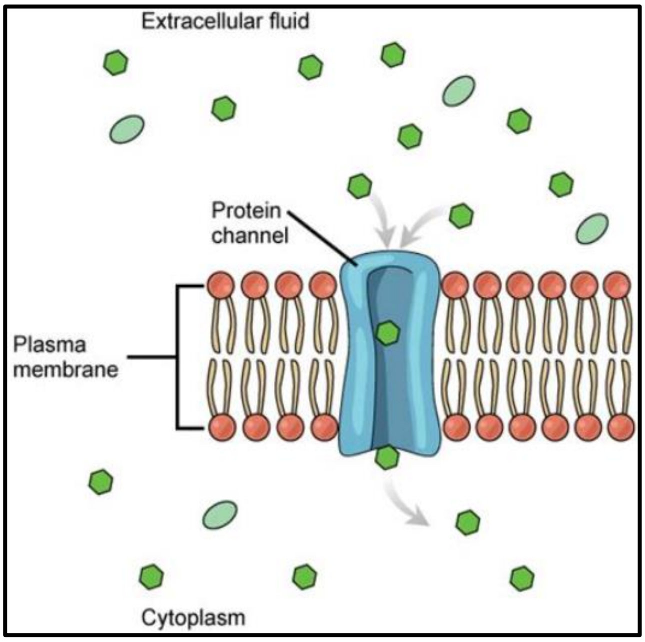

Figure 6: Protein Channel [6]

The process of the active transport required energy in the form ATP to displace the molecules from lower concertation to the Higher concertation, in this process an active sodium potassium pump is used. When the muscle is at rest stage means no activity is being performed the number of the K+ ions are higher in number inside the cell and tries to maintain the Na+ less in numbers inside the cell but as the concertation rate of the K+ is 100 times more as compared to the Na+ that's why number of K+ increases inside the cell and Na+ decreases inside the cell and same process happens in reverse at outer side of the cell. In the rest state of the cell the number of the K+ ions are increased inside the cell because when sodium potassium works it takes 2K+ inside the cell and leaves 3Na+ outside the cell.

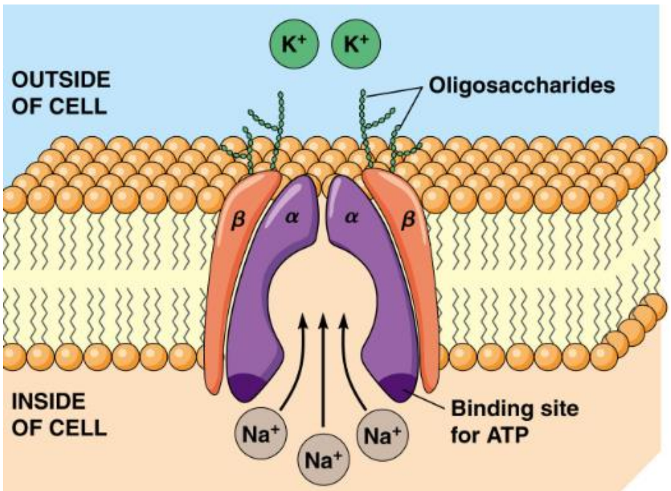

Figure 7 : Sodium Potassium Pump Working [6]

1.4. Types of Muscles

A muscular movement is essential for the performance of the various tasks for instance picking and lifting the things from one point to another point. There are multiple types of the muscles for example Sooth Muscle, Cardiac Muscle and skeletal muscles. The mentioned types are the main division of the muscles and there are around 600 muscles in our body. The movement of the muscle restricts the joint to go beyond a specific point. The type of each muscle is explained in in the next section of the document.

1.4.1. Voluntary muscles

In the first type of the muscle skeletal muscle is focused, this muscle is also known as the voluntary muscles because the movement of these muscles is entirely control by the human beings. The best example of these muscle includes movement of the arm, hand or leg etc. When the human wants to move these muscles, they can move it, but this is not true for the other types of the muscles. In human body there are approximately 640 muscles, but the interesting thing lies in the pair of these muscles as all of them lies in the form of bilateral muscles. In other words, there are 320 muscles that are voluntary controlled by the human body. The movement of these muscles is also very interesting because as these muscle lies in the form of bilateral so that when one opens other contracts at the same time.

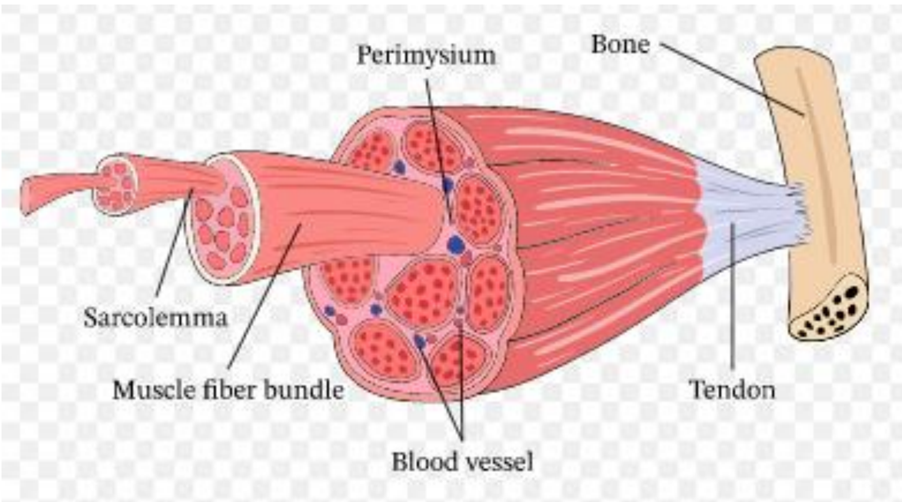

Figure 8: Voluntary Muscle [7]

1.4.2. Involuntary muscles

There is another type of the muscle in our body that is called as the involuntary muscles, the mean of involuntary resides in the unintentional control of the muscle. The best examples of these muscles include stomach, Heart and intestine, there are so many other muscles are also present in our body but common of the them are highlighted.

This type of the muscle can normally be observed inside the walls of the organs, these muscles has the capability to stay stretched for a longer period of the time. The activities associated with the muscle are called as the muscular activities, our stomach and intestine perform their function entire day without any pause inside them.

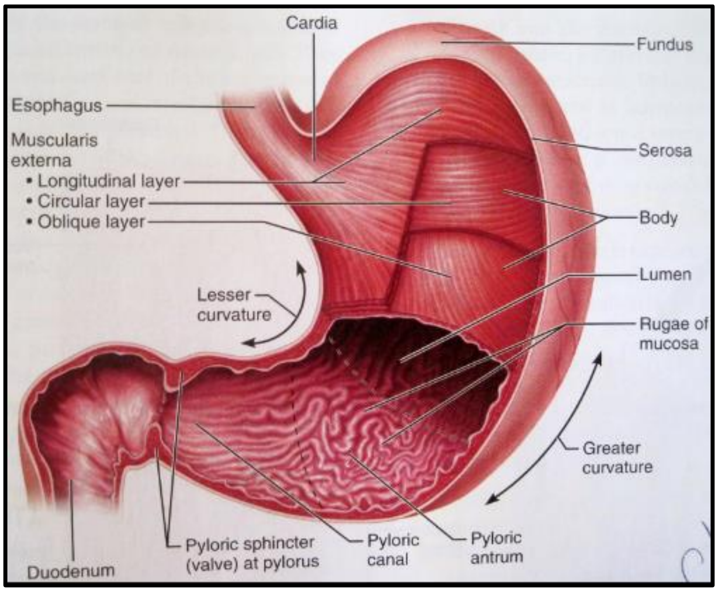

Figure 9: Uncontrolled Muscles [8]

1.4.3. Cardiac Muscles

The word itself represent that those type of the muscle that are related to the heart are called as the cardiac muscles. The structure of the cardiac muscles is similar like the skeletal muscles that are explained in the first type of the muscle. The location of these muscle is the heart of the subject, in this muscle there are two unique features can be observed. The first one is that when the muscle contracts it gets hard and when it releases the stiffness it becomes soft. The stretching or hardness of the muscle is similar like the skeletal muscle. The main purpose of the heart is to provide the blood to the whole body and that’s why it is also called as the pump inside body. The pumping power of the heart is very high so that we can sense the heart beat through simply placing the palm on to the location of the heart. There are various ways that are being used to take the ECG and to analyze it at the clinical level.

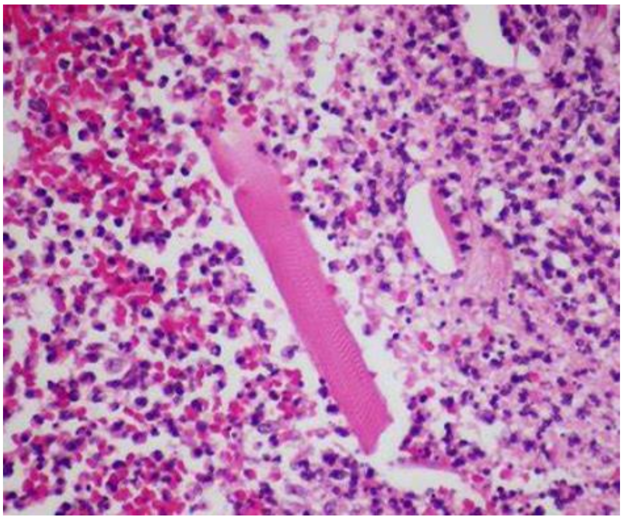

Figure 10:Cross-Striations [9]

1.5. Action Potential (AP)

The generation of the electric signal due to the exchange of ions across the membrane is called Electromyography and this signal is called as the myoelectric signal. The purpose of this signal is to facilitate the amputees in their routine task's performance. In the above section it seen that there are three main types of the muscles in human body. The myoelectric signal is based on the movement of the skeletal muscle or in other words those muscle that are controlled by the voluntary control of the muscle. A muscle is based on the muscle fibers in which each fiber length is approximate 30cm with diameter of 100micoremeters, if the muscle fiber is further zoomed then this can be observed that it has microfibrils which are filled with proteins. The conduction of the messages is based on the nerve impulses in which messages are generated from the brain and through the neuron transmitted to the desired muscle. In the human body there are motor units in which motor neurons are present. The terminal of the motor neuron is aligned in such a way it shifts the messages from one neuron to other neuron called motor neuron. When the contraction is applied to the muscle the protein interacts and then muscle contracts. In the contracted state the length of the muscle is around 57% as compared to the normal length whereas when the relaxation is applied the length of the muscle increases around 70% as compared to the normal value. When the stimulus is given to the cell membrane the polarization inside the cell occurs because of the movement of the ions. When a specific voltage level exceeds to a threshold value then channel for the Na+ becomes open and allows the Na+ ions to enter the cell. As the Na+ enters the cell then inside the cell it becomes positive and outside the cell it becomes negative. Hence a time reaches at which the net charge become positive inside the cell called the depolarization state [5].

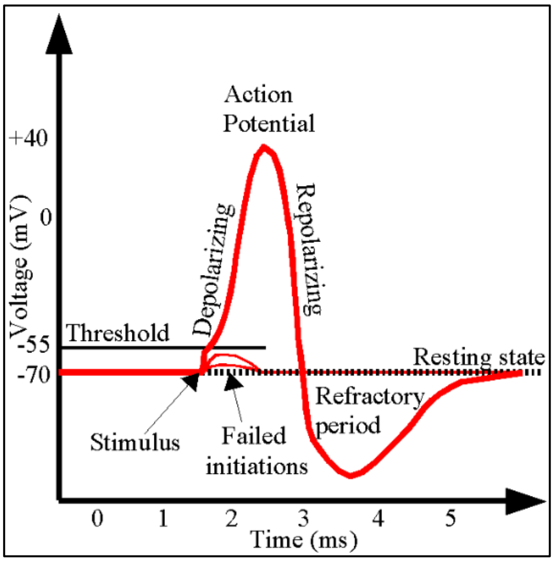

Figure 11: Generation of Potential [10]

In this process after the both gates open then sodium potassium pump starts its working to maintain the negative voltage across the cell at this phase it is called as the repolarization phase with -55mV across the cell membrane. The above represented process takes around 1milisecond for the brain to muscle and takes 300millisecond for heart for this process. The variation in the magnitude of the voltage across the cell membrane is called as the generation of the action potential.

1.6. EMG signal

An EMG signal is the representation of the electrical activity inside the muslce that can bse sensed through the sensor. The genration of the this signal is not smootgh becaue of the a lot of external factors on it. The main source of the external factor includes noises and power line interference. When the muscle is contracted the analysis of the time domain signal is shown in the figure11 in which it can be seen that there are multiple peaks other then the actual signal. The main types of the noises are ambient noise that produces due to the power line interference, artifacts, movement of the electrode placmenent and instavblity of the signal due to the settling time of the signal[6,7]. The magnitude of the voltage acquried from the EMG signal has a defined range of 1 to 10mV[6]. In the time domain of the EMG signal or in spectrum of the EMG signal this can be seen that there are a lot of amplitude components that are present in the signal. The frequency assosiated with the EMG signal has a range of 0 to 500Hz[8] but the main specturm of the signal at a specific frequency. The important thing in the EMG signal is to remove all the assosiated frequecnies with the signal. In the EMG signal there are multiple types of the noises that reduces the signal to noise ratio of the signal. The commonly assosiated noise has low frequency and high frequency components. The niose that comes from the line lies at 50Hz/60Hz whereas, the ambient noise lies in the range of 0 to 20Hz[6]. The visuallization and detecion of the EMG signal can be done perfectly when these noises would be removed from the main signal. The frequency components of the EMG signal is unstable due to the unstabllity of the motor units[6]. The raw data of the EMG signal is shown in the below Figures.

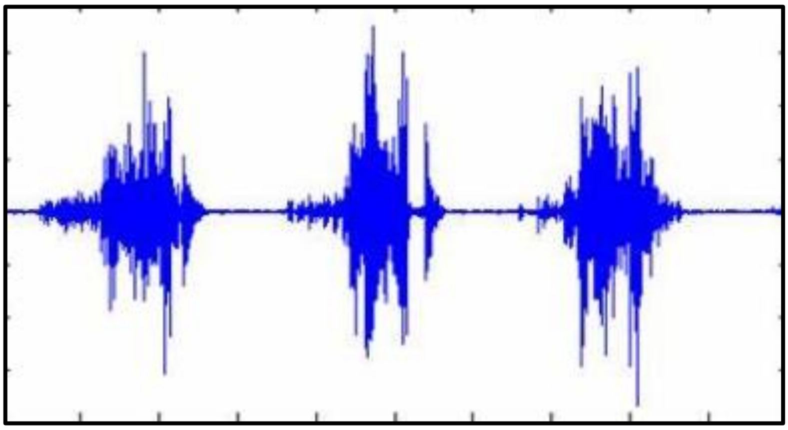

Figure 12: Raw EMG Signal [11]

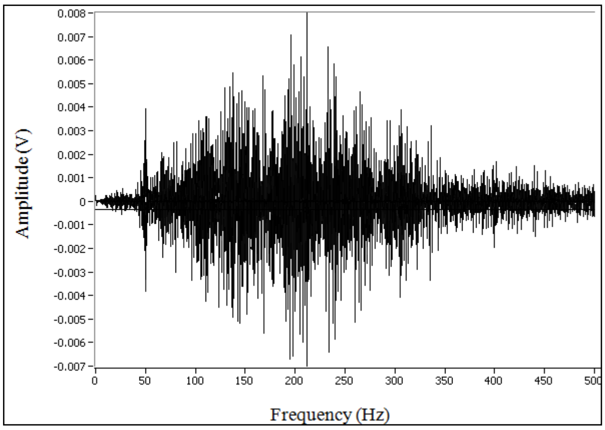

Figure 13: Meaningful Frequency Region [11]

1.7. Detection of Signal using Electrodes

The detection of the signal is required using developing of electrical contact with the skin, as the produced current needed to be amplified. The required task can be done using the piece of metals called electrodes. The purpose of the electrode is to convert ionic current (current produced due to ions) into the electronic current. The selection of the electrode is very important for the detection of the smooth EMG signal through our body.

