Design and Development of Low Cost Biosignal Acquisition System for ECG EMG and EOG

In partial fulfillment of the requirements for the degree of B.Sc. (Engg.) in Electrical and Electronic Engineering

Submitted by

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Exam Roll: 146; Registration No: 2013-012-407
Year: B.Sc. (4th year 1st semester)

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Declaration

We, hereby, declare that the work presented in this thesis work is the outcome of the investigation performed and authentically prepared by us under the supervision of **DR**. **MD. SHAFIUL ALAM**, Professor, Department of Electrical and Electronic Engineering, University of Dhaka. To the best of our knowledge, it contains no materials which are exactly same which were previously published anywhere in print or soft.

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Certificate

This is to certify that the 4th year 2nd semester thesis on **"Design and Development of Low Cost Biosignal Acquisition System for ECG EMG and EOG**" has been submitted for the partial fulfillment of the degree of B.Sc. (Eng.) in Electrical and Electronic Engineering from the University of Dhaka, carried out by **MD. SHAH KAMAL**, under my supervision. According to my knowledge and as per declaration, the whole work and project report has been prepared by the student and has not been submitted anywhere else to any degree. The project report can be considered for evaluation.

They are permitted to submit the project report.

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Abstract

A biosignal is a human body variable that can be measured and monitored continuously and provide information about health status. Among them well known bioelectrical Signals are- Electrocardiograph (ECG), Electromyography (EMG), Electroencephalogram (EEG) and Electrooculogram (EOG). Electrocardiogram (ECG or EKG) is an electrical activity of the heart over a period using electrodes placed over the skin. Electromyogram (EMG) is also another electro diagnostic signal for evaluating and recording the electrical activity produced by skeletal muscles. Where Electrooculogram (EOG) is a biosignal measuring from the corneo-retinal standing potential that exists between the front and the back of the human eye.

Those signals are useful for different applications like disease diagnosis, human machine interface (HMI), entertainment etc. In the last decade, there has been an increase in the development of devices for personal healthcare applications. This report presents a low cost biosignal acquisition system specialized for ECG, EMG and EOG. In this system we acquired these signals by placing the skin surface electrodes on different positions on body using a simple bio-amplifier circuit. The prototyping equipment was built in a common impressed circuit, composed by following blocks- a) instrumentation amplifier, b) low-pass filter (cutoff frequency 150 Hz), c) Amplifier, d) high-pass filter (cutoff frequency 0.1 Hz), e) Amplifier and finally f) Offset control. The implementation was done by operational amplifiers and elementary electronic devise like resistor, capacitor etc.

For computer interface Arduino UNO was used for analog to digital conversion (ADC). A model was developed in Simulink for visualizing and storing the signal in real-time. The system further stored the signal data in workspace of MATLAB where different analysis was performed.

Table of Contents

List of Figures

Chapter 1

Introduction & Objectives

Biosignal can be defined as any signal in living beings that can be continually measured and monitored. It can be both electrical and non-electrical signals. Bioelectrical signals can be sensed by non-invasive methods by using skin-surface transducer Human body generates a variety of electrical and non-electric signals. These signals indicate the physiological conditions of the body. Some of the vital bioelectric signals are Electrocardiogram (ECG), Electromyogram (EMG), Electroencephalogram (EEG) and Electrooculogram (EOG) [1].

ECG and EOG signals are bipolar low-frequency signals. The normal range of ECG signal is 0.05-100Hz having its amplitude ranges from 10μV to 5mV, whose typical value is 1mV [2]. EOG signal ranges between 15 μV to 200 μV with a frequency range of about 0-30 Hz [3]. Generally, the amplitude of the EMG signal ranges from 0- 10mV (peak-to-peak) and its frequency ranges from 0- 500Hz. The dominant energy in EMG is being 50-150Hz [4].

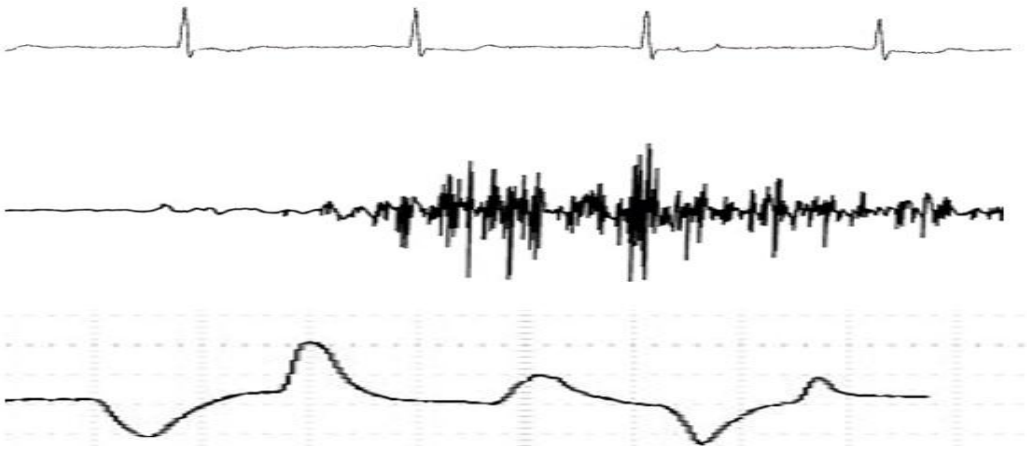

Figure 1.1: Waveform of ECG, EMG and EOG signals.

In recent years, development of personalized healthcare devices has received much attention. Various scientists are working not only in the development but also in the improvement of the efficiency of the personalized healthcare devices. Such devices are helpful in carrying out routine diagnostic tests of the vital parameters of the human body [5].

Amongst the various personal healthcare devices, devices that provide information about cardiac health have received special attention. This is because there has been an increase in the occurrence of cardiovascular diseases. Additionally, with the increase in the life expectancy of the human, the number of middle-aged and elderly people is growing in the society. Hence, it is important to monitor regularly the cardiovascular parameters for early detection of any pathological condition. Every year, across the globe, nearly 2000 people have been reported to die due to the physiological

conditions associated with cardiovascular diseases. The diagnosis of cardiovascular diseases is achieved mainly by analyzing the ECG signals. Any change in the physiology of the heart muscles is associated with the alteration in the features of ECG signal. Recent studies suggest that emotional and physical stress alter the heart rate and the body temperature of the patients [6]. The monitoring of the heart rate may divulge information about the disease conditioned situations associated with the autonomic nervous system (ANS) and other clinical conditions lack of Thyroid hormone receptor. Apart from this, the cost of the devices is much higher, which makes them out of the reach of the poor people. Recent advances in the field of instrumentation and sensor technology have allowed the development of ambulatory devices [7].

EMG measures electrical currents that are generated in muscle during its contraction. A muscle fiber contracts when it receives an action potential. The EMG observed is the sum of all the action potential that occur around the electrode site. In almost all cases, muscle contraction causes an increase in the overall amplitude of the EMG. The signals also have different signatures depending on age, muscle development, motor unit paths, skin fat layer, and gesture styles. The external appearances of two individuals' gestures might look identical, but the characteristic EMG signals are different. EMG testing has a variety of clinical and biomedical applications. EMG is used as a diagnostics tool for identifying neurological and neuromuscular diseases and problems, or as a research tool for studying kinesiology and disorders of motor control. The signals are sometimes used to guide botulinum toxins or phenol injections into muscles. EMG signals are also used as a control signal for prosthetic devices such as prosthetic hands, arms, and lower limbs. Another important application of EMG is human machine interface (HMI) and controlling of various devices [8].

The Electrooculogram (EOG) is the electrical signal that corresponds to the potential difference between the retina and the cornea of the eye. This difference is because occurrence of metabolic activities in the cornea region is higher than that in the retinal region. Primary applications are in ophthalmological diagnosis and in recording eye movements. Unlike the electroretinogram, the EOG does not measure response to individual visual stimuli. As EOG is the electrical recording corresponding to the direction of the eye, it makes the use of EOG for applications such as HCI very attractive. EOG-based techniques are very useful for patients with severe cerebral palsy or those born with a congenital brain disorder or those who have suffered severe brain trauma [9].

Our project aims to develop a low cost biosignal acquisition system which is affordable for the people of developing and underdeveloped countries. In our previous project, we have developed an EOG data acquisition system. In this project, we have modified the system for acquisition of ECG, EOG and EMG together. This report represents a prototype biosignal acquisition system, which is portable, battery powered and it includes computer interface facility. In this system biosignal is transferred to computer as an analog to digital (ADC) waveform by Arduino UNO, which is a very popular open-source hardware platform widely used due to its flexibility and usability. We developed Simulink model for digital filtration, visualizing and storing the signal in real-time. The system further stores the signal data in workspace of MATLAB, where different

analysis was performed. The equipment used in this system is battery powered and consumes less electricity.

The presented work organized in 5 chapters. First chapter is an introduction of project background, aims and objectives and outline of the project.

- Chapter 2 consists of literature review, study of anatomy and physiology of heart, muscles, eye, principles of ECG, EMG, EOG signals and summary of previous works.
- Chapter 3 summarized the materials and methods used for acquisition of signals, setup of placement electrode, digital filtration in Simulink and signal processing in MATLAB.
- In chapter 4 results are presented and designed system is tested with ECG, EMG, EOG signals so that the success rate of the system can calculate.
- Chapter 5 concludes the presented work and recommendation is summarized.

Chapter 2

Literature Review

2.1 Principle of ECG

Electrocardiography (ECG or EKG) is the process of recording the electrical activity of the heart over a period of time using electrodes placed over the skin. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle's electro physiologic pattern of depolarizing and repolarizing during each heartbeat [10].

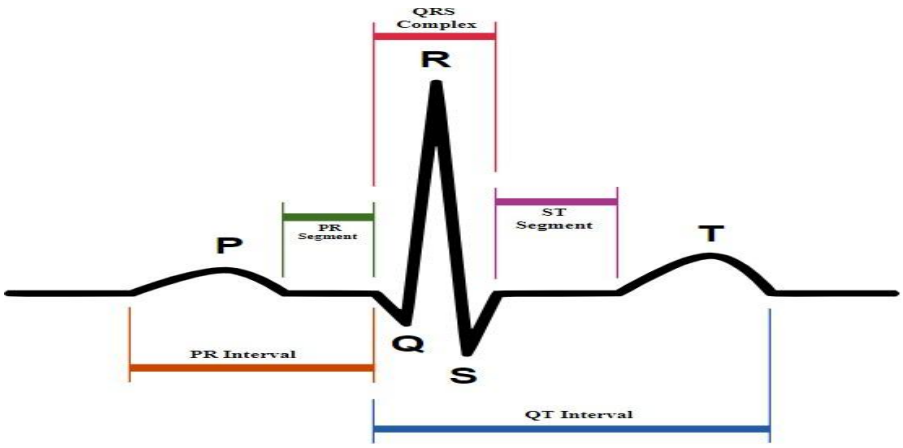

Figure 2.1: ECG waveform.

There are three main components to an ECG- the P wave, which represents the depolarization of the atria, the QRS complex, which represents the depolarization of the ventricles, and the T wave, which represents the repolarization of the ventricles. It can also be further broken down into the following-

- P is the atrial systole contraction pulse. P wave should be always before QRS complex, separated by PQ interval. P wave is a sign of normal atrial depolarization. Its duration is 110 ms and amplitude: 0.25 mV.
- PQ interval is a period of atrial contraction. The depolarization is delayed in AV node. Its duration: 120−200 ms and positivity is isoelectric.
- QRS complex represents ventricular depolarization and contraction. Duration of QRS complex is 100 ms or less. There are two phases of ventricular depolarization- 1. depolarization of interventricular septum: the vector is oriented from left to right and

anteriorly, 2. depolarization of ventricles: because the left ventricle is more massive than the right ventricle, the vector oriented from right to left and posteriorly. There are three waveforms in QRS complex-

i. Q wave − the first negative wave following P wave, may not always be presented.
ii. R wave − the first positive wave following P wave or Q wave.
iii. S wave − the first negative wave following R wave.

- ST segment is isoelectric line, period of no electrical activity of the heart. It should be in the same level as PQ interval. Every elevation or depression of this line is pathological. Its physiological duration is 320 ms.
- T wave represents repolarization of ventricles. The positivity or negativity should be the same as the major vector of QRS complex. Its physiological duration is 160 ms.
- U wave is ordinarily small and follows T wave and usually has the same polarity as T wave.

During each heartbeat, a healthy heart has an orderly progression of depolarization that starts with pacemaker cells in the sinoatrial node, spreads throughout the atrium, passes through the atrioventricular node down into the bundle of His and into the Purkinje fibers, spreading down and to the left throughout the ventricles. This orderly pattern of depolarization gives rise to the characteristic ECG tracing. To the trained clinician, an ECG conveys a large amount of information about the structure of the heart and the function of its electrical conduction system [11].

Heart rhythm is physiologically generated by SA node. Sign of its healthy function is P wave and PQ interval. Rhythm generated in SA node is called sinus rhythm. Heart frequency or heart rate is based on frequency of ventricular contraction. Can be easily counted from ECG curve. It is necessary to compare two QRS complexes and measure the time interval between their R waves to RR interval (in seconds). Normal heart rate is 55−90/min.

