Design and Development of Low Cost Active Electrode for SEMG

A dissertation submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering
In
Electronic Instrumentation and Control

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DECLARATION

I hereby certify that the work which is being presented in the thesis entitled, "**Design and Development of Low Cost Active Electrode for SEMG**" in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronic Instrumentation and Control Engineering submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala is an authentic record of my own work carried out under the supervision of **Dr. Ravinder Agarwal**, Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, Punjab.

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I certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

Electromyography is a technique for measuring and recording the electric activity of muscles. Surface electromyogram signal (SEMG) is a common method of measurements of muscle activity from the surface of the skin. This signal can be used in diverse applications e.g. in hand prosthesis movements, physiotherapy/rehabilitation, sports training and interactions of the human body to industrial products and work conditions. In the present research work, various aspects of surface electrodes have been studied thereafter an active electrode was designed. It improved the input impedance, decreased movement artifacts and increased signal to noise ratio. Its small and low cost active electrode will enhance the mobility and is affordable by user.

CONTENTS

CHAPTER 1
Introduction

Muscles are the "**engine**" that our body uses to propel itself. It would be impossible for us to do anything without our muscles. They turn energy into motion. All activities due to movements of our body such as, lifting arm, dancing, running, eating, or even eye blinking are caused by the contraction and relaxation of muscle. Everything that we conceive of with our brain is expressed as muscular motion. We express every feeling using different muscles such as the muscles of mouth and tongue (speech, singing), the muscles of hand (writing, painting) or with the skeletal muscles (body language, dancing). They do everything from allowing us to walk to keeping our blood flowing. Muscles support the joint and stop them from moving incorrect. They are efficient at turning fuel into motion. They are long-lasting, self-healing and are able to grow stronger with practice.

There are three different types of muscles in the body:

1. **Skeleton Muscles:** These muscles play major role in body movement. There are approximately 640 skeletal muscles within the typical human body, and almost every muscle constitutes one part of a pair of identical bilateral muscles, found on both sides of a joint, resulting in approximately 320 pairs of muscles. Two or multiple groups of skeletal muscle antagonize each other. It means that when one contracts, the other(s) elongates. These are connected to the bones by tough cords of tissue called tendons. As the muscle contracts, it pulls on the tendon, which moves the bone. Hence these muscles support the skeleton. These contribute to nearly half of human body mass.

2. **Smooth Muscles:** Also called involuntary muscles since we have no control over them, are found within the walls of organs. Smooth muscle has the ability to stretch and maintain tension for long periods of time. They are supplied by autonomic nerves, and therefore, are not under voluntary control and respond slowly to stimuli. It contracts involuntarily, meaning that we do not have to think about contracting it because our nervous system controls it automatically. For example, our stomach and intestines do their muscular thing all day long, and, for the most part, we never know what's going on

in there. They also help keep our eyes focused without us having to think about it. Muscles of the blood vessels and the arrector pili muscles of the skin are more examples of smooth muscles.

3. **Cardiac muscles:** Also an "involuntary muscle" but is more similar in structure to skeletal muscle, is found only in the heart. The primary functions of the cardiac muscles are to contract and release. Its features are endurance and consistency. It can stretch in a limited way, like smooth muscle, and contract with the force of a skeletal muscle. Unlike other types of muscles, cardiac muscle never gets tired. It works automatically and constantly without ever pausing to rest. Cardiac muscle contracts to squeeze blood out of the heart, and relaxes to fill it with blood [1].

An electrical impulse that produces contraction of muscle fibers in the body is known as *myoelectric signal*. This term is most often used in reference to skeletal muscles that control movements. Each skeletal muscle consists of many fibre cells, which range in length from few millimeters (mm) to about 30 centimeters (cm) and have diameters of between 10 to 100 micrometers. Each muscle fibre is filled with smaller fibre called myofibrils which are packed with a highly ordered array of protein filaments. Nerve's message is carried by motor neuron from the brain and causes these filaments to interact, thereby making the muscle to shorten. Generally, the muscle will shorten to about 57% of their resting length during contraction and will achieve 70% of the resting length with more signals received [2].

Motor neuron, axon, and all of the muscle fibers together form a *motor unit*. Motor unit is established when the brain makes decision for example to move the arm and the nerve impulse that stimulate contraction carried in nerve by bundles of wire-like motor neuron from brain to muscle. When motor neuron is near to a muscle, it divides into several branches called axon terminals with each serves different muscle fiber. Combination of each motor neuron and the muscle fibers it stimulates is called a motor unit as shown in Figure 1.1.

Nerves conduct impulses through a travelling wave of depolarization along their axon. During electrical stimulation of the nerve along its course, waves of depolarization will travel in the both direction from that point. The exchange of ions across the muscle fibres innervated by the recruited motor unit result in small electrical current, which combined for

particular motor unit, is referred to as the Motor Unit Action Potential (MUAP). The aggregated electrical signal generated from all of the MUAPs in a detected area is the myoelectric signal, which is also known as *electromyogram (EMG)* [3].

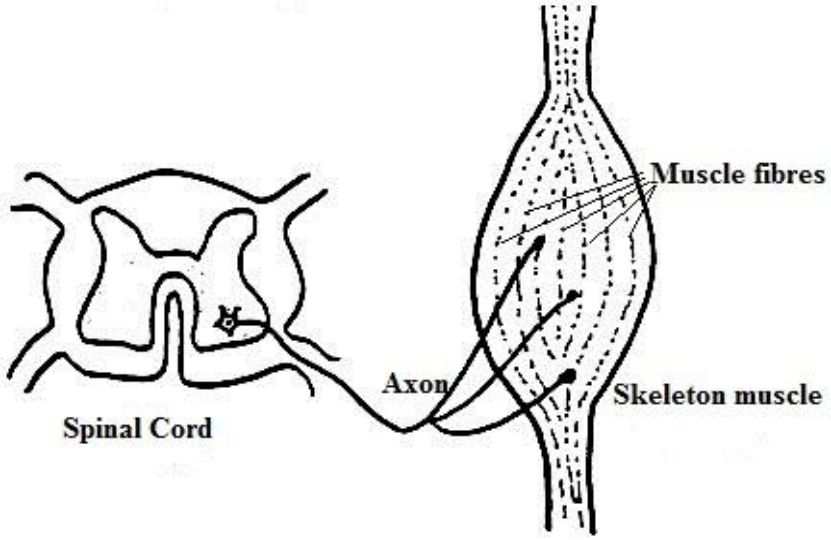


Figure 1.1: Motor unit [Online 1]

The EMG signal is a biomedical signal that measures electrical currents generated in muscles during its contraction representing neuromuscular activities. Biomedical signal means a collective electrical signal acquired from any organ that represents a physical variable of interest. The human body is made up of several tissues. Some of the tissues such as heart muscles, skeleton muscles, smooth muscles and nervous tissues produce electrochemical energy. The cells of these tissues contain ions like Na^+, K^+, Ca^+ and Cl^-.

Electrochemical signals are produced from the cells of these tissues when ionic concentrations within the cell change with respect to the concentrations outside the cell. These ions exist in the liquid medium of the cell and in the interstitial medium in between the cell. Under normal conditions, when cells are rest they have a greater concentration of K^+ and a lesser concentration of Na^+ inside the cell with respect to the interstitial medium. Within the cell, we have some ion channels through which specific ions can travel to and from the cell. It means that K^+ ions cannot travel through Na^+ channels, and Na^+ ions cannot travel through K^+ channels. These ion channels are called gated channels because they have molecular gates that can open and close.

When the cell is at rest, it is normally negative charged within with respect to the interstitial medium as shown in Figure 1.2. This occurs on account of an active Na/K pump. During this pumping action, two K^+ ions are pumped into the cell while three Na^+ ions are pumped out of it. Consequently, more positive ions leave than enter, which makes the cell more negative inside with respect to interstitial medium. The cell in resting stage thus has more K^+ ions inside it and is at negative potential. It is said to be *polarized*.

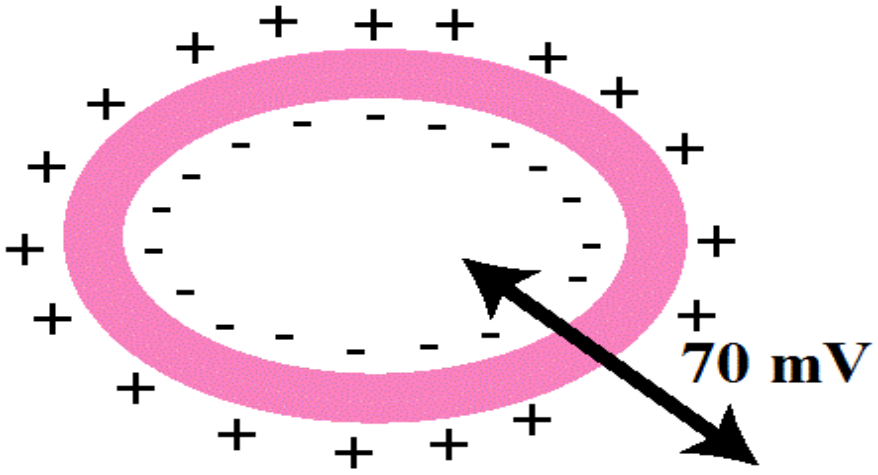


Figure 1.2: Resting cell potential [Online 2]

If a cell is given voltage stimulus to its cell membrane that causes it to be less negative inside, beyond a threshold negative voltage the Na^+ channels swing open, allowing Na^+ to rush into the cell. As this continues, it causes the inside of the cell to become more positively charged than the outside. The cell thus comes to net positive potential with respect to interstitial medium and is said to be *depolarized*.

When this happens the K^+ gate open, causing K^+ ions to rush outside the cell. The cell starts to become more negative inside again. Eventually all of the gates close again, and the Na/K pump acts to restore the cell membrane to its negative voltage inside with respect to the outside. This process of the cell turning negative again is termed as *repolarization* and is shown in Figure 1.3 [4].

The entire process may take as long as 1 millisecond in case of the nerve cell and as large as 300 milliseconds in case of a heart muscle. The change in voltage across the cell membrane

during this time is termed as action potential. The specific characteristic of the action potential depends upon the type of muscle or nerve fibre that is being stimulated.

The EMG signal is normally a function of time and is describable in terms of its amplitude, frequency and phase. The nervous system always controls the muscle activity (contraction/relaxation). Hence, the EMG signal is a complicated signal, which is controlled by the nervous system and is dependent on the anatomical and physiological properties of muscles.

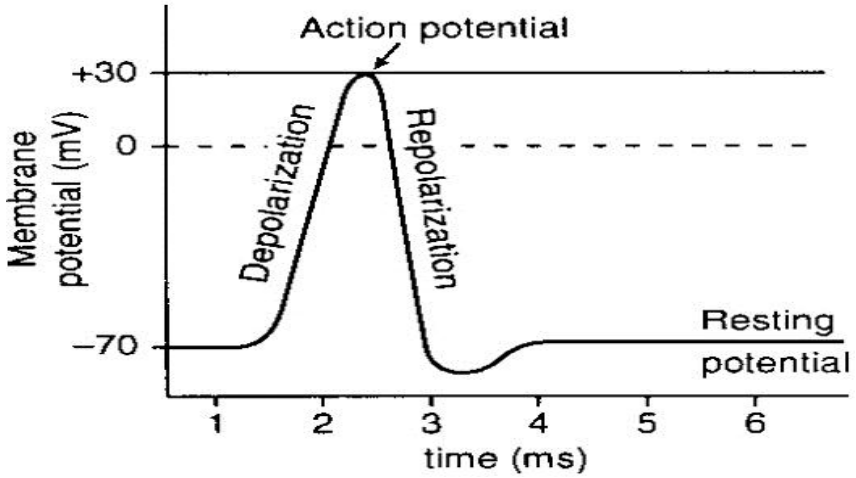


Figure 1.3: Action potential graph [Online 3]

1.1 History of EMG

The history of EMG has to do with the discovery of electricity and the development of the instruments to detect electricity. The theme of the development of SEMG can be traced back to mid-1600s, when Francesco Redi documented that a highly specialized muscle was the source of the electric ray fish's energy. By 1773, Walsh had been able to demonstrate clearly that the eel's muscle tissue could generate a spark of electricity. In 1790s Galvani obtained direct evidence of the relationship between muscle contraction and electricity. The first recording of this activity was made by Marey in 1890, who also introduced the term electromyography. Because of the stochastic nature of the myoelectric signal, only rough information could be obtained from its observation. The capability of detecting electromyographic signals improved steadily from the 1930s through the 1950s and researchers began to use improved electrodes more widely for the study of muscles [5-6].

1.2 Characteristics of EMG signal

It is well established that the amplitude of the EMG signal is stochastic (random) in nature and can be reasonably represented by a Gaussian distribution function. The amplitude of the signal can range from 0 to 10 mV (peak-to-peak) or 0 to 1.5 mV (rms) [7]. The usable energy of the signal is limited to the 0 to 500 Hz frequency range, with the dominant energy being in the 50-250 Hz range. Usable signals are those with energy above the electrical noise level. An example of the raw EMG signal as in Figure 1.4 and its frequency spectrum as shown in Figure 1.5 are presented below.

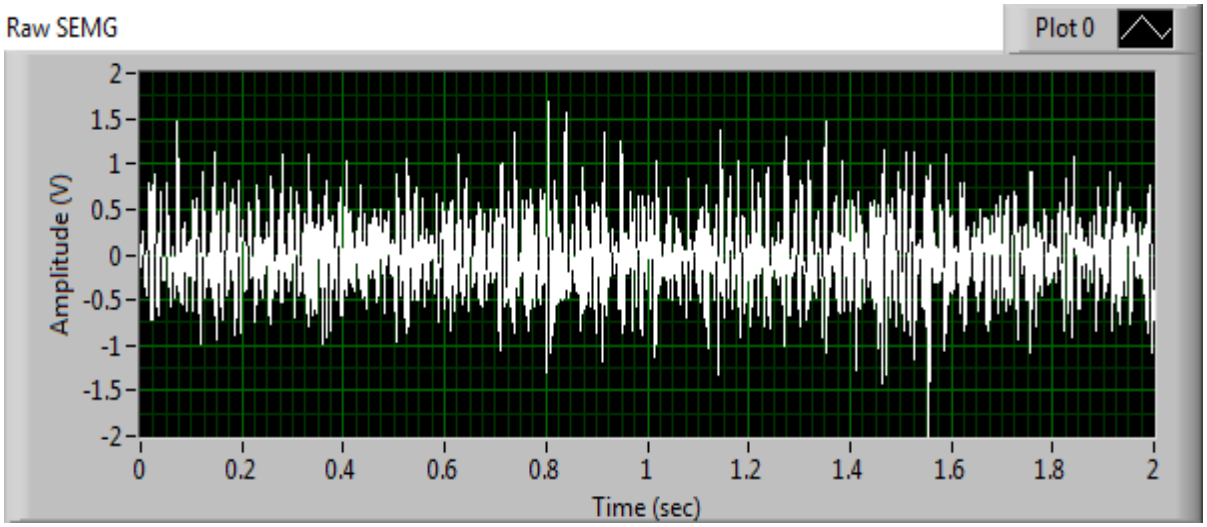


Figure 1.4: Raw EMG signal

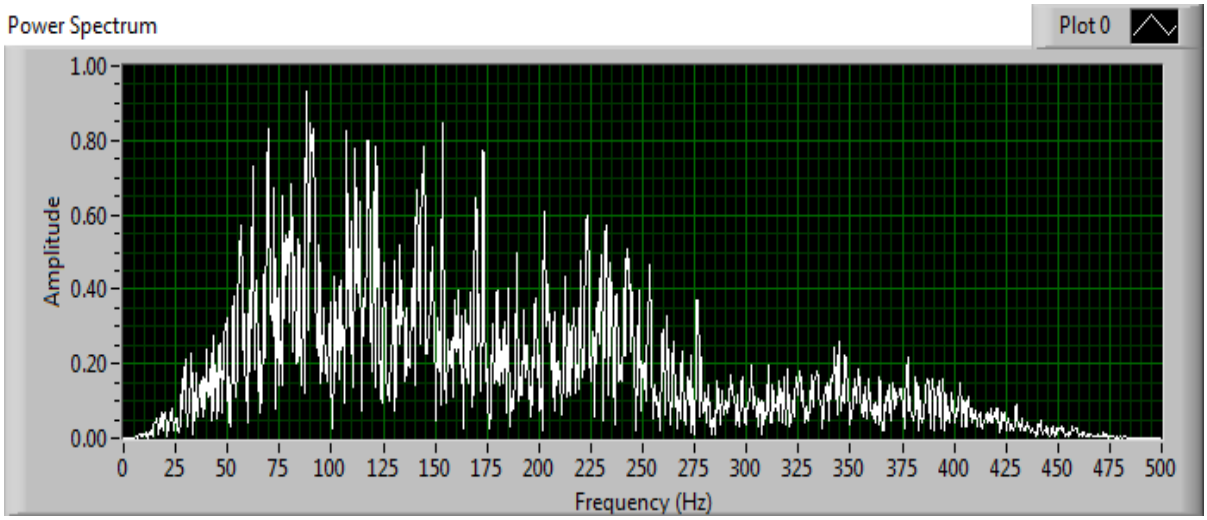


Figure 1.5: Useable Frequency spectrum of EMG signal

1.3 Electrodes

Devices that convert ionic potential into electronic potentials are called electrodes. These are the metal surface of the sensor which makes electrical contact with the skin. The electrodes used in electromyography are of a wide variety of types and construction. Their use depends on the first principle that they must be relatively harmless and must be brought close enough to the muscle under study to pick up the current generated by the ionic movement. The segment of the electrode which makes direct electrical contact with the tissue is referred as the *detection surface.*

1.4 Types of Electrodes

1. **Microelectrodes:** They have tips sufficiently small to penetrate a single cell in order to obtain readings from within the cell as shown in Figure 1.6. The tip must be small enough to permit penetration without damaging the cell. This action is complicated because of difficulty of accurately positioning an electrode with respect to cell.