1.7.1. Types of Electrodes

There are two main types of the electrode that can be used to convert the ionic current into the electric current for the signal conditioning circuit [9].

1. Invasive Electrode
2. Non-Invasive Electrodes

1.7.1.1. Invasive Electrodes

The acquisition of the signal through the body is the main requirement to make any system dependent on the signal because of the control on any prosthetic hand or limb. In the invasive based approach, a needle is inserted into the muscle under the supervision of the expert Doctors and professionals [3] for the acquisition of the signal/data. The insertion of the needle-based electrode produces slight pain in the arm of the amputee. When the recording of the EMG data is obtained the needle of the electrode retracts by displacing the needle few millimeters.

1.7.1.2. Types of Needle Electrodes

The division of the needle electrode is done into two types [9], the first one is the concentric and the other one is the monopolar electrode. These both designs are being used widely since their introduction. The properties of the both designs are different and unique to each other based on the functionality. Now a days, monopolar needles are being used very commonly among the other type of the electrodes. The material selection for the monopolar electrode is stainless steel with a gauge ranging of 26 to 31. The acrylic coating is applied on the needle of the electrode that acts as an insulator. The first coating of the needle is acrylic coating whereas there is another coating is applied on the needle called medical silicone to enhance the penetration and decrease the pain of the patient. The interesting phenomena of the monopolar based electrode is that it directly reaches to the area of interest, whereas, the magnitude of the activity is solely dependent on the area of the needle that is responsible for the conduction of the current. A reference electrode is used to get a voltage level of 0V that can act as the base line for the signal.

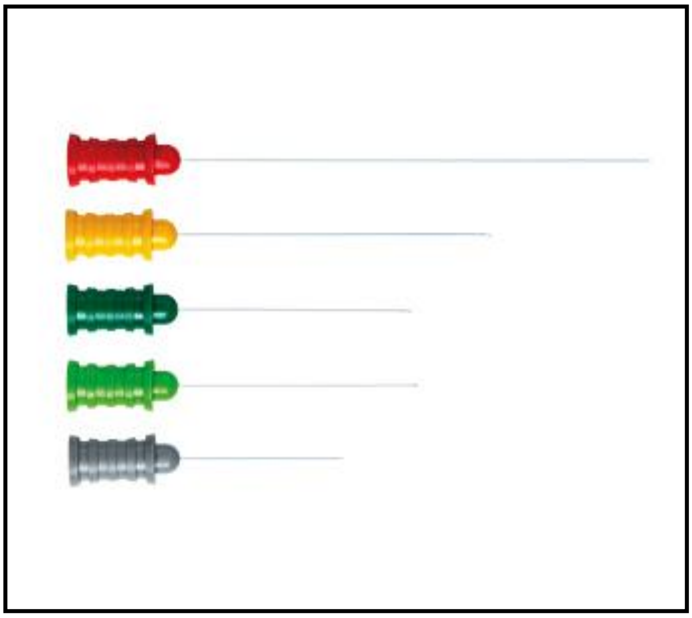

Figure 14:Monopolar Electrode Representation [11]

The other type of the electrode is the concentric electrode that is based on the cannula along with a core. As to get a signal there are two electrodes are needed, the core acts as the active electrode and cannula act as the reference electrode. The material type for the both electrodes is different in nature. The diameter of the canula lies in the range of 0.45 to 0.7mm whereas the core has a diameter of 0.1mm. The main function of the core is to get the signal whereas the main purpose of the cannula is to provide the reference for the signal. The out diameter of the core is mm. In this type of the electrode, the core is buried in the insulating material so that the connection between these both electrodes is electrically insulated. The shape of the electrode is elliptical that goes from 15° to 0°. The material selection for the concentric needle is stainless steel because of the biocompatibility. The significance of this electrode is that it acquires the signal from a specific point whereas this specific acquisition is not possible in the monopolar electrode.

The signal acquired from the concentric electrode has a good strength [9] because of the acquisition of the signal from specific point. The nip for the needle-based electrode is very sharp that’s why it takes lesser area for the picking of the signal.

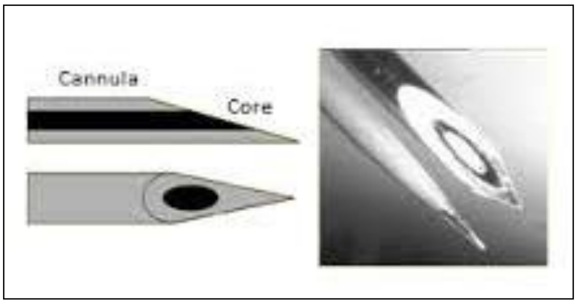

Figure 15:Concentric needle electrode [12]

1.7.2. Fine Wire Electrode

The comfort level of the patient is very important because of the insertion process inside the muscle. There is one more type of the electrode that is being used these days in order to get the signal from the muscle called fine wire electrode. The purpose of this electrode is to provide comfort level to the patient. The composition of this electrode based on the silver and platinum along with this wire electrode can easily be removed and inserted [13]. This electrode is suitable for many biomedical based processes.

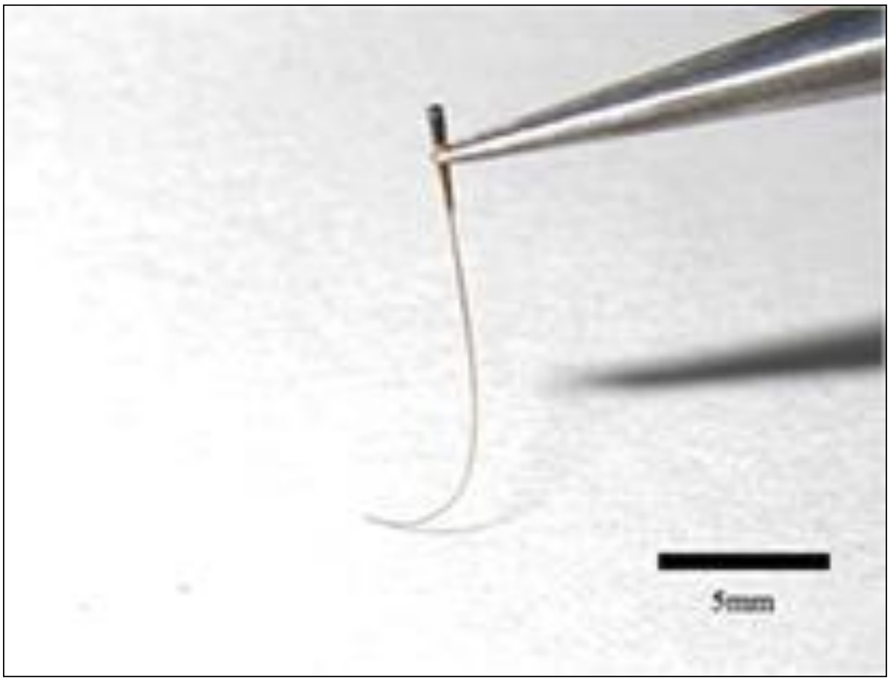

Figure 16: Wire Based Electrode [13]

1.7.3. Surface Based Electrodes

The surface-based electrodes are widely used to acquire the signal through the muscle of the subject. There are a lot of reasons due to which these electrodes are preferred for the acquisition of the data. The surface-based electrodes technique is simply based on the placement of the sensor on to the belly of the muscle to acquire the signal through the muscle. In the older times the acquisition of the signal was done through the saline solution in which the subject had to put the hand or leg inside it to acquire the signal and to observe the signal for the clinical testing but there are a lot of issues that were related with this process. The discovery of the surface-based electrode not only reduced the motion artifacts along with this it also produced a comfort level to the patient is that it simply picked the signal with the help of few wires and there is no need to put the hand inside the gel-based electrolyte or anything else. The surface-based electrodes are simply dependent on the contact of the skin with the metal to get the good quality signal. Once the problem of these surface-based electrodes introduced then there is alternative electrode work presented that that is called as floating electrode the problem in the surface-based electrode resides in the movement of the sensor due to which noise produced in the visualization of the signal. This problem was solved using the floating base electrode in with gel to gel contact was there that was stick with the skin of the subject to reduce the motion of the sensor and to produce a stable signal for the visualization. As far as types of the electrodes are concerned there are two major types of the electrodes that are being used the first is called gel-based electrodes in which a gel is located inside the contact with skin. The purpose is to provide a good contact with the skin to minimize the motion artifacts and to produce a good quality signal. On the other hand, a dry EMG electrode are being used that are perfect for the reusability because in the gel-based electrodes the reusability factor is very less because once the gel is used it can be used till the time when it does not get dry. The types of the skin-based electrodes are shown in the Figure16 in which this can be seen that the contact of the skin with the electrode is created through a gel that's why the gel plays a vital role in the detection of the signal in the skin-based electrodes.

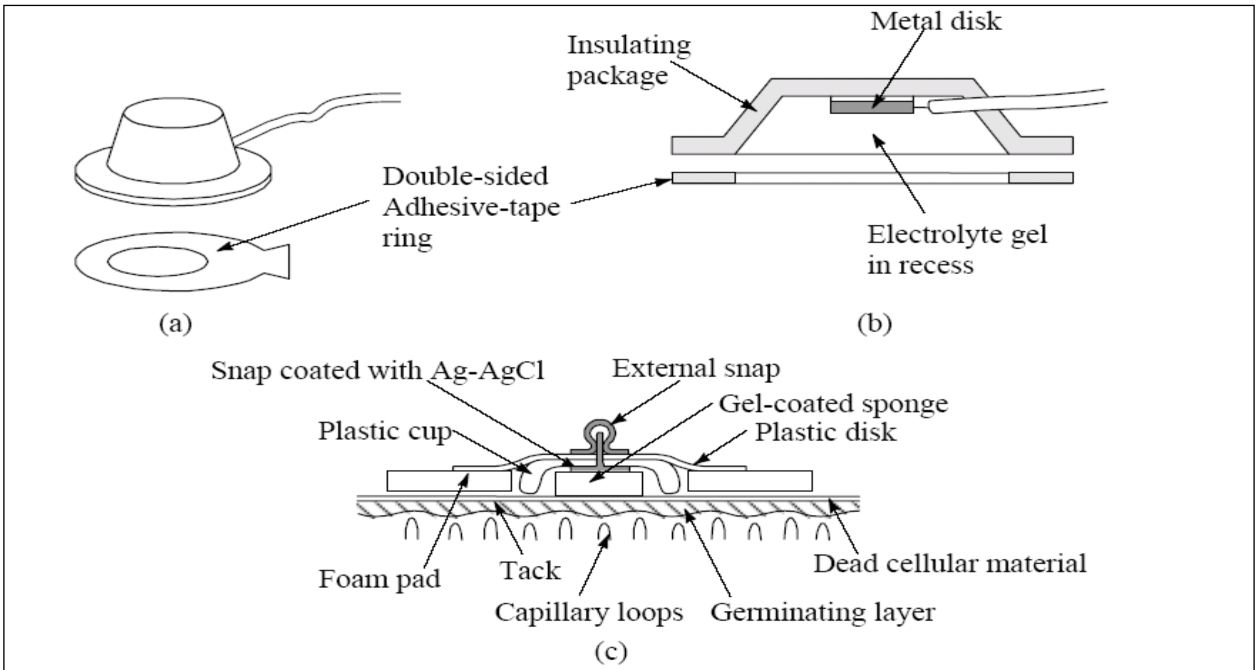

Figure 17: a) Floating electrode, b) Cross-sectional view, c) Disposable Electrode [14]

In the gel-based electrodes we have seen that there are so many factors that are associated to acquire a good quality signal for the processing. There is another type of the electrode that is called as a dry electrode in which there is no need to put the gel on skin in order to acquire the signal but as far as the dry electrode is concerned the best thing in the dry electrode is that it can directly be mounted on the surface of the skin along with the preparation of the skin is required. In the dry electrodes the motion artifacts are relatively reduced [10] because of the conduction of the metal along with the adjustment of the sensor whereas in the Gel-based electrodes there was a limitation to use a sensor again and again. There is another question that is related to the dry electrode is that how it can be adjusted with the skin the best answer to this is that it can be used using the suction technique through which it can be mounted on the skin. The internal mechanism of the dry electrode receives in the metal reaction in which we can observe the half-cell potential, it is nothing, but it simply represents the metals reaction with other metals and its corresponding voltages that are produced. As this is entirely related to the metals that's why it is important to notice that what half-cell potential associated to each metal is different. In the given table when the aluminum it produced three electrons along with the half-cell potential in the negative value. Through this the half-cell potential for the mercury is 0.79 whereas for the hydrogen is 0.00.

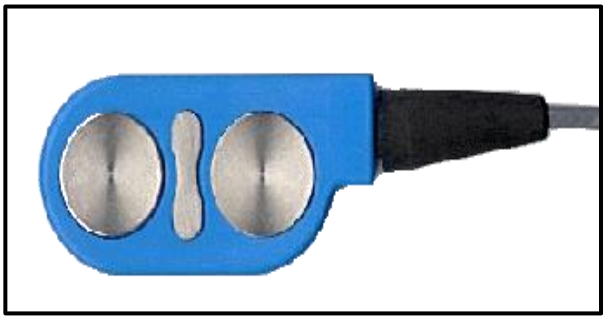

Figure 18: Dry Electrode [15]

Table 1: Half Cell Potential for Metals

Metal and Reaction	Half-cell Potential, V
$Al \rightarrow Al^{3+} + 3e^-$	−1.706
$Ni \rightarrow Ni^{2+} + 2e^-$	−0.230
$H_2 \rightarrow 2H^+ + 2e^-$	0.000 (by definition)
$Ag + Cl^- \rightarrow AgCl + e^-$	+0.223
$Ag \rightarrow Ag^+ + e^-$	+0.799
$Au \rightarrow Au^+ + e^-$	+1.680

1.8. Advantages of Electromyography

- EMG process is used to evaluate the strength of the muscle
- It helps to detect the abnormalities' through clinical testing.
- EMG signal are useful for the stroke patients
- EMG signals are useful for the control of actuators
- EMG signals are helpful in ergonomic studies

1.9. Utilization of EMG

There is a vast use of the EMG signals in towards the biomedical applications where the data of the subject is required. The EMG data can be used for the human machine interface along with other a lot of applications where the motion based on the signal is desired [13]. In the entire physiological studies, the EMG signal are considered as the back bone in the rehabilitation centers and other research areas [13]. The reason for the EMG signal resides in the assessment of the muscle based on the output acquired from the subject for posture analysis [14]. In many accidents the subject lost their hands, this EMG data can be used to replace their hands with artificial limbs to perform routine tasks. The purpose of the EMG is not only to get the signal but is also being used in many sports to evaluate the strength of the muscle and this data can be used to train accordingly. The major utilization these days are performed in the Gait libraries that are using it as a tool in the ergonomic assessment [15].