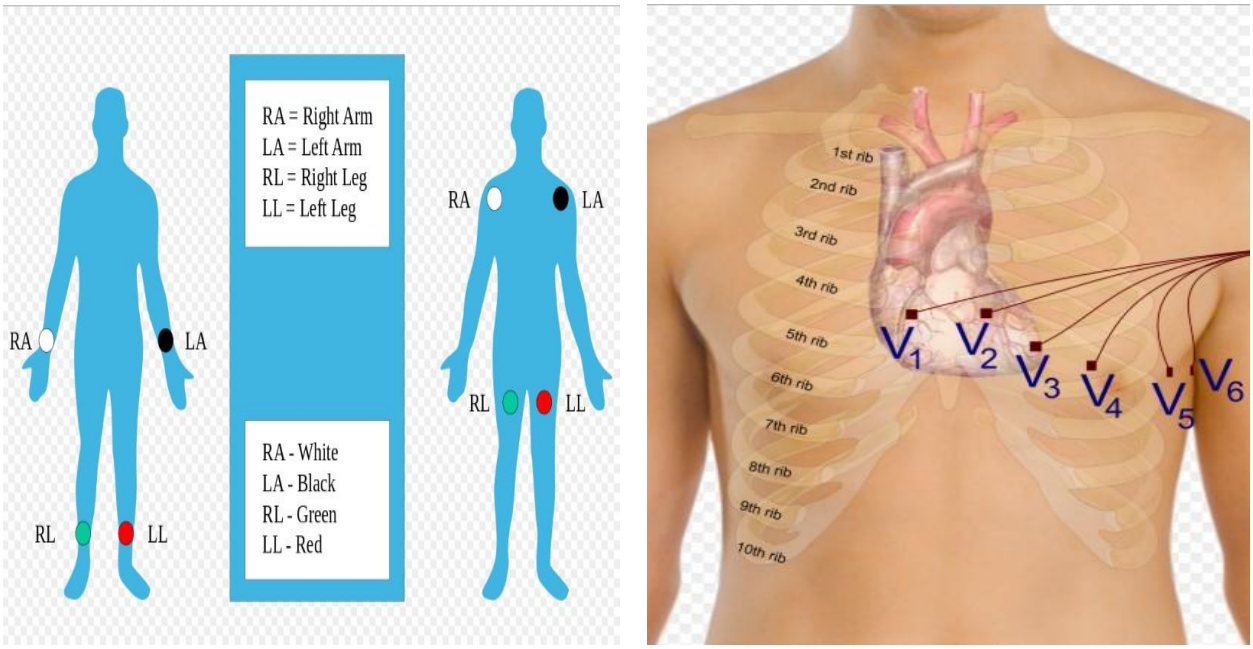

Figure 2.2: Proper placement of the limb electrodes (Left side Figure) and Placement of the precordial electrodes (Right side Figure).

Electrodes are the actual conductive pads attached to the body surface. Any pair of electrodes can measure the electrical potential difference between the two corresponding locations of attachment. Such a pair forms a lead. However, "leads" can also be formed between a physical electrode and a virtual electrode, known as the Wilson's central terminal, whose potential is defined as the average potential measured by three limb electrodes that are attached to the right arm, the left arm, and the left foot, respectively.

Commonly, 10 electrodes attached to the body are used to form 12 ECG leads, with each lead measuring a specific electrical potential difference (as listed in the table below). Leads are broken down into three types: limb; augmented limb; and precordial or chest. The 12-lead ECG has a total of three limb leads and three augmented limb leads arranged like spokes of a wheel in the coronal plane (vertical), and six precordial leads or chest leads that lie on the perpendicular transverse plane (horizontal). In medical settings, the term leads are also sometimes used to refer to the electrodes themselves, although this is technically incorrect. This misuse of terminology can be the source of confusion. The 10 electrodes in a 12-lead ECG are listed below [12].

Table 2.1: ECG Electrode Name and Placement.

Electrode name	**Electrode placement**
RA	On the right arm, avoiding thick muscle.

LA	In the same location where RA was situated, but on the left arm.
RL	On the right leg, lower end of inner aspect of calf muscle. (Avoid bony prominences)
LL	In the same location where RL was placed, but on the left leg.
V1	In the fourth intercostal space (between ribs 4 and 5) just to the right of the sternum (breastbone).
V2	In the fourth intercostal space (between ribs 4 and 5) just to the left of the sternum.
V3	Between leads V2 and V4.
V4	In the fifth intercostal space (between ribs 5 and 6) in the mid-clavicular line.
V5	Horizontally even with V4, in the left anterior axillary line.
V6	Horizontally even with V4 and V5 in the mid-axillary line.

Electrocardiography is one of the most basic noninvasive diagnostic methods in medicine. Graphic record of the electrocardiography is called electrocardiogram (ECG, EKG). It is based on recording of electric potential generated by heart on body surface. ECG is indicated if there is suspicion on-

- Heat disease: heart attack, arrhythmias, conduction disturbances, myocardial ischemia
- Metabolic disease: hypocalcemia or hypercalcemia, hypokalemia or hyperkalemia
- Endocrine disease: diseases of the thyroid gland (hypothyroidism and hyperthyroidism)

2.2 Principle of EMG

Electromyography (EMG) is the subject of detection, analysis and utilization of potential electrical signal produced from skeletal muscle cells during their activity of contraction or neurological communication. The recorded electrical signal is known as electromyography and the resultant record is electromyogram. Electromyogram is the combined action potential of the muscle cells of a muscle tissue. EMG signals have an amplitude of about 500uV to 5mV and the frequency range is 10Hz to 5000Hz. If this signal is detected from the surface of skin, it will be the superposition of signals from all the muscles underneath. So, if a single or smaller bunch of muscle fiber is working properly or not, cannot be detected from the skin [13].

Purposes of EMG signal can be divided into two categories,

1. Kinesiological EMG-

   i. functional anatomy
   ii. force development
   iii. Reflex connections of muscles.

2. Diagnostic EMG

   i. strength-duration curves to test nerve and muscle integrity

ii. nerve conduction velocity to test for nerve damage / compression
iii. ring characteristics of motor neurons and motor units, including analysis of
iv. motor unit action potentials to detect signs of pathology such as fibrillation potentials and positive sharp waves

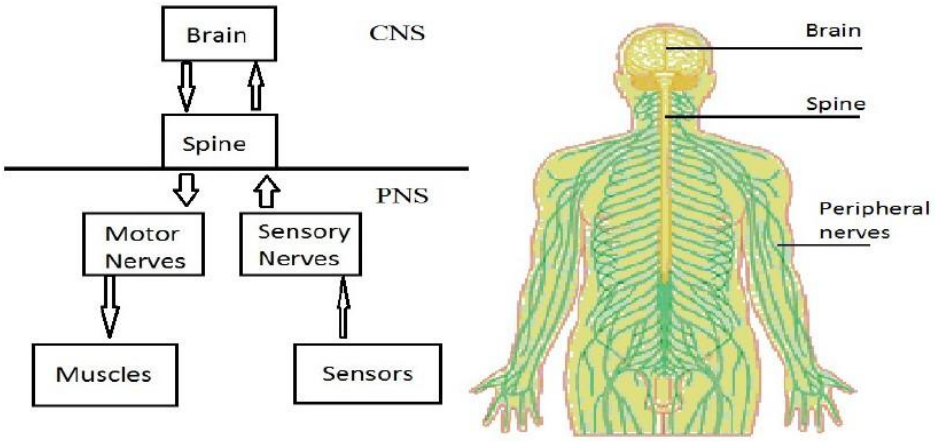

Figure 2.3: The nervous system.

Human body nervous system is divided into two parts shown in Figure 2.3. The first part is Central Nervous System (CNS) which consists of Brain and Spine. The rest of the nervous system is Peripheral Nervous System (PNS). CNS communicates with different organs using nerve fibers using electrical signals. There are two kinds of nerves- 1. Sensory Nerves: Sensory nerves are also known as afferent which carry information from sensory receptors towards the brain such as heat, pressure etc., 2. Motor Nerves: Motor nerves or efferent nerves carry electrical signals from brain to the muscles and glands.

Electrical signal from motor nerves is conducted to the muscle's fibers through Motor Units (Figure 2.4). Motor unit is the junction point where the motor neuron and muscle fiber meet. All muscle fibers in a motor unit are same type of fibers. When a motor unit is activated, all its fibers

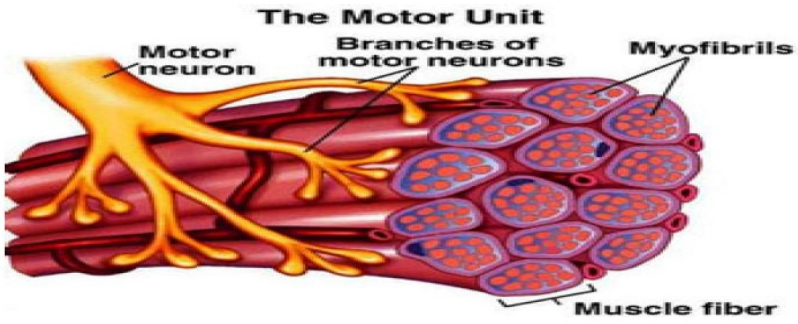

Figure 2.4: The motor unit.

contract. The electrical signal that is produced on the nerves or muscle cells is called action potential (AP). Action potential in neurons is called nerve impulses. Action potential initiates the

muscle contraction and holds the contraction until the signal is supplied by the nerves through motor units. A typical action potential consists of a repolarization state of cell membrane followed by a depolarization state. During the time of action potential, the membrane potential rises from Resting Membrane Potential (RMP), valued at -70mV to a higher potential of about +30mV.

A whole skeletal muscle is considered as an organ of the muscular system. Each organ or muscle consists of skeletal muscle tissue, connective tissue, nerve tissue, and blood or vascular tissue. Skeletal muscles vary considerably in size, shape, and arrangement of fibers. A large strong muscle (Figure 2.5) would have many fibers within each bundle. A smaller muscle used for precision movement, such as those in the hand would contain far fewer fibers per Fasciculi. Muscle fibers are covered in a fibrous connective tissue, known as Endomysium. Each muscle fiber itself

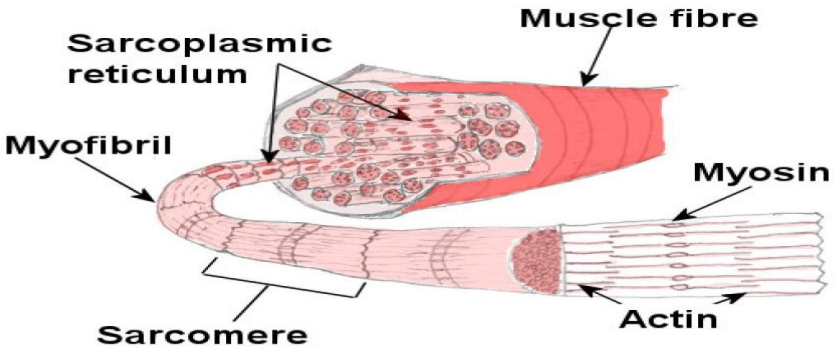

Figure 2.5: Structure of a Muscle Fiber.

contains cylindrical organelles known as Myofibrils. Each muscle fiber contains hundreds to thousands of Myofibrils.

These are bundles of Actin and Myosin proteins which run the length of the muscle fiber and are important in muscle contraction. Surrounding the Myofibril there is a network of tubules and channels called the Sarcoplasmic Reticulum in which Calcium is stored which is important in muscle contraction. Transverse tubules pass inwards from the Sarcolemma throughout the Myofibril, through which nerve impulses travel. As mentioned earlier, skeletal muscle fibers contain two types of filaments, Actin and Myosin.

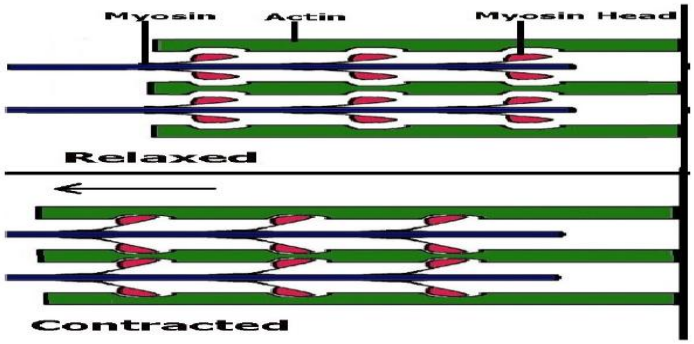

Figure 2.6: Muscle fiber contraction.

The steps for muscle contraction (Figure 2.6) are described below.

i. Depolarization of AP (Action Potential) releases Calcium ion from Sarcoplasmic reticulum.
ii. Calcium ions clean actin binding sites
iii. Myosin head attaches to the action, this is called cross-bridge
iv. Power stroke: myosin head pulls the actin filament
v. This process uses energy from ATP (adenosine triphosphate)
vi. Cross-bridge detaches when a new ATP binds with myosin
vii. In each stroke the myosin head moves about 10 to 12 nm

This process continues if ATP is available and AP continued [14].

2.3 Principle of EOG

The eye is a place of a steady electric potential field that is quite unrelated to light stimulation. This field can be detected even with the eyes closed or eyes in total darkness. This steady electric potential can be viewed as a fixed diploma with positive pole at the cornea and negative pole at the retina. The magnitude of this corneoretinal potential is in the range 0.4-1.0 mV. This potential is not generated by excitable tissue, but it is due to the occurrence of higher metabolic activity in the retina. For the invertebrates, the polarity of this potential difference is opposite to that found in vertebrates such as human beings. This corneoretinal potential is roughly aligned with the optic axis and hence rotates with the direction of gaze, which can be measured by surface electrodes placed on the skin around the eyes. Rotation of the eye and the corneoretinal potential form the basis for a signal measured at a pair of periorbital surface electrodes. The signal is known as the Electrooculogram (EOG) [15].

