Optomyography: Detection of muscle surface displacement using reflective photo resistor

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Jammalamadaka Raghavendra
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ABSTRACT

A human body can carry out many physiological complex processes which can be mechanical, electrical or bio-chemical. Each mechanical activity generates a signal that describes the characteristics of the particular action in the form of pressure or temperature. Any irregularity in the process changes the usual functioning thus affecting the performance of the system. Several techniques were introduced to evaluate these muscular signals in order to get a deeper understanding of the medical abnormalities. Displacement sensors, laser optics, electrodes, accelerometers and microphones are some of the widely used devices in measuring the electrical and mechanical activities produced in the muscles.

The aim of this thesis project was to find and implement a simple non-contact optical method to measure and monitor the displacements caused on the surface of the skin due to muscular movements. In this study, a device was developed using photo electric sensors that can record surface changes caused on the skin due to the movements forearm muscles.

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Sammanfattning

Människokroppens aktiviteter genererar olika mätbara signaler som kan vara biokemiska, elektriska, mekaniska. Naturligtvis, är det viktigt att kunna mäta dessa signaler för att kunna veta om kroppens olika organ fungerar som de ska göra eller inte.

När det gäller rent mekaniska aktiviteter, genereras signaler av olika typer som beskriver denna aktivitet, såsom tryck, temperatur och förflyttning. Och om en sådan process avviker från det normala fallet, kommer kroppssystemets prestanda att försämras.

Ett antal tekniker utvecklades för att kunna mäta dessa signaler och uppnå djupare förståelse av möjliga icke-normala medicinska konsekvenser. Förflyttnings sensorer, laser optik, elektroder, accelerometrar och mikrofoner är exempel på mättekniker som används för att studera elektrisk och mekanisk aktivitet i muskelvävnader.

Målet med detta arbete är att hitta, utveckla och implementera en enkel, användarvänlig, beröringsfri, optisk teknik för att mäta och studera de ytliga förflyttningar som förändrar hudytans landskap och resulterar från muskelaktiviteter och rörelser. Detta projekt resulterade i en enkel prototyp för ett mätinstrument som ser ut som ett armband med två fotoelektriska sensorer som används för att mäta hudytans förändringar på grund av olika arm- och handrörelser.

Table of Contents

LIST OF FIGURES

Abbreviations

CRO – Cathode Ray Oscilloscope

DC – Direct Current

EMG – Electromyography

EEG – Electroencephalography

ECG – Electrocardiography

IMU – Internal Measurement Unit

LED – Light Emitting Diode

LCD – Liquid crystal display

MMG – Mechanomyography

MUAP – Motor Unit Action Potential

PCB – Printed Circuit Board

RPR – Reflective Photo Resistor

1 INTRODUCTION

A human body is made up of the nervous system, the cardiovascular system and the skeletal system. Each of these systems has many subsystems that carry on specific activities that help beings to survive, grow and work. For example, the cardiovascular system contains the heart and its muscles that carry on an involuntary action of purifying and pumping oxygenated blood to other parts of the body [15]. Similarly, the skeletal system has muscles attached to bones, using which we perform specific works, like lifting things, running, writing and many more, in order to fulfill our daily needs. Any variations in the functionality results in damage to the normal process thus affecting the performance of the system. Within every action of the human body, either voluntarily or involuntarily, multiple systems work at the same time. Small electric currents are generated which can be either flux carrying charged particles or the current generated due to independent biological or bio chemical phenomena.

With the advancement of technologies and various methods that are present, these signals can be assessed to understand the bio-mechanics of a human body. One of the most familiar techniques is Electrocardiogram, used to observe the electrical signals derived from the heart activity. This method is widely used in diagnosing the disorders and functionality of the heart. Further the demand of simple, reliable, low cost and more effective human-machine interface has led to the invention of much simpler techniques such as surface Electromyography and Mechanomyography. In surface electromyography, electrodes placed on the surface of the skin over a targeted muscle group record the electrical activity and generate an output signal which can be observed in order to understand the muscle properties. Mechanomyography follows a non-contact detection using displacement transducers or fiber optic lasers to detect the muscle activity. The requirement of electronics in biomedical applications have broadened the study of these signals not just only to understand the mechanics of the body but rather to create a better human-machine interface.

1.1 Problem statement

Fig.1 shows the surface electromyography, with electrodes placed over the skin to detect the muscle activity. Fig 2a & 2b shows MMG implementation using lasers.

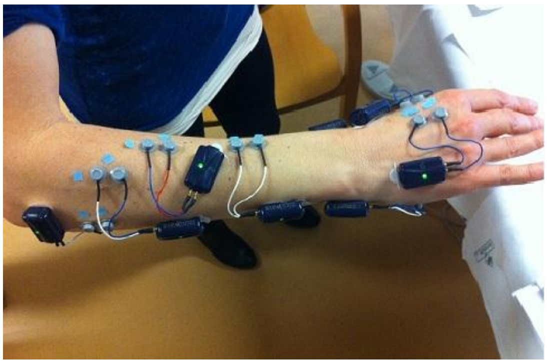


Fig1.1 Electrodes placed on the forearm, surface EMG.

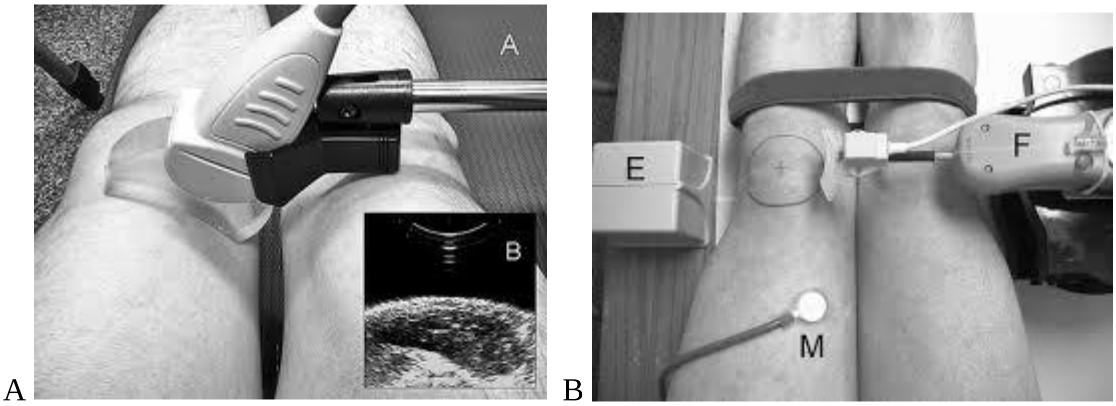


Fig1.2 (A, B). MMG using Lasers.