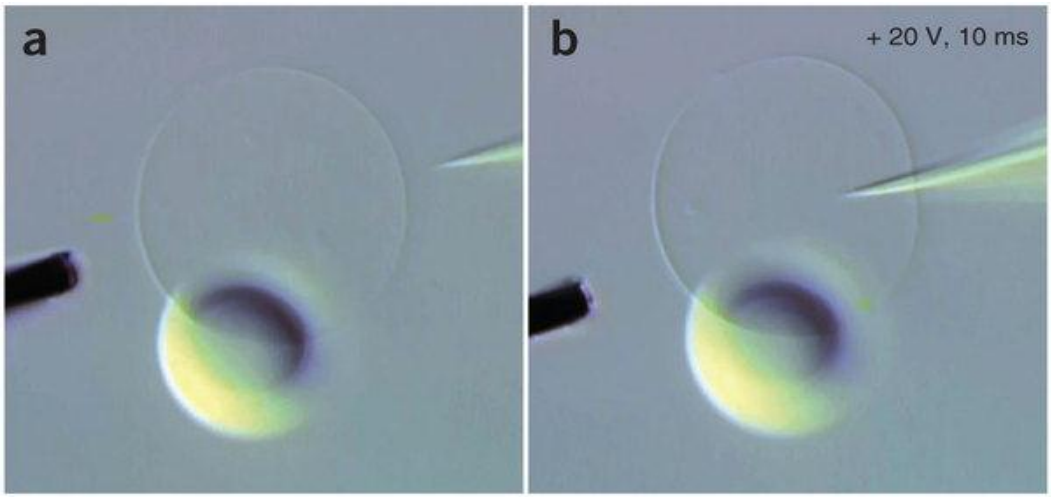


Figure 1.6: a) Cell and Microelectrode, b) Penetration of Microelectrode [Online 4]

2. **Needle electrodes:** These are used by inserting through a small section of skin just beneath the surface and parallel to it. They reduce interface impedance and movement artifacts. Often these electrodes are planted to permit repeated measurements over an extended period of time. Needle electrodes for EMG, as shown in Figure 1.7, consist merely of fine insulated wires, placed so that their tips, which are bare, are in contact

with the nerve, muscle, or other tissue from where the measurement is made. These types of electrodes are not used unless it is necessary to do so.

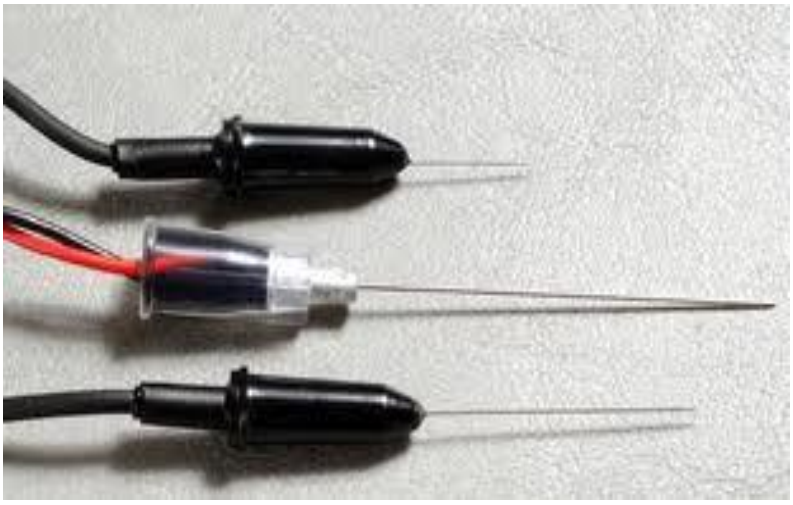


Figure 1.7: Needle Electrodes [Online 5]

3. **Skin surface electrodes:** These are used to obtain bioelectric potentials from the surface of the body. The earliest bioelectric potential measurements used immersion electrodes, which are simply buckets of saline solution into which the subject placed his hand and feet. A great improvement was the plate electrodes. These electrodes were separated from the subject's skin by cotton or felt pads soaked in a strong saline solution. Later a conductive jelly or paste replaced the soaked pads.

   All the previous electrodes suffer from common problem i.e. sensitive to movement. Even the slightest movement changes the thickness of the thin film of electrolyte between metal and skin. Later floating electrodes were introduced eliminating the movement artifact by avoiding any direct contact of metal with the skin. The only conductive path between metal and skin is the electrolyte paste or jelly, which forms an electrolyte bridge.

   Performance is not affected as long as the electrolyte bridge maintains contact with metal and skins both. In recent years disposable electrodes have been introduced to eliminate the requirement of cleaning and care after each use. These are cheap, small in size and require no maintenance. Two different types of skin surface electrodes are shown below in Figure 1.8 [4].

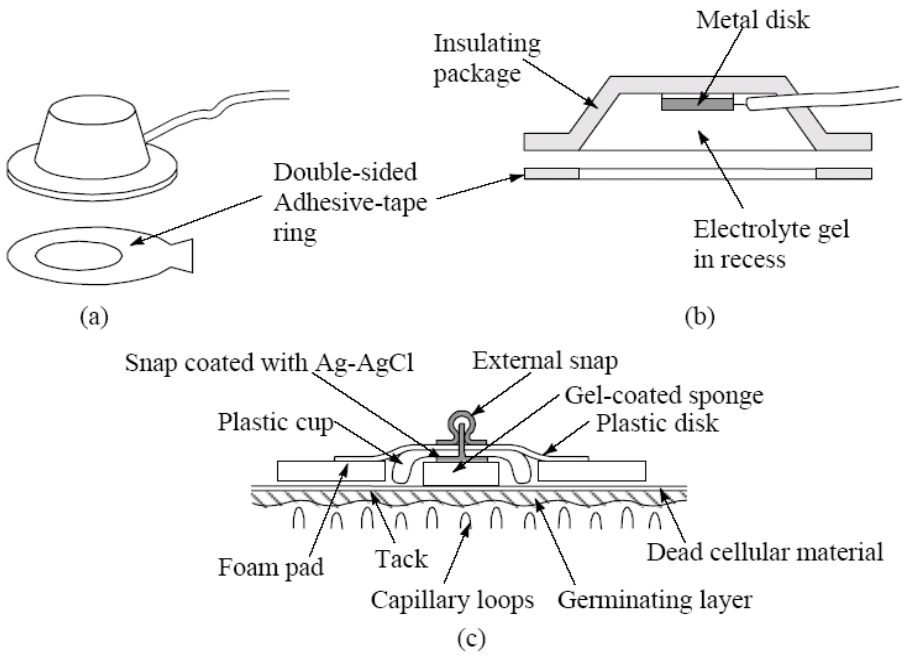


Figure 1.8: a) Floating electrode, b) Cross-sectional view, c) Disposable Electrode

1.5 Benefits of EMG

- EMG allows to directly "look" into the muscle.
- It allows measurement of muscular performance.
- Helps in decision making both before/after surgery.
- Documents treatment and training regimes.
- Helps patients to "find" and train their muscles.
- Allows analysis to improve sports activities.
- Detects muscle response in ergonomic studies [8].

1.6 Applications of EMG

EMG signals can be used for variety of applications like clinical or biomedical applications, human machine interaction, rehabilitation etc. Besides basic physiological and biomechanical studies, EMG is established as an evaluation tool for applied research, physiotherapy/rehabilitation, sports training and interactions of the human body to industrial products and work conditions. Clinical applications of EMG as a diagnostics tool can include neuromuscular diseases, low back pain assessment, kinesiology and disorders of motor control, posture analysis etc. Rehabilitation of a muscle may be necessary after post-surgery

or accident. EMG signal and its analysis also help in neurological rehabilitation. It can be used for preparing active training therapy and physical therapy of a muscle for a particular patient. EMG also helps in sports science. It is used in biomechanics and movement analysis of the sportspersons. It is helpful in preparing athletes strength training and sports rehabilitation after any injury. It is used diagnostically by gait laboratories and by clinicians trained in the use of biofeedback or ergonomic assessment [5].

1.7 Interim Conclusion

In this chapter importance of muscles was described. Their role in human body and its functionality was discussed. The biopotential signals from muscles help to diagnose them. These signals are generated from the cells of the muscles when they are stimulated by nerve cells. An electrical impulse that produces contraction of muscle fibers in the body is known as myoelectric signal. The aggregated electrical signal generated from all of the MUAPs in a detected area is the myoelectric signal, which is also known as electromyogram (EMG). To pick up these signals different types of electrodes are used which are explained above. At last applications of EMG were discussed.

CHAPTER 2
Literature Review

Electromyography (EMG) is a method for evaluating and recording the activation signal of muscle. A sensor is required to detect this activation signal while muscle contraction. There are two types of EMG sensors, namely passive and active. In recent years a good amount of work has been carried out to study, design and implementing EMG sensor and their classifications. Here in this chapter few of these have been discussed briefly.

C. P. Fermo [9], this work presents the development of a sensor for detecting human muscle contraction, which captures myoelectric signals (EMG), in order to control a myoelectric prosthesis of superior limb. A strategy is proposed for controlling the artificial hand, based on the myoelectric signal. This way, the patient has a more accurate and easier control of the movement of the prosthetic device, thus leading to a faster adaptation. Through a proposed control strategy, a method to analyze the pattern of the myoelectric signal is defined. It is stated that several kinds of actuating of the artificial hand can be obtained by a simple binary signal or through the analysis of the myoelectric signal pattern.

K. Rendek [10], this work presents differential amplifier designated as a part of modular biomedical sensor system (MBSS) used for EMG (electromyography) signal measurements. The design consists of the portable battery powered EMG sensors and computer (PC) extended by RF communication module used for transfer the EMG signals measured on separate body places. The wireless EMG sensor contains the electrodes placed on human body, analog amplifier, analog to digital converter, microcontroller containing complete radio block and power source.

Youn Wonkeun [11], this paper proposes a compact-size and a wireless surface EMG (electromyography) measurement system of a noninvasive type. The limitations of the current EMG sensor system include its large size, and the necessity of a wire. Study in this paper is focused on the development of a compact size preamplifier and wireless EMG measurement system. The EMG described herein is comprised of a preamplifier including an electrode for the measurement of the EMG signal, a main amplifier for signal processing,

DSP (digital signal processor) processor for A/D conversion and digital signal processing, and a Bluetooth module for wireless communication. EMG signal obtained by the developed system results in better signal-to-noise ratio (SNR) compared to commercially available EMG system. This SNR of the developed system can be attributed to repeated signal processing on analog circuit and DSP, which reduces the size of the developed system. In their power spectral density, the EMG signal was distributed between approximately 20Hz and 400Hz.

Chih-Cheng Lu [12], in this paper a lightweight concentric ring electrode with build-in amplifier that provides superior localized EMG signal from body surface was developed. A light weight (2gm) miniature (15mm in diameter 3.5 mm in thickness) active concentric ring sensor with high input impedance (10GΩ) was used to obtain localized EMG activity from body surface without skin preparation. The amplifier is mounted directly above the concentric ring electrode with low system noise (0.7mV rms at gain of 1000) with a high pass filter of 15 Hz and a low pass filter at 10 KHz. The reference connection is at the back, on top of the active sensor. The high common mode rejection ratio (118dB typical) with high input impedance and lightweight makes concentric ring EMG active sensor user-friendly and easily adaptable to most EMG acquisition system.

Richard A. Sherman [13], this paper concerns about instrumentation-related issues important for using psychophysiological recording and biofeedback devices to properly record and feedback signals from muscles using standard surface electromyography (SEMG) techniques. Issues appear at every stage in the recording and feedback process and these aspects are accordingly discussed in some detail. Some of the main stages discussed in this paper are signal production, its successful transfer from skin to machine and its recording, different placement of sensors and its basic components.

Young Darrin J. [14], this paper presents a wireless, subfascially implantable electromyogram (EMG) sensing microsystem for intelligent myoelectric control of powered prostheses. The implantable system consists of a custom-designed ASIC, an RF telemetry coil, and two Pt-Ir epimysial EMG electrodes, and is capable of wirelessly transmitting digitized EMG data to an external telemeter mounted in a prosthetic socket. The prototype microsystem is powered by a near-field inductive link operating at 8 MHz with 10% DC

power transfer efficiency. The EMG electrodes are interfaced with a differential capacitively-coupled amplifier with 38 dB closed-loop gain, 1 kHz bandwidth, and 78nV/$\sqrt{Hz}$ input-referred noise floor. The amplified EMG signal is then digitized on chip by using an 11-bit algorithmic ADC. The digital EMG data can be Manchester-coded and transmitted to the external telemeter using passive phase shift keying (PSK) modulation scheme over the same wireless link as the inductive powering system. The implantable microsystem consumes 83 µA and achieves 8.7-bit resolution when wirelessly powered by an external RF energy source.

Scott Day [15], Small electrical currents are generated by muscle fibers prior to the production of muscle force. These currents are generated by the exchange of ions across muscle fiber membranes, a part of the signaling process for the muscle fibers to contract. The signal called the electromyogram (EMG) can be measured by applying conductive elements or electrodes to the skin surface, or invasively within the muscle. Measurement of surface EMG is dependent on a number of factors and the amplitude of the surface EMG signal (SEMG) varies from the uV to the low mV range.

Chih-Jen Yen [16], this work presents a micro-power low-offset CMOS instrumentation amplifier integrated circuit with a large operating range for biomedical system applications. The equivalent input offset voltage is improved using a new circuit technique of offset cancellation that involves a two-phase clocking scheme with a frequency of 20 kHz. Channel charge injection is cancelled by the symmetrical circuit topology. With the wide-swing cascode bias circuit design, this amplifier realizes a very high power-supply rejection ratio (PSRR), and can be operated at single supply voltage in the range between 2.5– 7.5 V. It was fabricated using 0.5- m double-poly double- metal -well CMOS technology, and occupies a die area of 0.2 mm^2. This amplifier achieves a 160-µV typical input offset voltage, 0.05% gain linearity, greater than 102-dB PSRR, an input-referred rms noise voltage of 45 V, and a current consumption of 61µA at a low supply voltage of 2.5 V. Experimental results indicate that the proposed amplifier can process the input electrocardiogram signal of a patient monitoring system and other portable biomedical devices.

P. H. Chappell [17], Loss of a natural hand means that the neural connections between the brain and the palm, fingers and thumb are also lost, including any feedback paths e.g. sensing

temperature. In this research, the author is having an artificial hand with sensors allowing for the inclusion of automatic control loops, freeing the user from the cognitive burden of object holding which is similar to the natural low level spinal loops that automatically compensate for object movement. Force, object slip and finger positions are variables that need to be measured in a hand designed for the physically impaired person. A high specification is required for any sensor design.

Wendy Franks B [18], a low electrode-electrolyte impedance interface is critical in the design of electrodes for biomedical applications. To design low-impedance interfaces a complete understanding of the physical processes contributing to the impedance is required. In this work a model describing these physical processes is validated and extended to quantify the effect of organic coatings and incubation time. Electrochemical impedance spectroscopy has been used to electrically characterize the interface for various electrode materials.

R. Merletti [19], this review focuses on a few methodological aspects concerning electrical stimulation of the peripheral nervous system, detection, and processing of the electrically evoked myoelectric signals in skeletal muscles. The repeatability of electrically-evoked myoelectric signal shape as well as spectral and amplitude parameters, conduction velocity and elicited torque were tested, in isometric conditions. Contractions were elicited by stimulation of the main muscle motor point and repeated after removal and replacement of the stimulation and detection electrodes in the same carefully marked locations. Comparison of these parameters with those obtained during voluntary contractions provides additional insight into muscle physiology. The relationships between myoelectric signal amplitude parameters, spectral parameters, and conduction velocity were discussed with special reference to muscle fatigue.