Eye is one of the most complex organs present in the body which forms a kind of extension of the brain itself. With its numerous sensory neurons, complex optics and commendable architecture; the eye can be considered as the master sense organ among all the others. The separation of the two eyes in animals (which is about 6 cm in human beings) helps in forming a distinct image by each eye which is processed by the brain through superimposition of the two images thereby giving a perception of depth and 3-dimensional virtue to the surrounding objects. The curvature and architecture of the eye also help in identifying the distance of the light source. To better understand the functioning and optics mechanism of the vision system, the anatomy and physiology of the eye have to be described.

In the direction of light entering the vision system, the outermost transparent part of the eye consists of the cornea which forms a protective covering for the iris and the pupil and allows the entry of light into the eye. Covering the visible part of the eye is a mucous filled membrane called the conjunctiva which also covers the inner part of the eyelids. It provides moisture to the eye. The outer coating of the eyeball which appears white in color is known as the sclera. It forms a protective layer for the eye as well as covers the optic nerves behind the organ. Within the cornea lies a hollow space known as the anterior chamber which is filled with a clear fluid called aqueous

humor. This fluid contains nutrients which help in the survival of the cornea and the lens. The aqueous humor is constantly replenished for the inlet of fresh nutrient media.

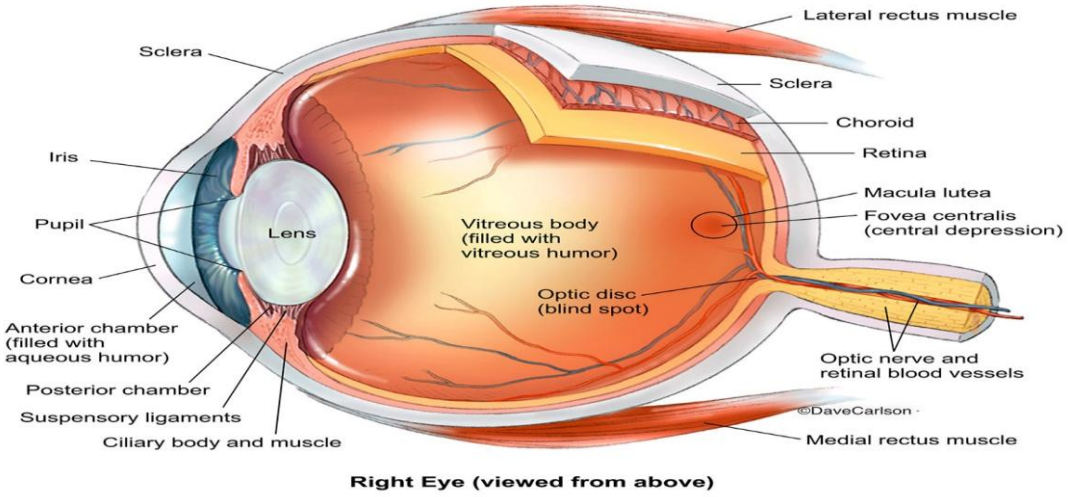

Figure 2.7: Anatomy of the human eye.

In Glaucoma, the drainage of this fluid is hindered which leads to build-up of intraocular pressure leading to loss of vision. Below the anterior chamber lies the pupil which forms the dark circle in the center of the eye. Its function is to regulate the amount of light received by the retina. This function is assisted by the iris which is the colored part of the eye surrounding the pupil. The iris extends to form the choroid which lies between the retina and the vitreous body, and it consists of a bunch of blood capillaries which provide nourishment to the cells in the retina. Below the iris is the lens of the eye whose function is to focus the incoming light upon the retina. The lens is a flexible crystalline part of the eye whose size can be increased and decreased based on the amount of focusing required which further depends upon the distance of the object (a property known as ‘accommodation’. The farther the object, the thicker the lens is required to be. The function and the position of the lens are controlled by a set of fibers known as the zonules of Zinn, which keeps the lens intact in its place and the ciliary body whose function includes accommodation, production of the aqueous humour and positioning of the lens. Between the lens and the iris lies another small hollow space known as the posterior chamber. Behind the lens and the retina lies the vitreous body filled with a jellylike substance known as the vitreous humour. This jelly helps in the refraction of light before it encounters the retina. The light which enters through the cornea, focused by the pupil, converged by the lens and refracted by the vitreous humour finally strikes the retina which consists of millions of photosensitive cells (known as rods and cones) and photoreceptive nerve cells which carry the signals of vision to the optic center of the brain. The center of the retina consists of the macula which is a highly pigmented yellow spot with the highest concentration of cone cells which makes it responsible for high resolution vision. The optic nerves as well as blood capillaries concentrate at the optic nerve head, also known as the optic disc, which forms the blind

spot of the eye. The nerves and capillaries together are carried to the brain where the photoreceptor signals are processed and image is envisioned.
The movement of the eye is controlled by two pairs of reductions and a pair of oblique muscles which provide directionality to the eyeballs thereby allowing a total of six degrees of freedom to the movement of the eye. The eye has one movement in the horizontal plane which is controlled by the lateral rectus and the medial rectus whose function is to abduct towards and abduct away the eyes from the nose respectively. The remaining four muscles function in the vertical plane. The superior rectus elevates the eye and inferior rectus depresses the eye while the superior and inferior oblique muscles control the intrusion and extortion of the eye respectively. These muscles also help in covering the optic nerves at the back of the eye as it is led towards the brain [16].

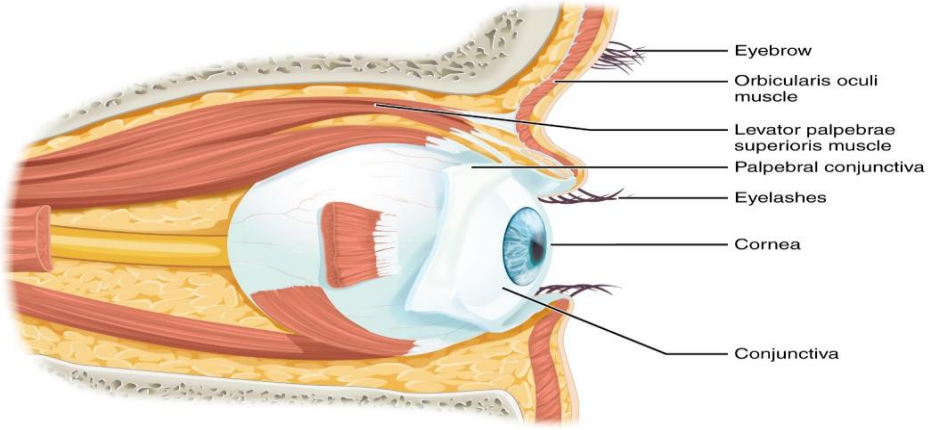

Figure 2.8: Lateral view of extraocular eye muscles.

Due to the higher metabolic rate at the retina compared to the cornea, the eye maintains a voltage of +0.40 to +1.0 millivolts with respect to the retina. This corneoretinal potential, which is roughly aligned with the optic axis and (as a result) rotates with the direction of gaze, can be measured by surface electrodes placed on the skin around the eyes. The actual recorded potentials are smaller in the range of 15 to 200 microvolts and require amplification before processing. With proper calibration, the orientation of the electric dipole can be used to specify the angular position of the eyeball with optimum accuracy which lies within 2 degrees vertically and 1.5 degrees horizontally [17].

2.4 Related Works Done in Biosignal Acquisition

In the last decade, there has been an increase in the development of devices for acquisition of biosignals. There is also huge development of personal healthcare applications and HCI using these biosignals.

In 2015 S K Nayak and his team of Department of Biotechnology & Medical Engineering, NIT Rourkela, India developed a low-cost personal healthcare device capable of recording Electrocardiogram (ECG), Phonocardiogram (PCG) and body surface temperature. The reading from the device can be recorded in any computer with the help of a customized software. Integrated

circuits such as instrumentation Amplifier (INA128P) and operational amplifiers (OP07CP, UA741CP) and passive components such as resistors, capacitors and electret microphone were used in their system. NI USB 6009, Multisim (Version 13.0) and Ultiboard (Version 13.0) of National Instruments, USA software was used for computer interface and analysis [18].

Md. Asif Ahamed and his co-author of Khulna University of Engineering & Technology, Khulna, Bangladesh developed a low cost wireless biosignal acquisition system for ECG EMG and EOG signals. In this system, Arduino UNO is used for visualizing and storing the signal in real-time. An application is developed by processing which stores the signal data in a text file, which can be used in MATLAB for analysis. In their system, biosignal is transferred by Bluetooth serial communication. This system can be used either Windows, Linux, Mac OS and suitable for both laptop and desktop computer [19].

In 1990 Knapp and Lusted introduced "Bio mouse" a bioelectric controller for computer music applications. This system consists of two separate components. A bioelectric interface and a signal processing unit. The bioelectric interface consists of electrodes and sensors that are placed on the user's body, which sense Electromyography (EMG). The incoming signals are connected to a patch box and are then processed in the signal processing unit. There the signals are digital analog converted, filtered and analyzed by a digital signal processing (DSP) chip. The unit analyses all input signals in real-time and receives and sends information to a host computer over a standard RS-232 serial interface. In addition, it receives and sends MIDI information. The Bio-mouse can be used to control synthesizers, sequencers, drum machines, or any other MIDI device [20].

Tanaka also used bioelectric signals to realize interaction in the context of music performance. She describes a system where EMG is combined with relative position sensing to overcome the inability of EMG to measure isotonic movements. EMG measures muscle activity without motion (isometric) very well, but motion without change in tension (isotonic) relatively poorly. Like in the "Bio-muse" project, the aim was to create multimodal interaction to increase the number of inputs to the control system and consequently the number of independent parameters that define the interaction [21].

D'Mello and D'Souza in developed a LabVIEW based EOG classification system. Ag/AgCl electrodes were used for EOG signal acquisition. To overcome the poor conductivity of skin, they used an electrolytic gel based upon Sodium Chloride. EOG signals were then amplified and filtered by using a high pass filter of 0.5Hz and low pass filter of 30Hz. M Series USB-6221 was used as a data acquisition interface. They used amplitude based EOG classification algorithm. They used the fact that amplitude of blink signal is higher than another eye movement. They compared the peak amplitude with a threshold value and if the amplitude was greater than threshold, then it was considered as a blink [22].

Wijesoma and his co-author developed initial model of a robotic wheelchair system based on electrooculography in. EOG signals were acquired using the MP150 Biopac system before they were digitally processed using MATLAB. Total signal amplification provided by the system was

around 5000. They developed an algorithm which created individual windows. The windowing depended only on past inputs and present input. Time domain and frequency domain analysis of the signals were performed within each window. Frequency domain analysis uses Discrete Fourier Transform (DFT). Upon identifying each intended eye movement, a command corresponding to the respective action was sent to the robot via the computer serial com port [23].

Chapter 3

Method & Materials

In this project we used AD 620 as an instrumentation amplifier, LM 741 as an operational amplifier, passive components such as capacitors, resistor etc. Ag/AgCl disposable electrodes were used in different positions of the body for signal acquisition. For computer interface Arduino UNO was used for analog to digital conversion (ADC). A model was developed in Simulink for visualizing and storing the signal in real-time. The system further stored the signal data in workspace of MATLAB where different analysis was performed.

3.1 Power Supply

As the power supply, two batteries are used in series for the negative and positive power supply. 9V of two Uniross extra heavy-duty batteries were used (Figure 3.1). But we did not provide 9V to the ICs rather we provided 5V through the LM 7805 voltage regulator IC. The circuit diagram is shown in Figure 3.1

3.2 Electrodes

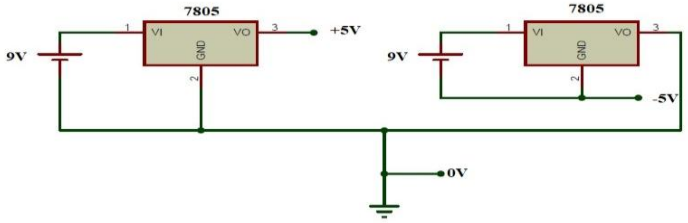

Figure 3.1: Power supply.

To detect biomedical signals a transducer is necessary to transfer the electrical activity on the tissue to the amplifier, they are called electrodes. Two major types of electrodes are described below.

Surface electrodes are non-invasive in nature. They receive information from the surface of the skin. These electrodes are comparatively harmless. Surface electrodes are made of metal or carbon (graphite). Typical surface electrode is shown in Figure 3.2.

Figure 3.2: Surface Electrode.

Surface electrodes have a huge value of impedance which is problem detecting smaller signals. Their output is also affected by the movement of the user. Using electrolytic gel between skin and electrode can reduce electrode impedance. The electrode is attached to the skin using adhesive or Velcro to remove the movement artifact. This is known as floating electrode. Electrical signals for a small group of muscle fibers cannot be detected using surface electrode, but when a sufficiently large number of fibber act together, the compound superposition of all the signals close to the electrode are received.

Needle electrodes are as the name explains, shaped like a needle and a conductive wire is placed inside the needle (Figure 3.3). They are invasive in manner and an electrical variation due to a single or a small group of beer can be detected by them. They are useful for problem detection on muscles in medical purpose. Needle electrode doesn't require electrolytic gel.