Although these methods are highly successful and widely used, certain factors affect the performance of these techniques. For example, in surface EMG, the performance of electrodes can be affected by sweat, fat and static current in surrounding atmosphere and as the number of electrodes increase; it decreases the mobility of the target. Though Piezo electric sensors [14], microphones and accelerometers are used in MMG the use of lasers [13] has become more popular due to its accuracy, the laser beam should be maintained at a particular distance from the skin and care must be taken to protect eyes from the laser beam which makes the technique limited to certain implications. The scope of this research is not to review the drawbacks in these techniques, but to come up with a non-contact simple and reliable method to record the muscle activities using photo electric sensors.

1.2 Aim and motivation

The main aim for this thesis is:

- To come up with a simple non-contact optical method for monitoring the changes in the activities of muscle fibers.
- The universal advantages of photoelectric sensors and their implementation in biomechanics.
- To find an alternative solution for the use electrodes and MMG sensors in biomechanics.

1.3 Objectives

The objectives of the thesis:

- To build an arm band using photo-electric sensors that could detect the muscle surface displacements.
- To find an appropriate sensor emitting a wavelength that can be reflected by the skin.
- To find a suitable interface to observe and process the recorded signals received at the output of the sensors.
- To assess the response time and sensitivity of these devices in detecting the surface changes over the target muscle.
- To differentiate among the different captured optical patterns due to variable hand gestures and finger movements for analysis.

1.4 Contributions

This thesis project makes the following contributions:

- A comprehensive review of the existing methods used in the detection of muscle activity and understanding the limitations and the past applications of photo electric sensors in the field of biomechanics.
- Designing a schematic circuit and build a real time prototype using photoelectric sensors.
- To demonstrate that photoelectric sensors can be used to detect surface displacements caused due to muscle activity.

1.5 Limitations

This thesis project had the following limitations:

- For the operating wavelength of the RPR-220 sensor, one has to take care that the distance between the skin and the sensor does not exceed the range 0.6cm – 0.9cm otherwise output experiences interference with the noise.
- The experimental setup was built according to the arm size of the subject so it cannot be tested on other subjects with bigger forearm. Different models have to be built for different subjects.

1.6 Outline

The rest of the thesis is organized as follows: Chapter 2 discusses anatomy of forearm muscles that are being considered target muscles and a brief overview of existing techniques used to study the muscle activities. Chapter 3 gives an overview of photo-electric sensors, its types and characteristics. Chapter 4 explains the methodology followed and the experimental setup followed by results in chapter 5 and conclusion in Chapter 6.

2 BACKGROUND

2.1 Introduction

This chapter will briefly describe the anatomy of the muscles, including the concept of motor units followed by the explanation of different common measurement methods and applications proposed to understand the physical and physiological movements of the signals generated during muscle movements and are discussed.

The human body includes several systems like the nervous system, the cardiovascular system and the musculo-skeletal system which are made up of several subsystems that carry on many physiological complex processes, e.g. ‘Action’, which can be mechanical, electrical or bio-chemical. Mechanical activities are accompanied by signals that reflect their nature of activities in the form of pressure or temperature [15].Every movement of the human body is carried on by the muscular system. Any muscle is constructed of discrete organs that contain skeletal muscle tissues, blood vessels, tendons and nerves. The muscular tissues are sub-divided further into Visceral, Cardiac and the skeletal tissues which perform different conscious and involuntary actions.

In this thesis we focus mainly on the skeletal muscles so the first two groups of tissues are not discussed here. Most skeletal muscles are attached to two bones through tough tendons which firmly attach muscles to bones. In case of fingers, they don’t have muscles and are moved through the tendons attached to the forearm. One can see the surface movements on their forearm when the fingers are moved.

In this thesis we study about the forearm muscles that are responsible for the movement of fingers and the palm. The reason to choose the forearm muscle group is because it is easily accessible, the contractions can easily be monitored and adjusted and it has been the subject of numerous studies in the past. An anatomical design of the fore arm muscles can be seen in the figure 2.1 which shows the types of forearm muscles responsible for different compound actions.

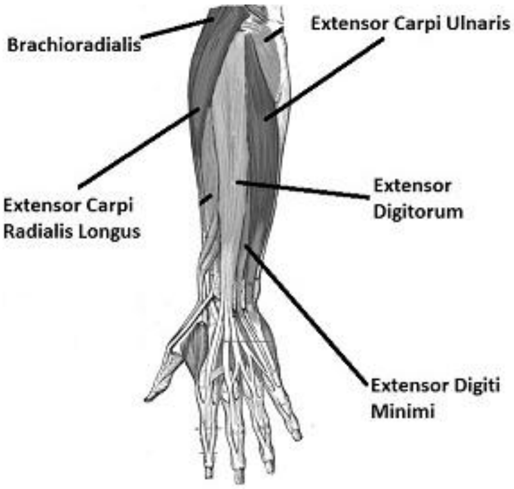


Fig 2.1. Anatomical picture of the forearm muscles.

As mentioned earlier, our fingers do not have muscles in them. They are moved by tendons, pulled by muscles in the forearm. The muscles can be felt when one moves his finger. For each different move, either by a finger or by entire wrist different level of force is exerted either by one or more group of muscles. To rotate the entire arm without moving the hand and the wrist or to move the wrist up and down, much force is applied by the posterior muscles, i.e., *Extensor Carpi Ulnaris*, while little force is applied on the anterior muscle, i.e., *Flexor Carpi Ulnaris*. As the forearm contains many muscles on the anterior and posterior side, our main aim was to observe the surface changes caused during the movement of the fingers, wrist and forearm and detect those changes using photo electric sensors.

2.2 Myography

The measurement of muscular phenomena such as velocity and intensity of muscular contractions is called myography. The lateral oscillations in the muscles, create respective mechanical oscillations at the surface of the skin, are long known. Different techniques are named according to the measurements that can be any electrical or mechanical activities produced by the skeletal muscles. EMG, ECG and MMG are some of the popular techniques that are widely used to study and understand the defects in human system using electrodes or microphones or piezo electric sensors to record the muscular activity.

2.2.1 Electromyography (EMG):

The demand for more advanced methods of surface EMG has a very important implementation not only in clinical diagnosis but also for biomedical engineering applications [9]. By examining the signal one can understand the nature and characteristics of the signal which further helps in rehabilitation of the disorders or in implementing a proper hardware for various applications. The forces and pressure applied of Motor Unit Action Potentials (MUAPs) in EMG signals provides detailed information in diagnosing neuromuscular disorders [6]. The old and invasive method of EMG uses electrodes which are inserted directly into the target muscle. The non-invasive technique uses surface electrodes placed over the skin over the target muscle group to record the fiber action potentials occurring beneath the skin. These advancements have led to an increased demand in developing human-machine interfaces. For example, the JPL Bio Sleeve [2], developed to supervise robots using hand gestures, uses 16 surface EMG sensors and an internal measurement unit (IMU) fitted in an elastic material worn on the forearm of the user. These sensors sense the underlying muscle activity for different gestures and the respective signals are recorded from the IMU. These signals are then mapped and coded for robotic controls. The prototype of a JPL Bio Sleeve is shown in the fig.2.2.