1.10. Conclusion

In this chapter the Entire discussion of the signal acquisition from the base of the muscle to the end terminal is discussed and the major outcomes are extracted. The outcome reflects that the electromyography is the very important process through which the analysis of the signal can be carried out to visualize the strength of the signal and for the diagnosis. In this chapter it is also discussed that there are a lot of other factors that impacts the output performance of the sensor for instance signal to noise ratio, response time and type of the electrode. The activation of the motor units along with the force applied for the contraction of the muscle. The analysis procedure for the EMG is also discussed in this section in which multiple motor units are responsible to provide an action potential through with the polarization and depolarization that can be observed.

CHAPTER 2: LITERATURE REVIEW

This chapter is based on the conduction of the literature review to acquire an idea about ongoing research in the field. In the recent years there has been a lot of work done to enhance the set points for the better detection of the signal and suppression of the noise signal. In this domain the important focus is to study the electrical signal that is generated through the muscle [13] for the acquisition of the data and visualization of it on the scope or processing through the controller. In this chapter the entire work done by the researchers is summarized for the better understanding of the proposed work.

The origin of the muscle generation is based on the exchange of the ions across cell membrane. The author Carlo J De Luca [1] studied that the origination of the muscle is based on the motor neurons that are responsible to conduct the nerve message to desired positions but there are so many noise factors that impacts the output of the signal and makes it noisy for the reading. In the result of a poor signal a false information can be intercepted. The power of the electronics is focused to the removal of the unwanted signal from the actual signal to get a better signal for the visualization. The removal of these noises is major concern for the proper detection of the signal. The data is acquired from the sensor and then passed through the high pass filter with selected cutoff frequencies of 1 to 30Hz in order to reduce the noise at low frequencies at a slew rate of 12db/octave. The author proposed that major power spectrum lies between the 20 to 200Hz because these low frequency signals contributes in the actual signal and produce the false information about the input signal. The experimentation revealed that the appropriate corner frequency for the signal is 20Hz.

Jingpeng Wang et al. [4] presented the electronics approach for the detection of the signal and to remove the associated frequencies with the signal. In this proposed work High and low pass filter are utilized based on the sallen key low pass filter to reduce the noise contents from the main signal with 2nd order and 4th order filters. The result shows that when the signal as passed through the 2nd order filter with cutoff frequency of 20Hz the roll off of the circuit 12db/octave where for the 4th order filter the roll off was 24db/octave. In this approach instrumentation amplifier was used to take the differential signal and then passed through the filtering stages, after passing through the filtering stages the sampling rate pf 500 to 40000Hz was applied to convert the analog signal into the digital signal. The effect of aliasing was absent with second order filter and for the 4th order filter high aliasing effect was observed after multiple attempts the Nyquist criteria was applied to avoid aliasing effect, after doing multiple attempts it was observed at 2000Hz sampling rate the aliasing effect was eliminated.

Pascal Leterrier et al. [5] proposed that due to the contraction of the muscle an electrical signal is generated with multiple noises contaminated with the actual signal. In this study it is shown that Ag/Agcl based electrode are used to detect the electrical activity inside the muscle but due to the limitation of the reusability factor the same electrode can't be used again and again. On the other hand, dry electrodes are considered better for the acquisition of the data monitoring but due to long use preparation of the skin is required in it to make a proper contact with the electrodes. The purpose of skin preparation is to remove the dead tissues from the surface of the skin and make the skin fresh for the provision of better signal. In this study, impact on the signal using different types of the electrodes are discussed and concluded that dry electrodes are better with skin preparation.

Carlo J. De Luca [6] discussed the main parameters associated with the EMG signal and their impact on the main output signal. The propped work is again based on the electronic side with signal conditioning circuit to suppress the external noises present in the actual signal. The first step was to acquire the signal from both point with a common reference terminal for the provision of the reference to the signals. The functionality of differential amplifier is to take the subtract the signal from another signal and amplify the signal only, the CMRR is used to remove the offset from the output signal and to completely subtract the signal from other signal. The suppression of the external noises is possible with CMRR of 90db along with High impedance in mega ohms. The purpose of the high input impedance was to reduce the loading effect with maximum voltage drop across the load. In this study specific parameters are discussed that are best for the detection of the EMG signal with maximum strength in the light of material selection. The SNR of the signal can be increased by applying band pass filter stage with band of 20 – 500Hz with roll off of the 12db/octave. This is also shown that silver electrode with 1cm interspacing is the best option for the detection of EMG signal with electrode dimension each of 1cm length and 1mm diameter.

M.B.I. Raez et al. [7] highlighted the muscle and nerve control of the EMG signal based on the different types of classification methods. The physiological measurement has been a vital role in the detection of the EMG signal and to detect the diseases. The most important parameter in the determination of the disorder lies in the firing of motor unit action potential and shape of them. In the domain of physiological measurements, a lot of work has been done in which mathematical modeling and its better detection is subjected. In this field machine learning is also playing its role for the training of the system and its evaluation under performed learning of the system.

Carlo De Luca [9] elaborated the factors effecting the EMG signals for instance causative, intermediate and deterministic. The main focus of his study is based on the factors that impacts the strength of the EMG signal along with invasive, non-invasive processes. In this paper signal conditioning techniques are also highlighted including averaging of the signal, rectification of the signal and power spectrum of the EMG signals.

Yu Mike Chi et al. [10] discussed the significance and usage of the dry electrodes with noncontact electrodes for the clinical testing. The mobile usage of the Ag/AgCl are good for the long-term use but not good for the repeatedly usage. In this paper skin-electrode junction impedance is also discussed and compared with the gel free electrodes, along with these methodologies are defined to reduce the skin impedance of the subject.

A Searle and L Kirkup [12] described the performance of the electrodes based on quantitative analysis, the electrode includes dry, wet and insulating type electrodes. In this paper the focus is developed is to highlight the types of the noises associated with the actual signal, this includes motion artifacts, static interference and impedance analysis. In order to perform the desired analysis experimentation was carried out in order to find the effect of each parameter on each sensor. The physical conditions were kept same while experimentation. In this experimentation, the performance of the dry electrode was comparatively better than the other two types of electrodes. In the start of the experimentation the motion artifacts were considered higher for the dry and insulating electrode but in the end of the experimentation the impact of motion artifacts for the dry electrode was lesser and for the wet electrode it was higher. In this experimentation the interference of the signal was also measured that was 40dB for the dry electrode.

Peter Konrad [13] showed in his studies about the utilization of the EMG signals in the field of the rehabilitation and ergonomics. In this manual the entire detail regarding the production of the EMG signal from the base of the muscle to the end terminal is highlighted. In this manual different type of the methods are also focused.

Raisy C D et al. [15] showed his studies in the similar domain but the acquisition of the signal was carried out from the neck instead of the biceps or triceps. In this study the signal was taken from the neck and then it was processed through the MATLAB. In this entire work the signal was processed through the MATLAB in order to increase the SNR of the signal.

Maged S. Al-Quraishi et al. [16] performed the experimentation on the ankle joint movement in order to acquire the signal from the four channels. The sampling rate for the EMG signal was taken as the 2000Hz and LabVIEW interface was used to display and store the data of the recorded signal. In this work the mean algorithm was used to find the mean value in the signal to observe the spectrum of the signal.

Rubana H. Chowdhury et al. [17] conducted the research on two major areas that are preprocessing that was used to filter out all the unwanted signal from the main signal and to make it free from all the types of the noises. In the second studies the focus is kept on the various types of the methods that are being used to acquire the EMG signal from the muscle. The summary of this paper is based on the advance developments in the field of the EMG signals. In this paper it is shown that a wavelet basic function has a lot of benefits because of the consistent derivatives and results in the suppression of the unwanted signals. In this paper the author evaluated that the usage of the long length filters produces the better energy concentration and for the more better results dB function is recommended with order of 4.

A.N. Norali et al. [18] reviewed the work regarding the EMG and speech processing in order to find out the suitable signal conditioning circuitry for the removal of noises from the signal. In this study it is shown that mean average value and root mean square value is the appropriate techniques to measure the strength of the EMG signal. In this study the impact and visualization of the signal through the spectrum analyzer is also carried out for the measurement of the signal.

Carlo J. DeLuca et al. [19] investigated the impact of the inter electrode spacing for the array of electrodes in order to find the cross-talk contaminations. In this study differential signal is acquired from the inter electrode spacing of 5mm to 40mm. In the throughout the experiment the cross-talk contamination was noted for each spacing of the electrode. In the end of the experiment it was observed that minimum cross contamination was noted when the inter electrode spacing was selected as 10mm. In this study two major electrode types were used that were bar electrode and disk electrodes. When the inter electrode spacing was increased from 10mm to 15mm the cross-talk contamination was increased but when the spacing was fixed at 10mm then cross talk contamination was minimum, this implies that the best distance is 10mm.

Dr. Scott Day [21] studied the origin of the production of EMG signal. In this study he discussed that action potential is generated due to the exchange of the ions across the membrane. When the nerve impulses are generated and reaches to the motor unit to muscle fibers then action potential is generated due to the activation of the motor units. The main factor impacts the activation of the muscle units whenever the flexion is given to the muscles. The peak of the voltage signal is corresponding to the amount of the force applied and whenever the exchange of the ions is greater than amount of the signal is produced. When the sensor is attached to the surface of the skin due to the difference of the skin and electrode impedances a DC voltage is generated. In the EMG signal analysis, the stability of the impedance is essential to acquire reliable signal at the output of the signal. When the signal is acquired from the muscle then its highly recommended to use the high input impedance circuits to avoid the impact of the loading.

HAKW. TAM and John G. Webster [22] showed in his studies that the main impact on the degradation of the EMG signal is based on the motion artifacts, the motion artifacts has very low frequency with varying signal magnitude. The minimization of the motion artifacts is the main concern to increase the signal to noise ratio of the signal. The abrasion on the skin may also decreases the motion artifacts but it might by discomfort for the patient.

. Paulo Roberto Stefani Sanches et al. [24] presented different approach for the signal conditioning circuit. In this approach field programmable analog arrays are used to apply the signal conditioning on the input signal. The entire processing was carried out using the FPAA and cutoff frequency was suggested as 1.5Hz.

Yinfeng Fang et al. [25] proposed another approach for the acquisition of the EMG data. In this work the EMG signal was acquired from the belly of the muscle using 18 dry electrodes (array of electrodes) similar like the myoarm band. The proposed work was effective due to the acquisition of the signal from multiple points, this acquisition was also used to determine the location of the muscle.

Mohammed M. Shobaki et al. [28] described that EMG signal can be used to identify the number of firing motor units and shape of the units. In this study the author measured the inter electrode distance and various other parameters to find the effective variable that impacts the output of the sensor. In this study it was suggested to use high input impedance based active filters to avoid the loading effect.

Dimitrios Barbakos et al. [29] developed a dry EMG sensor for the acquisition of the signal from belly of the muscle. In this study feature extraction was carried out to detect any problem. In the proposed work filtering techniques are employed to get the higher SNR signal with reduce motion artifacts. In the proposed work

A Melaku et al. [33] studied the impact of the inter electrode distance on the magnitude of the SEMG. The proposed work is based on the measurement of the output signal when the inter electrode distance is varied and it is concluded that amplitude of the signal was significantly changed when electrode spacing was kept between 10mm to 15mm.

CHAPTER 3: SURFACE ELECTROMYOGRAPHY (SEMG)

The generation of the electrical signal at the belly of the muscle is known as the surface-based electromyography. In this activity due to exchange of the ions an actional potential gets generated across the membrane of the cell. The potential generated due to ret and contracted state both are different. The process acquiring the signal through the muscle is done by the surface-based electrodes or other different types of the electrodes, in the invasive type of the electrodes the comfort of the subject is compromised, whereas in the noninvasive technique simply skin preparation is needed in the case dry electrodes.

3.1. Factors Impacting the Acquired signal

The important factors that impact the output signal acquired by the surface-based EMG sensor is affected by multiple sources.

1. Muscle Tissue
2. Diameter of targeted muscle fiber
3. Number of muscle fibers per bundle.
4. Noise Sources
5. Strength of the muscle
6. Depth of muscle.
7. Electrode Material
8. Interspacing of Electrodes
9. Skin Preparation

3.1.1. Impact of Noise

The analysis of the surface-based EMG signal is very important to get an idea about the strength of the muscle and detection of the disorder in the body. The quality of the signal can be best approximated using the signal to noise ratio of the spectrum. The main objective in the measurement of the SNR is to measure the signal quality with respect to the noise. The signal to noise ratio can expressed on the basis of the signal over noise ratio in dbs.

$$SNR= P_{signal}/P_{Noise} \tag{3.1}$$

As noise is undesired in the EMG signal but due to multiple factors noise gets added in the circuit and distorts the waveform of the actual signal and hence in the result quality of the signal gets suppressed.

3.1.1.1. Equipment Based Noise

The entire processing of the signal can't be done without utilization of the equipment. The quality of the equipment also plays a vital role in the detection of the EMG signal because poor quality equipment will likely to add more noise as compared to the good equipment, The frequency associated with the equipment goes from 0Hz to Kilo Hz range [6,17] and hence the usage of better quality equipment will suppress this issue.

3.1.1.2. Power Line Interference

According to the faraday law of electromagnetic induction, when current passes through any circuit it orients a magnetic field around it. The magnitude of the magnetic field is dependent on the amount of the current flowing through the circuit and nature of the conductor. Normally, all the appliances are AC dependent and originates the 50Hz/60Hz signal [6] in the actual signal and produces distortion. The magnitude of the signal is 3x more than the EMG signal [18,6] and that's why the rejection of this component is essential in the EMG signal analysis.

3.1.1.3. Artifacts

There is one more type of the noise that is associated with the EMG signal is called as the motion artifacts [6,15]. This is noise that is induced in the circuit due to the movement of the sensor and movement of the cable. The produced frequency has lesser magnitude because of the low frequency interpretation in the main signal. The motion artifacts can be removed properly with the help of input impedance of instrumentation amplifier [19].

3.1.1.4. Instability of the signal

The magnitude of the EMG is not defined because of the activation of the firing units and corresponding voltages. The reason for the inherent instability lies due to low frequency components with different magnitudes in the main signal, normally the range for the low frequency lies from 0Hz to 20Hz and this noise can be removed using high pass filter [6,19].

3.1.2. Position of the Muscle

The position of the muscle is also one of the important factors that effects the strength of the signal. When the sensor is placed on the belly of the surface if both the muscle will be at same position then acquired signal will be considered as the equal signal because due to the difference in the signal the associated noise also varies with the varying depth of the muscle [20]. The electrical activity picked by the both electrodes will be different due to the difference of the positions.