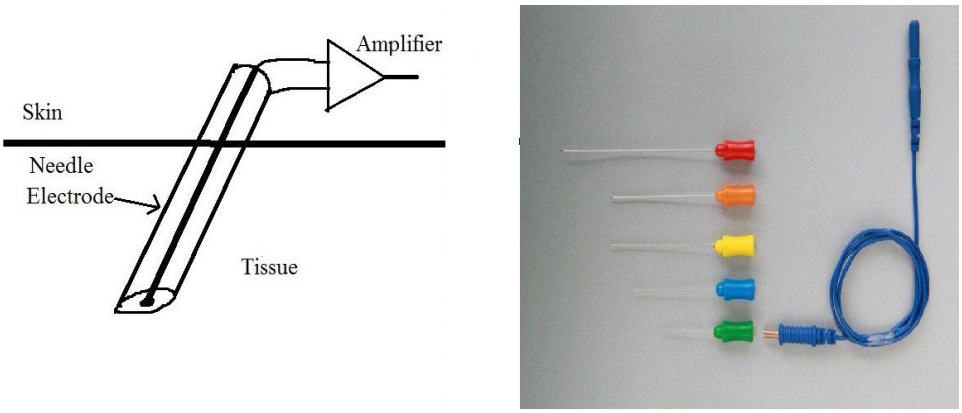

Figure 3.3: Needle electrodes.

Figure 3.4 shows the proper placement of electrode for acquisition of ECG signal where A and B electrodes were placed on chest to detect the ECG and E electrodes were placed on abdomen as the reference.

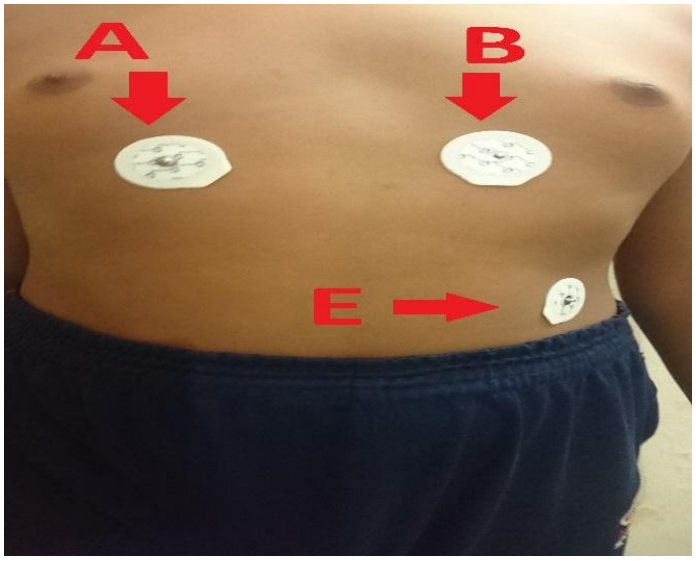

Figure 3.4: Placement of electrode for ECG.

Figure 3.4 shows the proper placement of electrodes for acquisition of EMG signal where A and B electrodes were placed on limb and biceps to detect the EMG and E electrodes was placed on between two electrodes as the reference.

Figure 3.5: Placement of electrode for EMG.

Figure 3.6 shows the proper placement of electrode for acquisition of EOG signal where A and B detect the Horizontal movement, C and D detect the vertical movement and E is the reference.

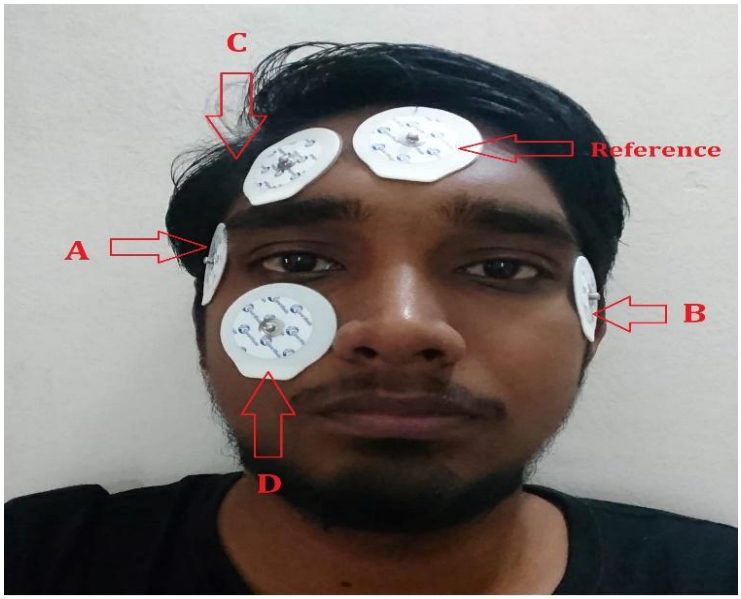

Figure 3.6: Placement of electrode for EOG.

3.3 Operational Amplifier

To detect EOG signal the amplifier should have a high gain and noise cancelling factor. The CMRR (Common Mode Rejection Ration) should be more than at least 60dB (better if greater than 80dB). This could be achieved by an Instrumentation Amplifier. To understand Instrumentation Amplifier there are some noise factors and basic amplifier circuits that is to be described. These are listed below with brief description.

3.4 Differential Amplifier

Differential Amplifier is a double ended input and single ended output device. The basic structure of a differential amplifier is given in Figure 3.7

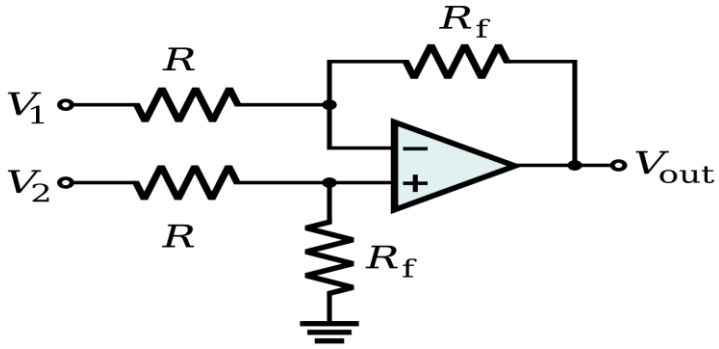

Figure 3.7: A basic differential amplifier.

In this case the amplifier uses two input resistors of same value R, negative feedback resistor R_f and a resistor of the same value of R_f connecting the non-inverting input of the amplifier to the ground. There are two input voltages V_1 and V_2. The output voltage equation for the circuit is,

$$V_0 = \frac{Rf}{R}(V2 - V1) \quad (3.1)$$

The differential gain of the following amplifier becomes,

$$Ag = \frac{Rf}{R} \quad (3.2)$$

So, the output voltage on equation (3.1) depends on the condition where the input resistance is equal, also the feedback and ground resistance need to be equal. The differential amplifier amplifies the difference between two input voltages but suppresses any voltage signal common to the two inputs. This technique is useful in case of EOG detection. In human body a 50 Hz AC noise is introduced due to the main AC power supply of our home/lab and this noise is common for any point of the body. So, this noise will be cancelled because the noise has almost same properties in both inputs of the differential amplifier. To do so the input impedance should be identical.

In this configuration, the input voltage signal (Vin) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes Positive in value in contrast to the Inverting Amplifier circuit. The result implies that the output signal is in-phase with the input signal. A basic diagram of such circuit is given in Figure 3.8.

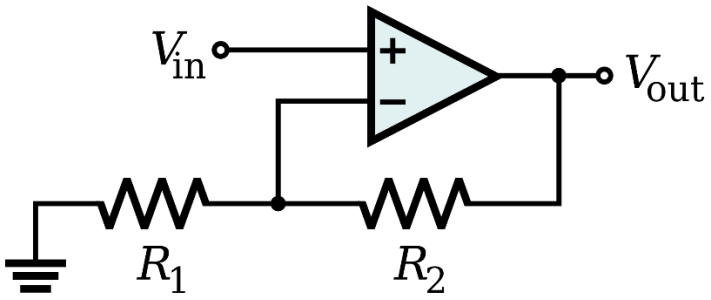

Figure 3.8: A basic non-inverting amplifier.

Feedback control of the non-inverting Operational Amplifier is achieved by applying a small part of the output voltage signal back to the inverting input terminal via a R2, R1 voltage divider network, again producing negative feedback Vf. This closed-loop configuration produces a non-inverting amplifier circuit with strong stability, and very high impedance input. The output voltage equation for this circuit is given below,

$$Vout = Vin\ \frac{R1+R2}{R1} \quad (3.3)$$

3.5 Instrumentation amplifier

An instrumentation amplifier is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment.

Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit are required for both short and long-term are required. Basic structure of such amplifier is given in Figure 3.9.

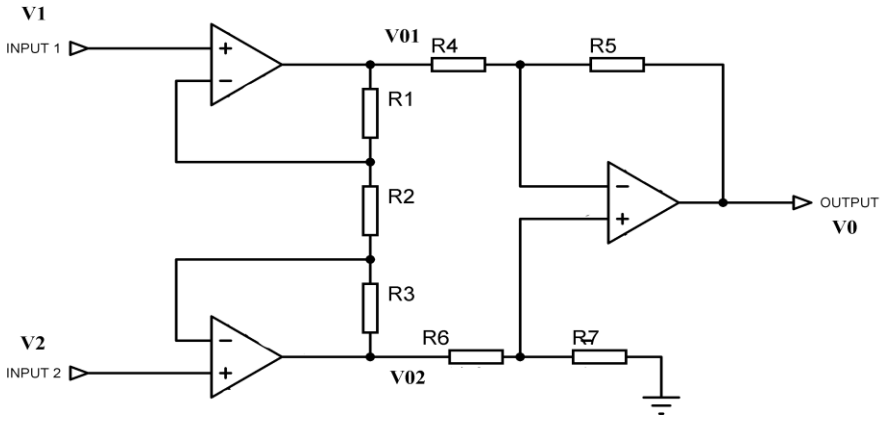

Figure 3.9: Instrument Amplifier.

As mentioned above this amplifier can be divided into two parts, the differential amplifier part and the input buffer amplifiers. These two parts may have separate gain. At the input buffers, two input voltages V1 and V2 are given. The output of the buffers is V01 and V02. This whole buffer part acts as a double-ended input and double-ended output amplifier. Output voltage equation for this part of circuit is,

$$V02 - V01 = (V2 - V1)(1 + \frac{2R1}{R2}) \tag{3.4}$$

The differential amplifier has output voltage given in equation (3.1)

$$V0 = (V02 - V01)\frac{R5}{R4} \tag{3.5}$$

So by combining the equation (3.4) and (3.5) we find,

$$V0 = (V2 - V1)(1 + \frac{2R1}{R2})\frac{R5}{R4} \tag{3.6}$$

In this project we used AD 620 as instrumentation amplifier. We select gain G = 500 and for this we choose gain resistor Rg = 100 Ω following the equation (3.7)

$$\text{G} = \frac{49.7K\Omega}{Rg} + 1 \tag{3.7}$$

Connection diagram of AD 620 is shown in Figure 3.10 [24].

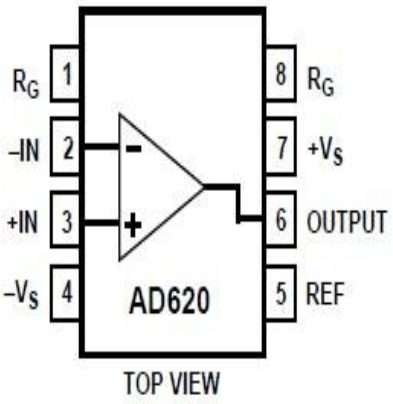

Figure 3.10: Connection diagram of AD 620.

3.6 Passive High Pass Filter

In this project we used passive high pass filter using 10MΩ resistor and 1µF nonpolar capacitor. Thus, the cutoff frequency of the high pass filter is,

$$Fc = \frac{1}{2\pi RC} = 0.016 \text{ Hz} \quad (3.8)$$

Circuit diagram of passive high pass filter is shown in Figure 3.11.

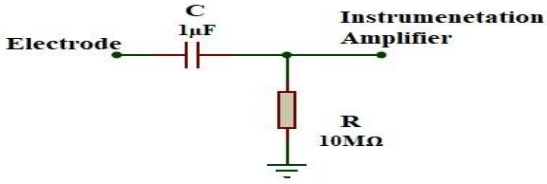

Figure 3.11: Passive high pass filter.

3.7 Passive Low Pass Filter

In this project we used passive low pass filter using 3.3kΩ resistor and 1µF nonpolar capacitor. Thus, the cutoff frequency of the low pass filter is,

$$Fc = \frac{1}{2\pi RC} = 48.22 \text{ Hz} \quad (3.9)$$

Circuit diagram of passive low pass filter is shown in Figure 3.12.

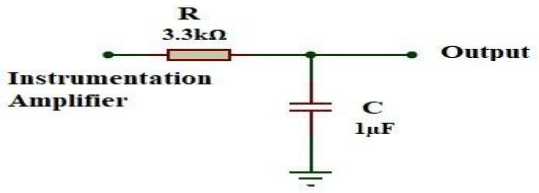

Figure 3.12: Passive low pass filter.

3.8 Arduino UNO

Arduino is becoming a vital part of many electronic design projects because of its functional capabilities and versatility Arduino UNO board has a microcontroller named ATmega328. For programming the microcontroller, integrated development environment provided by the Arduino platform is used. For visualizing and storing the signal an application is developed by Processing. Processing is an open-source programming language and integrated development environment (IDE). It is built on the Java language but uses a simplified syntax and graphics programming model and is available for Linux, Mac and Windows operating system. For receiving the signal data serial library of processing is used. In processing line () function is used for visualizing the signal and println () function is used for sorting the signal, which creates a txt file and saves the values received from Arduino ADC [[25].