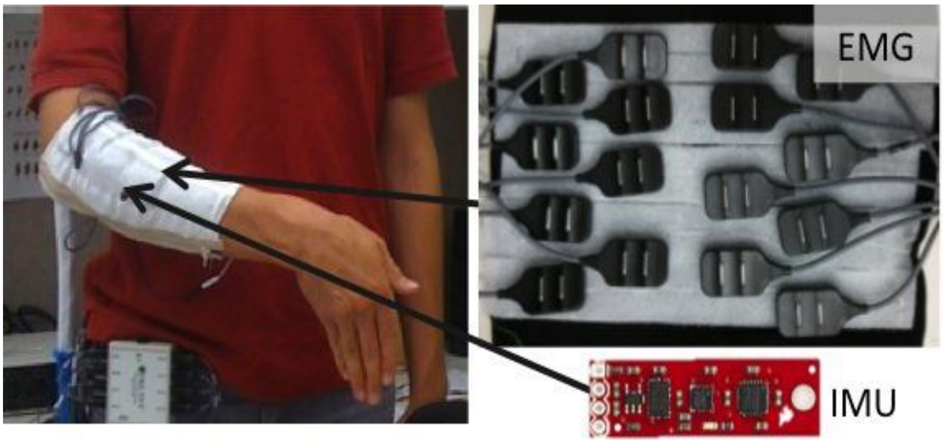


Fig.2.2 JPL Bio-sleeve.

Though this technology had very impressive results in controlling robots with respective hand movements, it still had the disadvantage of slipping or interference of signals thus limiting the usage. The surface of the human body is surrounded by electromagnetic radiations which add up in the EMG signals crating ambient noise whose amplitude sometimes is greater than the EMG signal and is dependent on the operational environment. While recording muscle activity, sometimes the activities in the neighboring muscles is carried on further and is picked up by the surface electrodes placed on the skin, thus leading to the instability of the signal [6].

2.2.2 Mechanomyography (MMG):

A prominent alternative to record and evaluate the muscle activity is the MMG. When a muscle contracts, due to the changes in the muscle shape, one can observe mechanical activity over the surface of the skin [19]. The study of these mechanical signals is referred to as mechanomyography (MMG) and the recorded signal is called as Mechanomyogram. These surface contractions can be measured using an accelerometer, microphone [3], laser optics [20] or displacement sensors placed on the surface of the target muscle group.

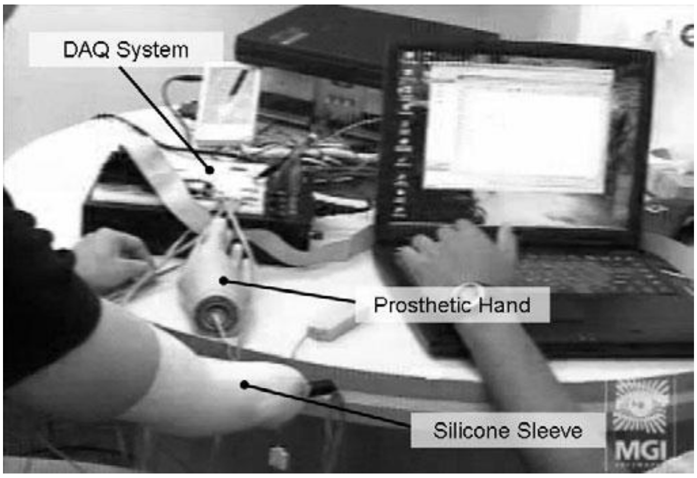


Fig.2.3 (A) Experimental setup for prosthesis using MMG sensors.

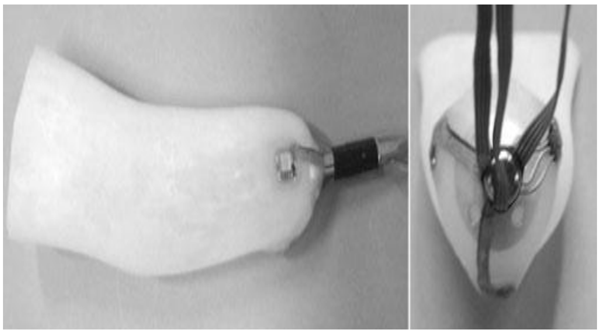


Fig.2.3 (B) - Silicon sleeve containing accelerometers.

Though MMG had successful implementations in recent years, e.g. applications to prosthesis control, selecting a proper sensor has been a challenge as in some cases, sensor placement on muscles and sensor weight may distort MMG signals, particularly in sensitive applications like prosthesis control and robotics.

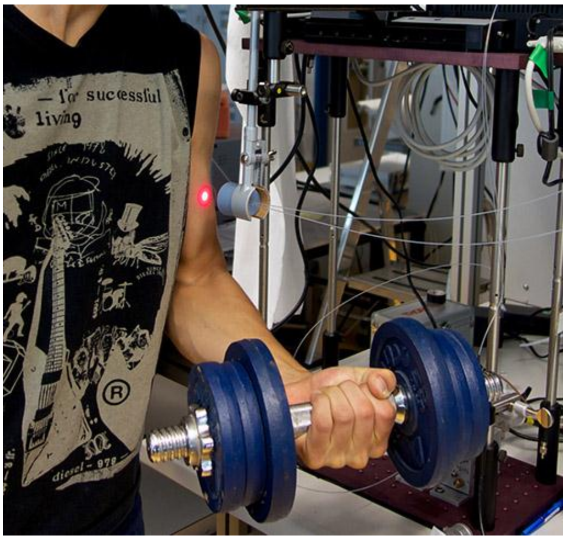


Fig.2.4 Measuring Biceps brachii muscle using laser.

The measurement of muscle activity using laser optics is successfully being implemented but has its limitations as care must be taken that proper distance is maintained between the laser and skin. Mobility is another issue as the setup is fixed at a position and separate transmitter and receiver systems have to be installed.

2.2.3 RPR-220 Reflective photo resistor:

As biological molecules have the tendency to absorb and reflect light, contrary to the common MMG sensors that are being implemented, in this research RPR-220 photoelectric sensors were used in detecting the surface displacements caused due to the muscle contractions and record different signal patterns for different hand and finger gestures. The main idea behind using RPR-220 is that:

1. RPR-220 includes both transmitter and the receiver together which avoids the necessity of installing separate receiver as in the case of MMG using lasers.
2. It operates at wavelengths around 940nm, generating near red light which is reflected after striking the skin surface. Making it safe to implement unlike lasers which have limitations for human exposure.

The details of photoelectric sensors and their characteristic are explained in the next chapter.

3 PHOTOELECTRIC SENSORS

3.1 Introduction

This chapter focuses on the introduction of photo electric sensors, types and their applications in the industrial and medical field. Followed by, a brief overview of the materials generally used for the construction along with the procedure used for the design. Although most of the photo electric sensors are used in the industrial applications, we have utilized it to detect the displacement changes over the surface of the skin.

