Development of EOG Based Human Machine Interface Control System for Motorized Wheelchair

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE DEGREE OF

Master of Technology

In

Biotechnology & Medical Engineering

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June 2013

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Date: 02.06.2013

Certificate

This is to certify that the thesis entitled "**Development of EOG Based Human Machine Interface Control System for Motorized Wheelchair**" by **JOBIN JOSE (211BM1209),** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Biotechnology Engineering during session 2011-2013 in the Department of Biotechnology and Medical Engineering, National Institute of Technology Rourkela is an authentic work carried out by him under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Acknowledgement

He gives strength to the weary and increases the power of the weak: Isaiah 40:29

The LORD is my strength and my shield; my heart trusts in him, and I am helped. My heart leaps for joy and I will give thanks to him in song. Psalm 28:7

Successful completion of this project is the outcome of consistent guidance and assistance from many people, faculty and friends and I am extremely fortunate to have got this all along the completion of the project.

I owe my profound gratitude and respect to my project guide, **Prof. A. Thirugnanam** and co-guide **Prof. Kunal Pal**, Department of Biotechnology and Medical Engineering, NIT Rourkela for their invaluable academic support and professional guidance, regular encouragement and motivation at various stages of this project. I am very much grateful to them for allowing me to follow my own ideas.

It is a privilege to express my profound indebtedness deep sense of gratitude and sincere thanks to Head of Department **Prof. K. Pramanik** for her constant encouragement.

I would like to extend my heartfelt gratitude to research scholars Ms. Tejinder Kaur, Mr. Biswajeet, Mr. Satish, Mr. Vinay Kumar and Ms. Beauty Behera whose ever helping nature and suggestions have made my work easier by many folds.

I am very much thankful to Tejinder, Sharanya, Sanjeev, Prasanna, Neeraj, Om Shankar and Lipsa for spending their precious time for carefully reading my thesis paper and solve all grammatical mistakes and suggesting valuable comments.

I would like to thank all my friends and classmates for their constant moral support, suggestions, advices and ideas. I have enjoyed their presence so much during my stay at NIT, Rourkela.

I will never forget the support provided by Mr. Rabindra Maharana for providing valuable information to improve my project hardware.

I am also grateful to NIT Rourkela for providing me adequate infrastructure, experimental facilities to carry out the present investigations. I acknowledge all staffs, research scholars, friends and juniors of Department of Biotechnology And Medical Engineering, NIT, Rourkela for helping me during my research work.

Last but not least I would like to thank my mother and sisters, who were always caring for me throughout my journey till date. They rendered me enormous support during the whole tenure of my stay at NIT Rourkela.

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Abbreviations

Abbreviations	Definition
IA	Instrumentation Amplifier
CMRR	Common Mode Rejection Ratio
DAQ	Data Acquisition
LED	Light Emitting Diode
EMG	Electromyography
EOG	Electrooculography
EEG	Electroencephalography
DRL	Driven Right Leg
HCI	Human Computer Interface
HMI	Human Machine Interface
BCI	Brain Computer Interface
VI	Virtual Instrument
CNS	Central Nervous System
Opam	Operational Amplifier
V	Volt
RF	Radio Frequency

Abstract

Rehabilitation devices are increasingly being used to improve the quality of the life of differentially abled people. Human Machine Interface (HMI) have been studied extensively to control electromechanical rehabilitation aids using biosignals such as EEG, EOG and EMG etc. among the various biosignals, EOG signals have been studied in depth due to the occurrence of a definite signal pattern. Persons suffering from extremely limited peripheral mobility like paraplegia or quadriplegia usually have the ability to coordinate eye movements. The current project focuses on the development of a prototype motor wheelchair controlled by EOG signals. EOG signals were used to generate control signals for the movement of the wheelchair. As a part of this work an EOG signal acquisition system was developed. The acquired EOG signal was then processed to generate various control signals depending upon the amplitude and duration of signal components. These control signals were then used to control the movements of the prototype motorized wheelchair model.

Keywords: Electrooculography (EOG), Eye movements, Rehabilitation aids, BCI, HCI.

Chapter I

Introduction and Objectives

1.1 Need for rehabilitation techniques

A large section of our society suffers from one or the other kind of disabilities due to accidents, neurological disorders, brain damages etc. These disabilities force these patients to depend on their family members or care-givers for day-to-day activities including mobility, communication with the environment, controlling the house hold equipment etc. Rehabilitation devices enable persons with disabilities to live, work, play or study independently. In other words they increase the quality of life led by the differentially abled people and increase their self-esteem.

A Rehabilitation device is one that assists a differentially abled individual to control his or her environment and communicate more effectively. These assistive devices promote greater independence by enabling people to perform tasks with the help of technology [1].

An ideal rehabilitation aid helps in collecting information from the surroundings, analyze the information, convey it to the user and finally receive commands from the user. With advances in image and signal processing, we can device systems that can interpret the information automatically. The use of these rehabilitation aids assists the differentially abled person to carry out his/her day to day activities independently.