T. S. POO [20], presents the development of low cost physiotherapy monitor system. The design of the low cost monitoring system has two channel input and a small size base platform. For the ease of study, the system will be designed based on one selected muscle. Simple EMG signal is output from the low cost platform and sent into computer. The signal is acquired from SEMG electrode attach on the muscle and is sent into computer as the

output from the develop platform. Small and low cost monitoring system will enhance the mobility and it's affordable by user.

P. A. Lichter [21], it investigates the design components for replacing external electrodes with fully implantable myoelectric sensors that include a wireless interface to the prosthetic limbs. This implanted technology will allow prosthetic limb manufacturers to provide products with increased performance, capability, and patient-comfort. The EMG signals from the intramuscular recording electrode are amplified and wirelessly transmitted to a receiver in the prosthetic limb. Power to the implant is maintained using a rechargeable battery and an inductive energy transfer link from the prosthetic. A full experimental system was developed to demonstrate that a wireless biopotential sensor can be designed that meets the requirements of size, power, and performance for implantation.

Mohan C. [22], describes a laboratory project involving controlling a motor in forward and reverse direction using electromyogram (EMG) signal without feedback. It could be used to implement a real time EMG signal based prosthesis hand and to study microcontroller applications. In this design, the low level signal of EMG is amplified, filtered with band-pass filter and rectified with precision rectifier before giving to microcontroller. The EMG signal is analyzed in the form of count. Since the project made with microcontroller and integrated technology, it gives knowledge of component level and system level design.

Hardeep S. Ryait [23], in this study, myoelectric signals were extracted by using a single-channel SEMG amplifier consisting of a differential amplifier, non-inverting amplifier, and interface module. Matlab softscope was used to acquire the SEMG signal from the hardware. After acquiring the data from six selected locations, interpretations were made for the estimation of parameters of the SEMG using the Matlab-filter algorithm and the fast Fourier transform technique. An interpretation of wrist/grip operations using principal component analysis (PCA) was carried out. Two acupressure points (on wrist) were also selected for the analysis with other points on the arm.

Lena Gourmelon [24], the SEMG signal is a combination of several activation signals sent through the muscle fibers triggering the contraction of the muscle. SEMG enables to access those signals non-invasively**.** Generally metal plate electrodes in combination with

electrolytic gel are placed in direct contact with the skin to measure SEMG. For prolonged monitoring of the muscle activity, this type of electrodes is not comfortable and can cause skin irritation. In this paper, we demonstrate capacitive electrodes capable of sensing the SEMG signal. These contactless electrodes do not require direct contact with the skin and thus they can be suitable for prolonged monitoring of the muscle activity.

Pascal Laferriere [25], in this study surface EMG signals from Fraunhofer Institute for Biomedical Engineering (IBMT) flexible dry electrodes and Orbital Research electrodes were compared to signals from conventional Ag/AgCl electrodes. EMG measurements were performed on the right tibialis anterior for a range of different activities, such as light twitches, isometric contractions, jumping, and walking. Signal feature comparisons, skin preparation effects (i.e., cleaning with isopropyl alcohol), and impedance–noise analyses were performed. Results showed that both dry electrodes had comparable sensitivity to the standard Ag/AgCl electrodes for detecting small unloaded muscle contractions and large loaded contractions. Results also showed that noise content and impedance are weakly correlated and skin preparation methods did not have a positive effect on skin/electrode impedance.

Andres Herrera [26], the objective of this research work was to design and construct a prosthesis that will be strong and reliable, while still offering control on the force exerted. The design had to account for mechanical and electrical design reliability and size. These goals were targeted by using EMG in the electrical control system and a linear motion approach in the mechanical system. The prosthetic gripper uses EMG to detect the amputee's intended movement. Two control systems were implemented for the gripper: (i) Electrical control to convert the amputee impulses into the gripper actions. (ii) Mechanical control to regulate the force exerted by the prosthetic fingers. The control system requires an adaptation mechanism for each amputee's characteristics.

S. H. Roy [27], this study compared the performance of surface electromyographic (sEMG) sensors for different detection conditions affecting the electro-mechanical stability between the sensor and its contact with the skin. These comparisons were made to gain a better understanding of how specific characteristics of sensor design and use may alter the ability of SEMG sensors to detect signals with high fidelity under conditions of vigorous activity. The

first part of the study investigated the effect of different detection surface contours and adhesive tapes on the ability of the sensor to remain in electrical contact with the skin. The second part of the study investigated the effects of different skin preparations and hydrophilic gels on the production of movement artifact resulting from sinusoidal and impact mechanical perturbations. It is found that contouring the detection surface and adding a more adhesive double-sided tape were effective in increasing the forces needed to disrupt the electrical contact between the electrodes and the skin for both dry skin and wet skin conditions. The mechanical perturbation tests demonstrated that hydrophilic gel applied to the detection surface of the sensor produced greater movement artifacts compared to sensors without gel, particularly when the sensors were tested under conditions in which perspiration was present on the skin.

D. K. Kumar [28], this paper reports experimental research undertaken to study the effect of variation of inter-electrode distance on the Surface Electromyogram (SEMG). The experiments were conducted on ten healthy subjects and they performed isometric contraction of their biceps of the right arm at 20, 50 and 80% of their maximal voluntary contraction (MVC). SEMG was recorded using surface electrodes with the distance between the two active electrodes maintained at 18 and 36mm. The distant electrode position was fixed for all the experiments. It was observed that at low levels of muscle contraction there was no significant variation due to the change in the distance between the electrodes while at 50% and 80% of MVC there was a significant change in the amplitude of the SEMG measured by the continuous RMS of the signal. The study has confirmed the well-known belief that there is an increase in the RMS of SEMG with muscle contraction but the clearly demonstrates that comparison should only be done if the distance between the electrodes is kept constant.

CHAPTER 3

Surface ElectroMyoGraphy (SEMG)

EMG signals can be acquired both invasively, using needle electrodes, and non-invasively, by placing electrodes on the surface of the skin. The latter non-invasive case is termed as *surface electromyography (SEMG)* and is a common method used for acquiring the signals from muscle in both static and dynamic contractions. Hence we can define surface electromyography (SEMG) as a non-invasive technique for measuring muscle electrical activity that occurs during muscle contraction and relaxation cycles.

3.1 Factors Effecting SEMG Signal

Many different factors enter into the production of EMG signal. These are:

- Type of muscle tissue.
- Use of muscle.
- Diameter of muscle fibre.
- Number of muscle fibres per bundle.
- Degree of individual development.
- Degree of fatigue present.

With regards to recording the EMG signal, there are few main issues of concern that influence the fidelity of the signal.

1. **SNR**: That is, the ratio of the energy in the EMG signals to the energy in the noise signal. In general, noise is defined as electrical signals that are not part of the wanted EMG signal. The noise may come from various sources such as:

   • **Inherent noise** is due to the electronic components used in the detection and recording of the signal**.** All electronics equipment generates electrical noise. This noise has frequency components that range from 0 Hz to several thousand Hz. This noise cannot be eliminated; it can only be reduced by using high quality electronic components, intelligent circuit design and construction techniques.

• **Ambient noise** - This noise originates from sources of electromagnetic radiation, such as radio and television transmission, electrical-power wires, light bulbs, fluorescent lamps, etc. In fact, any electromagnetic device generates and may contribute noise. The surfaces of our bodies are constantly inundated with electric-magnetic radiation and it is virtually impossible to avoid exposure to it on the surface of the earth. The dominant concern for the ambient noise arises from the 60 Hz (or 50 Hz) radiation from power sources. The ambient noise signal may have amplitude that is one to three orders of magnitude greater than the EMG signal.

• **Motion artifacts** - There are two main sources of motion artifact: one from the interface between the detection surface of the electrode and the skin, the other from movement of the cable connecting the electrode to the amplifier. Both of these sources can be essentially reduced by proper design of the electronic circuitry. The electrical signals of both noise sources have most of their energy in the frequency range from 0 to 20 Hz.

• **Inherent instability of the signal** - The amplitude of the EMG signal is quasi-random in nature. The frequency components between 0 and 20 Hz are particularly unstable because they are affected by the quasi-random nature of the firing rate of the motor units which, in most conditions, fire in this frequency region. Because of the unstable nature of these components of the signal, it is advisable to consider them as unwanted noise and remove them from the signal [15].

2. **Depth of the muscle** is an important variable. Figure 3.1 shows how one may think about this matter. Actually, the conducting medium acts as a partial short circuit to the electrical output of the muscle. Two muscles are shown which are about equally active, but they lie at different depths under the skin and therefore, the amount of conducting medium lying between the skin and muscle is different in the two cases.

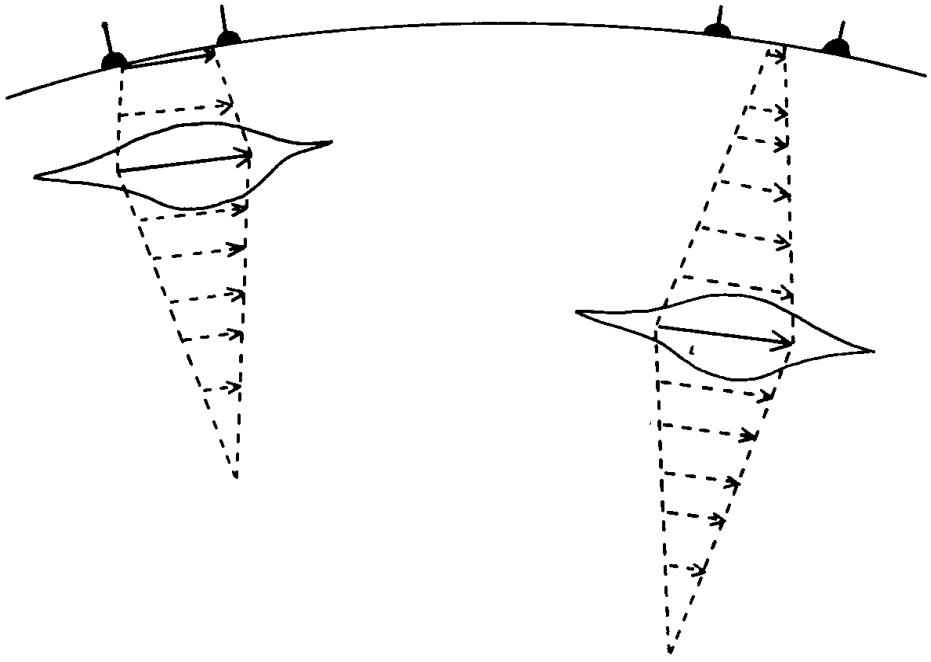


Figure 3.1: Surface activity and Depth of muscle [Online 6]

3. **Spacing of electrode** on the surface over a muscle is another important variable in this work. The little vectors just under the skin, shown in Figure 3.2, and which represent the amount of electrical potential reaching the skin, do not, of course, appear only at one small point.

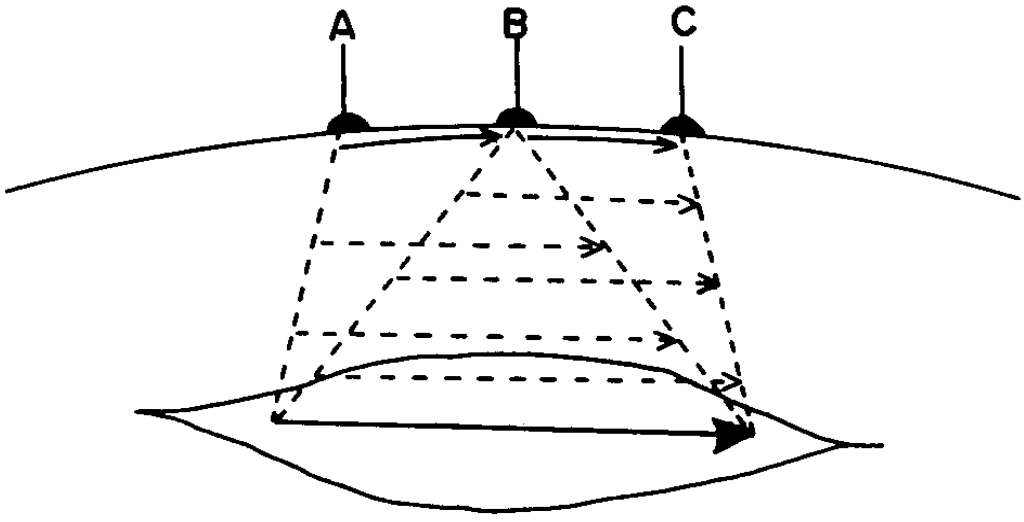


Figure 3.2: Effect of electrode spacing [Online 6]

They appear in varying degree all over the skin nearby but, in general are largest immediately over the muscle involved. Above figure shows the three electrodes placed immediately over a muscle. If the pair of electrode AB and the pair BC are of similar spacing and are more or less symmetrically placed over the muscle, one would expect to get about the same amount of electrical activity from each pair. Now if we consider the outside pair of electrodes AC, we are adding electrically the two small vectors AB and BC, and we would expect to get about twice as much electrical activity from the third pair. Thus, where fairly large muscles are involved we anticipate some proportionality between the electrode spacing and the amount of electrical activity picked up.

4. **Separation of Activity** from neighboring muscles is probably best accomplished with electrodes spaced closed together over the desired muscle. In case of two muscles with equal activity at different depths as shown in Figure 3.3, we can see how the mixed signal will be picked up by electrodes of different spacing.

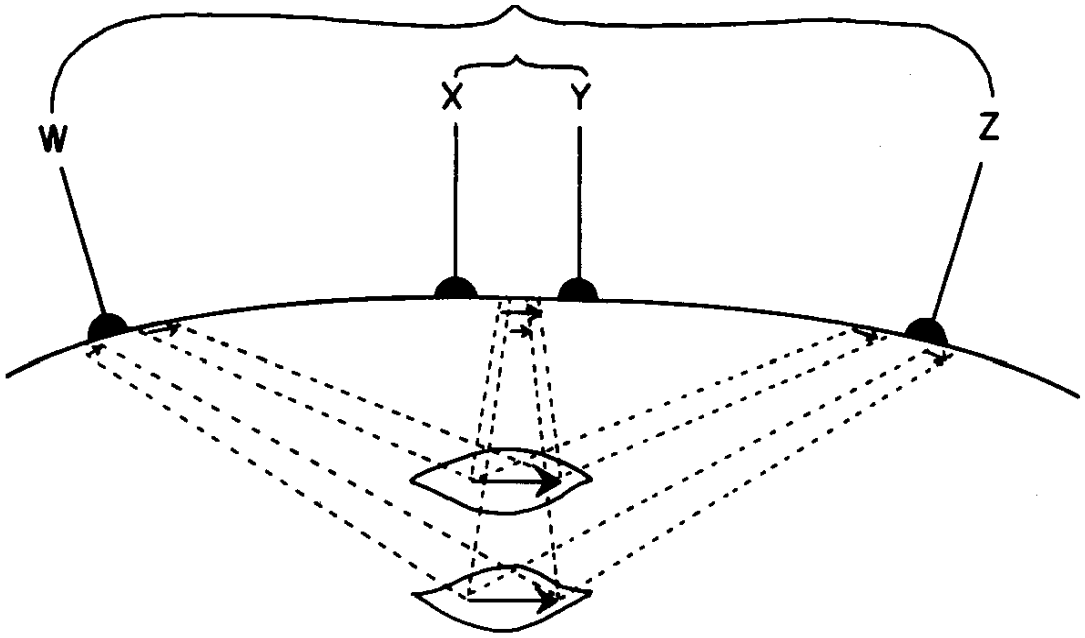


Figure 3.3: Differentiation of muscles at varying depths [Online 6]

With narrowing spaced electrodes we will obtain a certain ratio of desired to undesired signals from the two muscles. As the spacing is increased, both the desired and undesired signals increase so that the ratio remains constant for a time and there is no gain or loss in

differentiation. However, as the spacing between electrodes approaches and exceeds the physical size of the desired muscle, the desired signal no longer increases in proportion to the increasing electrode spacing. The signal from the undesired muscle may, at the same time, continue to increase in proportion to the spacing since the surface electrical field from this deeper muscle may be more uniform. Again from the figure, XY electrodes evidently would discriminate against the signals from the deeper muscles better than the WZ electrodes [29].