Photo electric sensors in general are a device used to detect the variations in light intensity either by detecting or non-detecting the sensors light source. These sensors are made up of an LED, a phototransistor which acts as a receiver, a signal converter and an amplifier as shown in the fig 2.1 [8].

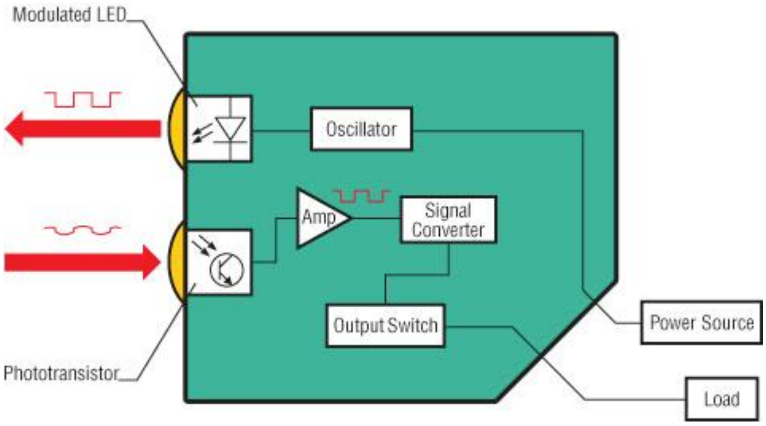


Fig.3.1 Block diagram of a photoelectric sensor.

A beam of light (visible or infrared) is emitted from the transmitting LED which when reflected from the target is detected by the receiver.

3.2 Types of photoelectric sensors

Based on the type of sensing modes, photo electric sensors are categorized into thru-beam, retro-reflective, and diffuse reflective sensors.

3.2.1 Thru-beam sensors

In thru-beam sensors, the transmitter and receiver are setup at a distance as shown in the fig 2.2. The light from the transmitter is focused directly at the receiver and when an object or target crosses the beam, the output signal is generated at the receiver.

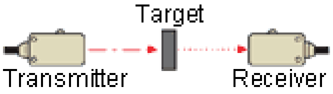


Fig3.2 Thru-beam photoelectric sensor

The sensing mode is also called as opposed mode sensing and is available in many styles. The main advantage of this sensing mode is that opaque objects can be detected regardless of shape, color or material.

3.2.2 Retro-reflective sensors

In retro-reflective sensors, unlike the thru-beam, the sensor consists of both transmitter and receiver embedded in the same device, but a reflector is used to reflect light from the transmitter back to receiver. Detection occurs when an object blocks the light from the transmitter to the reflector as shown in the fig 3.3.

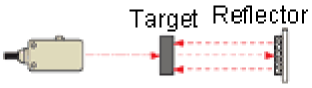


Fig.3.3 Retro-reflective photoelectric sensor

Though these sensors have an easily adjustable optical axis and are simple to setup, they restrict the installation in a limited space. Due to the use of reflector the efficiency of these sensors is more compared to diffused mode sensors, allowing them to sense long rages. Retro-reflective sensors with polarized filters have a low hysteresis value that allows them to detect small changes in the light making them able to detect clear objects. These sensors when operated within a certain distance, or dead zone, eliminate the risk of falsely identifying glossy targets as reflector which is a common mistake while using standard retro-reflective mode sensor [7].

3.2.3 Diffused reflective sensors

Also called as Proximity mode the diffused sensors have a similar setup as of retro-reflective sensors but without a reflector. Detection occurs when the light from the transmitter strikes a target and is reflected at arbitrary angles some of which is received by the transistor [7].

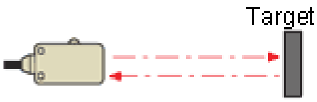


Fig.3.4 Diffused reflective photoelectric sensor

This mode is widely used for shorter sensing ranges as most of the energy is scattered when reflected from the target. The main advantage of using these devices is that it does not require the setup of a separate receiver or any reflective plates and has an easily adjustable optical axis.

3.3 Optical fundamentals of Photo electric sensors

Perceptive knowledge of the relation between the light from the LED with various transparent and semitransparent materials, colored objects, reflecting objects and mirrors helps us understand the reaction of photoelectric systems with targets and noise in the operational conditions. Though most of the photoelectric models have same electric circuitry, based on the choice of the photo elements and their location with respect to lens, they are differentiated as proximity, retro-reflective or diffused mode. These changes create different beam shapes and directions that are responsible for different sensing characteristics.

3.3.1 Effect of different optical components

As mentioned earlier, a photoelectric sensor consists of an LED and a transistor acting as a receiver which detects the reflected source light from the target. Different material combinations used in the construction of LED results in emission of various colors and wavelengths from UV, near IR to visible light e.g. gallium arsenide, gallium aluminum arsenide or gallium phosphide. The detector in most cases is made up of a silicon junction diode that develops a current with an impact of light [5]. Variety of optical performance characteristics can be obtained by considering different lens and different material combinations for LED and detector. For example, large lenses when used can direct light towards a target and collect any received light and in some cases where a small integral lens is immersed on the semiconductor element directs more energy on the target and improves overall sensor sensitivity.

Choosing the right sensor!

As each application differs in the combination of circuit elements, wavelengths and operating environments, when implementing a sensor in an application, one has to consider several characteristics to achieve effective results. Effective sensing distance, repeatability, switching frequency, speed of response and sensitivity play an important role while choosing a right sensor.

For a photoelectric sensor of specified light source, the output depends on the base current generated at the collector-base junction. The DC current gain varies with change in the photocurrent, voltage and temperature. When a light of low intensity is detected by the transistor, the gain at the base is small but increases with increasing intensity until a maximum range and then starts to decrease. The transistor versus light intensity graph is shown in the fig3.5 [17].

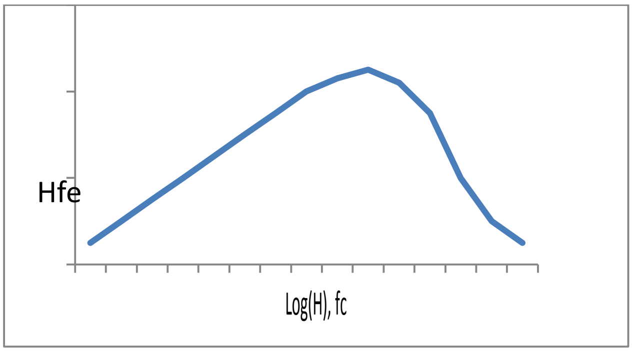


Fig3.5 Transistor Gain vs. Light intensity.

3.3.2 Dark current- ($\mathrm{I_D}$)

The maximum collector current permitted to flow at a specified collector-emitter test voltage is known as dark current. This generally prevents the phototransistor from being turned off completely while operating in dark environments. The dc current gain of the transistor multiplied by the collector-base junction gives the value of the dark current of a particular phototransistor. Dark current is changes with temperature; it increases with increasing temperature generally defined at$25^0\mathrm{C}$.