The code for ADC is given below.

```
/*AnalogReadSerial
// the setup routine runs once when press reset:
void setup() {
  // initialize serial communication at 9600 bits per
second:
  Serial.begin(9600);
}
// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // print out the value you read:
  Serial.println(sensorValue);
  delay(1);        // delay in between reads for stability
}
```

Total circuit diagram of EOG acquisition is shown in Figure 3.12 and ECG and EMG is shown in Figure 3.13.

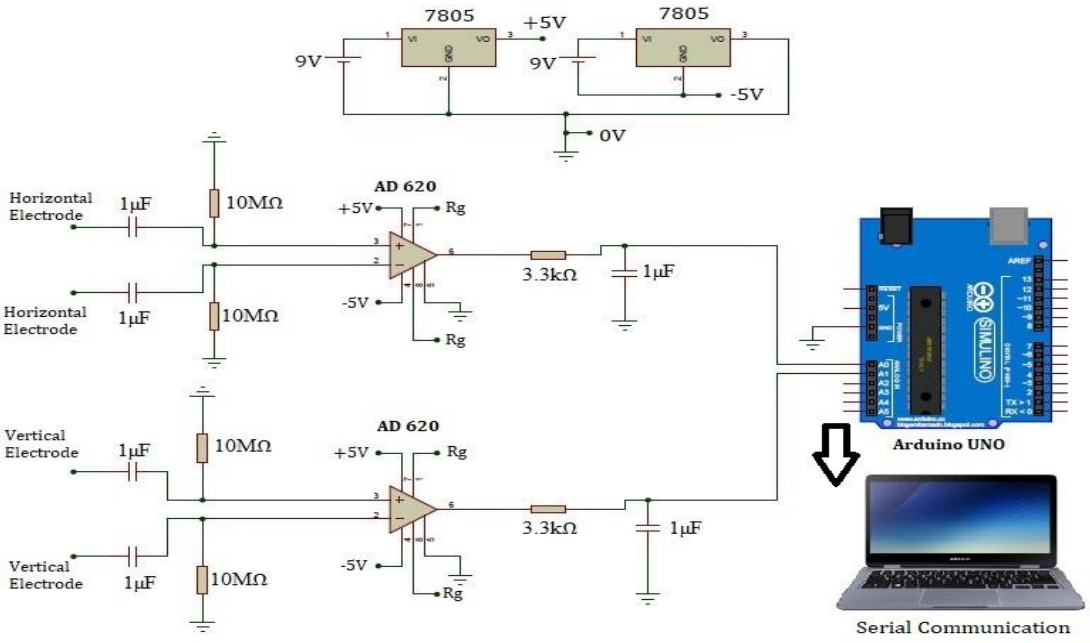

Figure 3.12: Circuit diagram of EOG acquisition system.

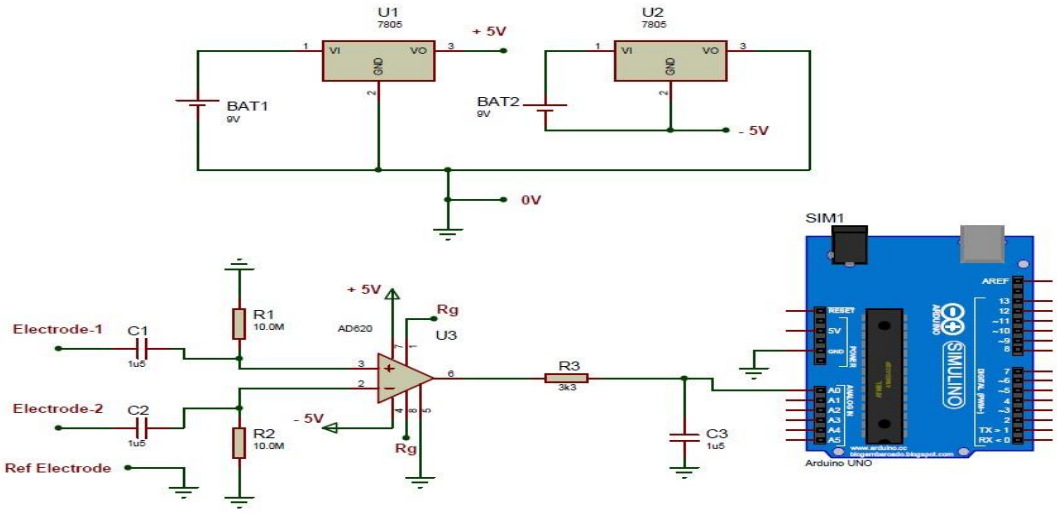

Figure 3.13: Circuit diagram of ECG and EMG acquisition system.

Prototype of acquisition system is shown in Figure 3.14.

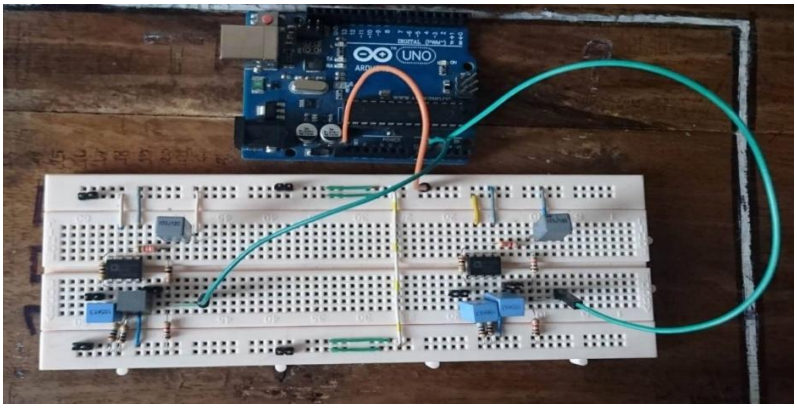

Figure 3.14: Prototype of EOG acquisition system.

3.9 Simulink & MATLAB

Simulink, developed by MathWorks, is a graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. MathWorks and other third-party hardware and software can be used with Simulink. In this project, the acquired signals were visualized by Arduino using Simulink hardware support package for Arduino. DSP toolbox in Simulink provides a lot of facilities of designing different types of digital filter. The Simulink model used in this system is shown in Figure 3.15.

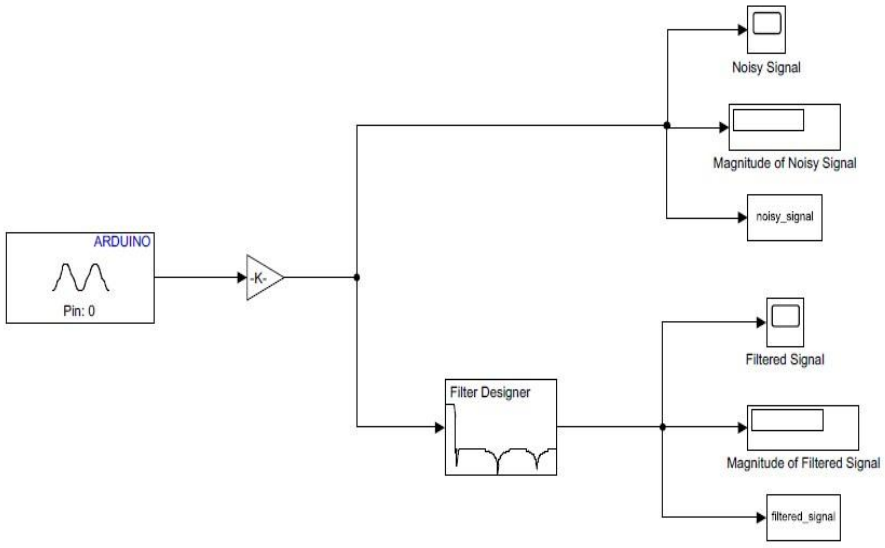

Figure 3.15: Simulink model used in this system.

For digital filtration of ECG and EOG signal, we choose lowpass Equiripple FIR type filter where sample frequency was select at 1000 Hz, pass band at 40 Hz and stop band at 45 Hz as both ECG and EOG have the frequency range below 50 Hz. Figure 3.16 shows the filter block specifications.

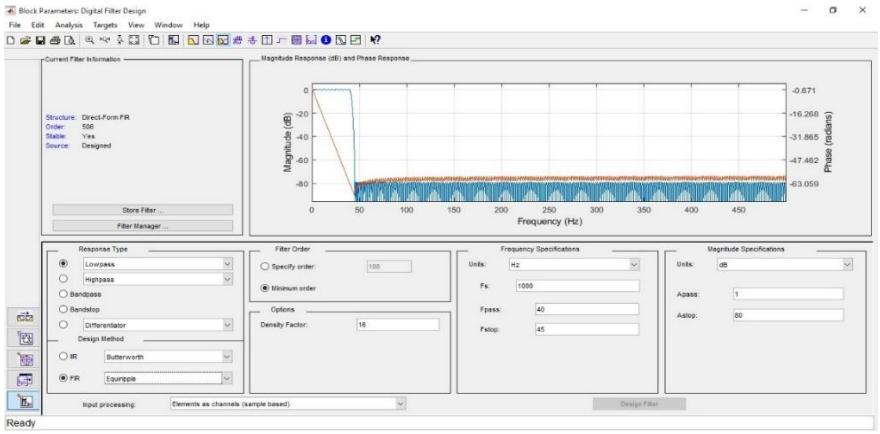

Figure 3.16: Filter block specifications in Simulink.

As EMG has a wide range of frequencies, so we select, pass band at 100 Hz and stop band at 105 Hz in lowpass Equiripple FIR type filter.

In Simulink model we visualized real time signals and perform digital filtration. In the model the sample time was selected at 0.001 s and it stored all the data with respect to time. The stored data was sent to MATLAB for further analysis and future use.

In this project we collected data from three subjects, and they are 13, 24 and 45 years old. The acquired signals were collected using Ag/AgCl disposable surface electrode placing on different positions of the body. ECG signal was acquired placing two electrodes on the chest and reference electrode on the abdomen. EMG signals were acquired both biceps and limb muscles. EOG signal was acquired using five electrodes where two detect horizontal movement and two detect vertical movement of eye and rest one acted as reference electrode. The placement of electrodes is shown in Figure 3.4, 3.5 and 3.6.

Figure 4.1 shows the ECG, EMG and EOG signals of subject-1 in Arduino plotter.

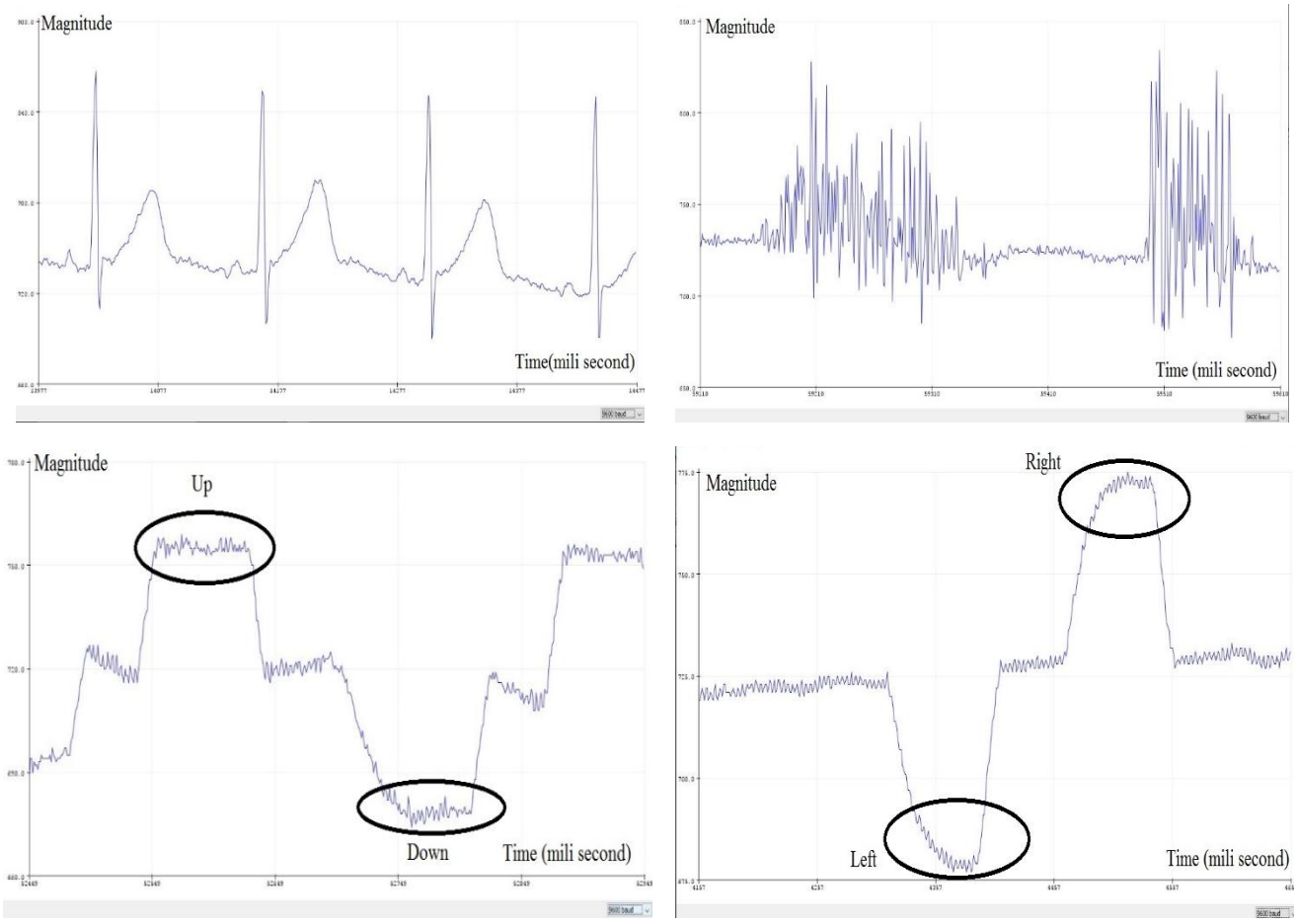

Figure 4.1: ECG, EMG, EOG for horizontal movement and EOG for vertical movement of subject-1. (clockwise from top to left)

Figure 4.2 shows the ECG, EMG and EOG signals of subject-2 in Arduino plotter.