3.2 Advantages and Disadvantages of SEMG

The use of SEMG signal has many advantages:

- Surface EMG provides a safe and easy method that allows objective quantification of the energy of the muscle.
- Since it is a non-invasive method therefore it is not necessary to penetrate the skin and record from single motor unit to obtain useful and meaningful information regarding muscles.
- This technique allows the observer to see the muscle energy at rest and changing continuously over the course of the movement.
- With the use of multiple sensor arrays, it becomes possible to differentiate how different aspects of muscle do different things.
- The tracings and numerical printouts associated with SEMG provide information to clinicians and researchers regarding mechanisms of muscle function and dysfunction.
- The biological information obtained via SEMG methods can be feedback to the patient, providing the basis for neuromuscular reeducation and for self-regulation. Such information can fine tune the response of the patient's nervous system to the therapist's verbal instructions.

Disadvantages of SEMG are:

- We can monitor only few muscle sites. We cannot have EMG of those muscles which are deep inside the human body.

- One channel of SEMG information is very limiting. At a minimum, a four channel SEMG instrument allows one to study the right and left aspect of two opposing groups. At this level information becomes more meaningful and practical.
- Major difficulty with SEMG is the possibility of crosstalk, a phenomenon where energy from one muscle group travels over into the recording field of another muscle group. When this happens, problem may arise in the specificity of SEMG recording [30].

3.3 Types of Surface Electrodes

The first is active electrodes, which have built-in amplifiers at the electrode site to improve the high dry skin impedance. Figure 3.4 shows two types of active electrodes. No skin preparation is required for these electrodes. They decrease movement artifacts and increase the signal to noise ratio. Another reason to use active electrodes is safety. Because the dry skin-electrode impedance is very high (a few megaohms) then the isolation barrier is much higher and a chance for an electric shock is very less.

Figure 3.4: Active electrode [Online 7]

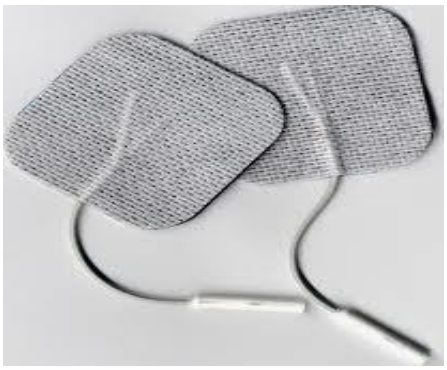


Figure 3.5: Passive electrodes [Online 8]

The other is a passive electrode, which detects the EMG signal without a built-in amplifier, making it important to reduce all possible skin resistance as much as possible (requires conducting gels and extensive skin preparation). An example of passive electrode is shown in Figure 3.5. They are sensitive to movement hence causing movement artifacts. Even the slightest movement changes the thickness of the thin film of electrolyte between metal and skin and thus causing changes in the electrode potential and impedance. With passive electrodes, signal to noise ratio decreases and many movement artifacts are amplified along with the actual signal once amplification occurs.

3.4 Electrode Configurations

There are also some electrode configurations that can also aide in decreasing unwanted noise. Figure 3.6(a) shows a monopolar arrangement, the easiest as it is a single electrode and a ground. However, this arrangement picks up more unwanted signals than any of the other potential configurations.

Bipolar arrangements as shown in Figure 3.6(b) are widely used in movement analysis. In this arrangement, there are two active electrodes and a ground. The process is to look at what is common with the two active electrodes and determine that this is noise and throw it away, keeping what is different in the two electrodes as the signal of interest. This is termed a differentially amplified system and is less prone to interference from adjacent and deeper muscles.

Figure 3.6: (a) Monopolar Electrodes [Online 9] (b) Bipolar Electrodes [Online 10]

A third arrangement is that of a double differentiated system. This is a system that has three active electrodes and one ground, therefore, possessing the ability to have two pairs of bipolar signals which are then again differentially amplified. This gives a smaller pick-up area, therefore, even less noise than the bipolar electrode by itself. These electrode arrangements are unique to the amplified system purchased and much thought should be given when purchasing a system so that at minimum a bipolar system is acquired [31].

3.5 Interim Conclusion

In this chapter non-invasive method for EMG detection i.e. Surface EMG was described. All the factors that effect SEMG while recording were discussed. Its advantages and

disadvantages were presented. Electrodes used to detect these myoelectric signals and their types were discussed. At last the electrode configurations used to detect SEMG signals was discussed. These configurations help to reduce noise.

In the following chapters, design and implementation of the active sensor for detecting SEMG signal is discussed. The signals captured were processed and presented in the last chapter.

CHAPTER 4
Materials and Methodology

This chapter describes about the active electrode, its block diagram, components used, NI-DAQ for acquiring the SEMG signals. Labview is used for analyzing SEMG signals. SEMG signal is a very complex signal which is affected by various factors like anatomical and physiological properties of the muscles. The SEMG sensor is an electrochemical transducer that detects biopotentials using metallic contacts placed on the skin tissue. The transducing element depends on the ability of the interface between the sensor and skin to conduct an exchange between the ionic current of the various tissue media and the electron current flow of the recording instrumentation [27].

In the present research work an active SEMG sensor has been developed. It has built-in amplifiers at the electrode site to improve the impedance. No skin preparation is required for using this sensor. It decreases movement artifacts and increases the signal to noise ratio.

4.1 Block Diagram

The whole system of the active electrode is divided in two parts - amplifiers and filters. Figure 4.1 shows the block diagram of the sensor developed. There are total four stages, in which first is instrumentation amplifier. The next stage is that of High Pass filter which is followed by output Amplifier with gain of 1000. The last stage is a Low Pass Filter.

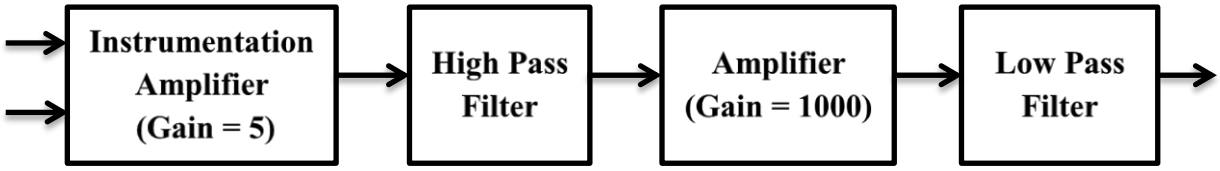


Figure 4.1: Block diagram of the SEMG sensor

4.1.1 Instrumentation Amplifier

In order to eliminate the potentially much greater noise signal from power line sources, a differential detecting configuration is used. The instrumentation amplifier is an amplifier

which accepts a differential input voltage and produces an amplified output voltage which is an amplified difference of the two input voltages. Its circuit is a combination of the differential input/output amplifier and the difference amplifier. The difference amplifier uses the differential output voltages from the differential input/output amplifier to drive the grounded load. The differential input/output stage offers a very high input resistance at each input terminal. The common mode signal attenuation for the instrumentation amplifier is provided by the difference amplifier.

The signal is detected at two electrodes and electronic circuitry subtracts the two signals and then amplifies the difference. As a result, any signal that is "common" to both detection sites will be removed and signals that are different at the two sites will have a "differential" and will be amplified. Any signal that originates far away from the detection sites will appear as a common signal, whereas signals in the immediate vicinity of the detection surfaces will be different and consequently will be amplified. Thus, relatively distant power lines noise signals will be removed and only local EMG signals will be amplified [32].

4.1.2 Filters

When a muscle contracts, it produces many different frequencies. Thus, when viewing a raw signal some distinctive looking peaks repeating a few times a second and other different looking peaks coming hundreds of times per second will be seen. The maximium amount of usable signal is present in bandwidth DC to 500Hz of the EMG signal. Frequencies outside this range are rarely of use and can be avoided by using a filter. In the present work two types of filter have been used. These are High pass and low pass filters [13].

A low-pass filter is an electronic filter that passes low-frequency signals and attenuates signals with frequencies higher than the cutoff frequency. High pass is just opposite to low pass filter i.e. it is an electronic filter that passes high-frequency signals and attenuates signals with frequencies lower than the cutoff frequency. High pass and low pass filters are generally used together to set the bandwidth of the signal selected for observation. In the present active sensor, SEMG signal is filtered using a band-pass filter consisting of a high-pass filter with 10 Hz cut off frequency to reduce motion artifacts and a low- pass Filter with 500 Hz cut off frequency to reduce noise and remove unusable signal [22].

4.2 Circuit Diagram

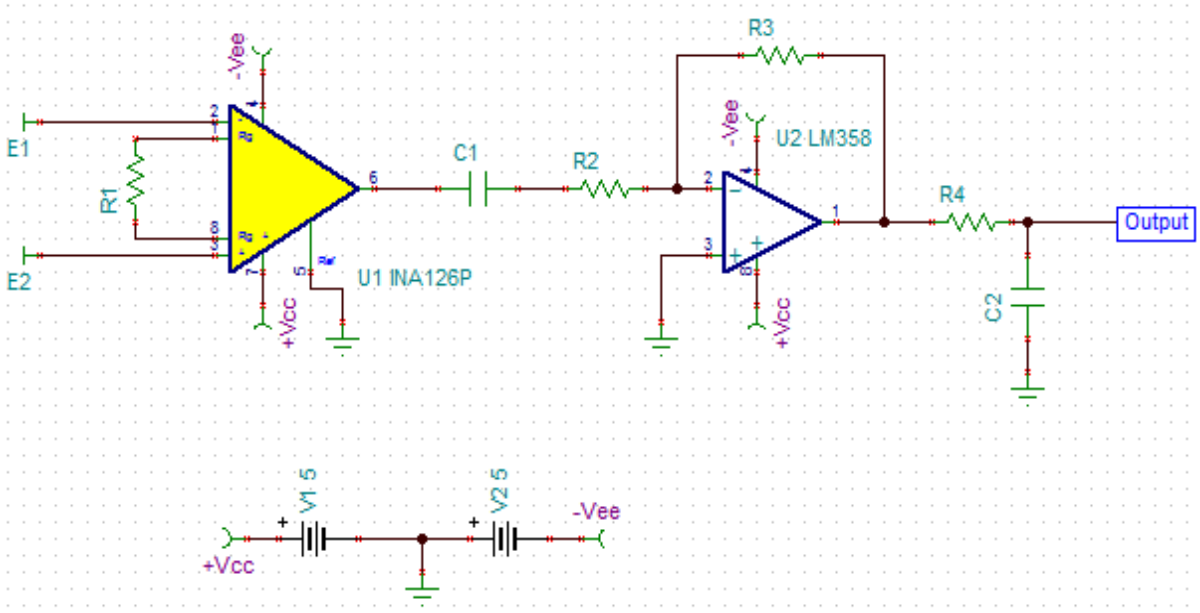


Figure 4.2: Schematic of the sensor

4.3 Components Description

1. In first stage of instrumentation amplifier, INA 126 as shown in Figure 4.3, is used thus eliminating the noise from external source. Its gain is set at five using external resistor (R_G) according to equation (1). The technical description of the IC is as follows:

Figure 4.3: 8-pin INA126 SOIC [Online 11]

These are precision instrumentation amplifiers for accurate, low noise differential signal acquisition. Their two-op-amp design provides excellent performance with very low quiescent current (175μA/channel). This, combined with a wide operating voltage range of ±1.35V to ±18V, makes it ideal for portable instrumentation and data acquisition

systems. It has an excellent common mode rejection. Gain can be set from 5V/V to 10000V/V with a single external resistor [33].

Gain (G) is set by connecting an external resistor (R_G) according to the following equation (1):

$$G = 5 + \frac{80k\Omega}{R_G} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Other features of this instrumentation amplifier are:

- CMRR: 90 dB
- Low quiescent current: 175μA/chan.
- Wide supply range: ±1.35V to ±18V
- Low offset voltage: 250μV max
- Low offset drift: 3μV/°C max
- Low input bias current: 25nA max

2. For the next stage amplifier IC LM358, as shown in Figure 4.4, is used. A gain of 1000 is set for this amplifier.

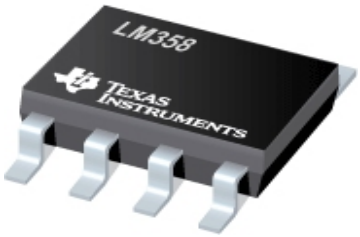


Figure 4.4: 8-pin LM358 SOIC [Online 12]

This device consists of two independent operational amplifiers designed to operate from a single supply over a wide range of voltages. Dual supplies can also be used for its operation if the difference between the two supplies is 3 V to 32 V, and V_{CC} is at least 1.5 V more positive than the input common-mode voltage. The low supply-current drain is independent of the magnitude of the supply voltage. These devices can be operated

directly from the standard 5V supply used in digital systems and easily can provide the required interface electronics without additional ±5V supplies [34].

3. Electrodes are the metal surface of the sensor which makes electrical contact with the skin. In the present work three circular electrodes with diameter 0.6 mm and thickness 0.6 mm have been used. These are made up of steel. All the three electrodes are arranged in an equilateral triangular shape with distance of 1 cm from surface to surface. Hence the distance between centers of the two electrodes is 16 mm. The three electrodes of the sensor form a bipolar arrangement of electrodes as shown in Figure 4.5. In this arrangement, there are two active electrodes and a ground. Any common signal between the two active electrodes is rejected. These three electrodes are connected to an instrumentation amplifier which amplifies the difference between the two active electrodes with respect to the ground electrode.

Figure 4.5: Equilateral triangle arrangement of three electrodes

Figure 4.6 shows the top view of the active sensor developed. It shows the actual sensor circuitry on the surface of the PCB.

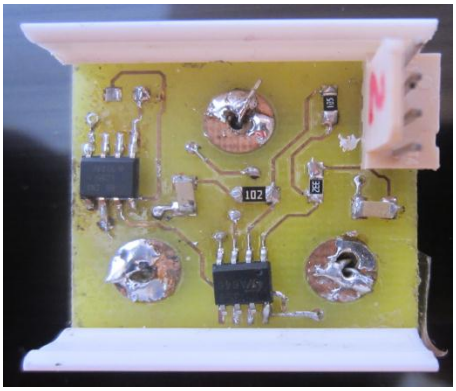


Figure 4.6: Top view of the sensor

4.4 LABVIEW

LabVIEW, abbreviated as Laboratory Virtual Instrument Engineering Workbench, is a powerful and flexible instrumentation and analysis software system. It is an interactive program development and execution system designed for people, like scientists and engineers, who need to program as part of their jobs as it uses terminology, icons and ideas which are familiar to them.

It is a graphical programming language that uses icons instead of lines of text to create applications. It relies on graphic symbols rather than textual language to describe programming actions. Its graphical nature makes it ideal for test and measurement (T&M), automation, instrument control, data acquisition and data analysis applications. This results in significant productivity improvements over conventional programming languages. In contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution. The design engineer can easily see the flow of data in the virtual sense. This helps in more rectified and appropriate systems.

LabVIEW offers more flexibility than standard laboratory instruments because it is software-based. It has extensive libraries of functions and subroutines to help you with most programming tasks, without the fuss of pointers, memory allocation, and other arcane programming problems found in conventional programming languages. LabVIEW also contains application-specific libraries of code for data acquisition (DAQ), General Purpose Interface Bus (GPIB), and serial instrument control, data analysis, data presentation, data storage, and communication over the Internet.

LabVIEW also includes traditional program development tools. You can set breakpoints, animate program execution to see how the program executes, and single-step through the program to make debugging and program development easier.

LabVIEW programs are called virtual instruments (VI) because their appearance and operation imitate actual instruments. They are LabVIEW programming element. VIs have both an interactive user interface and a source code. A VI consists of a front panel, bock diagram and an icon that represents the program [35-36].

4.4.1 Front Panel

The front panel is the interactive user interface of a VI, so named because it simulates the front panel of a physical instrument as shown in Figure 4.7. The front panel can contain knobs, push buttons, graphs, and many other controls (which are user inputs) and indicators (which are program outputs).