3.3.3 Response time

The amount of time the sensor takes to detect a target and change its output state is called as the response time. It depends on the size of the target and the velocity of displacement of the target. The speed of response can also vary depending on the value of load resistance and capacitance of the collector-base junction. The response time usually expressed in rise time (t_r)-the time required for output to rise from 10% to 90% and fall time (t_f)-the time taken for output to fall from 90% to 10% in its operating voltage.

In this thesis, RPR-220 sensor was used due to its high sensitivity and its simple construction. Compared to other optical sensors emitting IR light which were already used in detecting the muscle displacements this sensor has a higher wavelength of 940nm. The light emitted from the transmitter does not penetrate into deeper layers of skin and is limited to the top layers. This automatically eliminates the detection of pulse signal at the output.

4 METHODOLOGY

In this chapter, the experimental procedure, circuit designing tools used and challenges faced in obtaining the desired result are discussed. A detail study carried out on different sensors used in industrial and biomedical applications and their properties were compared. In this research, an optical sensor that emits light with a wavelength that is scattered by the skin but not completely get absorbed is required. Depending on the wavelength, the inherent optical properties of skin layers determine the reflective and absorption properties of the skin. The epidermis layer of the skin consists of melanins and keratins [21]. Melanins have high refractive indices which scatters light to a high degree. The reflective properties of the skin increase with increase in the wavelength of the incident light, as shown in the fig4.1.

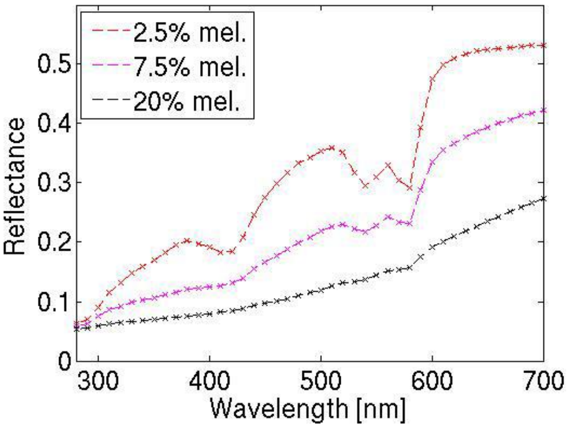


Fig4.1. Reflective properties of skin depending on wavelength

The two optical sensors- TRCT1000 and RPR-220 were chosen, operating at wavelengths 950nm and 940nm respectively, and the differences and advantages were compared. TRCT1000 optical sensor is a very well-known sensor that is used in the detection of human pulse. Though their operational wavelengths are same the maximum operational distance of TRCT1000 from the skin is limited to 0.6mm. At this distance the output signal detects the pulse, which in this application will become the noise.

The figure 4.2 shows a block diagram of a RPR-220 photo reflective sensor. It consists of GaAs LED transmitter that emits infrared light of wavelength 940nm and a high-sensitivity detector - silicon planar transistor with a sensitivity wavelength of 800nm. The transistor generates an output signal when it detects the reflected source light from a target. It also has a built-in visible light filter that minimizes the influence of stray light. Though RPR-220 has a wide implementation in industrial appliances like compact disc players, copiers, game machines and office automation equipment, in this research we have used it as a displacement detector.

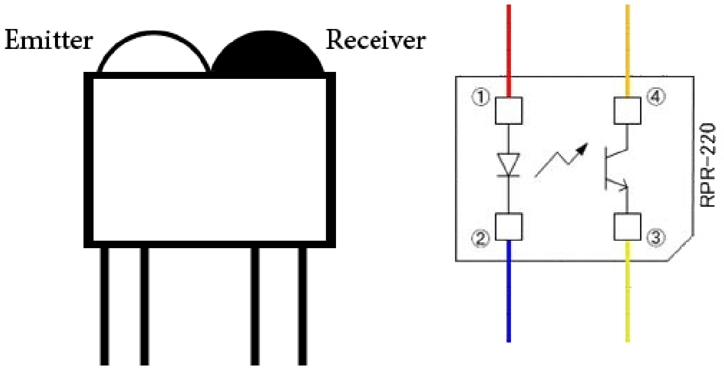


Fig4.2 RPR-220 photo reflective sensor.

The experiment was conducted by testing one sensor initially to understand the working procedure and the results were observed in muscle surface detection. The output from the sensor receiver was connected to a CRO to observe the changes in the signal for different predefined movements.

An arm band was made that could be worn around the forearm, with two RPR-220 sensors targeting two major muscles, Brachioradialis and Extensor Carpi Ulnaris [16], as the surface displacements are clearly visible and can be controlled. The setup was installed with care that the distance between the skin and the sensor head is not less than 0.6cm. The sensors were driven using an external voltage generator, activating the photodiode. The reflected light was detected by the emitter and the signal was measured at the output. Initially, when the hand was at rest, the output voltage was constant at 2V which was considered as the reference signal. For predefined movements being made, observations were made for variations in the amplitude and output frequency for respective hand and finger movements. As the measurements of the surface displacements were recorded using optical signals, this thesis is named Optomyography. Figure 4.3 is the flow chart explaining the step by step procedure followed in this research followed by the block diagram of the circuit implemented.

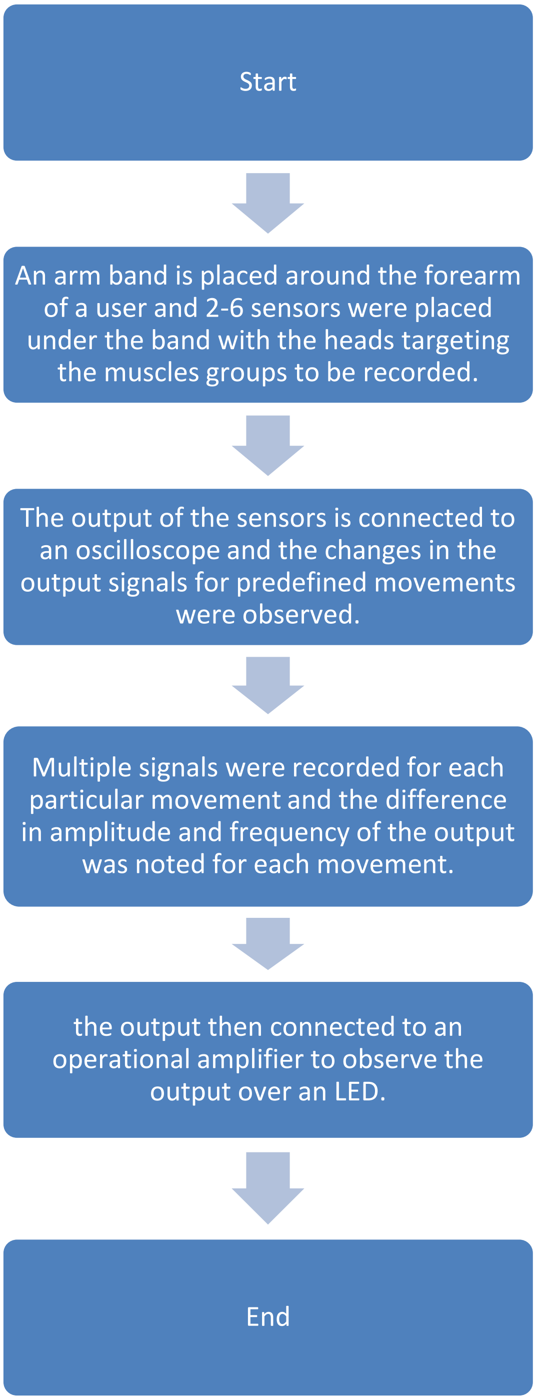


Fig.4.3 flow chart explaining the step-by-step procedure followed.