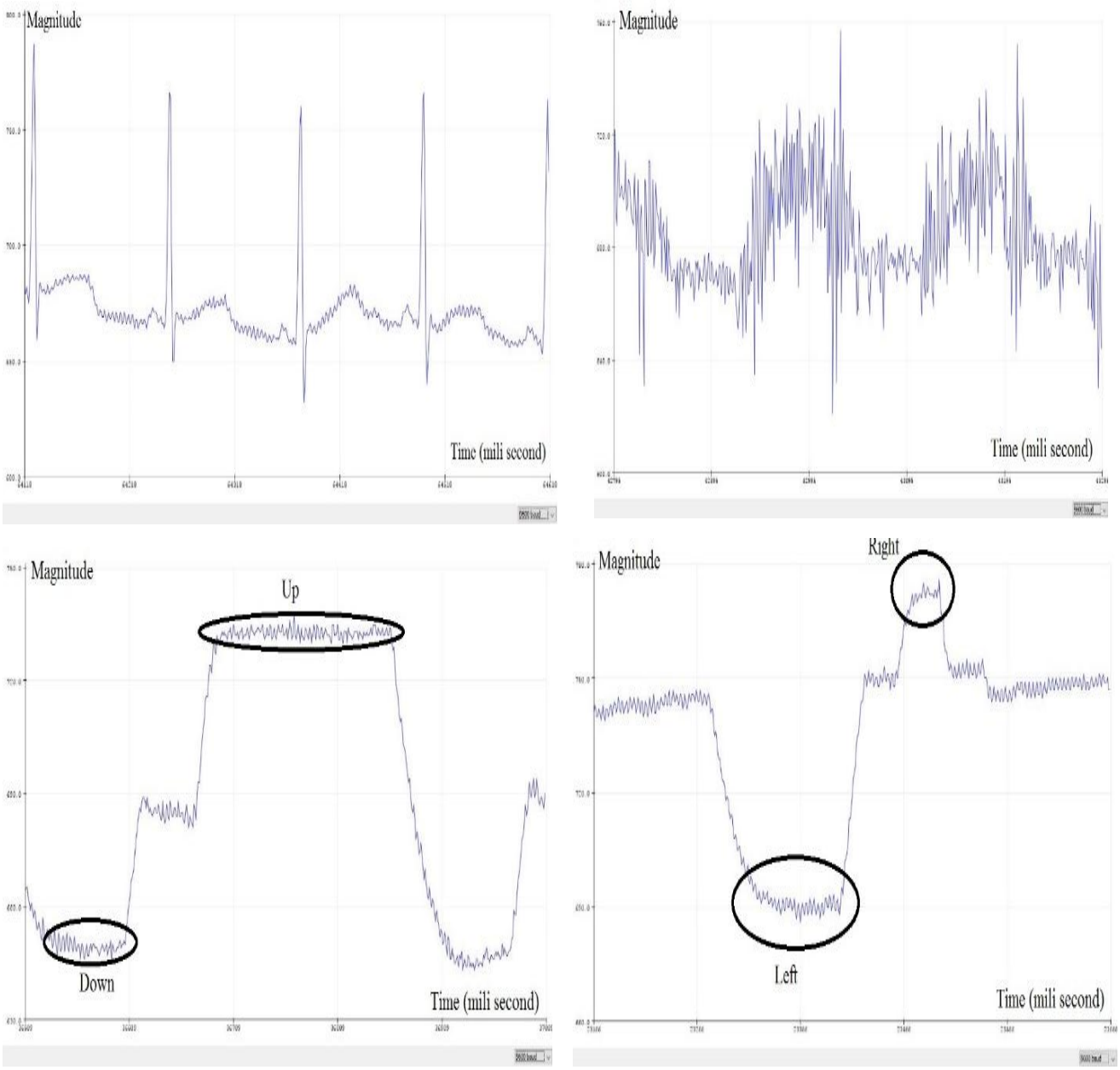

Figure 4.2: ECG, EMG, EOG for horizontal movement and EOG for vertical movement of subject-2. (clockwise from top to left)

Figure 4.3 shows the ECG, EMG and EOG signals of subject-3 in Arduino plotter.

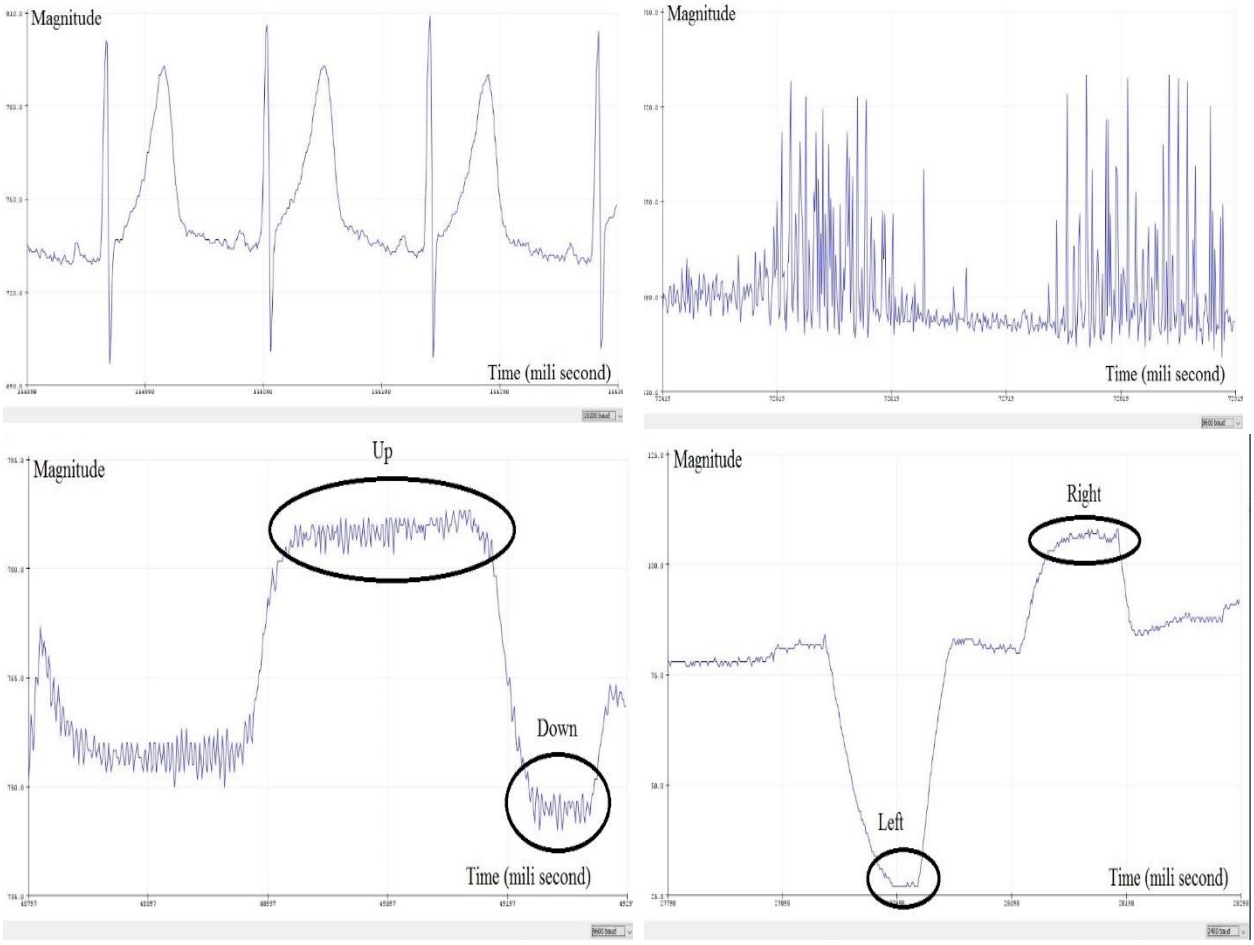

Figure 4.3: ECG, EMG, EOG for horizontal movement and EOG for vertical movement of subject-3. (clockwise from top to left)

In the above figure it is clearly seen that the waveforms of ECG and EMG of those three subjects are almost same. There is slight difference in magnitude. The negative peak of ECG of subject-3 is higher than other two subjects. There is difference in EMG waveform among the subject. The main reason was the different placement of electrodes. We placed electrodes on biceps for subject-1 and subject-3, but for subject-2, we placed electrodes on limbs. The griping variation also causes the difference in EMG waveforms.

Using Simulink model, we stored the signals in MATLAB and did Fast Fourier Transform (FFT) for spectral analysis. Here are the following figures, the plot of ECG signals and their spectrum.

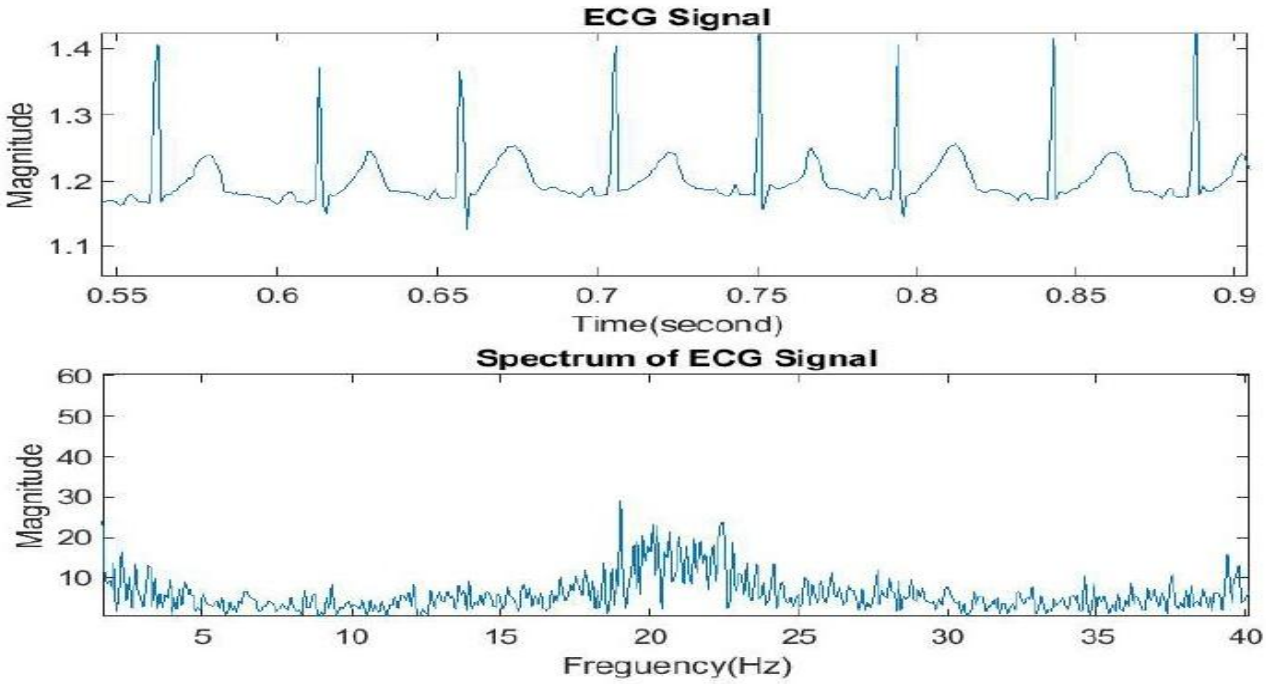

Figure 4.4: ECG signal and ECG spectrum of subject-1.