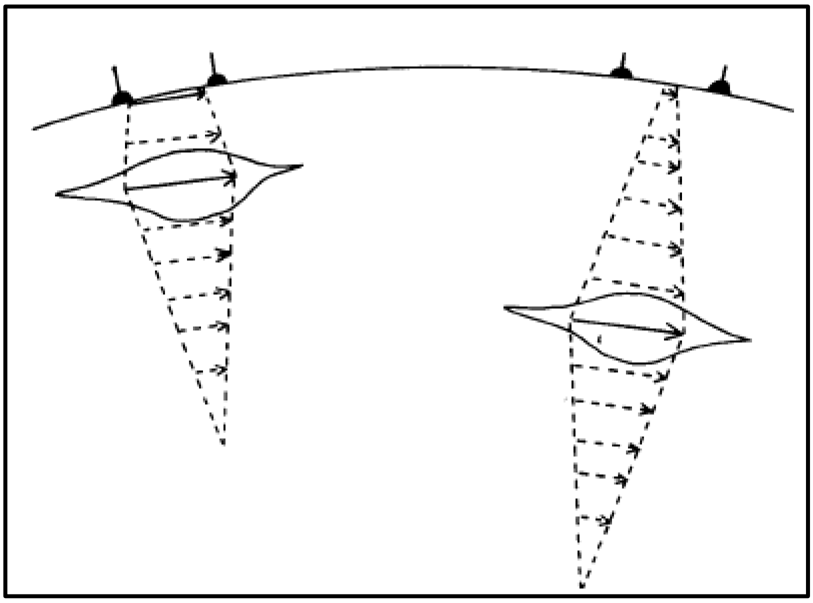

Figure 19: Position of the Sensor [16]

The spacing of the electrode is very important in the light of signal strength because the SNR of the signal directly impacts the distance of the electrodes. The location of the muscle is extremely important because of the interference of the neighboring muscle [20]. The same activity is shown in the Figure-19, in which its clearly explicit that when the spacing of the sensor will be equal then larger magnitude of the signal will be received, in the result a better SNR will be observed. In case of the low distance the SNR of the signal will be reduced and hence the signal quality will be compromised.

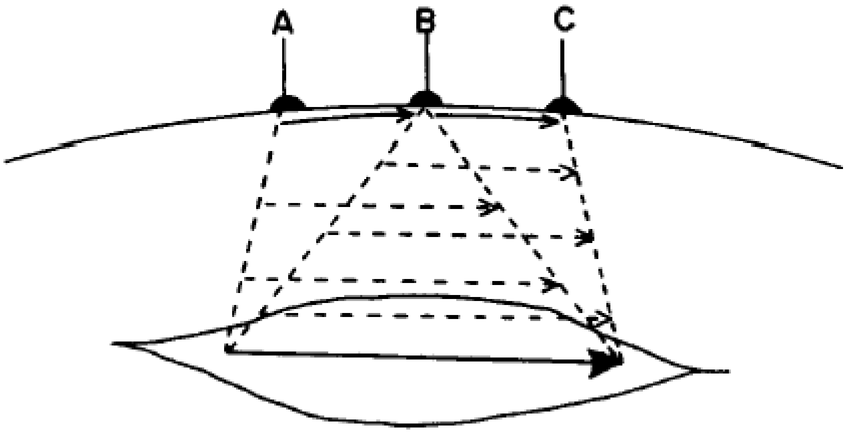

Figure 20: Effect of electrode spacing [17]

3.1.3. Activity Separation

Separation of activity from neighboring muscles is probably best accomplished with electrodes spaced closed together over the desired muscle. Two muscles with equal activity at different depths as shown in Figure 20 are under consideration. We can witness how the neighboring muscle signal will be picked up by electrodes of different spacing.

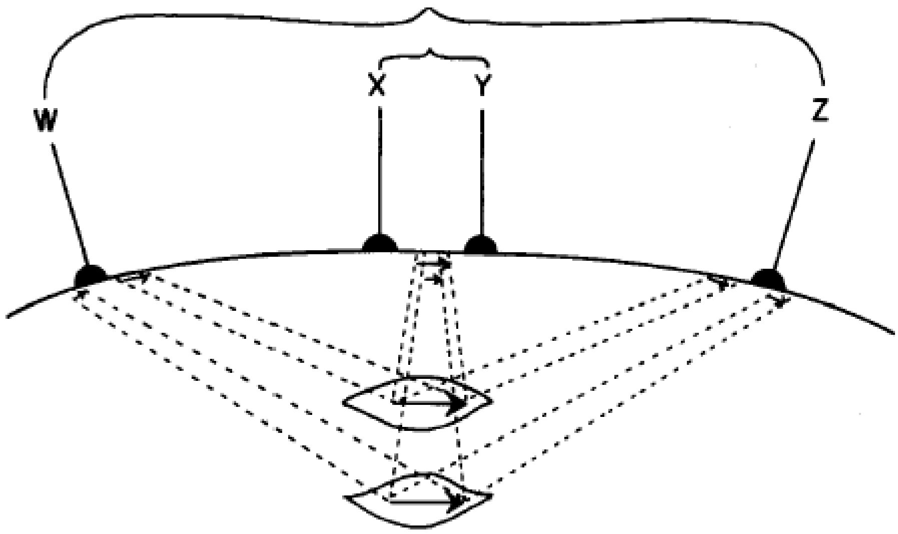

Figure 21: Differentiation of muscles at varying depths [17]

The separation of the activity is the best technique to enhance the signal to noise ratio of the actual signal. In this activity the experimentation can be carried out to evaluate the impact of the signal to noise ratio with varying electrode spacing. The labelling of the electrode is represented. When the spacing between the electrode will be increased then SNR will be increased till the time when the length of the muscle in the same proportion of the electrodes but when the length of the signal is increased then SNR of the signal stared to decrease due to high magnitude of the noise and reduced magnitude of the signal [20].

3.2. The Significance of Skin – Electrode Impedance

One more very interesting factor is the skin to electrode impedance, the purpose of the study of specific factor resides in the determination of the impedance at both sides because it is required to have the minimum amount of the impedance between these contacts. The stable response of the signal is dependent on time, that’s mean with the passage of the time the response of the signal becomes better and provide the good strength of the signal. The nominal time required for the settlement of the sensor lies in the range of 10minutes to 30miutes [5]. The impact of the impedance can also be seen in the signal to noise ratio of the actual signal because an idea electrode has minimum impedance in the flow of current. The stability time of the signal makes the response of the system entirely dependent on the response time of the signal. The significance of the better electrode to skin interface yields the following outcomes.

- The strength of the signal will be increased

- The poor skin to electrode interface leads to the more precise signal conditioning with saturation of the operation amplifiers.

3.3. Minimization Techniques

In the Ag/AgCl based electrode the skin to electrode contact is better due to the gel interface but in the dry electrode the strength of the signal can be increased by doing preparation of the skin before the application of surface sensor. In the result of skin preparation, a larger signal with reduced artifacts can be seen on the scope. The standard value of the voltage at the time of the trials is measured as the ± 10 mV [22].

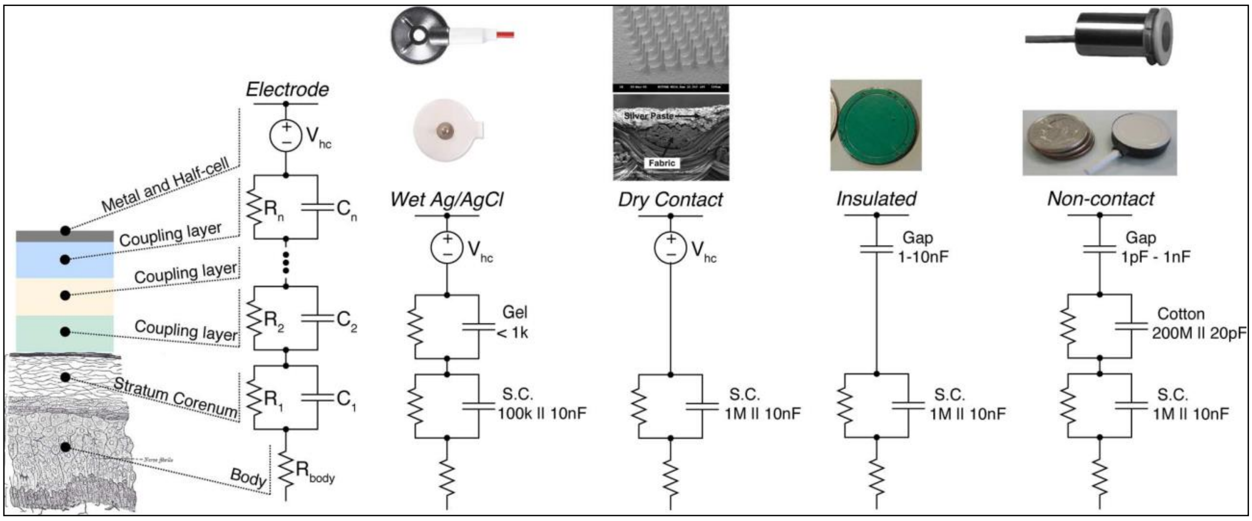

Figure 22: Skin-electrode impedance against different surface electrodes [18]

3.4. Pros and Cons of surface Based EMG

The use of SEMG signal has many advantages:

- Detection of the Energy Level present in Muscle
- Painless way to acquire EMG signal
- Muscle activity detection
- Firing rate assessment
- Numerical printouts determination.

The limitation of the SEMG includes:

- Accessibility to the limited muscle
- Cross talk

3.5. Types of the Surface Electrodes

The data acquisition process is very interesting to understand the insights about the EMG signal and its relevant study. In this section type of the sensors will be discussed that can be used to acquire the readings. There are two types of the surface electrodes that are being used to acquire the signal [10,23] each of them has its own significance and issues.

3.5.1. Passive Electrodes

In the various biomedical applications passive electrodes are being used to acquire the signal and to process it using the signal conditioning circuit. The reason for the maximum utilization resides in their cheapness. In this type of the sensor the gel-based contact does not last long and provide ineffective signal for the assessment. On the other hand, dry passive electrodes are best, but they need too much skin preparation. The limitation of the dry EMG electrode is that it does not contain any signal conditioning circuitry that's why they introduce the resistance to the flow of the Raw signal.

Figure 23: Passive EMG electrode [19]

3.5.2. Active EMG electrodes

The other type of the electrode is called as active electrode, in this type there is an active circuit inside the casing to remove the motion artifacts. The significance of this electrode is that it has good SNR because of the everything covered inside the circuit along with this there is no need of skin preparation [2,23]. The limitation of this circuit resides in the affordability range of the amputees or for clinical testing.

Figure 24: Active EMG electrode [20]

3.6. EMG Signal Acquisition Circuitry and Configuration

The measurement of the EMG signal is the difficult to do, because of the high frequency signal involved in it. In this process the raw EMG signal is acquired from the muscle then passed through the instrumentation amplifier. The reason for the differential amplifier is to reject the noise that is common at both ends and then amplify the signal. The acquired Raw EMG signal has very low magnitude that's why there is a need to subtract the signal one electrode from the other electrode and then amplify the signal using decent gain value. In the differential operational amplifiers, the input impedance has the range in mega ohms whereas the output impedance reaches to the milli ohms value. The acquired Raw EMG signal has bunch of frequencies so that there is a need to remove all the components present externally in this circuit and to make the system independent of the noise. In this INA gain can also be adjusted using the external resistors that relate to the ICs. The CMRR of the INA is also very high that determines the amount of the magnitude rejection. The slight change in the rail voltages produces the offset in the output of the signal and that offset can be removed using the external potentiometer. The adjusted gain applies to the all magnitude of the inputs and provides the corresponding resultant signal at pin6 of the amplifier

.

$$Gain=(1+2*R_1*Rgain)*R_3*R_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (3.1)$$

$$Vout=(V2-V1)\times Gain \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

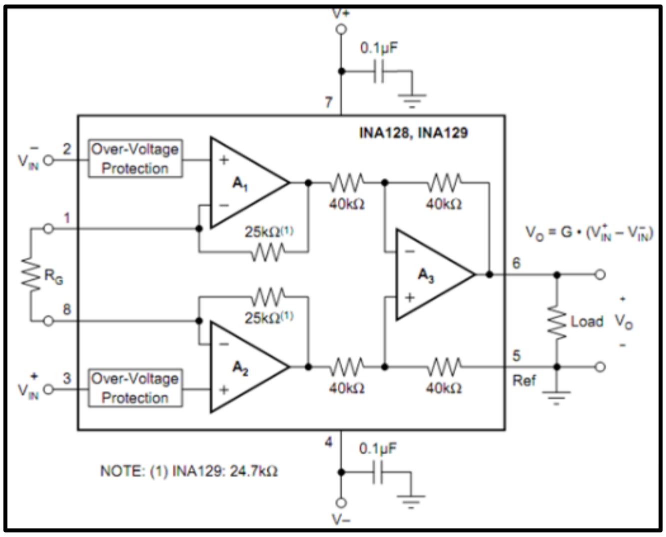

Figure 25: Three amplifier-based instrumentation amplifier [21]

3.6.1. Monopolar Configuration

The input pins of the INA2 and INA3 are dedicated for the input signals that are desired to be subtracted. In the monopolar configuration only one electrode is there to acquire the signal and the other electrode act as the reference electrode of the circuit [9,23]. In this configuration the actual activity determination is slightly impossible due to the high noise content and floating state of the signal [9].

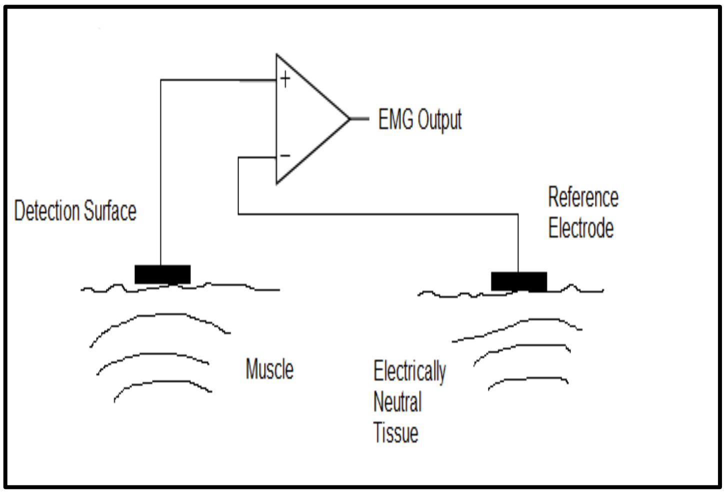

Figure 26: Monopolar signal acquisition technique [21]

3.6.2. Bipolar Configuration

The other well-known type of the electrode configuration is called as the Bipolar electrode in which 2 dedicated points are left for the acquisition of the EMG signal and then highlight the acquired signal using gain. This configuration is best because of the subtraction of the noise associated with both ends of the electrodes [9,23].

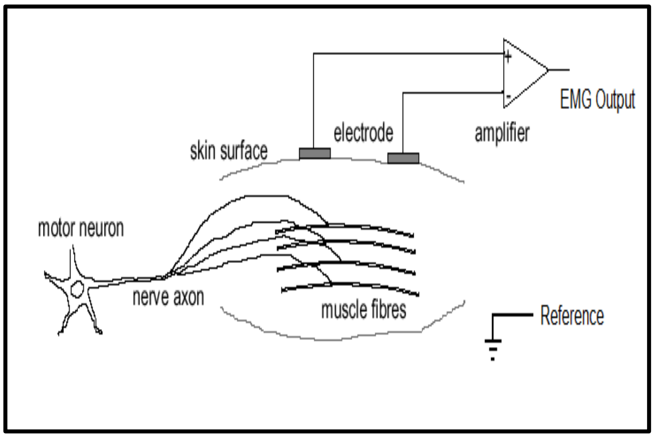

Figure 27: Bipolar signal acquisition technique [22]

3.7. Conclusion

In this chapter entire discussion related to the surface EMG signal is carried out to get an idea about the signal conditioning circuit and types of the electrodes. In this section it is noticed that right type of the electrode reduces the noise associated with the actual signal and produces good quality signal with boosted signal to noise ratio and reduced motion artifacts.