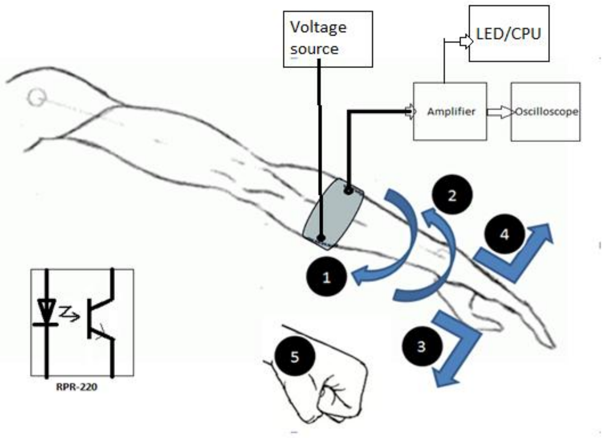


Fig 4.4 Block diagram

4.1 Procedure

A forward Input voltage of +5V is applied to the transmitting LED via a current limiting resistor. The output amplitude of the signal from the transistor value was calculated which varied from 2V to 2.5V. For each different finger movements and hand gestures different voltage levels and frequency changes were noted. As the output signal was very small in amplitude, an operational amplifier was used to amplify the the signal to see the changes in the output over an LED. For each movement, the changes in the output was clearly seen with the changes in the intensity of the LED.Furthermore, six RPR-220 sensors were used to understand the role of different muscle groups for each movements. The circuit schematic and a PCB model were designed using OrCAD tools and the prototype of the arm band with six sensors and a PCB unit can be seen in figure 4.5. The simulation was performed by recording output signals for 14 hand gestures. Each movement was performed for four consecutive times to observe the stability of the output. The results with pictures are given in chapter 5 followed by conclusion and future applications.

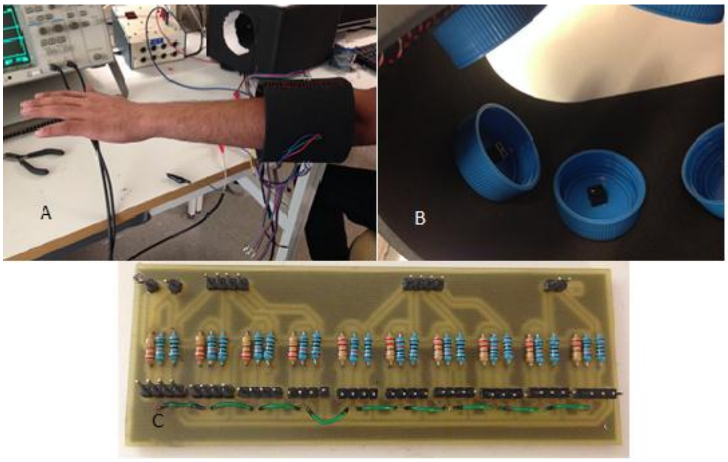
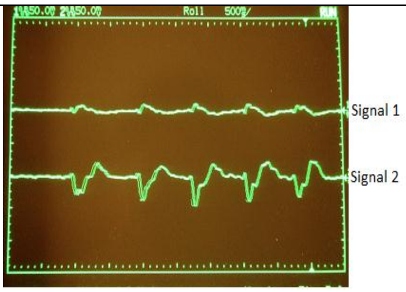
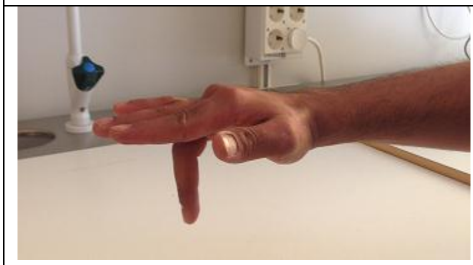
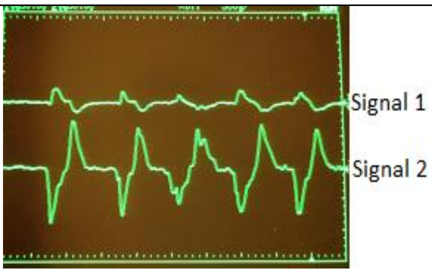
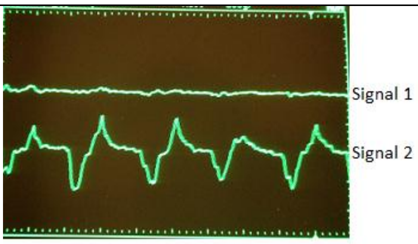
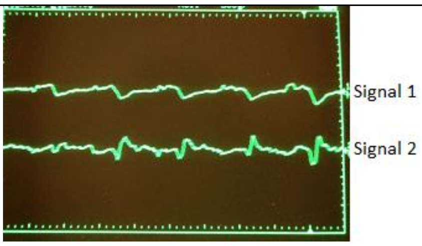
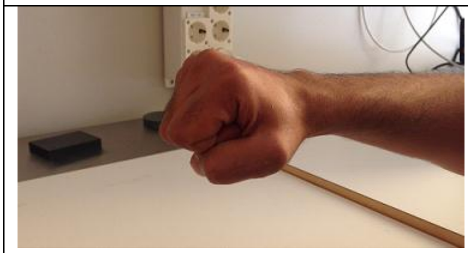
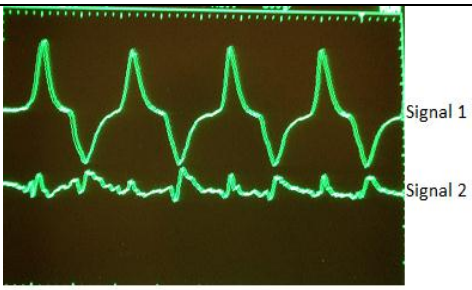
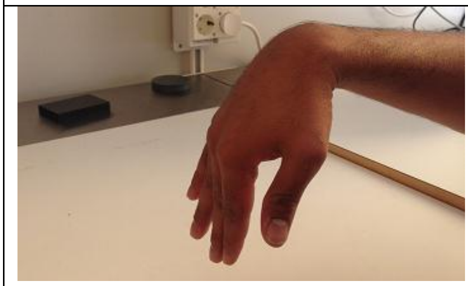
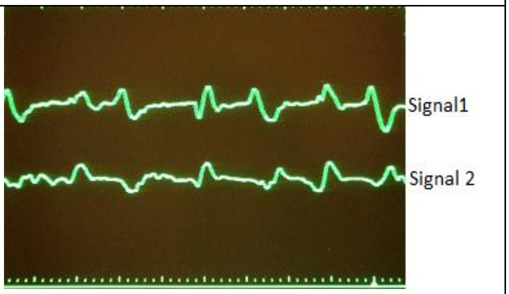
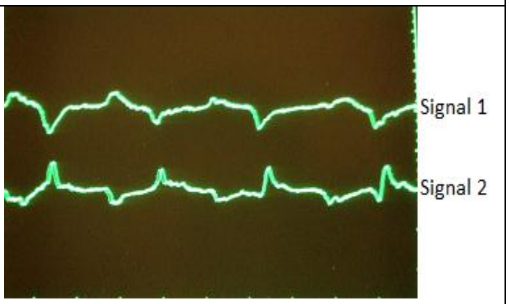
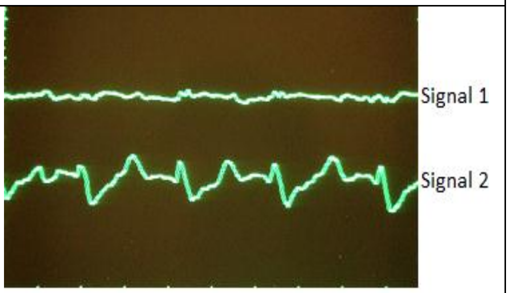
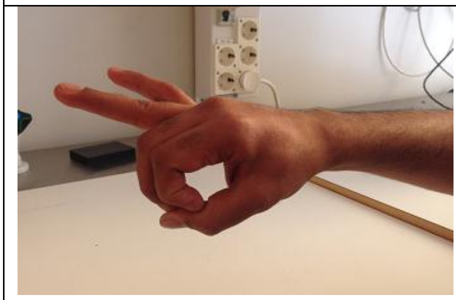
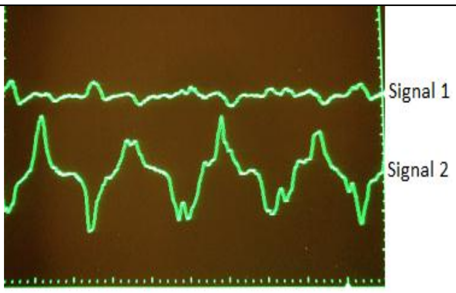