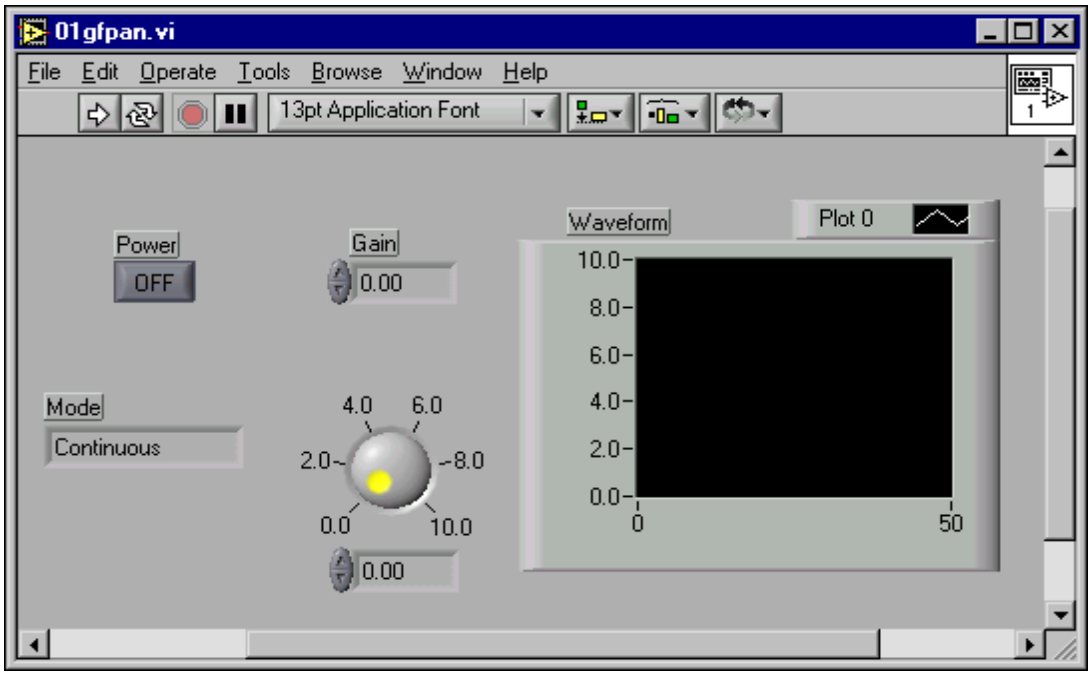


Figure 4.7: Front panel of a VI [Online 13]

4.4.2 Block Diagram

The block diagram contains the graphical source code as shown in Figure 4.8. The block diagram is the actual executable program. Block diagram objects include terminals, subVIs, functions, constants, structures, and wires, which transfer data among other block diagram objects. Wires are drawn to connect the appropriate objects together to define the flow of data between them. Front panel objects have corresponding terminals on the block diagram so data can pass from the user to the program and back to the user. The wire diagrams that are constructed do not define an order in which elements are executed.

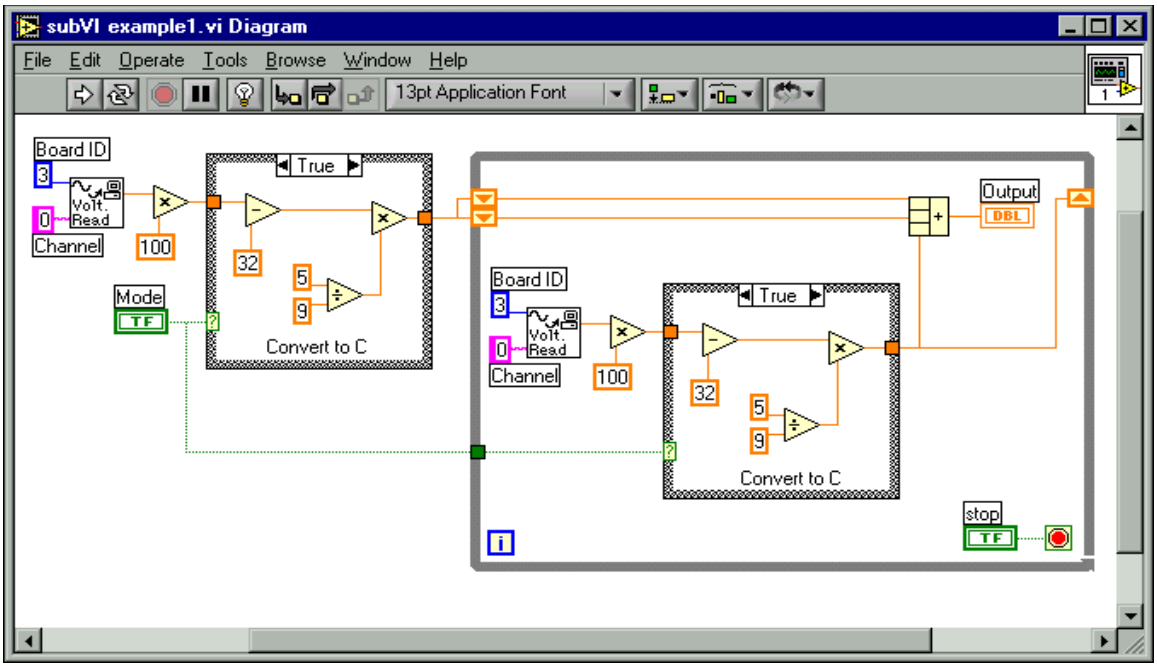


Figure 4.8: Block diagram of a VI [Online 13]

4.4.3 Icon

The icon and connector of a VI allow other VIs to pass data to the VI. The icon is a VI's pictorial representation and is used as an object in the block diagram of another VI. A VI's connector is the mechanism used to wire data into the VI from other block diagrams when the VI is used as a subVI. VI is hierarchical and modular. Much like parameters of a subroutine, the connector defines the inputs and outputs of the VI [35-36].

4.5 NI-DAQ

Data acquisition (DAQ) is the action of obtaining data from an instrument or device. These DAQ boards perform a variety of tasks, including analog measurements, digital measurements and timing input/outputs. NI-DAQ is a robust, time-proven driver for NI data acquisition and signal conditioning hardware. Using NI-DAQ, one can easily acquire, analyze, and present measurements in LabVIEW.

In this study, NI data acquisition card PCI – 6024E has been used for acquisition of SEMG signals. NI-DAQ also provide software driver which allow us to communicate between DAQ card and LabVIEW. NI-DAQ is the robust driver software included with all National

Instruments data acquisition and signal conditioning products. This easy-to-use software tightly integrates the full functionality of your DAQ hardware to LabVIEW, Lab Windows/CVI, and Measurement Studio for Visual basic.

The PCI-6024E features 16 channels of analog input, two channels of analog output, a 68-pin connector and eight lines of digital I/O. We are concerned only with the analog inputs of DAQ card. There are other functions also on this card, which include digital inputs, digital outputs, analog outputs, function generator, external triggering, dedicated port for thermocouple and transistor. It has a 12 bit successive approximation analog to digital converter. It has maximum sampling rate of 200000 samples/second. The DAQ card gets the operating power from a 68 pin connector which is used to connect it to computer system. The DAQ which has been used in this study is shown in Figure 4.9.

Figure 4.9: Data Acquisition System (NI-DAQ (PCI-6024E))

4.6 Methodology for SEMG Signal Acquisition

SEMG signals were acquired by using above explained active electrodes. Signals from active electrode were given to NI-DAQ card and were saved in computer with the help of LABVIEW. Five healthy male subjects were selected for signal acquisition in the age group of 24-28 years. Four continues trials were taken from every subject for different movements.

4.6.1 Sensor Locations

Four positions for each subject were selected on the arm. These are:

1) M1- Smaller forearm extensor.
2) M2- Flexor carpum ulnaris.
3) M3- Biceps.
4) M4- Triceps.

4.6.2 Activities Performed

Subjects were seated on a chair. Each subject was asked to perform eight different movements for different muscles activation. These eight different movements are as follows:

1) A1- Arm was perpendicular to body with hand at rest.
2) A2- Hand was moved upside perpendicular to the arm. This position is called extension hand and is shown in figure 4.10.
3) A3- Hand was moved down perpendicular to the arm. This position is called flexion hand and is shown in figure 4.11.
4) A4- In this movement subject was asked to close the hand keeping arm perpendicular to the body.
5) A5- Arm was in rest with downward position parallel to body.
6) A6- Hand was moved upside. This position is called flexion elbow and is shown in figure 4.12.
7) A7- Arm was rotated in clockwise direction.
8) A8- Arm was rotated in anticlockwise direction.

Figure 4.10: Extension hand

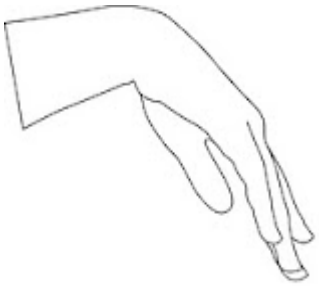


Figure 4.11: Flexion hand

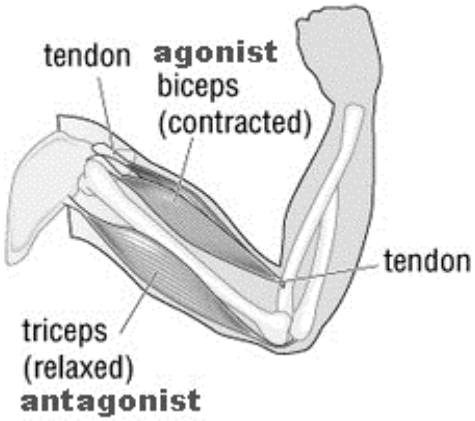


Figure 4.12: Elbow flexion

4.6.3 Parameters Calculated

Different parameters are calculated for every SEMG signal acquired from all the subjects. The calculation of parameters for every signal was done in LABVIEW. Following are the parameters:

1.) **Root Mean Square value (RMS):** It is a statistical measure of the magnitude of the varying quantity. The RMS value of a set of values (or a continuous-time waveform) is the square root of the arithmetic mean (average) of the squares of the original values (or the square of the function that defines the continuous waveform). The RMS value is given by equation 2. RMS value is a quantity used to quantify ac quantities. Hence signals with higher energy have higher RMS values.

$$V_{rms} = \sqrt{\frac{(x_1^2 + x_2^2 + x_3^2 \ldots\ldots\ldots\ldots + x_n^2)}{n}}$$

…… (2)

2.) Standard Deviation: The standard deviation provides us with a measure of just how spread out the scores is, a high standard deviation means the scores are widely spread; a low standard deviation means they're bunched up closely on either side of the mean. Standard deviation is widely used measurement of variability or diversity used in statistics and probability theory. It shows variation or dispersion from the average (mean, or expected value).

3.) Energy: It is also defined as simple square integral (SSI). It is a summation of square values of the EMG signal amplitude. Energy of the signal can be calculated according to the equation 3.

$$E = \sum_{n=1}^{N} |x(n)|^2$$

…… (3)

4.) Integrated EMG (IEMG): It is defined as a summation of absolute values of the EMG signal amplitude. Integrated EMG is normally used as an onset detection index in EMG non-pattern recognition and in clinical application [37].

$$IEMG = \sum_{n=1}^{N} |x(n)|$$

…… (4)

5.) Power Spectrum: For a given signal, the power spectrum gives a plot of the portion of a signal's power (energy per unit time) falling within given frequency bins. Power spectrum gives the signal frequency. Here, periodic signals give peaks at a fundamental and its harmonics; quasi periodic signals give peaks at linear combinations of two or more irrationally related frequencies (often giving the appearance of a main sequence and sidebands); and chaotic dynamics give broad band components to the spectrum.

CHAPTER 5
Results and Discussion

The observations were taken from five subjects from two points at a time. Firstly data was collected from positions M1 and M2 simultaneously for activities A1, A2, A3 and A4. Then data was collected from other two positions that are M3 and M4 while performing activities A5, A6, A7 and A8. Four observations were taken for every movement.

5.1 RMS Values

At all different movements, RMS values of the recorded SEMG signal were calculated. Table 5.1 shows RMS values of the signal acquired from five subjects from positions M1 and M2 while performing activities A1, A2, A3 and A4.

Table 5.1: RMS values for five subjects from positions M1 and M2

Muscle	Movement	S1	S2	S3	S4	S5
M1	A1	0.03	0.04	0.03	0.05	0.04
	A2	0.18	0.19	0.15	0.21	0.17
	A3	0.04	0.06	0.04	0.06	0.07
	A4	0.12	0.07	0.10	0.07	0.11
M2	A1	0.02	0.05	0.02	0.06	0.04
	A2	0.03	0.06	0.02	0.07	0.07
	A3	0.17	0.15	0.17	0.15	0.14
	A4	0.06	0.10	0.08	0.08	0.11

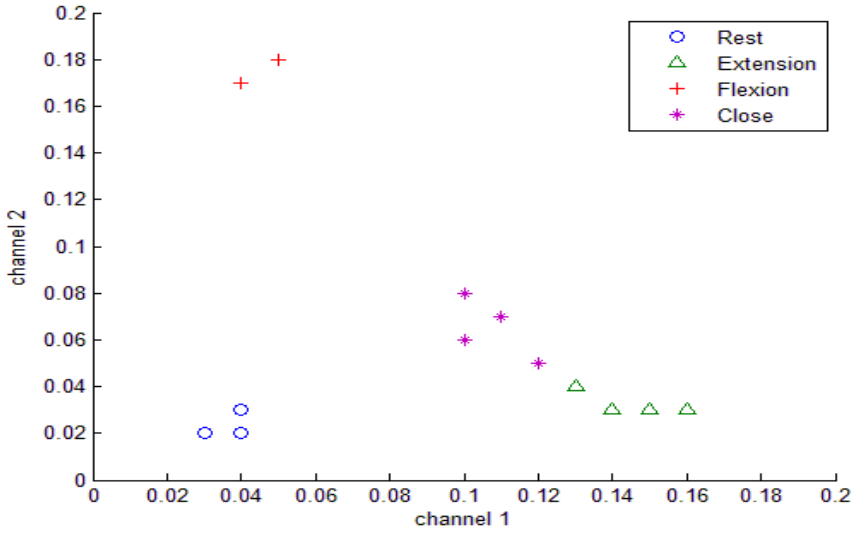


Figure 5.1: Plot for RMS values from M1 and M2 for four activities of subject 1

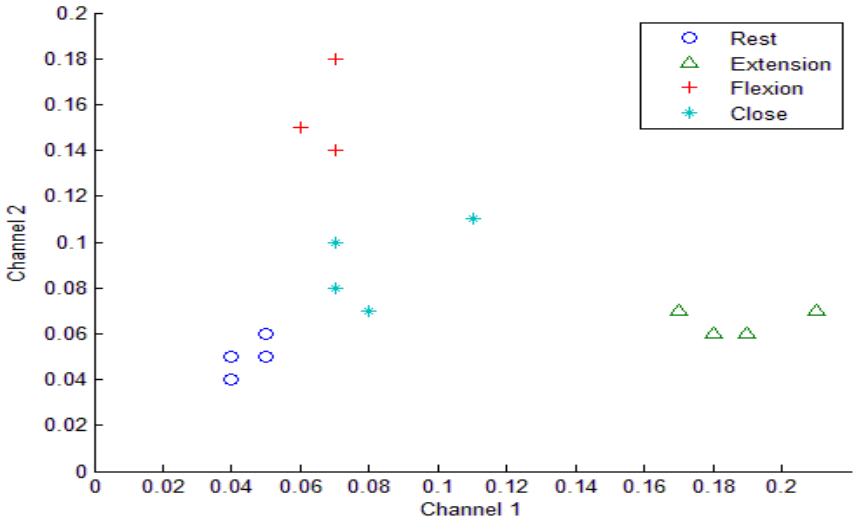


Figure 5.2: Plot for RMS values from M1 and M2 for four activities of subject 2

Figure 5.1 and Figure 5.2 shows the plot of RMS values of four different movements of the subject 1 and subject 2 respectively. Clearly all the four movements can be identified from the plot. At A1, both muscles are at rest hence RMS values of both muscles are low. At A2 i.e. hand extension, muscle 1 is activated hence RMS values of signal from channel 1 are more than channel 2. At A3 i.e. hand flexion, muscle 2 is activated hence the RMS values from channel 2 are more than channel 1. At A4, both the muscles contribute to close the hand hence there are increased values of RMS than rest position from both channels. This shows

that the active sensor developed can be used at these two positions to control four wrist movements of a prosthetic arm. Here it can be observed that for hand extension, muscle 1 is more dominant and for hand flexion muscle 2 is dominant.

Table 5.2 presents the RMS values of the SEMG signals from muscle positions M3 and M4 while performing the activities A5, A6, A7 and A8 of all subjects.