CHAPTER 4: PROPOSED METHODOLGY

This chapter is based on the proposed methodology that is adopted to develop the proposed sensor. In the proposed work a novel approach is adopted to develop a sensor that can provide the same output as the commercially available sensor. The bench mark sensor in this work is taken as the Z03-002 motion lab sensor. The parameters like Electrode impedance, response time, Signal to noise ratio are considered as the reference parameters. The design of the PCB is done in the Altium software, the casing is designed in the solid works. The fabrication of the PCB is done through PCB WAY and casing is developed through the injection Molding Machine. The acquisition of the EMG required multiple interfaces to get the desired signal with the help of electrodes. The actual spectrum of the signal lies at a specific range of the input frequencies that's why it is needed to remove the unwanted signal from the actual signal. The nature of the input signal is bipolar in nature means the positive peaks and negative peaks of the signal determines the overall strength of the signal. The received signal is not powerful enough to determine the activity of the signal that's why there is a need of applying some filtering techniques on it. The proposed methodology reflects the same working but the frequencies for the acquisition of the signals are very critically selected through the utilization of the Fast Fourier Transform of the signal. The mentioned approach is clearly explained in the next section. The magnitude of the signal determines the maximum convergence of the power at a specific frequency. In the proposed methodology following stages are implemented step by step to get the desired output of the signal in which the flexion magnitude and rest magnitude both are represented as the output of sensor. The measured data is in time domain through cathode ray oscilloscope.

4.1. Block Diagram

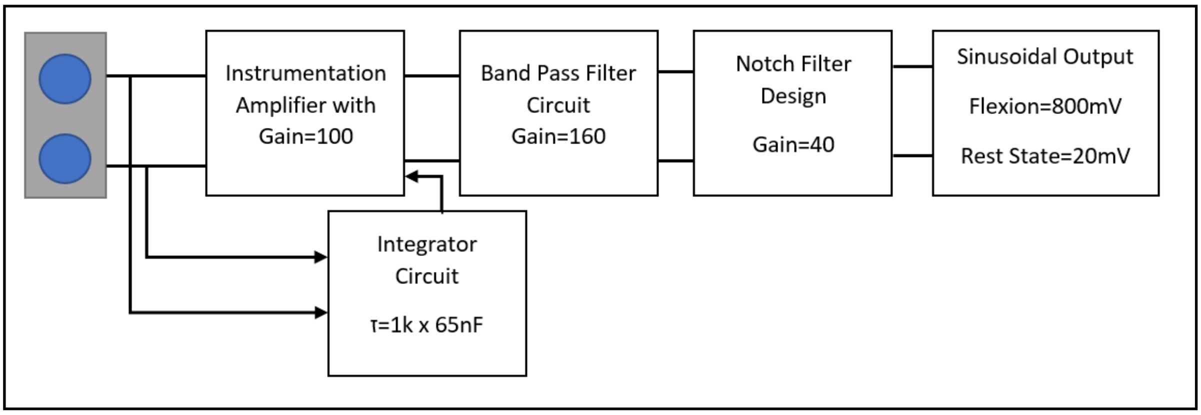

Figure 28: Block Diagram of Proposed Approach

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4.2. Data Acquisition

In the above block diagram, the complete process of the EMG sensor development is shown, in this diagram the first step was to acquire the signal through the SS316L stainless steel electrode and then to pass it through the Instrumentation amplifier. The purpose of using the stainless-steel electrode is to acquire the good quality signal after application of the skin preparation. The acquired signal is then passed through the band pass filter to select the band of frequencies. Once the band is extracted then notch filter design played its role to remove the power line interference from the signal. The source of the power line interference is cable wires or other laptop charging wires. The input magnitude of the signal has very less magnitude along with range of 0.5KHz frequency range but this is very difficult to monitor the frequencies involvement in the actual signal. The contaminated signal has variety of frequencies so that flexion of the muscle leads to the corresponding activity whereas, the rejection of the signal can be smoothly done through the determination of the actual signal. The rejection of the signal is completely done through the desired cutoff frequencies. The magnitude of the activity can't be determined easily without removal of the notch-based frequencies. The SNR of the signal also plays vital role in the determination of the signal quality in addition to the other quantities such as quality of the electrodes, skin preparation, amount of the force exerted and so on. The role of 50Hz not only destroys the actual signal but it also disturbs the overall spectrum of the signal. The removal of the 50Hz can also be done only by incorporating the notch filter in the circuit. Once the notch filter is employed in the circuit the strength of the signal got to increase because of the reduction of the noise in the actual signal. The SNR of the signal is the measure of signal quality with respect to the resting state of the signal so that whenever the actual activity will be sensed through the sensor then corresponding action will be generated. The entire internal working of the signal generation total relies on the distribution of the Ions through the sodium potassium pump. The selection of the specific metal for the detection is required to sense the signal from the belly of the muscle. The reason for the specific electrode type is important in the light of skin preparation element and the amount of the impedance by the electrodes. The detail section corresponding to the selection of the electrodes is highlighted to focus the properties of the electrodes and the types of electrodes.

4.2.1. Selection of Electrodes

In the proposed sensor the selection of the electrode is done to provide the maximum conductivity of the signal. There are various options that are available but due to some constraints of the material the selection of the material becomes much tricky. The performance of the gold is best among all as it produce high voltage of half-cell potential but due to the cost factor gold can't be used. The other option is to use silver-based electrodes, but they cause abrasion on the skin with long time use [36]. In the proposed work SS316L is used acquire the EMG signal from the surface of the skin. The reason for the selection of the electrodes is based on the conductivity ability of electrodes. The proposed stainless-steel electrodes have better conduction as compared to the standard stainless-steel electrodes. In the bench mark sensor Z03-002 SS315L is used to acquire the activity of the muscle but the major difference of the SS316L and SS315L resides in the content of carbon present in it along with that corrosion resistance and mechanical properties. The important thing in the stainless-steel electrode SS316L is that, it has carbon content of 0.03%.

Table 2: Properties of SS316 Vs SS316L

Properties	**316**	**316L**
Tensile Strength	75,0000	70,000
Yield Strength	30,000	25,000
Elongation	40%	40%
Carbon	0.08	0.03
Chrome	16.0-18.0	16.0-18.0
Manganese	2.00	2.00
Nickel	10-14	10-14

4.2.2. Instrumentation Amplifier

An Instrumentation Amplifier is simply an Integrated Circuit through which the difference of the two signals can be acquired. The working of this IC is based on the simply differential amplifier configuration in two ended configurations, but the difference lies on the layout of integrated circuit. In this IC there are three operational amplifiers out of them 2 acts as the front-end amplifiers on them the input of the circuit is given whereas the other one is the magnitude enhancer through which the gain of the amplifier can be controlled. The gain of the instrumentation amplifier determines the increase of the magnitude with respect to the input through the external resistor values. The nominal value of the external resistor lies in the range of 30k to 1M but due to the issue of saturation the value is adjusted as per the required output of the circuit. This IC is available in through hole package and surface mount-based package. The acquired signal from the surface of the skin is passed through the instrumentation amplifier to take the differential of the signal. The acquired signal from both points is given to the input of the INA128 to enhance the magnitude of the subtracted signal. The gain of the subtracted signal is adjusted using the external values of the resistors. In the proposed developed sensor, the gain of the INA is adjusted to 40 mean the input signal is amplified 40 times to reach a better magnitude of the signal. The schematic of the instrumentation amplifier is shown below, in this value of the resistor R3 decides the boosting element of the signal magnitude. The gain of the magnitude is controlled though the resistor values, but the important element of this IC is based on the high input impedance and low output impedance along with very high value of common mode rejection ratio.

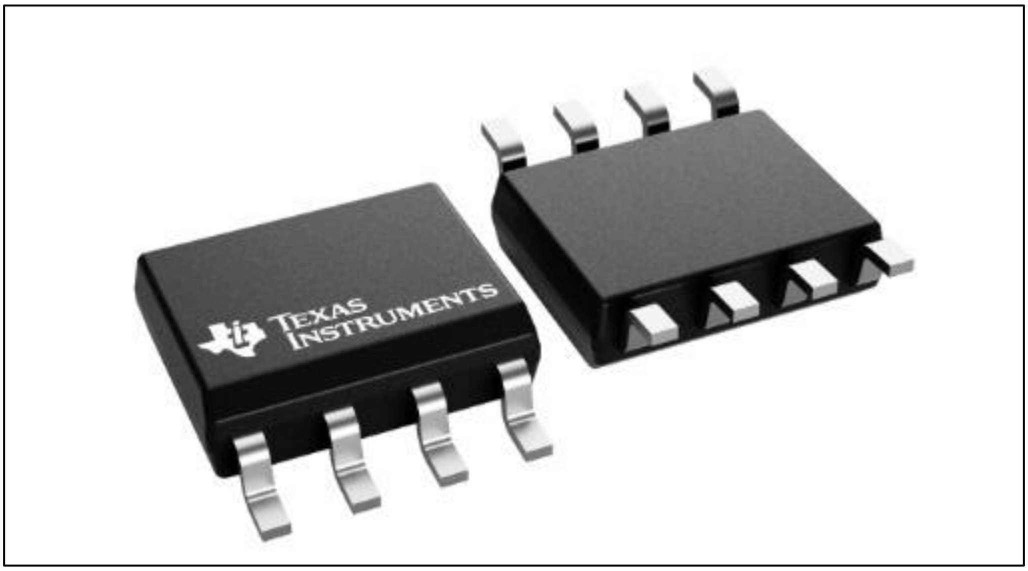

Figure 29: Instrumentation Amplifier [23]

The version INA128/129 both possess the same properties but there is a slight variation in the CMRR of ICs. In the proposed system the same IC is incorporated to acquire the base level signal of the sensor. The signal is first passed through the INA with the scaling factor of 40 to increase the output voltage 40 times as compared to the input. The resistor connected between the pin 1 and 8 is shorted with the R3 through which the gain is controlled. The electrodes are represented as the E1 and E21, these are the two points through which the signal is obtained and boosted. The reference pin of the circuit is shorted with another stage of the amplifier and act as the feedback system to the first system. The loading effect in the proposed approach is minimum because of the high input impedance of the amplifier.

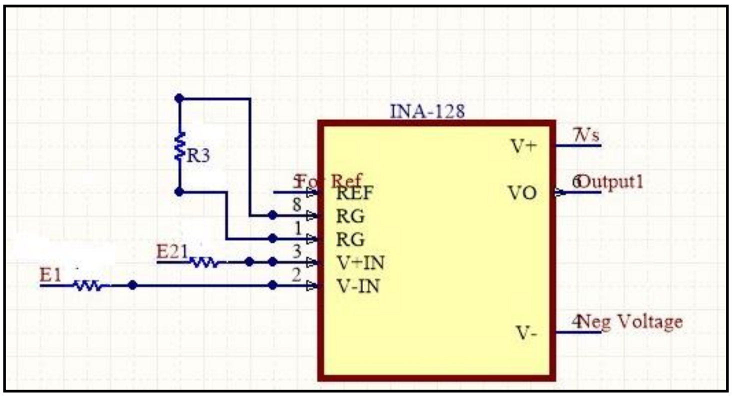

Figure 30: Instrumentation Amplifier Circuit

4.2.3. Band Pass Filter Design

The selection of the filter is very important in the determination of the band of frequencies through which the cutoffs can be achieved. A band pass filter can be simply implemented through two ways, the first way is to implement it using the passive approach whereas, the other one is the approach the relies on the active approach. In the passive approach simply RLC based circuits are implanted to set the cutoff frequencies but the response of the active amplifier is not that good, so that an active approach is needed to implement the circuit for reduction of the loading effect as the input impedance of the passive RLC circuit is maximum so that in order to reduce the effect of loading or high input impedance an active filtering is proposed. In the active approach, contribution of the active part plays a vital role in the selection of the cutoff frequencies, another significance of using the active amplifier is to enhance the order of the circuit to get sharp roll off for the circuit. The order of the circuit increases with decreased roll off through the active part of the circuit. The contribution of the active circuit also reduces the loading effect with offering of internal gain adjustment.

Figure 31: TL072 CP Integrated Circuit [24]

In the Figure-31 the four pins based integrated circuit is shown. This IC is based on 8 pins with biasing pins of +ve, -ve and ground. The integrator circuit can be used to act as an active amplifier circuit with variable gain. In the proposed approach same Integrated circuit is used to get the signal from the INA and to apply some filtering techniques on it, in this IC there are 2 amplifiers that are enclosed in a single unit to provide the differential gain as well as the front-end amplifier to enhance the magnitude of the actual signal. The nature of output signal may have a lot of noise because of the wide spectrum of the frequencies. A band pass filter's response can be selected easily through the ordering of the filter because higher order filters determines the response of the integrated circuit. In EMG signals the sharp cutoff is recommended because of the selective frequencies that needs to be discarded from the output of the signal. In proposed scheme band pass filter approach is adopted to remove the unwanted signal from the actual signal but the problem is based on the response of the filter that can be adjusted through the gain of the amplifier. In this circuit the gain is adjusted using the external resistor values as -R2/R1 that shows the pass band gain of the signal. A band pass filter design is used to filter out the unwanted frequencies from the main signal, the important parameter in this filter is to decide the slew rate of the amplifier. The acquired signal has a range of 0 to 500Hz through the electrodes. In the given signal multiple types of the noises plays important role in the strength of the signal. The main signal is contaminated with the multiple noises for instance 0 to 20Hz frequency is due to the motion artifacts. The filtering of this frequency is required to attain a better signal quality at the output of the circuit. In the proposed circuit a band pass filter is designed to select the lower cutoff and higher cutoff frequencies for the selection of band of frequencies. The cutoff is adjusted from 10Hz to 180Hz to capture the main muscle activity. In the proposed work, a precision amplifier is used. The purpose of utilizing a precision amplifier is to provide high quality signal at the output of the signal. The main essence of utilizing the TL072 CP is to provide a high CMRR IC in the processing circuit to obtain minimum loading effect. The reference of the INA determines the offset removal of the input signal. In this design a reference adjustment circuit is used to provide a floating reference based on the input EMG signal for the measurement of the actual signal. The reference voltage is used to set the voltage level of the INA128 so that whenever the input voltage will exceed to a specific voltage then corresponding output voltage will be generated based on the input signal. The time constant of the output reference signal will be determined through the RC circuit. The value of the RC is decided based on the output signal and corresponding voltage signal that needs to be suppressed from the output voltage. Normally, the reference of the IC is grounded to get the output but for the EMG signal reference PIN is shorted with the RC parallel circuit for the desired reference voltage of the IC.