Fig. 4.5 A – Prototype of the arm band around the forearm of the subject B – Inner view of the band with sensors. C – Designed PCB circuit.

5 RESULTS

The outputs were recorded for 14 different hand gestures, where each movement was repeated for four consecutive times to observe the stability of the output signal. The signal outputs for respective gestures are mentioned in the following figures. Two sensor outputs were observed simultaneously with first sensor targeting Extensor Carpi Ulnaris while the second senor targeting Brachioradialis.

	Signal 1 Signal 2
	Signal1 Signal 2
	Signal 1 Signal 2
	Signal 1 Signal 2
	Signal 1 Signal 2

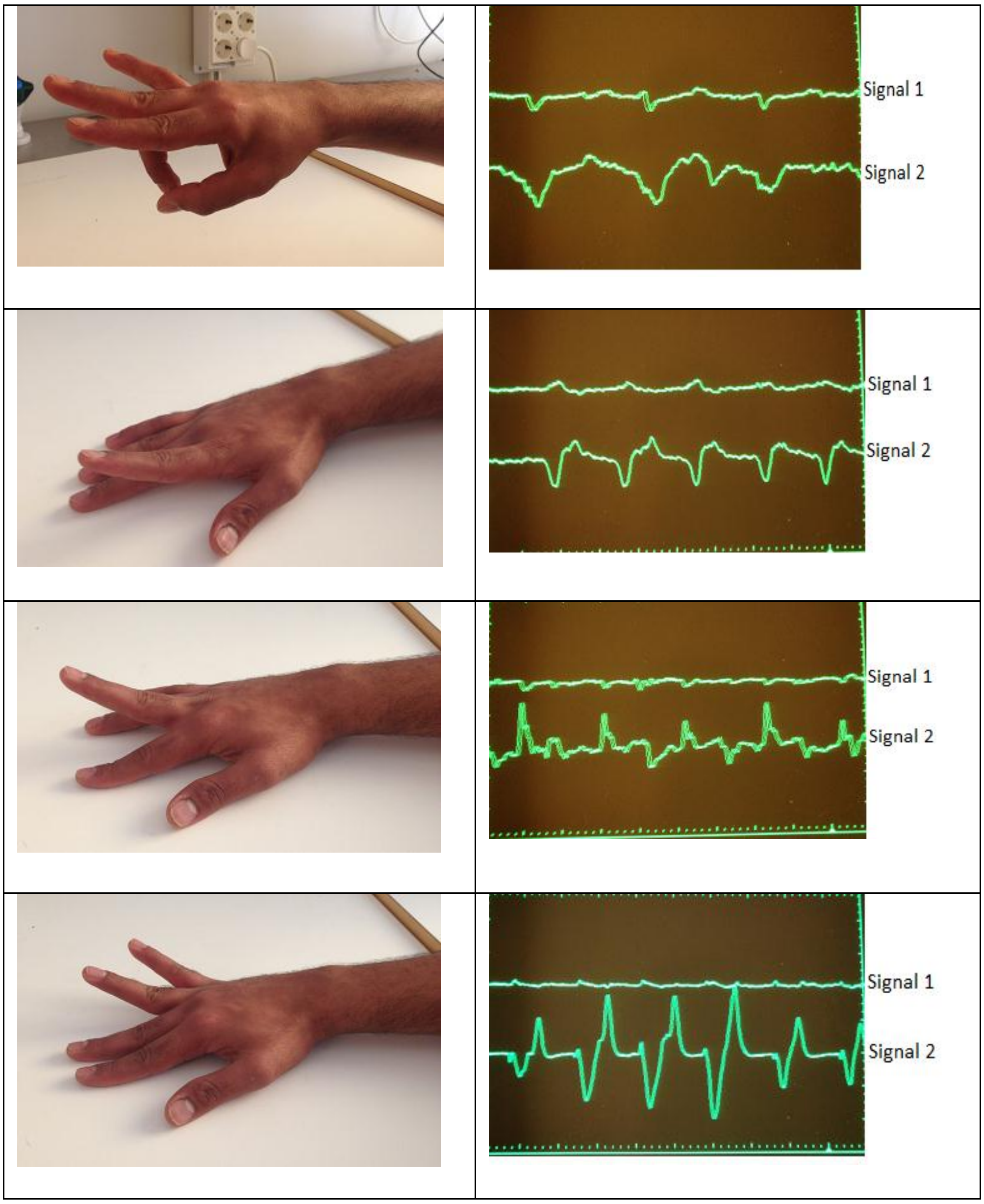


Fig 5.1 Different hand gestures and their respective outputs for four consecutive movements.