Table 5.2: RMS values of SEMG signal from position M3 and M4 of five subjects

Muscle	Movement	S1	S2	S3	S4	S5
M3	A5	0.02	0.02	0.04	0.04	0.02
	A6	0.40	0.45	0.38	0.37	0.43
	A7	0.15	0.19	0.19	0.13	0.17
	A8	0.02	0.03	0.08	0.09	0.02
M4	A5	0.03	0.04	0.08	0.07	0.03
	A6	0.04	0.04	0.05	0.05	0.04
	A7	0.08	0.08	0.12	0.10	0.08
	A8	0.14	0.13	0.29	0.24	0.14

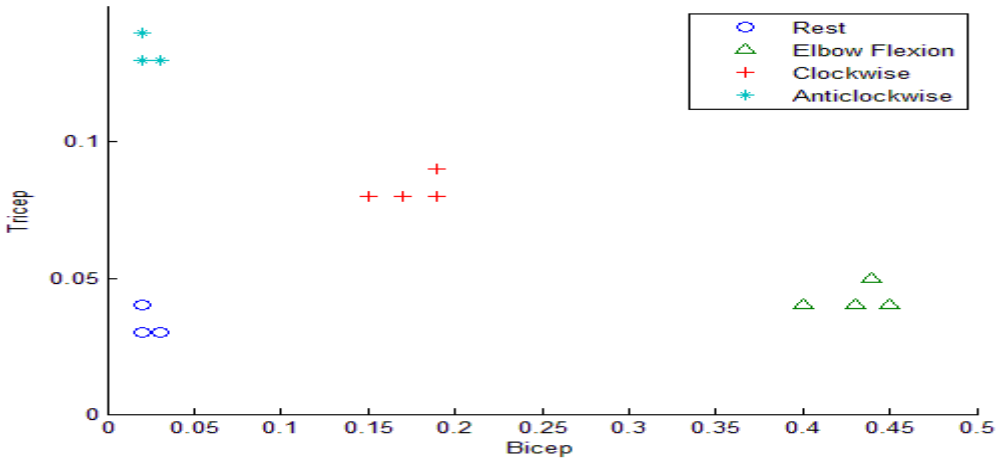


Figure 5.3: Plot for RMS values from M3 and M4 for four activities of subject 1

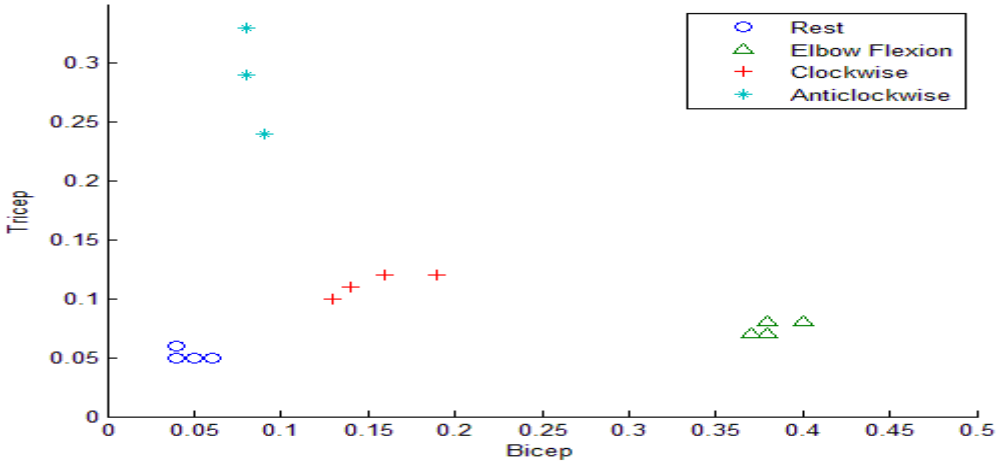


Figure 5.4: Plot for RMS values from M3 and M4 for four activities of subject 2

Figure 5.3 and Figure 5.4 shows the plot for RMS values of SEMG signals for four different movements of the subject 1 and subject 2 respectively from bicep and triceps. Clearly all the four movements can be identified from the plot. At A5 both muscles are at rest hence RMS values of both muscles are low. At A6 i.e. elbow flexion, muscle 3 is activated hence RMS values of signal from bicep are more than triceps. At A7 i.e. clockwise rotation, both muscles are activated hence the RMS values from triceps and biceps are higher than there RMS values at rest. At A8 i.e. anticlockwise rotation, triceps contribute more to rotate the arm hence there are increased values of RMS of triceps than RMS values of biceps. Hence the same active sensor can also be used between elbow and shoulder to control the four movements of a prosthetic arm. Here it is observed that for elbow flexion, biceps are more dominant muscles and for anticlockwise rotation, triceps are more dominant muscles.

5.2 Standard Deviation

Table 5.3 shows the standard deviation of SEMG signals from muscles M1 and M2 of all the five subjects.

Table 5.3: Standard deviation of SEMG signals from M1 and M2 of five subjects

Muscle	Movement	S1	S2	S3	S4	S5
M1	A1	0.08	0.028	0.021	0.026	0.025
	A2	0.119	0.184	0.211	0.174	0.115
	A3	0.074	0.051	0.035	0.067	0.029
	A4	0.125	0.056	0.124	0.078	0.1
M2	A1	0.061	0.01	0.011	0.044	0.042
	A2	0.064	0.016	0.014	0.056	0.05
	A3	0.096	0.175	0.167	0.174	0.095
	A4	0.051	0.061	0.081	0.069	0.067

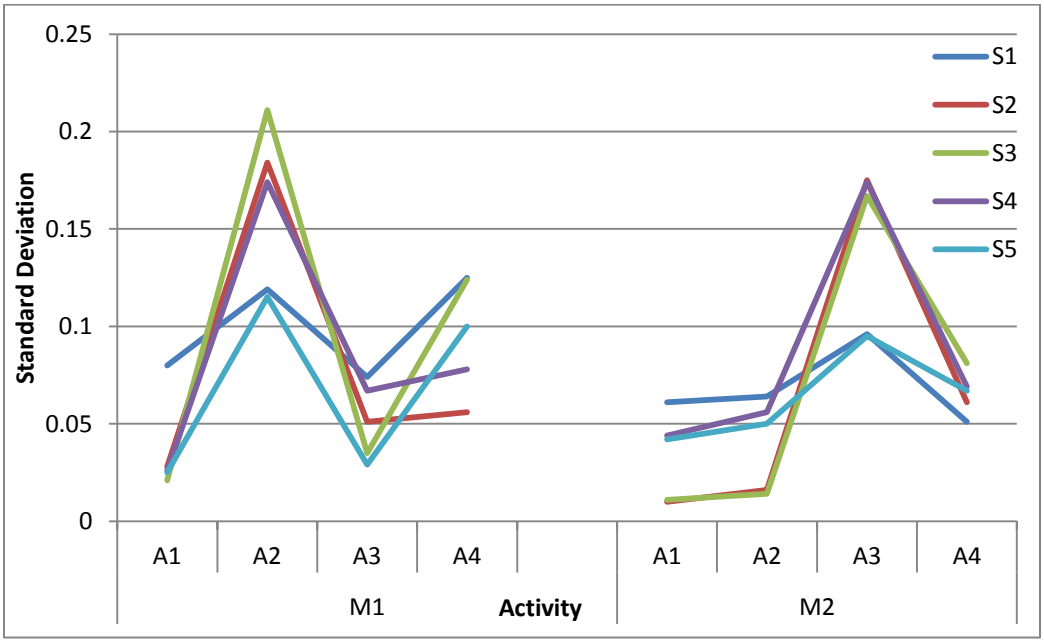


Figure 5.5: Plot for standard deviation of SEMG signals from M1 and M2 of five subjects

Figure 5.5 represent the standard deviations calculated for SEMG signals from muscle M1 and muscle M2 of all subjects. It is observed that the standard deviations of those signals are more which have more RMS values. In activity A2 i.e. hand extension, muscle M1 is having highest RMS values hence the standard deviation for this activity is highest. Similarly for

activity A3 i.e. hand flexion, muscle M2 is having more RMS values than muscle M1 hence muscle M2 is having more values for standard deviations than muscle M1.

Table 5.4 presents the standard deviations of the SEMG signals from muscle positions M3 and M4 while performing the activities A5, A6, A7 and A8 of five subjects.

Table 5.4: Standard deviation of SEMG signals from M3 and M4 of five subjects

Muscle	Movement	S1	S2	S3	S4	S5
M3	A5	0.015	0.011	0.114	0.013	0.0108
	A6	0.359	0.452	0.376	0.427	0.398
	A7	0.186	0.186	0.136	0.170	0.153
	A8	0.012	0.014	0.069	0.013	0.073
M4	A5	0.025	0.025	0.038	0.026	0.039
	A6	0.032	0.037	0.110	0.032	0.113
	A7	0.075	0.082	0.087	0.080	0.087
	A8	0.142	0.133	0.240	0.142	0.327

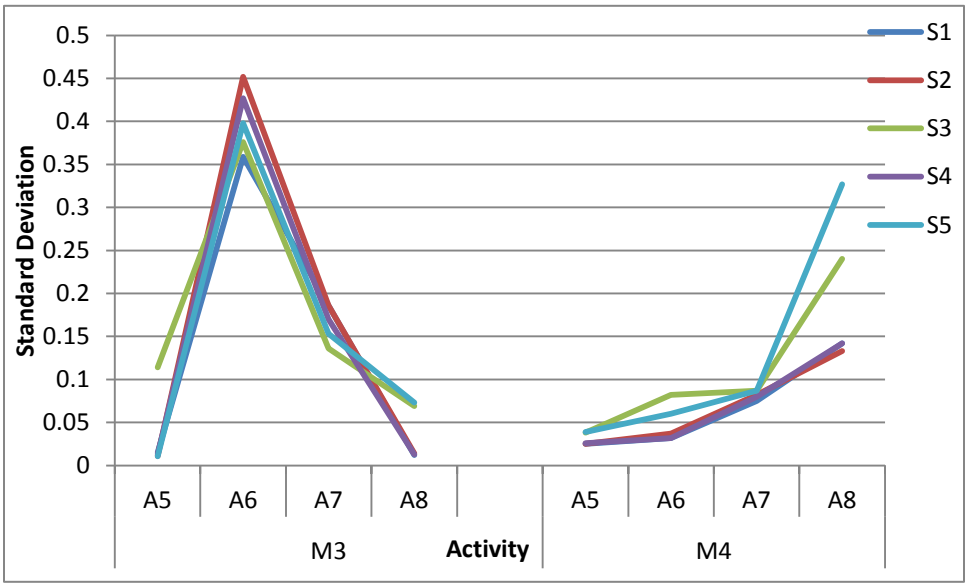


Figure 5.6: Plot of standard deviations of SEMG signals from M3 and M4 of five subjects

Figure 5.6 represent the standard deviations calculated for SEMG signals from muscle M3 and muscle M4 of five subjects. It can be observed that the standard deviations of those

signals are more which have more RMS values in Table 5.2. In activity A6 i.e. elbow flexion, muscle M3 i.e. biceps, is having highest RMS values hence the standard deviation for this activity is highest. Similarly for activity A8 i.e. anticlockwise rotation, muscle M4 i.e. triceps, is having more RMS values than muscle M3 hence muscle M4 is having more values for standard deviations than muscle M3. Here it is observed that for higher RMS values of SEMG signal standard deviations are also high.

5.3 Energy of the signal

Table 5.5 presents the energy contained in the SEMG signal recorded from muscle M1 and M2 of five subjects while performing activities A1, A2, A3 and A4.

Table 5.5: Energy of Muscles M1 and M2 of all subjects

Muscle	Movement	S1	S2	S3	S4	S5
M1	A1	1.469	4.52	4.45	1.902	4.34
	A2	89.94	104.42	136.09	58.49	93.53
	A3	3.02	10.03	11.25	5.15	15.60
	A4	31.22	11.72	15.91	23.14	20.36
M2	A1	0.737	7.48	9.74	0.761	8.09
	A2	1.377	9.85	14.40	1.993	11.80
	A3	55.53	38.16	65.99	56.88	93.86
	A4	5.844	32.09	17.57	9.141	16.73

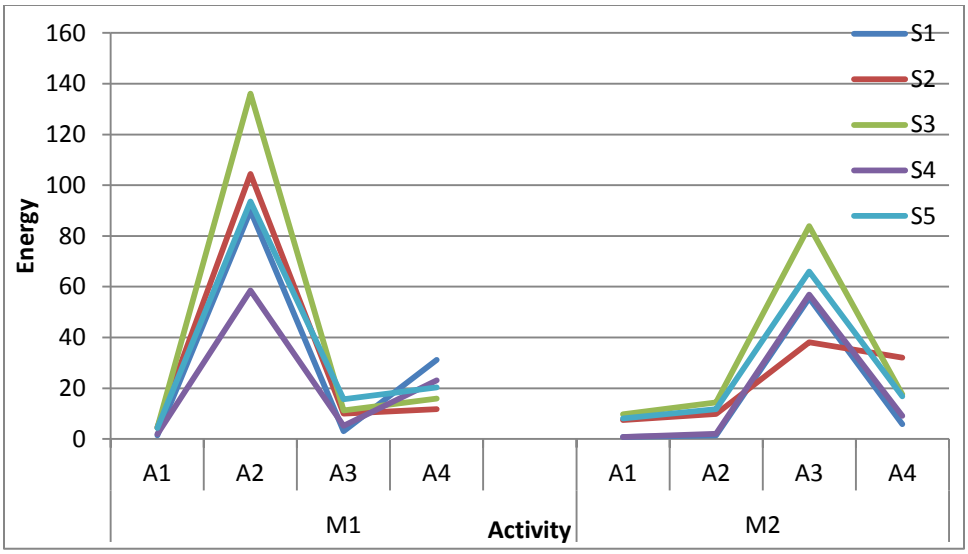


Figure 5.7: Energy of signal from muscle M1 and M2 for five subjects

Figure 5.7 shows a plot for energies of different subjects from muscle M1 and M2 while performing different activities. Clearly signal with maximum RMS is having maximum energy. It is observed that M1 muscle has maximum energy while hand extension and M2 muscle has maximum energy while hand flexion.

Table 5.6 shows the energy of the SEMG signal from muscle M3 and M4 of five subjects while performing activities A5, A6, A7 and A8.

Table 5.6: Energy of SEMG signal from muscle M3 and M4 of five subjects

Muscle	Movement	S1	S2	S3	S4	S5
M3	A5	15.08	37.04	8.69	40.71	21.02
	A6	407.87	478.49	428.39	427.65	356.02
	A7	30.13	72.55	107.85	58.19	138.22
	A8	22.86	18.64	19.47	16.95	18.09
M4	A5	6.56	6.55	6.19	6.52	21.12
	A6	20.09	24.87	22.90	24.66	27.52
	A7	29.13	40.66	43.41	38.50	41.35
	A8	108.03	322.91	259.09	176.26	146.41

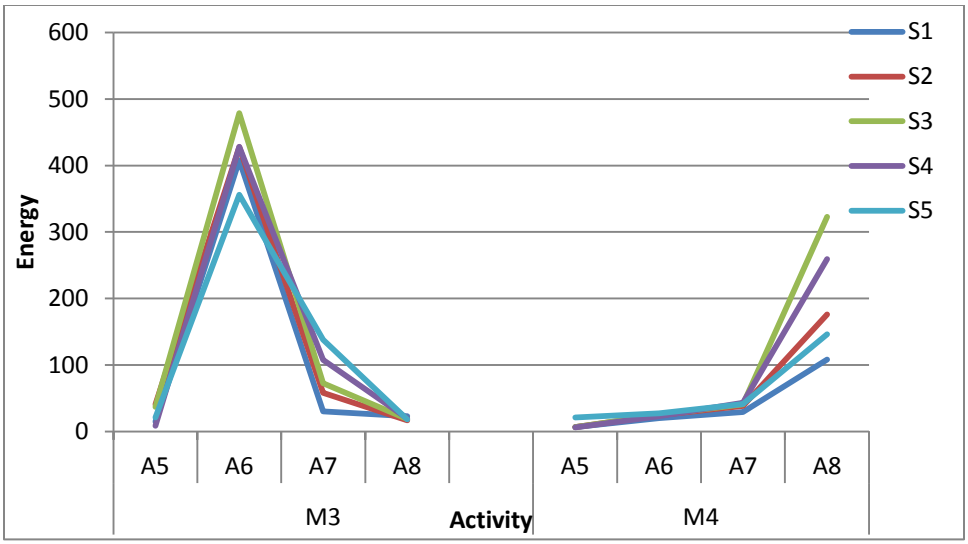


Figure 5.8: Plot for energy from muscles M3 and M4 for five subjects

Figure 5.8 shows a plot for energies of different subjects from muscle M3 and M4 while performing different activities. Clearly signal with maximum RMS is having maximum energy. It is observed that M3 muscle has maximum energy while arm flexion and M4 muscle has maximum energy while anticlockwise rotation.

5.4 Integrated EMG

Table 5.7 presents the values of integrated EMG of all the subjects from muscles M1 and M2 while performing activities A1, A2, A3 and A4.