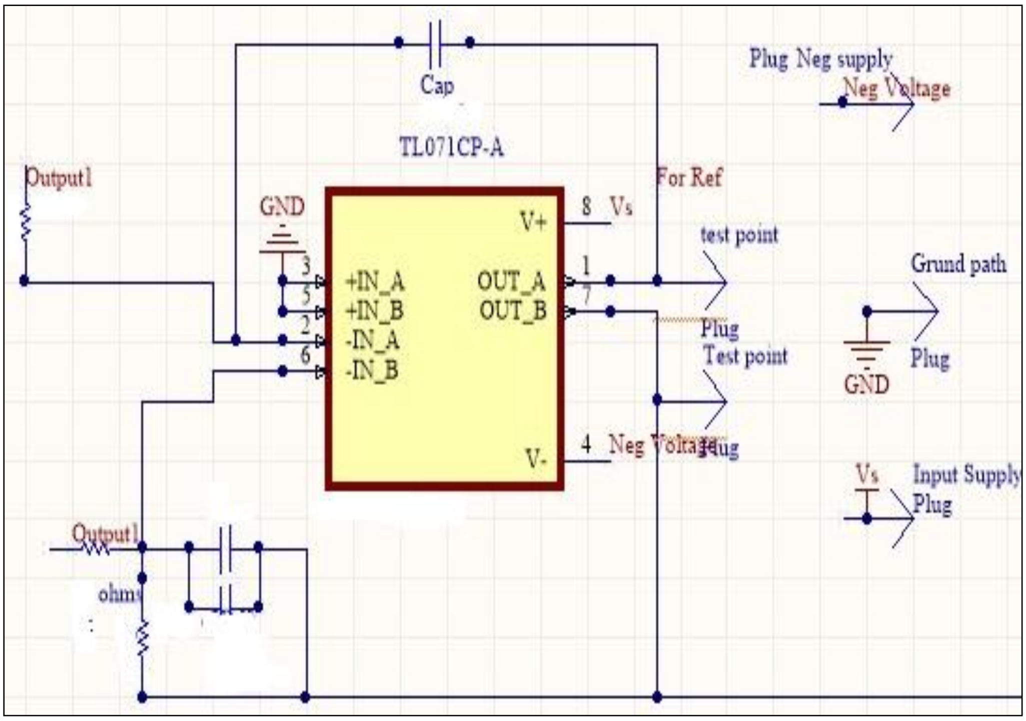

Figure 32: Band Pass Filter Circuit

4.2.4. Reference Adjustment

The reference adjustment of the INA128 is used to set the reference voltage based on the input voltage. In this circuit the reference pin is looped back into the stage1 to set the reference voltage. The output reference voltage is adjusted through the TL072CP Integrated circuit. In the above Integrated circuit, a single IC possess twice operational amplifiers due to which the same power consumption is utilized by the both circuits. The magnitude of the power is dependent on the connected cascaded stages through which the current and voltage of the circuit can be controlled. In the proposed circuit RC time constant is used to set the time constant of the Integrated circuit, in the controlled circuit the gain of the IC can be controlled through the external resistors but in case of integrator circuit the combination of R and C are used to set the value of the components.

4.2.5. Notch Filter Design

In the EMG signal the most important parameter is to remove the external frequencies that are dependent on the line noise. According to the right-hand rule, a current conductor possesses magnetic field around the conductor. The magnitude of the magnetic field is dependent on the magnitude of the current that passes through the conductor. The magnitude of the signal produced due to the line noises is very high in nature because of the high amount of the current. The produced magnetic field around a conductor not only give disturbance to the sensor but it also destroys the entire magnitude of the actual signal. The reduction or suppression of the line noise is essential and to perform the suppression methodology there are two approaches that are adopted to reduce the power line interference from the signal. In the notch filter circuit, a band selective filtering is adopted to specific range of the frequencies. The band selective filtering is the best approach to stop a specific band of the frequencies but in this approach Q factor of the circuit plays a vital role to define the bandwidth of the circuit. In this approach pass band gain of the circuit again plays a vital role in the determination of the output signal.

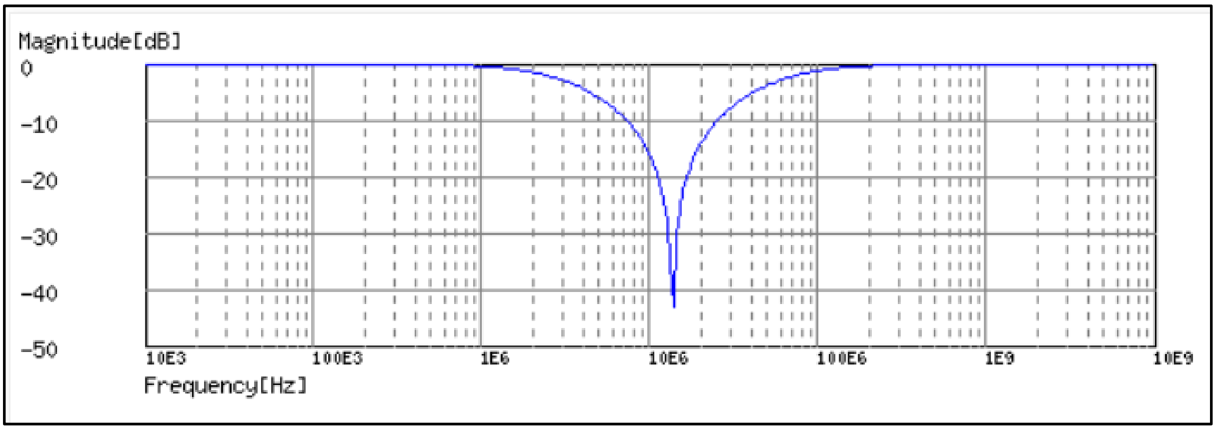

Figure 33: Notch Filter Response

The problem of removal of the 50/60 Hz noise is the major issue faced in the various ECG or EMG based circuits. The corresponding noise signal is removed with the help of notch filter approach. The selection of the notch filter is based on the acquired signal magnitude and its pass band gain magnitude. There are various options are available for the notch filter selection but the effective one based on the variable Q factor is considered as the Q-Based Notch Filter. In this filter approach a variable Q is adjusted to set the pass band of the amplifier as the higher value of the Q will decrease the band width of the circuit. The resultant signal at the output of the notch filter is used to trigger the circuit accordingly. In the proposed design Q of 2.5 with K as 0.99 is adjusted to make the response of the system much smooth and better with gain of 160. In the circuit value of R1 and R2 are kept same to provide the same ratio to the output but the value of the capacitor is different. An active notch filter doesn't allow the circuit to go into the loading issues because of the gain adjustment and suppression of the unwanted frequency at the same time. The first stage of the circuit removes the line frequency from the signal whereas, the second stage of the amplifier amplifies the signal to maximum magnitude. The magnitude of the output signal was observed through the cathode ray oscilloscope and circuit is tested in function generator to assess the response of the circuit without physically testing the system with previous stages. When the frequency of the function generator approached to 40Hz then response of the system started to go down by increase of the frequency. The initial magnitude of the signal was set at 100mV peak to peak with variable frequency from 10 to 100Hz. The response of the circuit is evaluated through the spectrum analyzer also in which the spectrum of the signal was observed but on the spectrum analyzer the peak of the signal showed the decreasing behavior of the 50Hz signal arriving from the function generator.

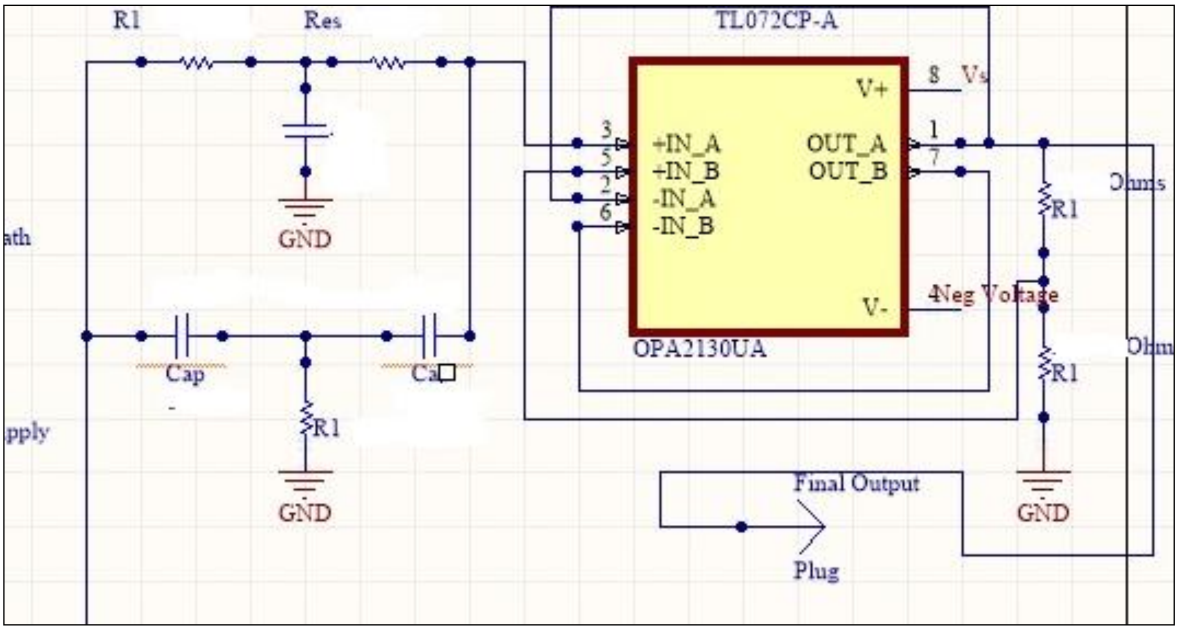

Figure 34: Notch Filter Stage

4.2.6. Practical Implementation phase

In this phase the experimentation is carried out to practically implement the circuit using through hole and surface mount components. The testing of the circuit is carried out using multiple power equipment's to monitor the results. In the first stage of the practical implementation the circuit of the INA is developed on breadboard to get the basic signal from the belly of the muscle. The gain of the INA is set to 40 to enhance the strength of the signal because the acquired range of the signal is in milliamps. The conversion of the milliamps signal is shifted to high range using the external gain adjustment of the circuit. The proposed circuit is implemented to find the convergence of the expected results to measured results. The implementation of the circuit is carried out in multiple stages for the verification of the circuit. The first version of the circuit is implemented on the Bread Board to reduce the "Change Cost" of the circuit. The issue is that once the circuit is implemented on the actual PCB then change of value or any component is not possible, though change can be incorporated but aesthetics of the circuit goes lost. The left side of the circuit shows the bread board-based implementation of the circuit whereas, the right side of the circuit shows the implementation of the breadboard-based circuit. The primary verification of the circuit was carried out on breadboard-based stage and then further it was tested on the PCB. The breadboard circuit implementation is only testing of the circuit whereas, the right side of the circuit is designed using the printed circuit board. The fabrication is done through the manual process to just test the results of the breadboard circuit and PCB based circuit. The acquired signal had a small magnitude because of the size and too many wires across the signal detection points. The circuit provided the reduced SNR due to the merging of the multiple nodes at the same point. In addition to the multiple nodes the soldering it self created too much resistance due to which the output signal had noise.

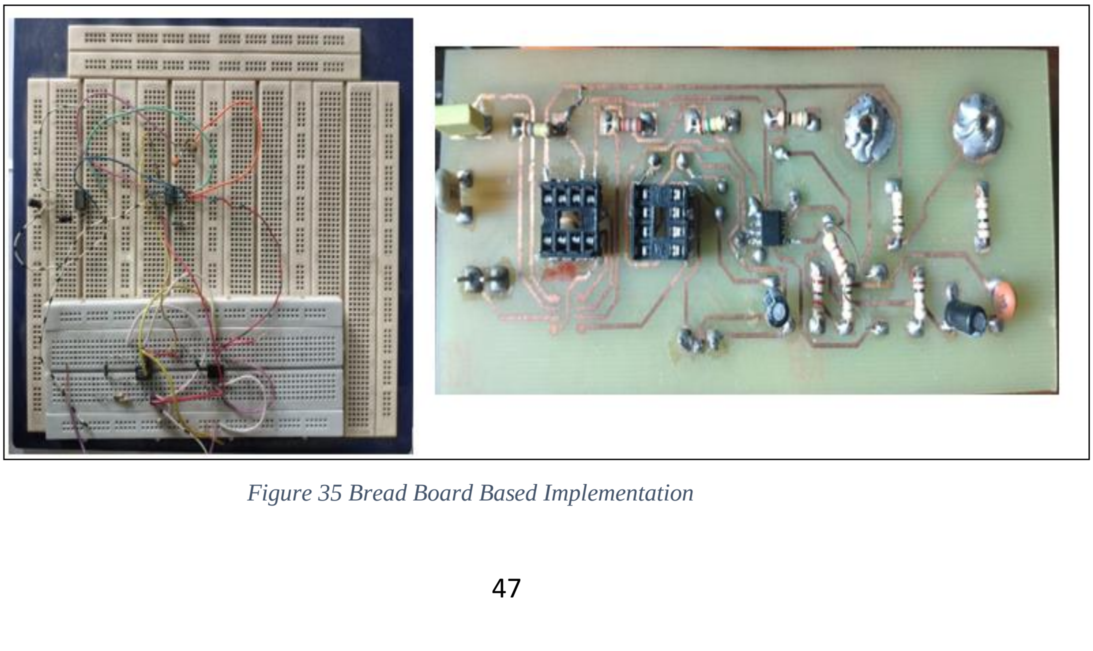

Figure 35 Bread Board Based Implementation

4.2.6.1. Second Version of Circuit

In the first version of the circuit, the size of the circuit was significantly large as compared to bench mark sensor. The size of the circuit was 5 inches by 2 inches due to which the mounting and other stuff was not possible. Based on the above circuit a new version was designed in the Altium Designer to reduce the size of the board with same output signal. The version-II had a size of 2.5 inches by 2 inches. In this variant the main emphasis was put to increase the signal to noise ratio and reduce the external noise of the circuit. The miniature circuit got fabricated through the PCBWAY with manual mounting of the components. In this design a dual layer PCB was designed to minimize the internal capacitances role. The top layer in this design was kept as the main input of the sensor because of the input electrodes. The other electrode is kept as reference electrode because the INA was shorted to the other end of the amplifier to get the subtracted signal. The magnitude of the circuit at multiple nodes in this circuit were slightly larger in magnitude as compared to the variant-I because of improvement of the wiring and reduced sizing. The problem in this circuit resides on the notch filter because it was not incorporated in this design. The signal generated with 50Hz line disturbed the actual signal and destroyed the main signal when the amputee sat neared to the power line appliances. The solution of this problem was again a difficult task to acquire. The absence of the notch filter reduced the signal to noise ratio of the acquired signal. The usage of surface mount components also played a vital role in decrease of the loss as all the resistors had tolerance of 1% from their mean value. In the second variant of the circuit due to less usage of the copper the quality of the signal was good, but the only limitation was based on the notch filter. In the next variant of the circuit to boost the signal to noise incorporation of the notch filter was carried out for the better SNR of the signal.