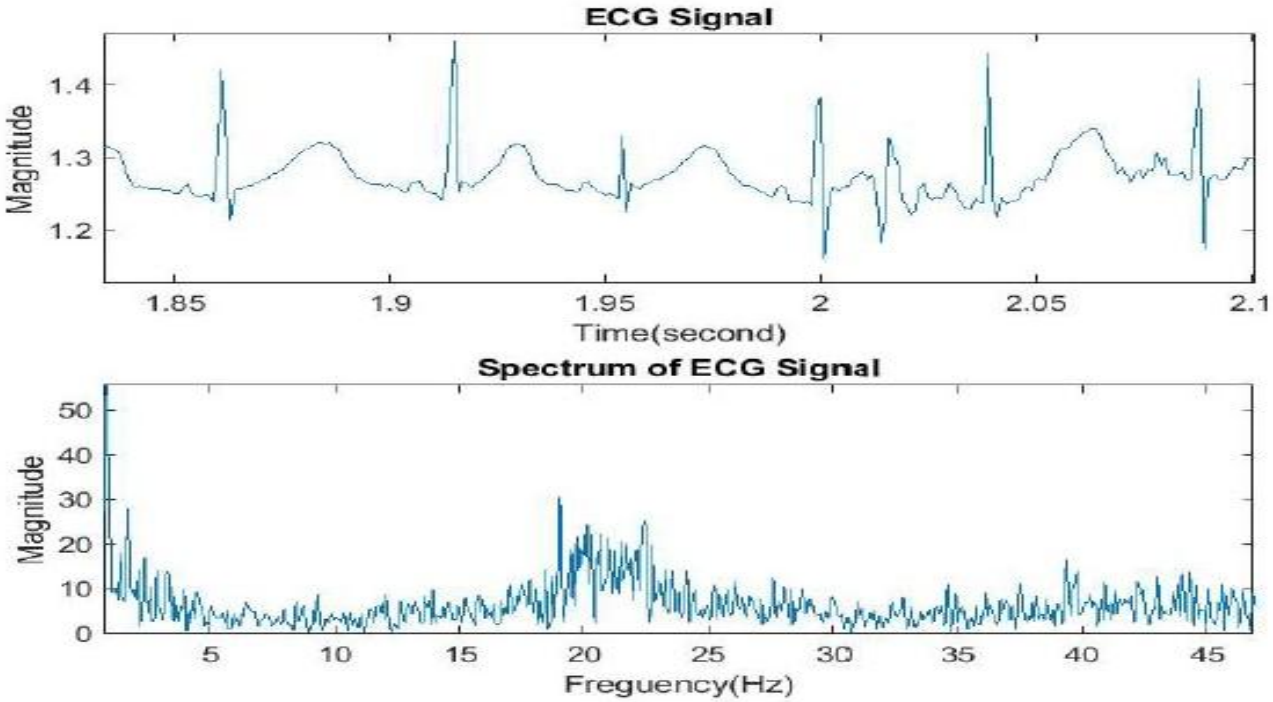

Figure 4.5: ECG signal and ECG spectrum of subject-2.

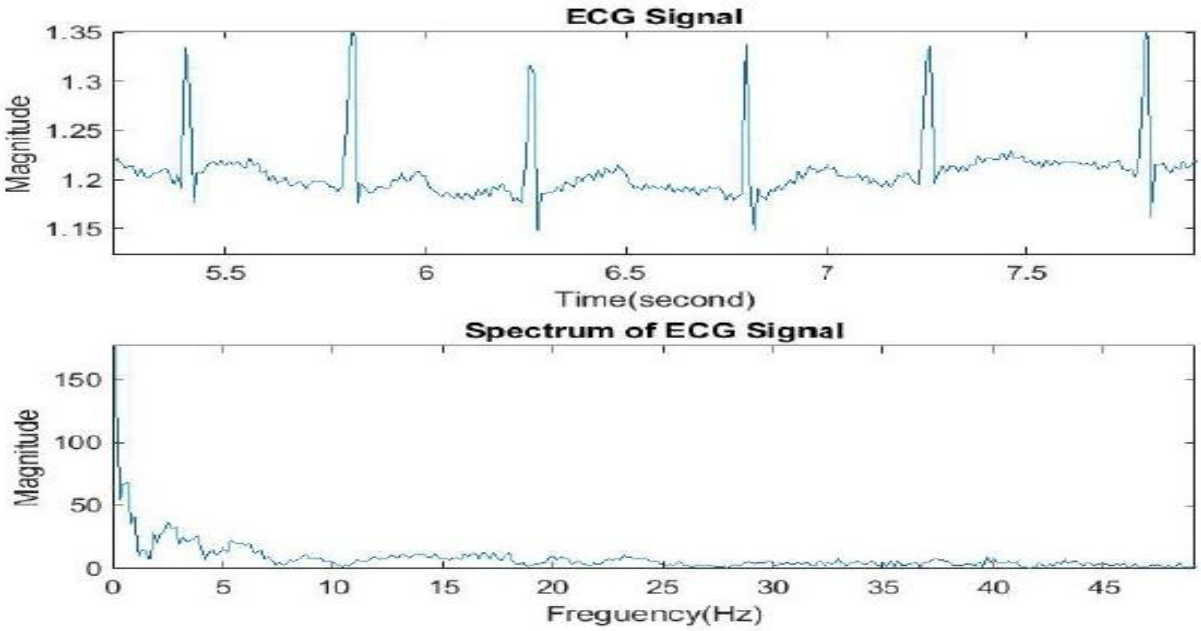

Figure 4.6: ECG signal and ECG spectrum of subject-3.

From the above figures, most of the higher magnitude spectral lines of suject-1 and subject-2 lies 15 to 25 Hz, but for subject-3 it is 0 to 10 Hz.

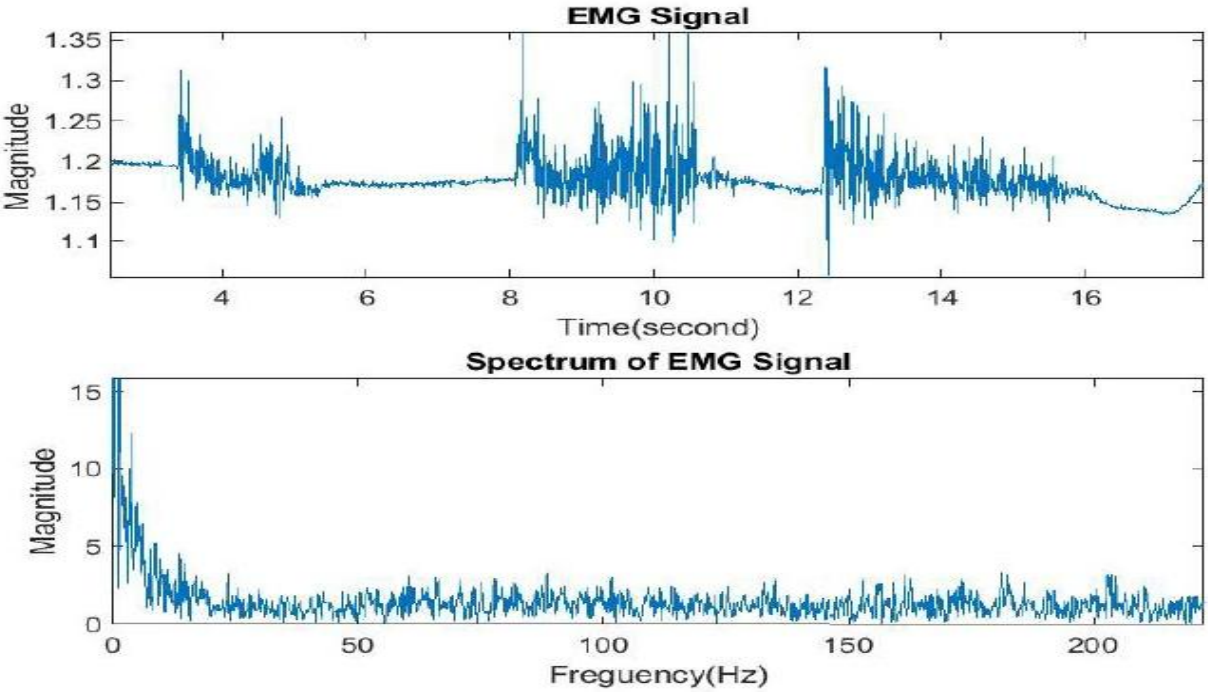

Figure 4.7: EMG signal and ECG spectrum of subject-1.

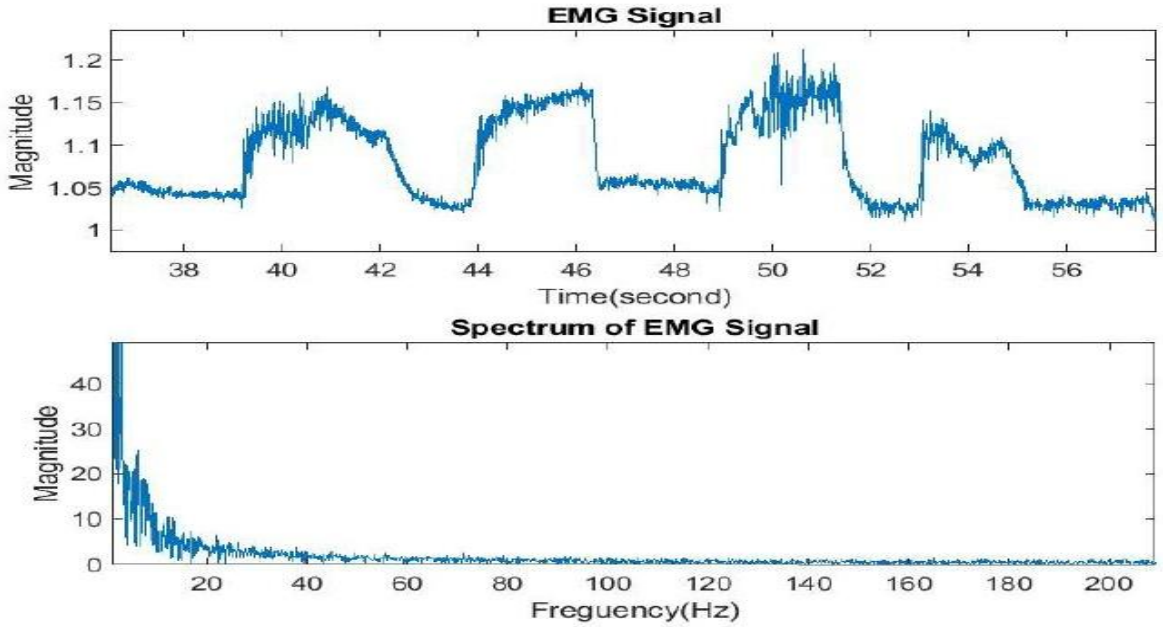

Figure 4.8: ECG signal and ECG spectrum of subject-2.

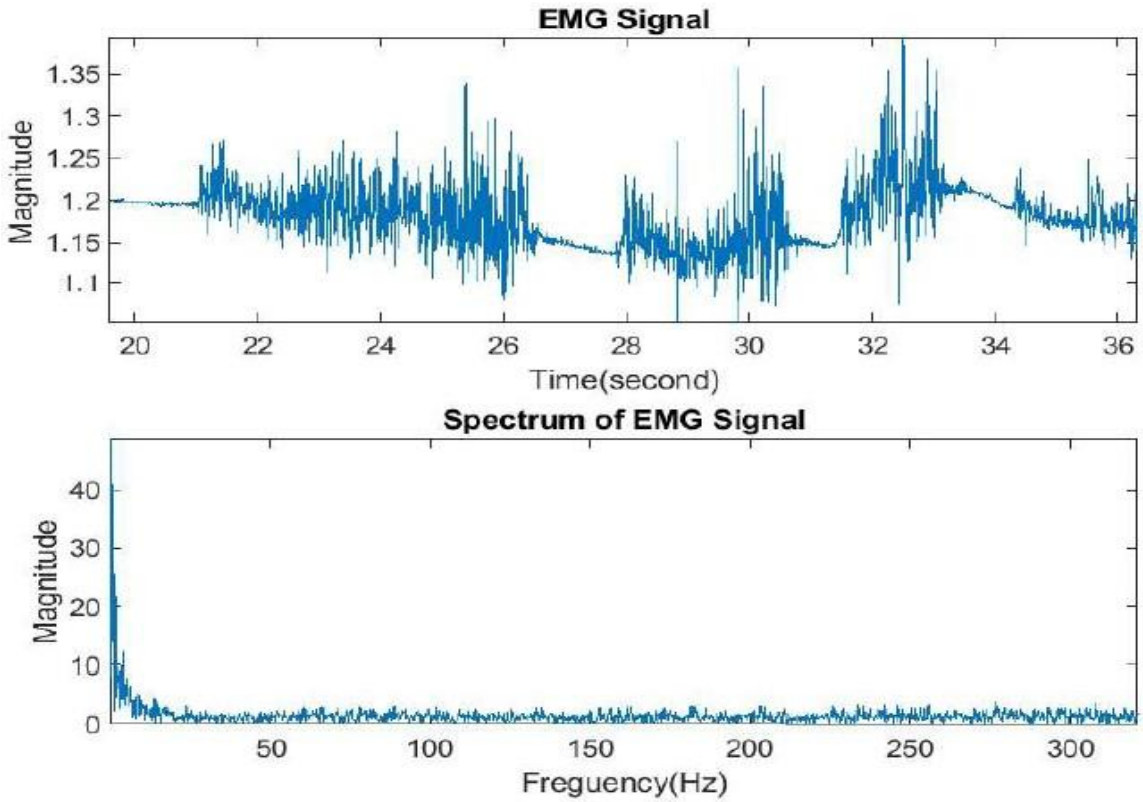

Figure 4.9: ECG signal and ECG spectrum of subject-3.

From the above figures, spectral lines are lied all the wide range of frequency for all subject. But higher magnitude spectral lines lie betwwen 0 to 10 Hz.