Table 5.7: Integrated EMG for all subjects from muscles M1 and M2

Muscle	Movement	S1	S2	S3	S4	S5
M1	A1	43.75	47.96	68.15	48.18	75.54
	A2	307.47	168.43	285.29	178.03	261.32
	A3	61.63	53.41	74.57	78.44	74.57
	A4	174.71	152.68	98.13	151.59	98.13
M2	A1	33.79	34.30	53.65	34.41	53.65
	A2	40.98	38.78	79.12	37.21	79.12
	A3	208.62	238.13	342.59	217.03	342.59
	A4	78.85	94.10	91.20	98.74	91.20

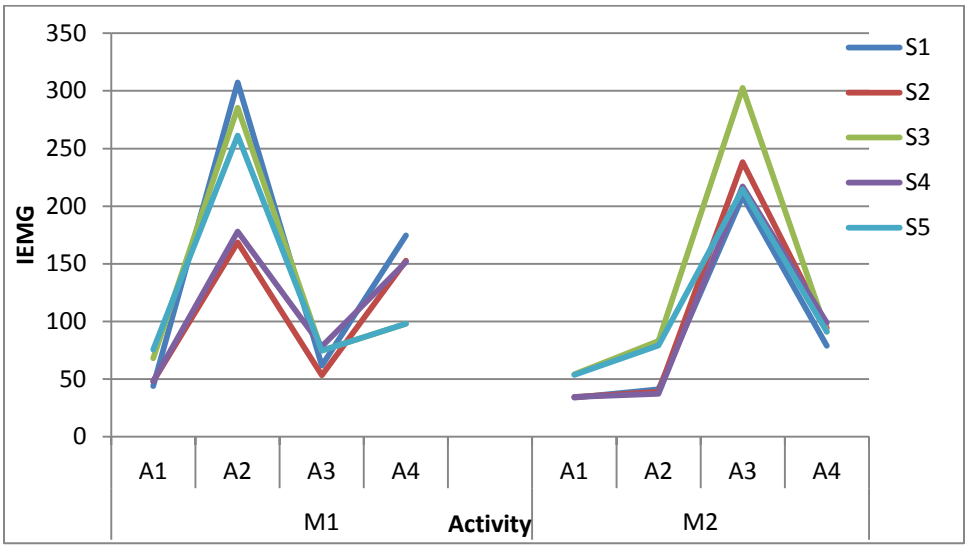


Figure 5.9: IEMG of all subjects from muscles M1 and M2

Figure 5.9 shows a plot for Integrated EMG of different subjects from muscle M1 and M2 while performing different activities. Clearly signal with maximum RMS is having maximum Integrated EMG. It is observed that M1 muscle has maximum value of IEMG while performing hand extension and M2 muscle has maximum energy while hand flexion.

Table 5.8 presents the values of integrated EMG of all the subjects from muscles M3 and M4 while performing activities A5, A6, A7 and A8.

Table 5.8: IEMG values of all subjects from muscle M3 and M4

Muscle	Movement	S1	S2	S3	S4	S5
M3	A5	36.53	34.59	59.93	38.79	36.23
	A6	552.74	704.17	763.66	670.01	645.83
	A7	181.69	282.88	303.06	269.54	249.94
	A8	34.57	43.19	126.92	36.59	35.58
M4	A5	48.02	48.06	61.41	49.18	49.25
	A6	58.24	67.24	85.15	61.66	58.18
	A7	110.39	121.95	150.78	117.91	116.92
	A8	193.38	189.85	243.67	177.86	196.03

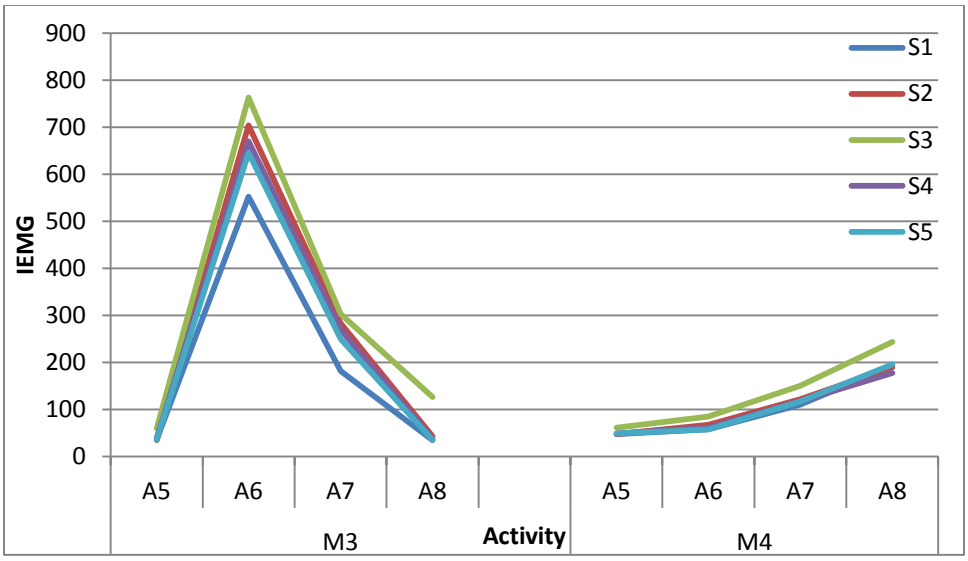


Figure 5.10: IEMG of all subjects from muscles M3 and M4

Figure 5.10 shows a plot for Integrated EMG of different subjects from muscle M3 and M4 while performing different activities. Clearly signal with maximum RMS is having maximum Integrated EMG. It is observed that M3 muscle has maximum value of Integrated EMG while performing elbow flexion and M4 muscle has maximum energy while anticlockwise rotation of the arm.

5.5 Power Spectrum

Figure 5.11 shows the raw SEMG signal captured from biceps at rest. Overall amplitude of the peaks in power spectrum is below 0.04 since the muscles are not contracted. Figure 5.12 shows the raw SEMG signal and its power spectrum while muscles are at maximum contraction. Figure 5.13 shows the raw SEMG signal and its power spectrum while the arm was rotated clockwise. Figure 5.14 shows the raw SEMG signal and its power spectrum while the arm was rotated anticlockwise.

Figure 5.15 shows the raw SEMG signal captured from muscle M2 at rest. Overall amplitude of the peaks in power spectrum is below 0.04 since the muscles are not contracted. Figure 5.16 shows the raw SEMG signal and its power spectrum during hand extension. Figure 5.17 shows the raw SEMG signal and its power spectrum during hand flexion. Figure 5.18 shows the raw SEMG signal and its power spectrum while the hand was close.

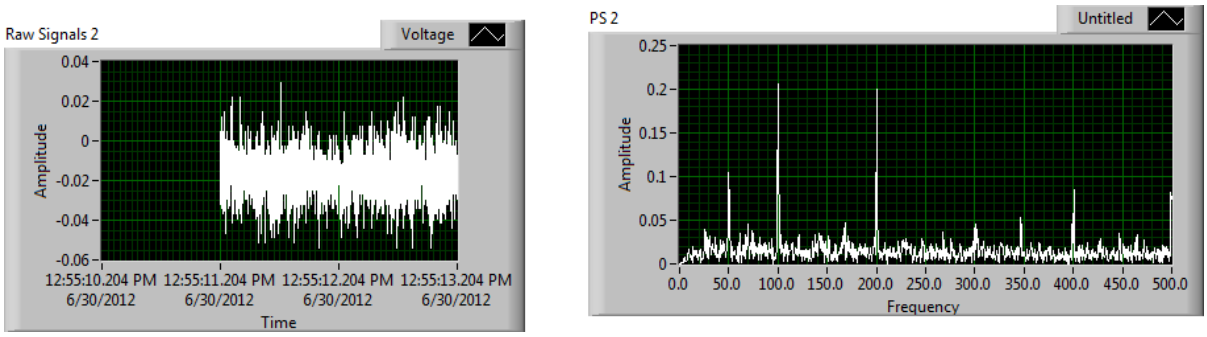


Figure 5.11: Biceps at rest

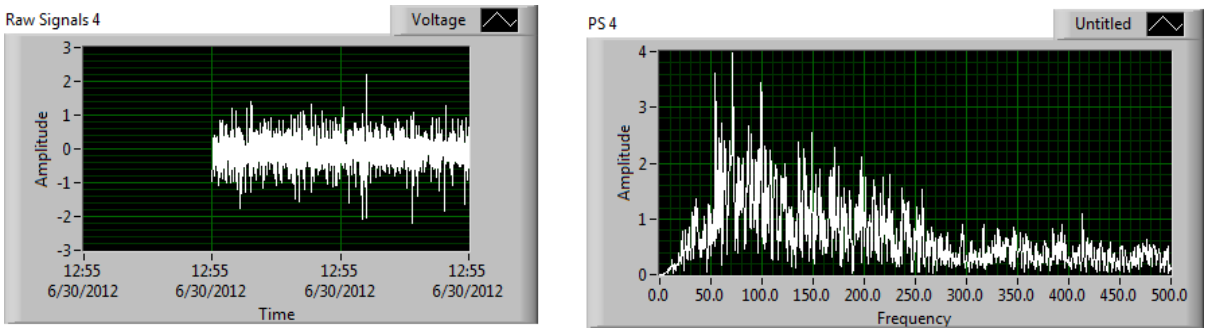


Figure 5.12: Biceps at elbow flexion

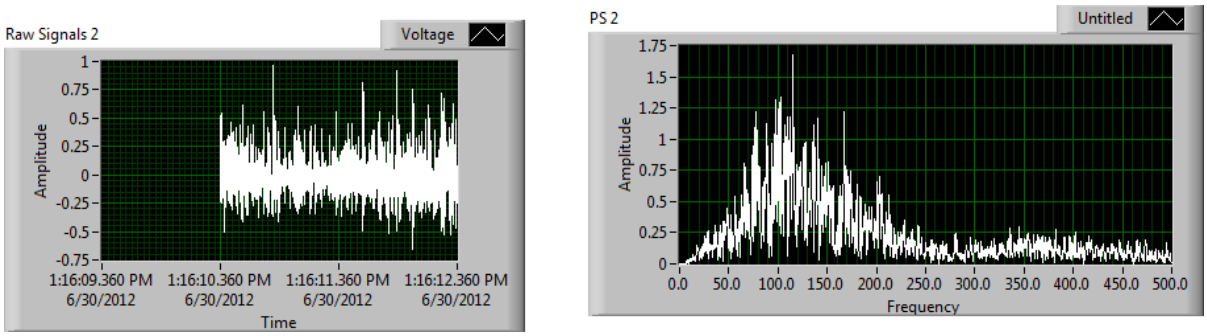


Figure 5.13: Biceps at clockwise rotation of arm

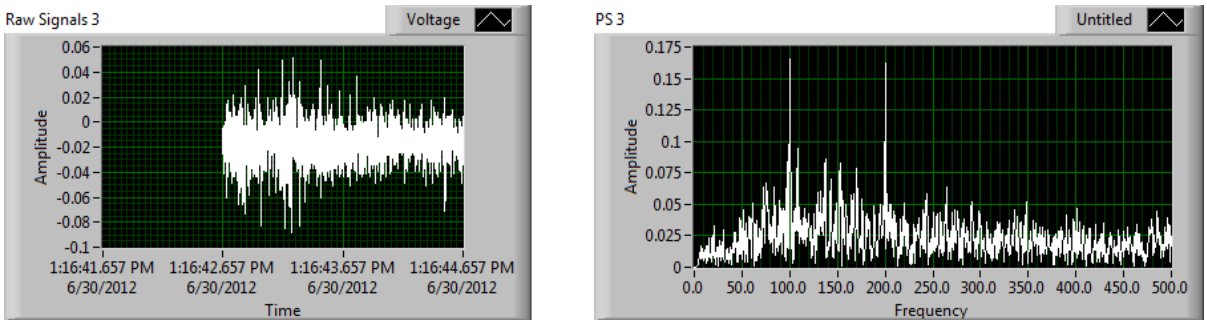


Figure 5.14: Biceps at anticlockwise rotation of arm

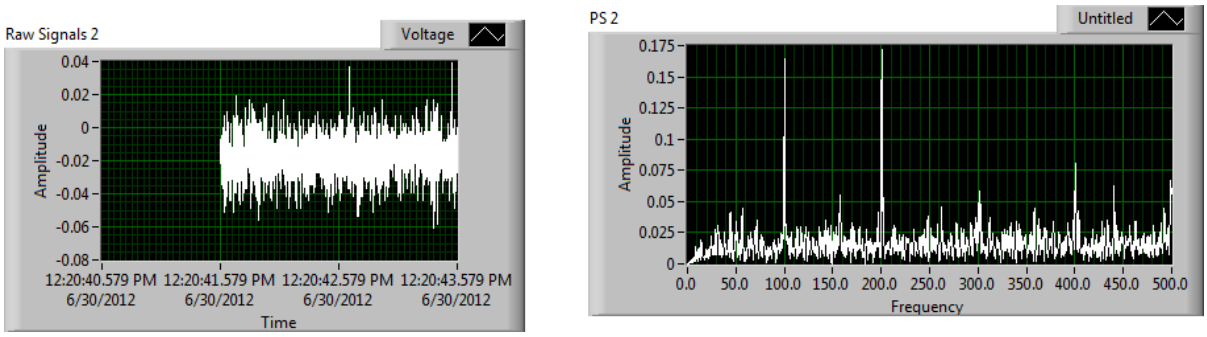


Figure 5.15: Muscle M2 at rest

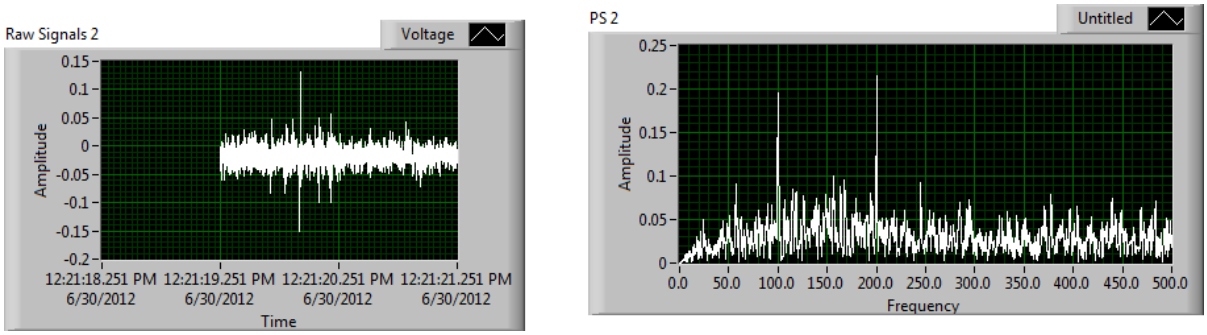


Figure 5.16: Muscle M2 at hand extension

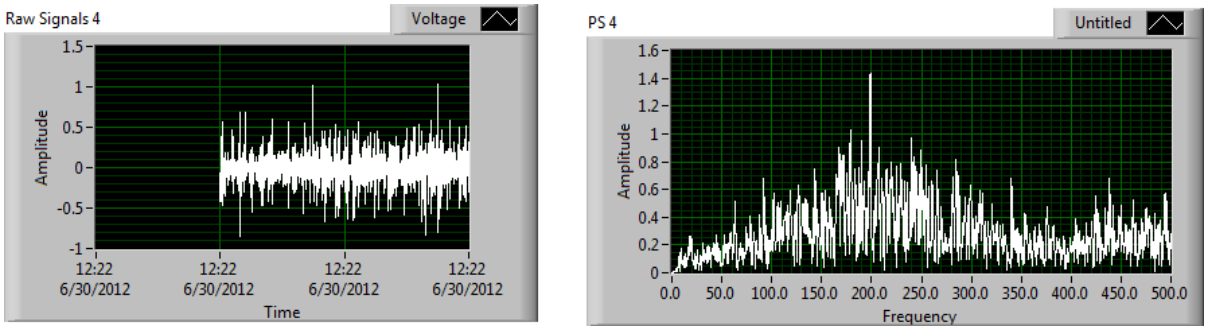


Figure 5.17: Muscle M2 at hand flexion

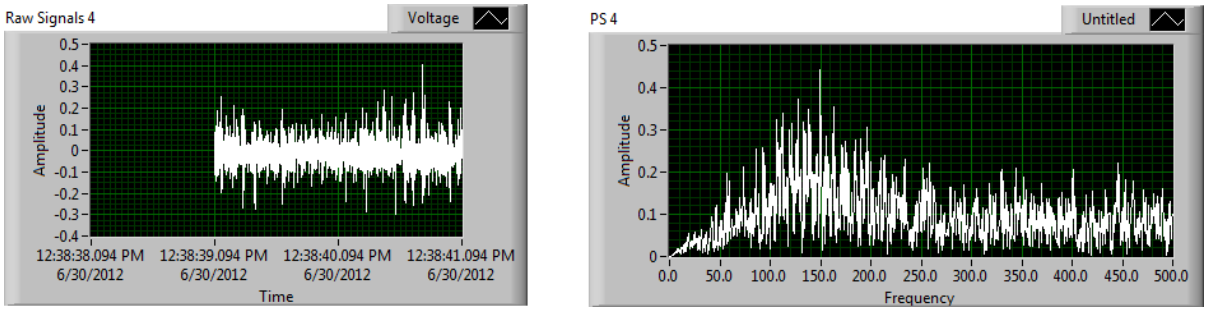


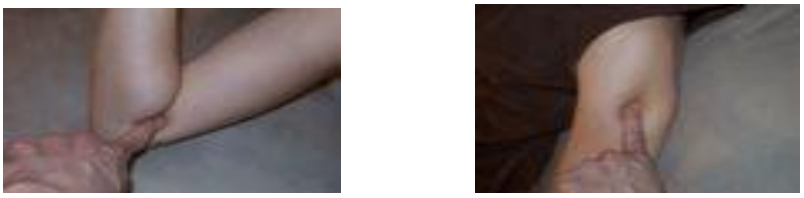
Figure 5.18: Muscle M2 at close hand

5.6 Comparison

In comparison to previous work [38], SEMG signals were picked up from two acupressure points namely P1 and P2 located on the arm as shown in Figure 5.19 (a) and 5.19 (b). These signals were picked up using an active electrode. The signals were taken for four different movements of the arm. These are mentioned below:

1. m1 – first motion (move arm up)
2. m2 – second motion (move arm down)
3. m3 – third motion (move arm clockwise (cw))
4. m4 – fourth motion (move arm anti-clockwise (acw))

SEMG signals were taken for the different movements and at the different forces [without weight (ww), 10 kg, 20 kg and 30 kg] with the help of a force gripper. The SEMG signals sensed were transferred to computer using NI-DAQ. They were saved and analyzed using LABVIEW.