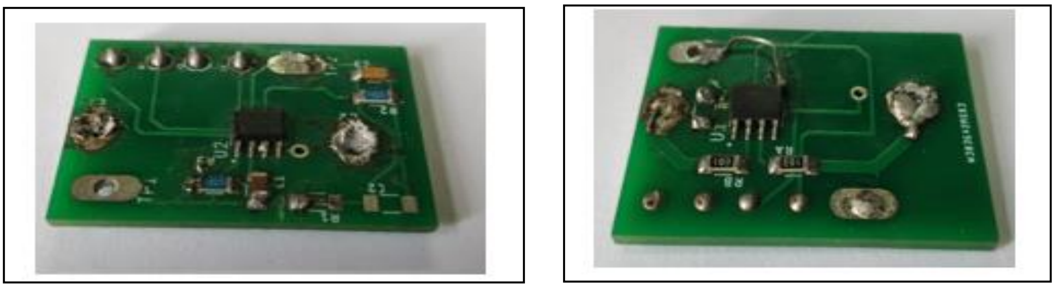

Figure 36: Improved Circuit Variant-II

4.2.6.2. Third Version of Circuit

The third version of the circuit consists of the reduction of the PCB size to approach the benchmark sensor requirements. The circuit layout is further minimized with the manual footprint creation of the ICs and through utilization of the miniature sized components. In this version due to the notch filter and compact size as per the IPC Footprint Complaint Wizard the size and standard layout of the board was changed. The output response of the signal got also improved through 2-layer board of the PCB. The Gerber files were important to the Gerber viewer to maintain a consistent pitch in the circuit.

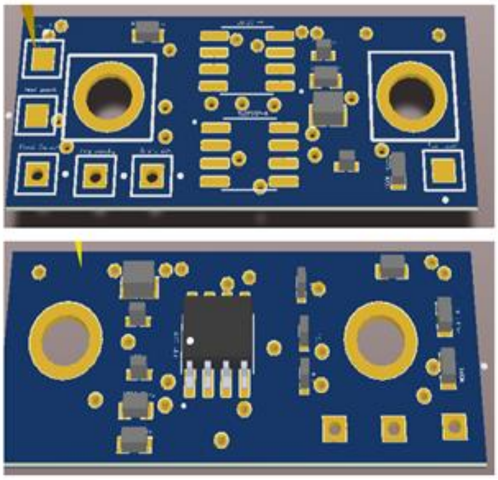

Figure 38: Schematic View

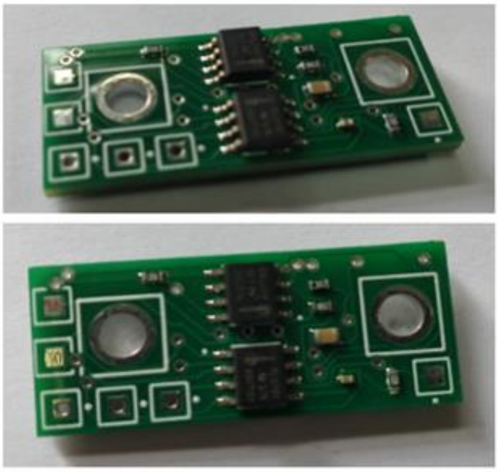

Figure 39:Actual Representation

Once the implementation and results from the version-III were acquired then casing of the PCB was designed in Solid works to protect it from the external environment. The casing of circuit was based on the snap fit mechanism to lock and unlock the casing. The first version of the casing was designed in solid works and got fabricated through the ABS based printer. The finishing of the ABS printer was not good so that to improve the quality of the casing SLA based printing was carried out. The finishing through the SLA printer was quite good because of the compact layers. The casing of the sensor was developed for the protection and unlocking of the circuit. The grubs spacing of the circuit was defined in the solid works to hold the wire so that external pressure could be observed but due to the mass production the injection mold was designed for the rapid production of the casing. The significance of mold production resides in the quick development of the casing with bunch of casing at a same time.

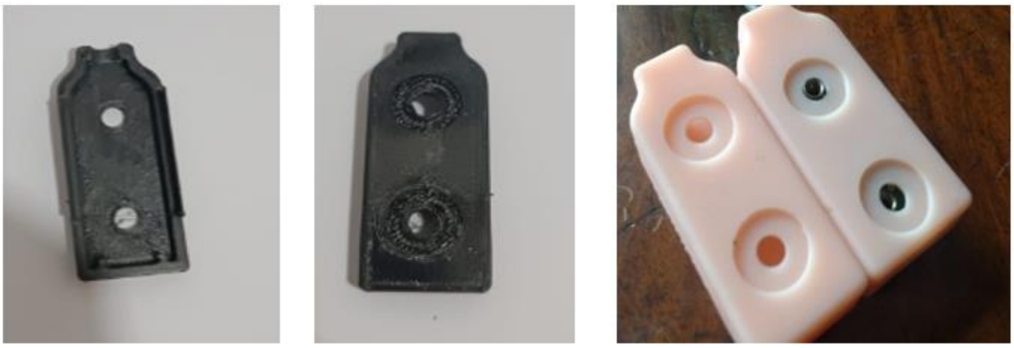

Figure 40: Variants of the Manufactured Casing

4.2.6.3. Mold Manufacturing

The manufacturing of the casing needs too much time through the 3D printer because of the slicing of the layers. The process of the mold can make the manufacturing of the casing faster through mold process. The mold process is best for the rapid production in through the bunch of the casing can be developed in minutes. The manufacturing of the mold is done through the local market. The significance of using the mold-based manufacturing is to reduce the time that is required for the fabrication. The mold is designed on CNC machine for the precision of the mold through the proper monitoring of the temperature. The designed mold of the sensor was then used to produce the desired number of casing with very finishing. The manufacturing process through the injection mold-based manufacturing is very fast due to the machine-based system as compared to the standard 3D printer.

Figure 42:Die Manufacturing

Figure 41:Develoeped Sensor Side view

Figure 43: Developed Sensor

4.2.6.4. Final Assembly

The final assembly of the circuit is shown in the Fig43 below, in this assembly the left side image shows the assembled version of the circuit whereas the right side of the circuit shows the mounting of the sensor on subjects. The reason for the mounting of sensor on the amputees lies in the detection level of the signal on amputees. The developed sensor is based on the bench mark sensor and to compare the properties of the bench mark sensor both sensors are compared after fitting on the arm of the amputees. The left side of amputee is Transradial with lower elbow amputation in an electrocution shock. The strength of the signal for the both amputees is different because of the strength of the muscle. The ground reference is provided through the elbow point to provide a reference to the acquired signal. The signal to noise ratio of the sensor on each subject is measured through the spectrum analyzer. The entire results are shown in the result section with detailed discussion of each output. The resultant signal is measured on the cathode ray oscilloscope to find the magnitude of variation in the main signal. The right side of the image shows the amputee with Transradial amputation in an accident. The magnitude of the signal of both amputees lies in the strength present in their residual stump. The flexion signal in the normal amputee is relatively higher than the amputee due to the infrequent usage of the muscle for the activity. The routine analysis and exercise in the gym can improve the health of the muscle, that’s why most of the rehabilitation centers recommend exercise before the application of prosthetic limb. The final assembly of the sensor includes the mounting of electrodes on a circuit along with coaxial cable in order to suppress the power line interference of the signal. The reason for the using the coaxial cable is to acquire the voltage from the circuit and to read the voltage in any digital circuit. The wire of the sensor has 4 pins that are used to energize the internal circuitry. The red pin in the wire is used to connect with the +ve voltage, green wire is used to connect with -ve voltage, ground is used to provide the reference with overall ground reference of the body. The fourth pin is white pin that is used to acquire the signal.

Figure 44: Fitted Form

4.3. Feature Comparison of Sensors

The output of the sensor is explained in the result section, the developed sensor is compared with the already existing sensor called Z03-002. The parameters of the developed sensor are compared with the developed sensor to get an idea about the performance of the sensor. The first parameter of the sensor is output means, the output voltage nature of the sensor. In Z03-002 the bench mark sensor has sinusoidal type output whereas, the developed sensor also has the same sinusoidal output. The electrode type of the sensor is very important in the light of signal acquisition circuitry. In these both sensors the material type for the both sensors is same that is SS-315L whereas in the developed sensor the material type is SS-316L along with interelectrode distance of the 2cm. The distance of the sensor is very important because it determines the number of motor units capturing. The required power supply for Z03-002 is 5V whereas in the developed sensor the range for the power supply is 3.7V. The magnitude of the power supply is important because it determines the amount of the power drawn by the circuit.

Table 3: Feature Comparison of Different Sensors

Feature	**Z03-002**	**Developed Sensor**
Output	Sinusoidal	Sinusoidal
Electrode Type	SS-315L	SS-316L
Inter-electrode distance	2cm	2cm
Power Supply	±5V	±3.7V
Mass	10g	12g
SNR	40dB	15dB
Response Time	400ms	200ms
Price	$420	$42

CHAPTER 5: RESULTS AND DISCUSSION

In this chapter the focus is to discuss the obtained results and magnitude of the voltages on different subjects. The sensor is mounted on 3xsubjects and their data is recorded through the spreadsheet and plotted in the excel file. The signal to noise ratio, response time and electrode impedance of the commercial sensor Z03-002 is compared with the developed sensor.

5.1. Experimental Setup

The time domain signal of the cathode ray oscilloscope is shown to distinguish the activity and resting state of the signal. The experimentation setup is shown below, in which the spectrum analyzer is used to acquire the FFT of the signal to inspect about the involved frequencies in the actual signal.

Figure 45: Testing Setup

The acquired signal was passed through the Fast Fourier Transform in which the signal is divided into the multiple peaks based on the involved frequency of each signal. The spectrum analyzer is the best option to look at the contamination of frequencies. The raw data had multiple peaks that's why there was a need to remove to unwanted frequencies from the signal and then notch filter will be applied. The significance of the spectrum analyzer is to carefully look at the frequencies of the signal so that cutoff frequency could be adjusted accordingly.

5.2. Time Domain Output Signal

The resting potential of the signal is represented with a straight line, the knob of the oscilloscope is adjusted to the 50.0mV each box, that shows the y-axis is the voltage magnitude. The third firing of the motor units is representing the strongest electrical activity out of these three signals. The peak voltage of the signal is 170mV signal when the maximum force is applied from the muscle. The base line noise is controlled with maximum voltage of the 20mV. The reason for the controlled voltage signal is implication of the notch filter. The amount of the flexion applied on the surface of the sensor determines the magnitude of voltage quantity.

In the time domain signal the variation can be observe through the flexion and rest state of the muscle. The purpose of this rest state is to get an idea about the overall focus of the signal in order to find the signal to noise ratio of the signal. In the below Figure45 the mean activity of the signal is shown at three intervals. The first peak has magnitude of 120mV with resting state signal of 20mV, in the next spike the again muscle activity is sensed with magnitude of 100mV with rest activity as 20mV. In the last activity of the signal the concentration of the signal has higher focus with voltage magnitude of the 100mV.The determination of the signal to noise ratio through this activity can't be easily evaluated because of the inconsistency of the signal.

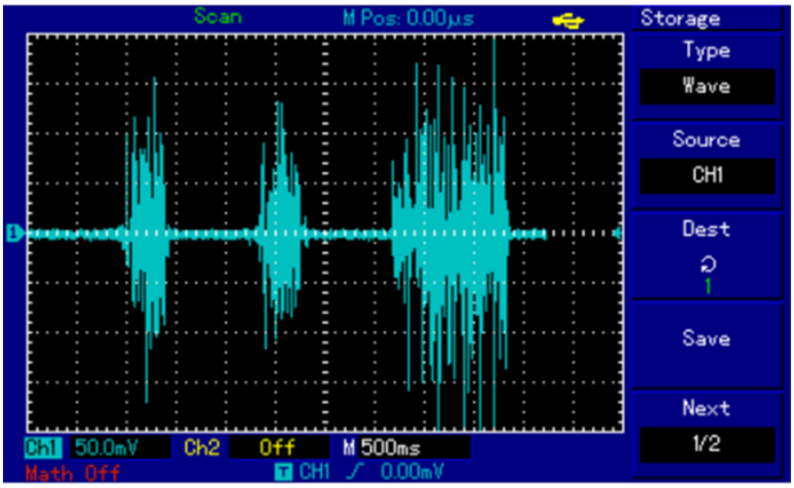

Figure 46:

5.3. Averaging Filter Results

The averaging of the filter is performed in the microcontroller to clearly find the maximum value of the input signal. In the time domain signal the determination of the SNR is easy to find the mean value of the signal by averaging them over a window. The standard