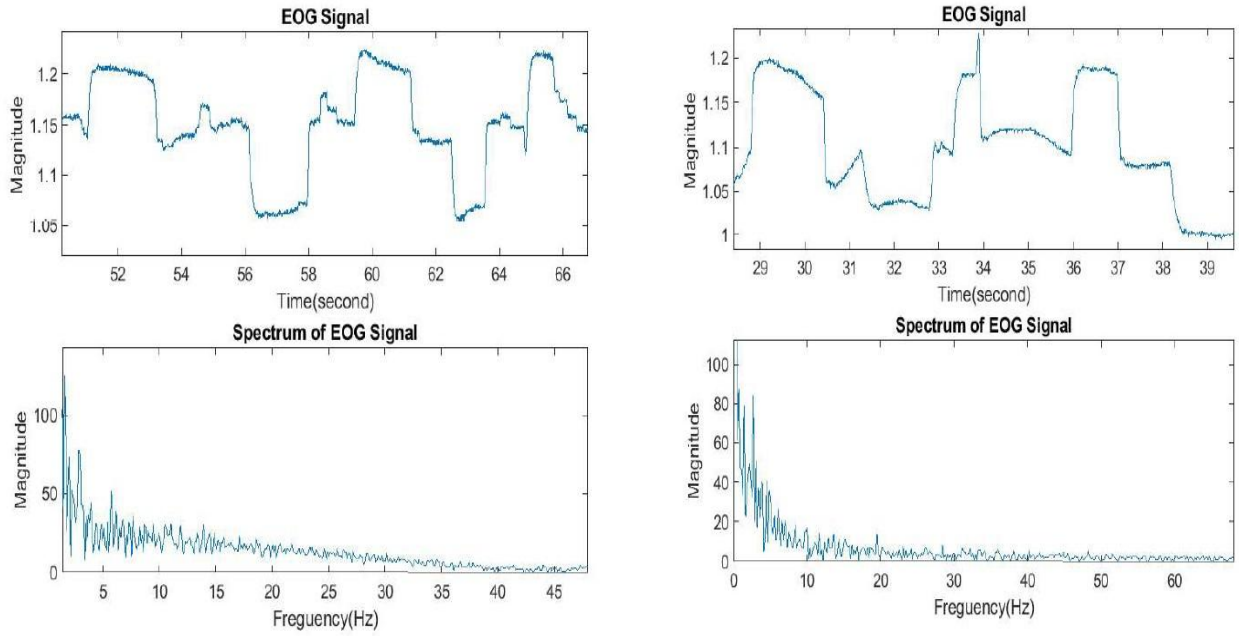

Figure 4.10: EOG signal and EOG spectrum of subject-1. (Left figure for horizontal movement and Right figure for vertical movement)

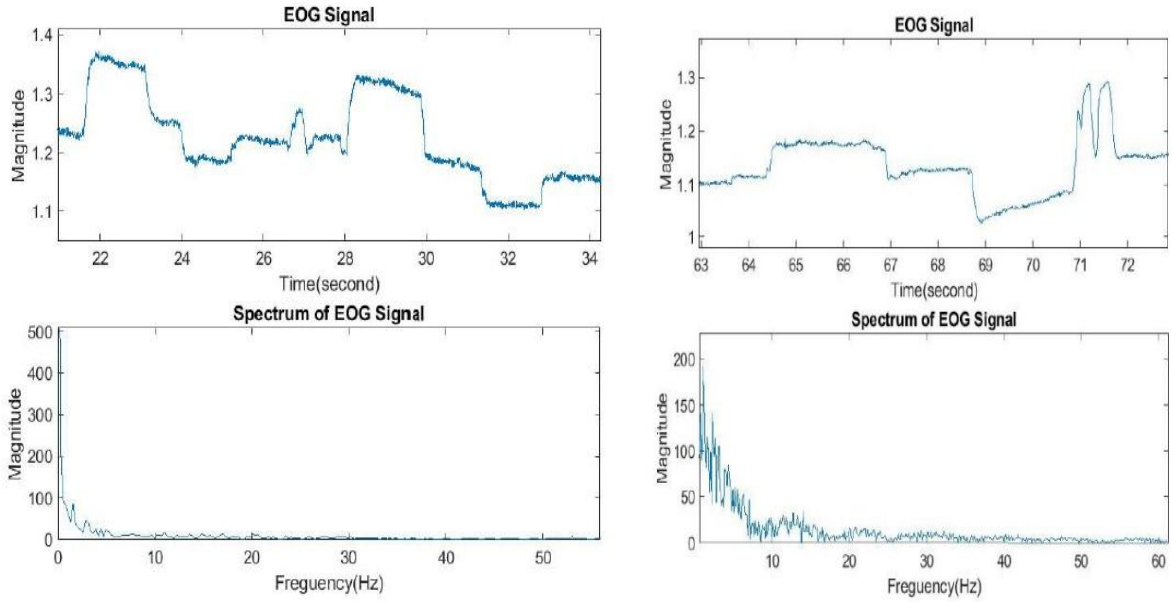

Figure 4.11: EOG signal and EOG spectrum of subject-2. (Left figure for horizontal movement and Right figure for vertical movement)

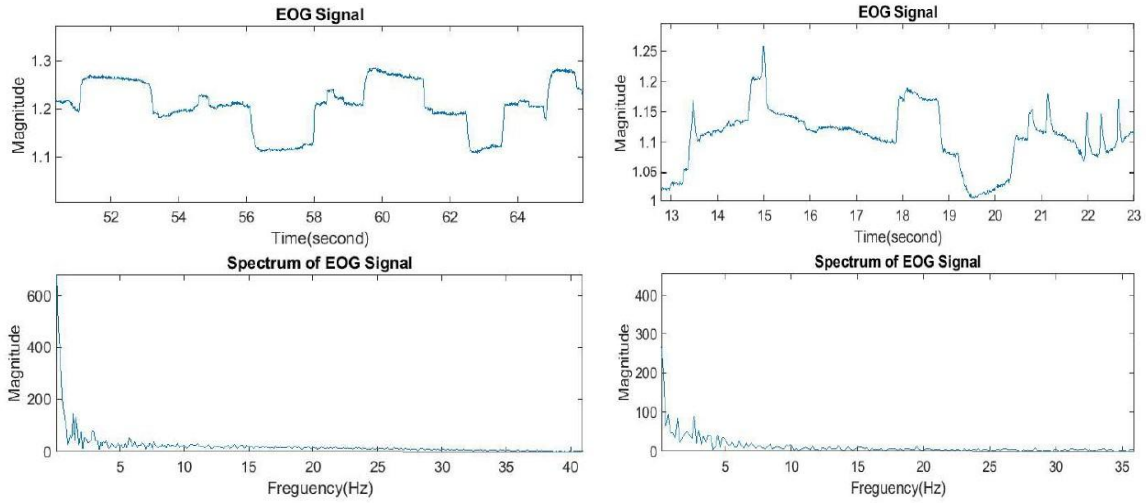

Figure 4.12: EOG signal and EOG spectrum of subject-3. (Left figure for horizontal movement and Right figure for vertical movement)

From the above figures, higher magnitude spectral lines lie betwwen 0 to 10 Hz for all subject.

The over cost of these system try keep less as much as possible. Table 4.1 shows the overall cost of the system.

Tabble 4.1 Cost of Materials of the System.

Components	**Quantity**	**Unit Price (USD)**	**Total (USD)**
Arduino UNO	1	8.24	8.00
AD 620	2	6.00	12.00
Power Supply, Cables, Resistors, Capacitors, Electrodes	-	-	7.00
Total			**27.00**

Chapter 5

Conclusion

5.1 Discussion

In this project, we designed and developed a low cost bioamplifier for acquisition of ECG, EMG and EOG signals, made an interface to computer through Arduino and Simulink and did some signal processing. The system was constructed using only accessible and under commercial values components.

However, it has not been a limiting factor for the amplifier to perform adequately for the acquisition of signals. These biosignals were clearly amplified without interferences and getting excellent gain values. The offset was correctly adjusted giving stable signal amplifier outputs. Although this amplifier was developed especially for signal acquisition cases, its implementation is a function of what we choose, the border on the usefulness of this device is vast and even improving it is a good challenge, provided that the principal objective that is low cost, can be supported. The component used for this system consumes very low power. It takes maximum current of 60mA and it can function up to 22 hours continuously by using two 9V battery.

Although taking necessary precaution, there is noise in acquainted signal. This noise due to 50 Hz line voltage, contact deflection between connecting wire and bread board, using normal cable and noise of surrounding environment. The problem can be solved by using optocoupler circuit, making the circuit in PCB, using co-axial cable and shielding the system.

5.2 Future Scope

The prospects of current project are vast. In this system, one can easily detect the ECG, EMG and EOG signals and can do analysis in MATLAB or other signal proessings platform. Further modification of this system can acquire EEG signal. As the system can stored data so it is possible to send these data to remote places using GSM module. The acquired EMG and EOG signal can be used to make assistive control device for the disable people like prosthetic hand, wheel chair control etc. It alos possible to make personal health monitoring devices which affortable the people of developing countries.

Reference

[1] E. Kaniusas, *Biomedical Signals and Sensors I: Linking Physiological Phenomena and Biosignals*. Springer Science & Business Media, 2012.

[2] A. M. Al-Busaidi and L. Khriji, "Digitally filtered ECG signal using low-cost microcontroller," in *Proc. Int. Conf. Control, Decision and Inf. Technol. (CoDIT)*, 2013, pp. 258-263.

[3] B. S. M. Parameshwari, B. S. Madhurya, and K. U. Rao, "Preparation of papers a cost effective prototype for electrooculogram for effective eye tracking," *Int. J. Innov., Manag. Technol.*, vol. 4, no. 5, pp. 494-497, Oct. 2013.

[4] H. Dong-Mei, Y. Yi, and W. Zheng, "Measurement system for surface electromyogram and handgrip force based on LabVIEW," in *World Congr. Med. Phys. Biomed. Eng.*, Springer, Berlin, Heidelberg, 2009, pp. 67-70.

[5] C. Y. Park, J.-H. Lim, and S. Park, "ISO/IEEE 11073 PHD standardization of legacy healthcare devices for home healthcare services," in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, 2011, pp. 547-548.

[6] M. El-Hanjouri, W. Alkhaldi, N. Hamdy, and O. A. Alim, "Heart diseases diagnosis using HMM," in *Proc. 11th Mediterr. Electrotech. Conf. (MELECON)*, 2002, pp. 489-492.

[7] L. Wikström et al., "Abnormal heart rate and body temperature in mice lacking thyroid hormone receptor α1," *EMBO J.*, vol. 17, no. 2, pp. 455-461, 1998.

[8] C. M. Light and P. H. Chappell, "Development of a lightweight and adaptable multiple-axis hand prosthesis," *Med. Eng. Phys.*, vol. 22, no. 10, pp. 679-684, Dec. 2000.

[9] L. N. S. A. Struijk, "An inductive tongue computer interface for control of computers and assistive devices," *IEEE Trans. Biomed. Eng.*, vol. 53, no. 12, pp. 2594-2597, Dec. 2006.

[10] L. S. Lilly, Ed., *Pathophysiology of Heart Disease: A Collaborative Project of Medical Students and Faculty*, 6th ed. Lippincott Williams & Wilkins, 2016, p. 74.

[11] A. Kumar, "ECG- simplified," LifeHugger, Feb. 11, 2010. [Online]. Available: http://www.lifehugger.com [Accessed: Oct. 11, 2018].

[12] "12-Lead ECG placement guide with illustrations," Cables and Sensors, Jul. 11, 2017. [Online]. Available: https://www.cablesandsensors.com [Accessed: Oct. 11, 2018].

[13] S. Y. Botelho, "Comparison of simultaneously recorded electrical and mechanical activity in myasthenia gravis patients and in partially curarized normal humans," *Am. J. Med.*, vol. 19, no. 5, pp. 693-696, Nov. 1955.

[14] J. Yang, E. P. Pitarch, K. Abdel-Malek, A. Patrick, and L. Lindkvist, "A multi-fingered hand prosthesis," *Mech. Mach. Theory*, vol. 39, no. 6, pp. 555-581, Jun. 2004.

[15] J. C. Barcia, "Human electrography interface," Master's thesis, Lisbon Technical Univ., 2010, pp. 03-09.

[16] A. C. Guyton and J. E. Hall, *Textbook of Medical Physiology*, 11th ed. Elsevier Saunders, 2006, pp. 626-639.

[17] M. Merino, O. Rivera, I. Gómez, A. Molina, and E. Dorronzoro, "A method of EOG signal processing to detect the direction of eye movements," in *Proc. 1st Int. Conf. Sensor Device Technol. Appl. (SENSORDEVICES)*, Venice, Italy, 2010, pp. 100-105.

[18] S. K. Nayak et al., "Development of a simultaneous acquisition system for ECG, PCG and body temperature signals," in *Proc. IEEE Annu. India Conf. (INDICON)*, 2015.

[19] A. Ahamed, A. Ahad, H. A. Sohag, and M. Ahmad, "Development of low cost wireless biosignal acquisition system for ECG EMG and EOG," in *Proc. Int. Conf. Elect. Inf. Commun. Technol. (EICT)*, 2015.

[20] H. S. Lusted and R. B. Knapp, "Bio-mouse: A bioelectric computer input device," *Cybernet. Syst.*, vol. 21, no. 1, pp. 1-10, 1990. *(Note: Reference updated for standard naming)*.

[21] A. Tanaka, R. B. Knapp, and R. Amyot, "Multimodal interaction in music using the electromyogram and relative position sensing," in *Proc. IEEE Int. Conf. Acoust., Speech, Signal Process. (ICASSP)*, 2002.

[22] P. C. D'Mello and S. D'Souza, "Design and development of a virtual instrument for biosignal acquisition and processing using LabVIEW," *Int. J. Adv. Res. Elect., Electron. Instrum. Eng.*, vol. 1, no. 1, pp. 1-5, 2012.

[23] W. S. Wijesoma et al., "EOG based control of mobile assistive platforms for the severely disabled," in *Proc. IEEE Int. Conf. Robot. Biomim.*, Hong Kong, China, 2005, pp. 490-493.

[24] Analog Devices, "AD620: Low cost, low power instrumentation amplifier datasheet," [Online]. Available: http://www.analog.com/media/en/technical-documentation/datasheets/AD620.pdf [Accessed: Oct. 11, 2018].

[25] Arduino, "Arduino Home Page," [Online]. Available: http://www.arduino.cc [Accessed: Oct. 11, 2018].