(a) (b)

Figure 5.19: (a) First acupressure point (b) Second acupressure point

Similar data was collected using the active electrode developed in this work from same two acupressure points for the same movements. Subjects, NI-DAQ card and place to capture SEMG signal were same [38]. RMS values were calculated for each signal after saving them using LABVIEW. Table 5.9 shows the RMS values of the signals of the point P1 from previous work. Table 5.10 shows the RMS values of the SEMG signals of point P1 picked up by active electrode developed.

Table 5.9: RMS values of signals from all subjects from P1

Force	Movements	S1	S2	S3	S4	S5	S6
ww	M1	0.114769	0.108026	0.107988	0.091603	0.10012	0.09211
	M2	0.0737	0.07272	0.071322	0.069343	0.063241	0.072126
	M3	0.100124	0.09089	0.094311	0.092713	0.0838	0.082508
	M4	0.082162	0.0847	0.0778	0.0854	0.081222	0.07941
10	M1	0.138502	0.119026	0.112832	0.119215	0.11705	0.118123
	M2	0.082698	0.0737	0.080969	0.0828	0.081858	0.0751
	M3	0.100518	0.1065	0.098012	0.102551	0.10815	0.102612
	M4	0.091959	0.08896	0.0915	0.10091	0.1025	0.10144
20	M1	0.184817	0.15233	0.153057	0.131356	0.124581	0.127392
	M2	0.09979	0.10908	0.090032	0.094173	0.0932	0.09065
	M3	0.146418	0.144675	0.130625	0.121876	0.1226	0.111496
	M4	0.093588	0.10792	0.087878	0.1140	0.1176	0.096974
30	M1	0.218532	0.208692	0.193092	0.16615	0.17215	0.16215
	M2	0.165761	0.15233	0.163225	0.111684	0.10779	0.10643
	M3	0.1875	0.19634	0.18427	0.158894	0.140094	0.15394
	M4	0.175489	0.1633	0.17143	0.136559	0.13156	0.12932

Table 5.10: RMS values of signals picked up by active electrode developed from P1

Force	Movements	S1	S2	S3	S4	S5	S6
ww	M1	0.0646	0.0641	0.0612	0.0754	0.0816	0.0756
	M2	0.0571	0.054	0.0498	0.0624	0.0702	0.0658
	M3	0.0625	0.0618	0.06	0.068	0.0719	0.07
	M4	0.0591	0.0629	0.061	0.0672	0.0707	0.069
10	M1	0.1292	0.1278	0.1285	0.1305	0.0977	0.1197
	M2	0.0754	0.0816	0.0756	0.097	0.0838	0.0951
	M3	0.1151	0.1188	0.11	0.117	0.091	0.1098
	M4	0.0913	0.104	0.0939	0.099	0.0898	0.1016
20	M1	0.1612	0.151	0.1614	0.2161	0.2083	0.1914
	M2	0.1217	0.1123	0.122	0.1423	0.1381	0.1249
	M3	0.1418	0.149	0.1456	0.1813	0.1793	0.1729
	M4	0.1019	0.109	0.1165	0.1776	0.1691	0.1526
30	M1	0.2205	0.1958	0.1972	0.2536	0.2489	0.2318
	M2	0.1925	0.1774	0.1814	0.1891	0.1754	0.1691
	M3	0.2051	0.19	0.191	0.2361	0.2241	0.217
	M4	0.1896	0.1874	0.1878	0.2018	0.1989	0.1838

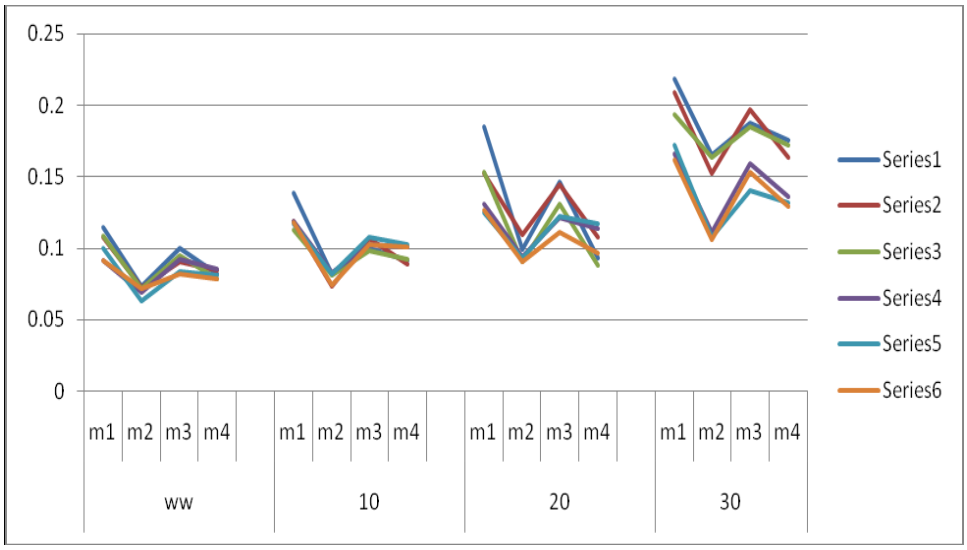


Figure 5.20: Plot for RMS values of signals from P1

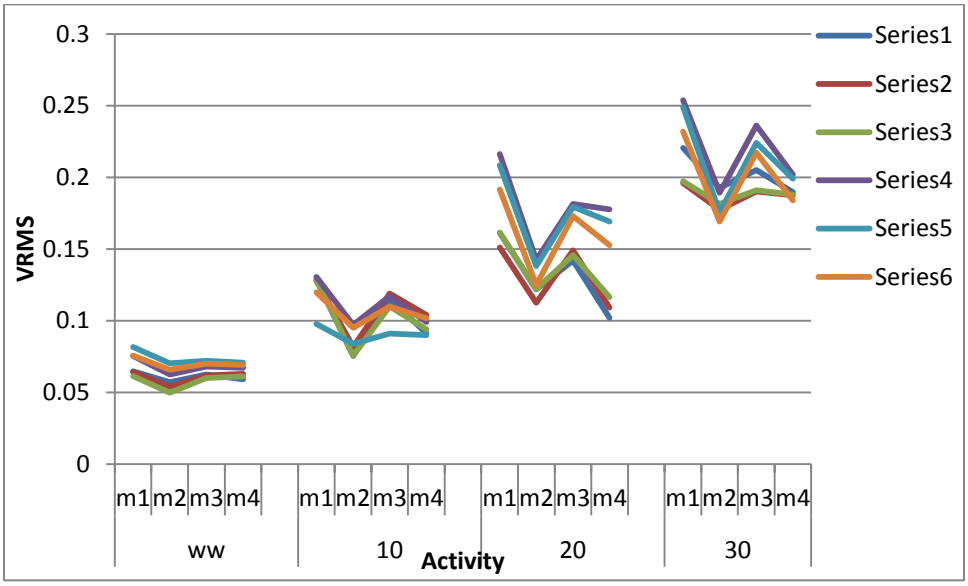


Figure 5.21: Plot for RMS values of signals from P1 picked up by active electrode developed

Figure 5.20 and Figure 5.21 presents the plot for the RMS values from previous work and from present active electrode developed respectively. It was observed that the overall range for RMS values increases from 0.1553 to 0.2536. Overall plot is similar but with better accuracy.

Table 5.11 shows the RMS values of the SEMG signals of the point P2. Table 5.12 shows the RMS values of the SEMG signals of point P2 picked up by active electrode developed.

Table 5.11: RMS values of signals from all subjects from P2

Force	Movements	S1	S2	S3	S4	S5	S6
ww	M1	0.082188	0.074673	0.07652	0.087912	0.08708	0.08478
	M2	0.055836	0.05886	0.063856	0.07912	0.0708	0.07748
	M3	0.06924	0.07	0.074387	0.0719	0.0671	0.0692
	M4	0.05275	0.04621	0.052496	0.051404	0.0512	0.047993
10	M1	0.0914	0.084963	0.08963	0.103211	0.10391	0.103773
	M2	0.0705	0.0725	0.067795	0.096234	0.09336	0.09136
	M3	0.073156	0.06569	0.074164	0.09233	0.09263	0.09036
	M4	0.057018	0.0604	0.055684	0.060149	0.059413	0.05528
20	M1	0.125043	0.128653	0.126782	0.117123	0.113457	0.113854
	M2	0.116782	0.115043	0.11083	0.113082	0.1109	0.107165
	M3	0.11282	0.11043	0.10783	0.0983	0.102935	0.095004
	M4	0.09411	0.08965	0.08893	0.080912	0.08108	0.07998
30	M1	0.158894	0.144354	0.141988	0.164313	0.158313	0.15513
	M2	0.141923	0.141257	0.135	0.142851	0.14082	0.1331
	M3	0.1297	0.1327	0.1282	0.10898	0.1146	0.10946
	M4	0.10082	0.10243	0.10783	0.098989	0.1044	0.095389

Table 5.12: RMS values of signals picked up by active electrode developed from P2

Force	Movements	S1	S2	S3	S4	S5	S6
ww	M1	0.0848	0.0836	0.0837	0.0472	0.0589	0.0552
	M2	0.079	0.0859	0.0838	0.0294	0.0389	0.0402
	M3	0.0679	0.0646	0.0657	0.029	0.0397	0.0486
	M4	0.0474	0.0479	0.0464	0.0541	0.0563	0.053
10	M1	0.094	0.0975	0.096	0.0788	0.078	0.0778
	M2	0.0771	0.0725	0.0702	0.0365	0.0474	0.0358
	M3	0.0532	0.0649	0.0566	0.0327	0.0335	0.0319
	M4	0.0445	0.0457	0.0445	0.0493	0.0518	0.049
20	M1	0.1417	0.1529	0.1537	0.1256	0.1182	0.1187
	M2	0.0704	0.0727	0.0714	0.0586	0.0412	0.0573
	M3	0.0784	0.0807	0.0849	0.0799	0.1044	0.0833
	M4	0.0581	0.0594	0.0585	0.0612	0.06	0.0585
30	M1	0.3271	0.2367	0.3503	0.1917	0.1811	0.1942
	M2	0.0978	0.0993	0.0994	0.0884	0.0928	0.0839
	M3	0.1055	0.1204	0.1241	0.1349	0.0998	0.1425
	M4	0.0685	0.0743	0.0691	0.0644	0.0678	0.0664

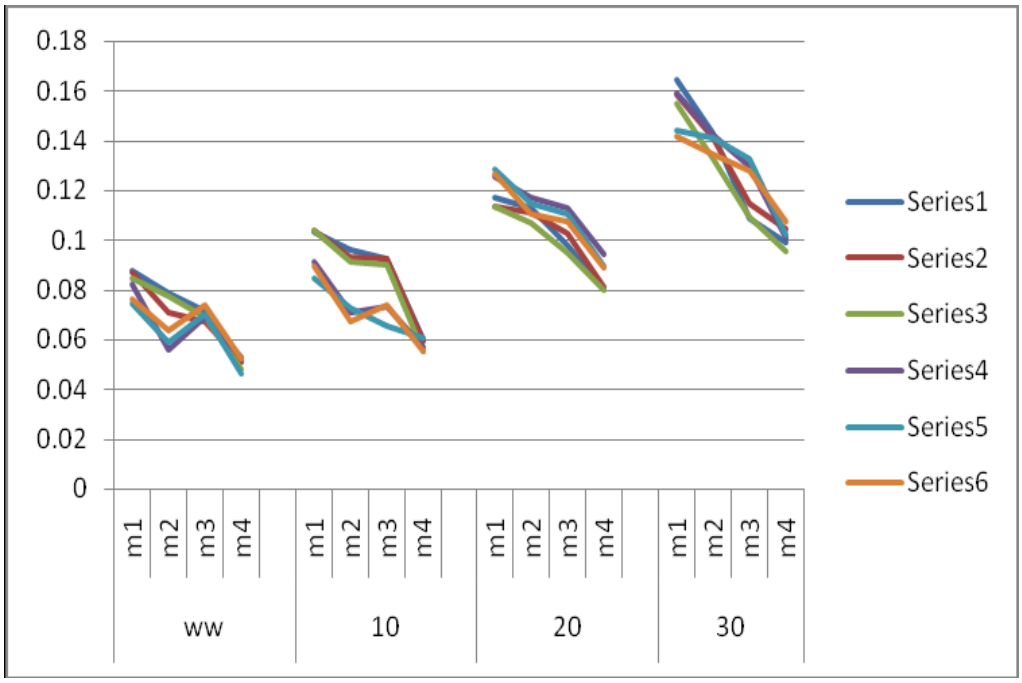


Figure 5.22: Plot for RMS values of signals from P2

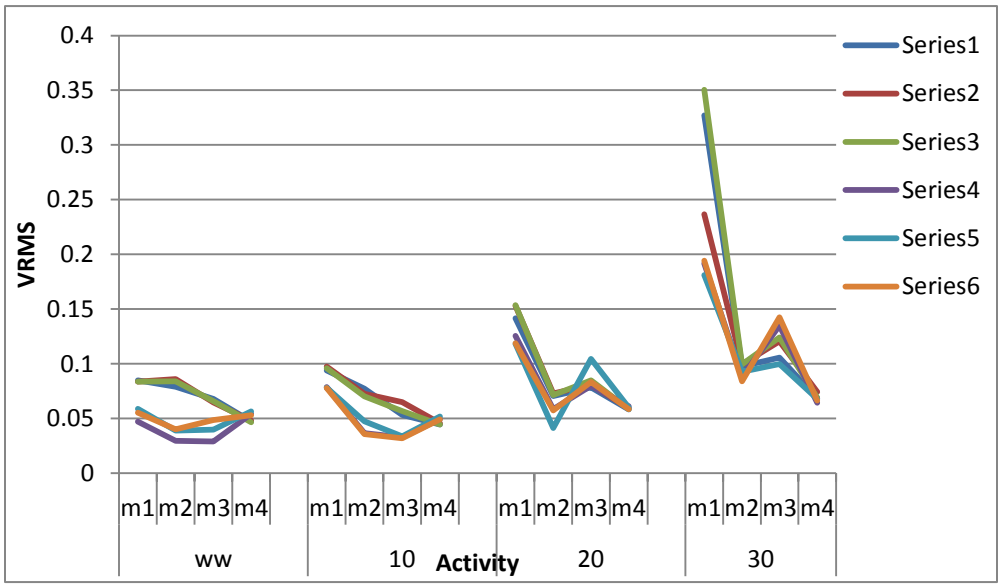


Figure 5.23 : Plot for RMS values of signals from P2 picked up by active electrode developed

Figure 5.22 and Figure 5.23 presents the plot for the RMS values from previous work and from present active electrode developed respectively. It can be observed that the overall range for RMS values was 0.1085. This range is increased with present active electrode to 0.3209. This plot is also similar hence proving the accuracy of present active electrode.

5.7 Conclusion

The electromyogram (EMG) signal is the electrical physiological signal of activation of a motor unit associated with a contracting muscle and serves as a potential resource for a man-machine interface. It is very random in nature and is hard to differentiate with other noise signals. Even low electrode impedance values did not guarantee low signal noise, implying that other factors must be considered in assessing signal quality. Present available sensors are very expensive and big in size, so it limits the use while taking EMG signal. The active sensor that has been designed in this work reduces noise of the signal to minimum. It's low cost and small size is of great use for SEMG study purpose as it enhances the mobility and is affordable by user. Further this sensor can be directly used to provide input to some microcontrollers for prosthetic control.

5.8 Future Scope

- Further reduction in size can be done using MOIC IC's.
- Some signal processing can be done within the sensor to further improve its output.

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