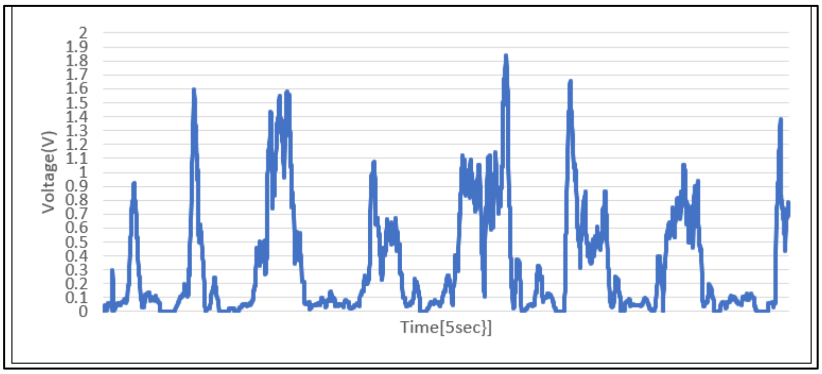

Figure 47: Result of Normal Person

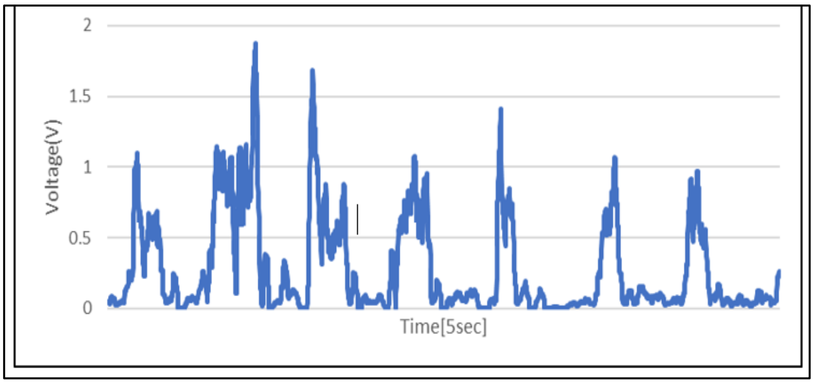

Figure 48: Result of Normal person using Developed Sensor

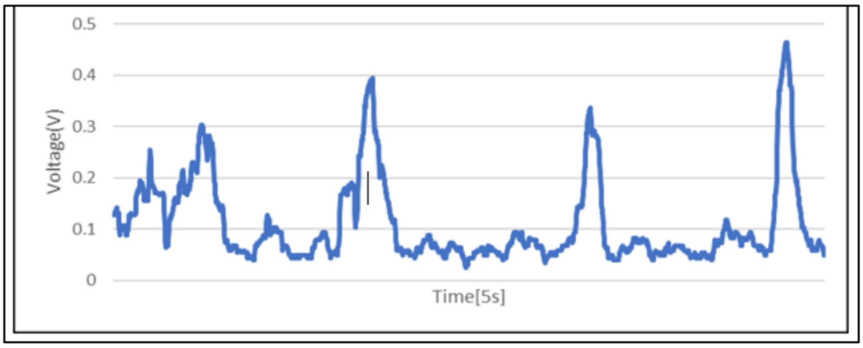

Figure 49: Result of Subject1 using Benchmark product

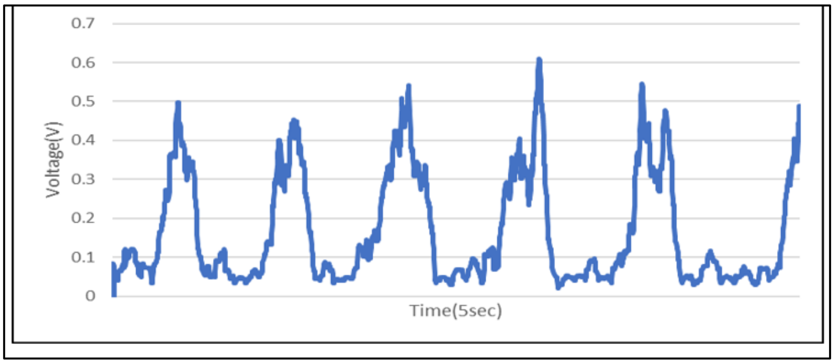

Figure 50: Result of Subject1 using developed sensor

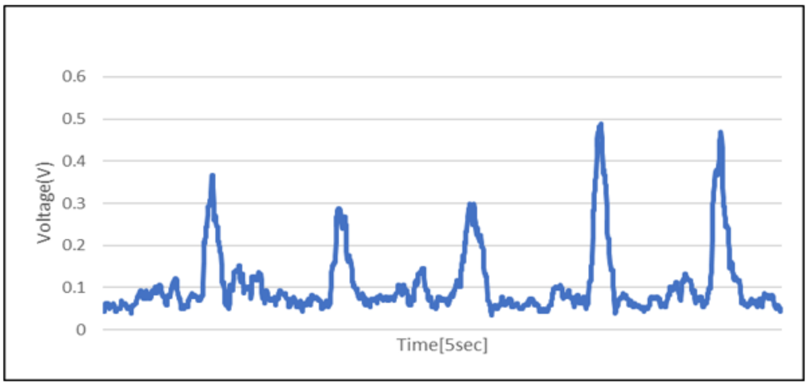

Figure 51: Result of subject2 using z03-002

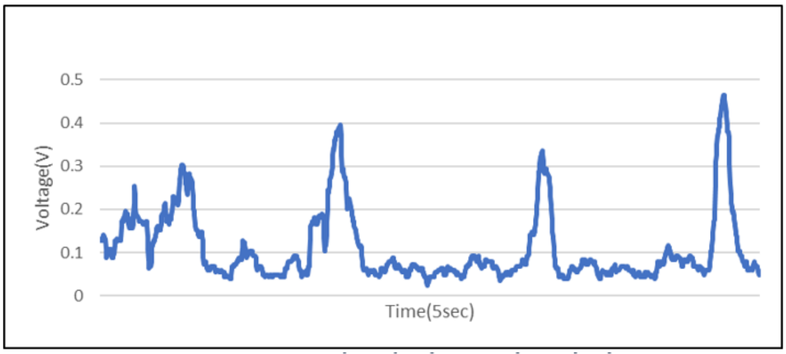

Figure 52: Amputee-II Data Acquisition using Developed Sensor

The result acquired from the Z03-002 sensor has an SNR of 15dB whereas the developed sensor has the SNR of 40dB. The subject-II has SNR of 13dB through the Z03-002 but the same SNR was increased with developed sensor to 38dB. The magnitude of SNR is the key role of the determination of SNR because the quality of the signal is the actual measure of the sensor. In the subject-III the magnitude of signal with Z03-002 is 15.1 whereas, the developed sensor has the SNR of 39.5dB. The result section concludes that the quality of sensor is comparatively better than the existing sensor by incorporating the notch filter in the circuit.

5.4. Response Time

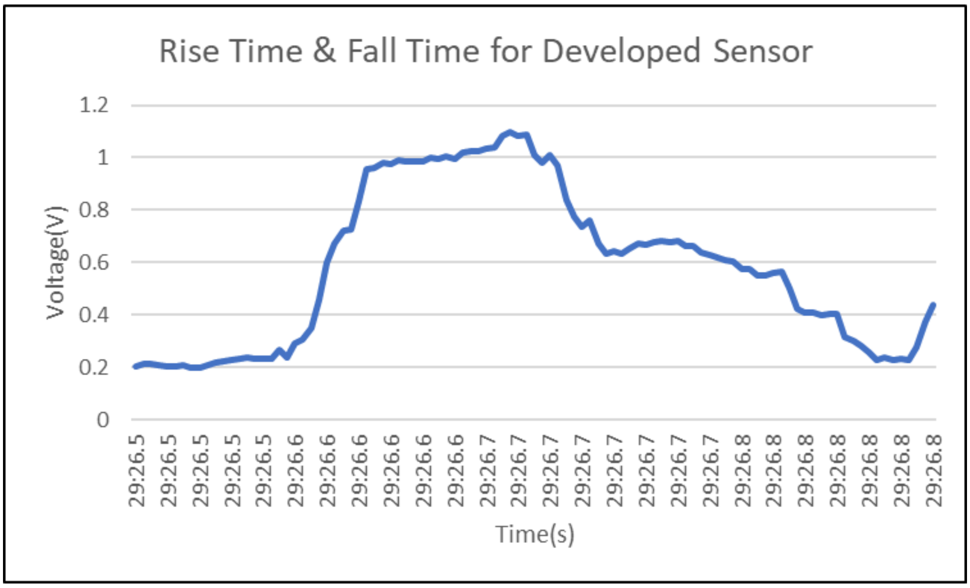

Figure 53:Devloped Senor Calculation

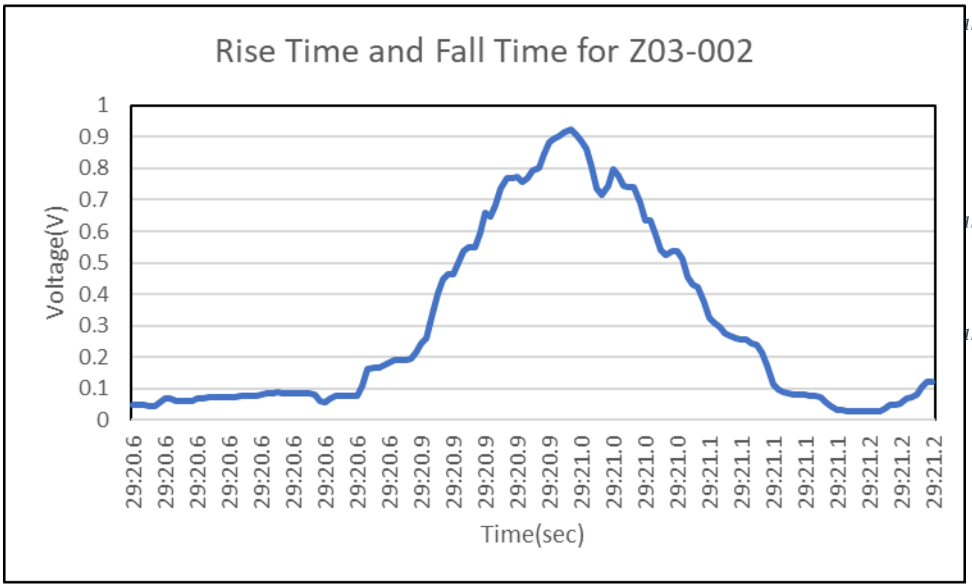

Figure 54: Benchmark sensor calculation

Table 4: Rise and Fall Time Summary

Sensor	Rise Time	Fall Time	Response Time
Z03-002	200ms	200ms	500ms
Developed Sensor	100ms	100ms	200ms

5.5. Electrode Impedance

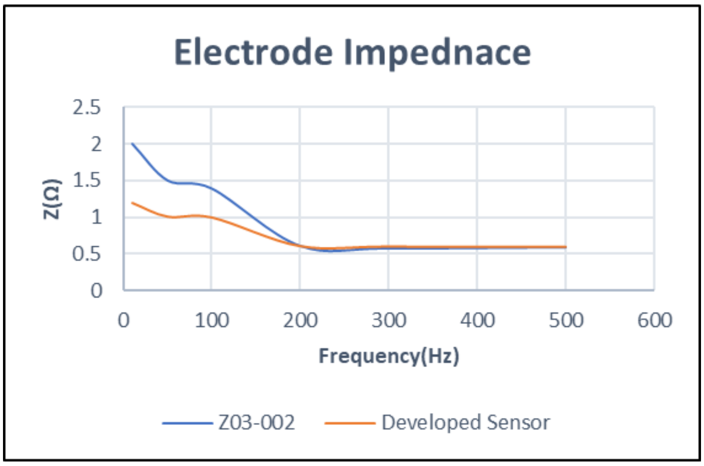

Figure 55: Impedance calculation

5.6. Input Impedance

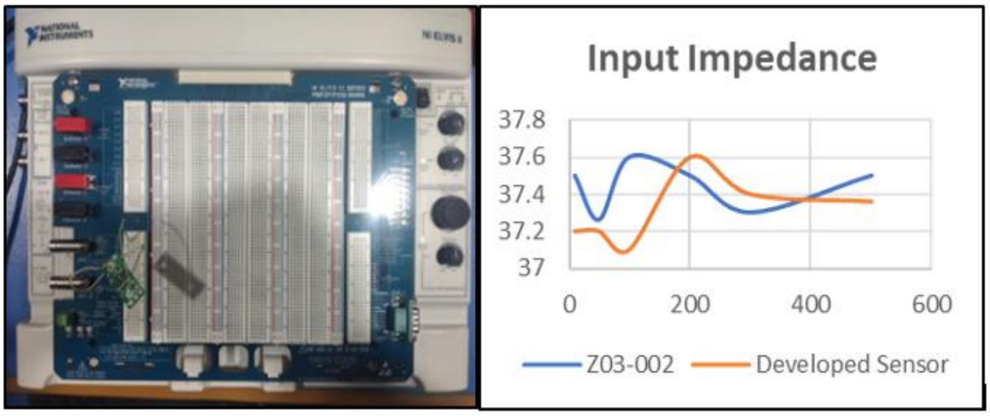

Figure 56: Input Impedance of Sensor

5.7. Discussion

The acquisition of the EMG signal is very important and essential in the clinical testing for the diagnosis of the disorders. In the proposed research work, an active surface-based EMG sensor is proposed. The primary acquisition of the signal is done through the differential amplifier in which signal is acquired from 2xpoints and its subtraction is taken with reference of the ground. The gain of the INA is set as 35 to 40 to enhance the magnitude of the Raw signal that is the contamination of the multiple frequencies. The value of external resistor Rg is adjusted trough the loop of pin1 to pin8 to adjust the gain value. The formula for the Gain calculation is 1+50k/Rg, in this expression the Rg value decides the overall gain of the integrated circuit. The reference pin of the IC is further connected to feedback path from the RC timing constant circuit. In this circuit the feedback loop is used to set the reference of the signal to remove the offset of the IC. The time constant is adjusted to as RC and output of the RC time constant circuit is shorted with the reference pin of the IC. The gain of the circuit is adjusted to 160 through the external resistor values of the R2/R1. The acquired signal and then passed through the narrow band filter circuit through which the pass band gain is controlled by the R values of the external resistors. The spectrum of the signal is mostly converged at the frequency range of 10Hz to 180Hz because of the mean value of the PSD at 200Hz. The reason for the selection of the lower cutoff frequency is to remove the artifacts from the actual signal. The cutoff frequencies of the signal are adjusted using the 1+R2/R1 non-inverting formula, mean the output won't have the phase shift in it because of the noninverting gain. The output at this instant is filtered out through the combination of the external resistors. The attenuation factor of the band pass filter is measured as the -12dB/Octave. The sharp transition of the response makes sure the attenuation at defined level of the frequency magnitude. The acquired filtered output of the signal is passed through the notch filter where the Q factor is controlled through the value of the pass band gain factor. The gain is controlled again through the external resistor whereas, the control of bandwidth is achieved through the value of Q as 2.5 with K as 0.99, the reason for the narrow band width is to get the better signal quality in order to get desired signal. The developed sensor is compared with the already developed sensor Z03-002, the time domain signal of the sensor shows the mixed signal through which the determination of the SNR, response time is slightly difficult to measure but the mean signal can be measured through the time domain response. The output magnitude of the signal in case of the Z03-002 lies in the millivolt range but upon the exposure of the power line interference the output of the signal goes to maximum rail voltages. The suppression in the proposed sensor is carried out through the T-Twin notch filter to suppress the power line interference to ±20mV range of the signal. There are two main ways to measure the SNR of the signal, the first way is to check find the mean value of the signal is acquired through the averaging filter in the controller. The obtained value of the sensor is then used to measure the signal to noise ratio of the signal is then acquired by 20xlog (Ratio of Signal to Noise), for the case of the power the same formula gets change to 10log (Ratio), the determination of the SNR is important to determine the rest activity of the signal and action signal of the muscle. The amount of the force exerted on the sensor is directly proportional to amount of applied action potential. The developed sensor is tested on 3x subjects that includes 1xNormal and 2 amputees for the determination of the strength of the signal.

CHAPTER 6: CONCLUSION

The contraction of the muscle is based on the exchange of the ions that is the present beneath the muscle. In this activity various processes works to provide the desired signal. The nature of the EMG signal is very random in nature because of the immense noises involved in the actual signal. The current EMG sensors are expensive and because of this most of the amputees can't afford this, the control of the EMG signal can be acquired through the microcontroller using which the millivolts signal can also be measured. The best thing of the active EMG sensor is to use it without any specific method for the skin preparation. In the proposed approach the sensor is developed to meet the cost element and to acquire the same properties as compared to the available sensor. The commercially available sensor is extremely costly and import tax also imposes on it, in the proposed sensor all the utilized integrated circuits are economic by looking at the properties of the Z03-002 Sensor. The filtering approach of the filter is decided based on the response of the filter to filter out all the unwanted signal from the actual signal and to make the signal clean. The proposed sensor is compared with the commercially available sensor to compare the properties of the sensor with the standard available sensor. The signal to noise ratio, electrode impedance and input impedance of the electrode is compared with the Z03-002 sensor. The scope of this sensor is to use it in multiple applications where the main concern is to acquire the signal and determine the muscle activity at motor cortex point. The number of the neurons fired can also be the area of interest while using this proposed sensor. The future scope of the sensor lies in the further boosting of the signal to noise ratio as well as reduction of the size by looking at the standard available electrode spacing. The unit sensor can also be incorporated into the development of the myo arm band in order to further acquire the activity of the entire muscle. The clinical testing requires the amount of the flex required in order to provide the desired activity so that whenever the input of the patient will be detected then it must be transmitted wirelessly to the desired designation in order to monitor the muscle activity. In this regard the integration of the Bluetooth module in the existing sensor will also be the good approach to assess the activity of the patient. As far as the main issue is to acquire the data painlessly that's why active sensor is the best approach to utilize in the clinical testing and further utilization of the signal in biomedical based application for instance control of the robotic hand etc. The stroke patient recovery is also being widely adopted through this sensor using the any open source available algorithm.

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Completion Certificate

It is to certify that the thesis titled "Design and Development of Surface Based Active Sensor for Biomedical Applications" submitted by registration no MTS317846CEME, S/O Muhammad Aslam Mechatronics Engineering is completed in all respects as per the requirements of Main Office, NUST (Exam branch).

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