From the recorded signals, in Signal1 which is the output from sensor1, one can clearly observe that when the contractions of Extensor Carpi Ulnaris occurs the signal starts with a raise in amplitude until it reaches a peak value and falls during expansion of the muscle where as in the case of signal2 which is the output of sensor2 focusing brachioradialis, the signal starts with a fall in amplitude during contraction of muscle then increases the amplitude with expansion.

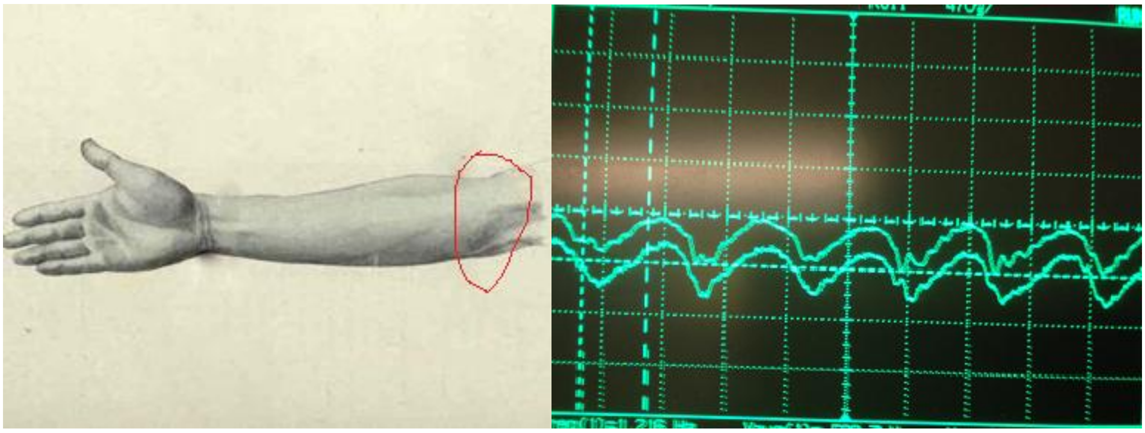


Fig 5.2 Output obtained by flexing (the encircled area in red) the Bicep Brachii muscle

Figure 5.2 shows the output signals obtained from two sensors one focusing the brachioradialis and the second focusing the extensor carpi ulnaris while *tightening* the Biceps Brachii muscles.

5.1 Advantages

- This method is cost effective, reliable and easy to install compared to the existing methods of EMG and MMG in muscle surface detection.
- The use of multiple sensors yields in multiple outputs, thus making it easy to understand the simultaneous function of muscle groups by comparing signals at different points on the skin surface.
- These sensors can be replaced for laser sensors used in MMG detection as it is safe and easy to install.
- As water is a very good reflector for IR light, these sensors also function precisely in detecting the surface changes even under the presence of sweat.
- The proposed model can also be used by astronauts in space so that they can perform certain actions simply by the movement of their fingers or wrist.

5.2 Limitations

- The mobility of the user in this experiment is confined to a particular region where the output signals are observed due to the fixed cable length.
- Care must be taken that the sensor to skin distance is in the range of 0.6cm – 1cm, otherwise results in an inaccurate measurement.
- The surface displacements cannot be precisely measured over a damaged skin surface due to the irregularities.
- RPR-220 is designed to be used with ordinary electronic equipment or devices such as audio visual equipment, communication devices and electronic toys. If used for equipment with high reliability results in malfunction of the sensor.

6 DISCUSSION

6.1 Results from literature

The study of existing techniques used in the surface measurement of muscles showcased that non-invasive devices like electrodes and accelerometers were widely used. The limitations in these sensors increased the demand of non-contact sensors. Laser sensors were the first non-contact optical sensors used to detect the surface displacements caused over the muscle surface. The study of methods implemented using laser sensors show that light can be successfully used for the measurements. These sensors had limitations of mobility, safety and installations and the applications are limited to clinical purposes. Continuous developments are made in finding the appropriate sensors which can be both used in clinical purposes as well as in building better human-machine interfaces. From the study it was found that IR optical sensors were little used in clinical purposes. One experiment used an array of TRCT-1000 to detect the surface displacements of biceps brachii muscles. The results were promising but the sensors were in contact with the skin and the noise from the pulse signals complicated the installation. Another experiment conducted at Cornell University, by Fisher, Singh and Gupta used one photodiode and four photo transistors to detect the movements of fingers and wrist. Their model used four different receivers and also limited the mobility of the user.

6.2 Prototype and Circuit design

Initially a test experiment was carried out with one RPR-220 sensor to determine the detection of surface displacements. Later another sensor was used to observe the variations in the two output signals for a particular movement. The sensors were placed on a material which is typically made up of lower density rubber composite (used in making mouse pads). The material was flexible and could be easily designed to resemble an armband. Though the test experiment with one and two sensors gave positive results, the sensors had to be precisely placed at a particular distance of 0.6m - 1cm based on the circuit to design a simple and user friendly band. The output of the test experiment was a very low voltage signal which was observed on a CRO. The outputs from 15 different gestures were recorded to observe the variations at two different places in the forearm.

Furthermore, a model was designed with six RPR-220 sensors placed around the arm band. The reason was to observe the various output signals obtained for one particular movement. As CRO had only two channels, the outputs from six sensors could not be observed at the same time. Two outputs had to be observed at one time and this had to be repeated all the time. So LEDs were used to observe the changes in the intensity for respective changes in the output voltage levels. As such low changes in the voltage levels cannot be used to drive an external LED; an operational amplifier using LM324 circuit was designed to amplify the output obtained at the sensor end. For a particular movement as the surface displacements vary around the forearm, LED’s glow at different intensities depending on the movement at the respective sensor.

7 CONCLUSIONS

This study concludes that optical IR sensors like RPR-220 can be successfully implemented for muscle surface displacement detection. The captured optical patterns were different and unique for respective muscle actions. The arm band prototype built using multiple photo electric sensors was successful in detecting one or multiple muscle activities at the same time. The proposed model is easy to setup, reliable and safer in clinical purposes compared to the use of lasers.

Furthermore, the model could be used as a simple human-machine interface that can be implemented in wide range of applications. As the present model connects the sensors output to a computer through cables, this feature can be further simplified by implementing Bluetooth or Wi-Fi which increases the mobility of the user. The output recorded signals can be further processed in a computer or microcontroller and implement in wide range of applications. Example, if each signal is assigned with a particular command of action, one can implement these sensors in prosthesis control or robotics.

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