1.2 Overview of current rehabilitation techniques

With improvement in technology, there is a vast development in the field of rehabilitation techniques. Researches are going on to develop reliable, low cost and easy to use devices. Out of all the rehabilitation techniques, HCI (Human Computer Interface) and HMI (Human Machine Interface) are the latest and most effective techniques. Researches in these fields are being carried out extensively. The main objective of the HMI system is conversion of signals generated by humans through various gestures to control some electromechanical devices. While in HCI system some key strokes or cursor movements on the screen are controlled by using these signals. In HCI and HMI both biosignals and non biosignals are used as a medium of control. The chief biosignals used in the Interface are Electromyography (EMG), Electroencephalography (EEG) and Electrooculography (EOG). HMI is commonly used by motor impaired patients to control wheelchair.

Rehabilitation devices are broadly classified into two categories; the first category includes all those devices which are biosignal and the second category includes non biosignal based devices. Non biosignal rehabilitation aids provide 100% accuracy and require less training for patients but the usage of these devices is limited to patients with partial or complete flexibility in their body parts. Biosignal based rehabilitation devices mainly use biosignals like EEG, EOG or EMG as control signals. The advantage of using biosignal approach is that when patients become completely paralyzed, the only resource available to them then is biosignals. However it usually needs user training and has lesser accuracy than non biosignal approaches. The biosignal approach usually requires user calibrations because biosignals produced by each individual are unique due to difference in individual physiological properties and skin conductance.

1.2.1 Non biosignal approach

In general non biosignal based rehabilitation devices include techniques which make use of sip-n-puff response, tongue control, eye tracking, head movement tracking and chin control.

The sip-n-puff technology is an old technique which is used to control motorized wheel chair by quadriplegic patients. In this method, control signals are given to a device using air pressure by "sipping" (inhaling) or "puffing" (exhaling) on a pneumatic tube. SNP technology generally makes use of four control signals which are produced by hard sip, hard puff, soft sip and soft puff. Typical application of Sip-and-Puff devices is the control of motorized wheelchair. Control typically consists of four different inputs from the user. An initial hard puff will enable the wheelchair to move forward, while a hard sip will stop the wheelchair. Conversely, an initial hard sip will enable the wheelchair to move backward, while a hard puff will stop the wheelchair. A continuous soft sip or soft puff will enable the wheelchair to move left or right respectively depending on the duration of sipping or puffing. The mouth-controlled input provides users a simple and effective way to control mouse movement. However, the basic disadvantage of the sip and puff technique is that muscles of many paraplegics and other paralyzed patients are not capable of sip and puff action.

Another common technique is the Head Movement Tracking technique. In this, head movements are transformed into cursor movements on the screen. Cursor movements are proportional to head movements. Head movements are calculated by different methods like accelerometer placed in a patient's cap or by capturing video of head movements. But the problem with this technique is that differentially abled people of certain categories such as cerebral palsy patients cannot even move their head comfortably [2, 3]. Another problem of this technique is that forehead always needs to face the camera [3].

In the chin control technique, the chin sits in a cup shaped joystick handle and is usually controlled by chin movements. This system is applicable only for patients with good head control. It provides more flexibility than head control

Eye tracking technique is of two types: biosignal based and non biosignal based. Biosignal based technique uses EOG, which will be discussed later. Non biosignal based technique uses a camera to continuously track the features of the eye and depending upon these features, the computer locates the user's gaze [2].

Tongue controlled rehabilitation is achieved by many methods. In one method, a permanent magnet is attached to the tongue and movement of tongue to an air-core induction coil changes the inductance of coil obeying Faraday's laws [4]. In another method, a pressure sensitive isometric joystick is operated by the patient's tongue. This joystick and the two switches provide cursor control and left/right button [3].

1.2.2 Biosignal approach

As mentioned earlier, these biosignal based rehabilitation devices mainly use biosignals like EEG, EOG or EMG as control signals. The advantage of using this approach is that when patients become completely paralyzed, the only resources available to them are biosignals.

1.2.2.1 EEG based methods

The Electroencephalography (EEG) records electrical brain signals from the scalp, where the brain signal originates from post-synaptic potentials, aggregates at the cortex, and transfers through the skull to the scalp [3]. BCI is a device that extracts EEG data from brain and converts it into device control commands using signal processing techniques. The cerebral electrical activities of the brain are recorded via the EEG, through electrodes that are attached to the surface of the skull. The signals measured by the electrodes are amplified, filtered and digitized for processing in a computer where feature extraction is performed. This is followed by classification and a suitable control command is generated [5].

This is one of the most important technologies for patients with paralysis who suffer from severe neuromuscular disorders, since BCI potentially provides them the means of communication, control, and rehabilitation tools to help compensate for or restore their lost abilities [3]. EEG techniques are non-invasive and low cost. But it brings great challenges to signal processing and pattern recognition, since it has relatively poor signal-to-noise ratio and limited topographical resolution and frequency range [6].

1.2.2.2 EMG based methods

EMG measures electrical currents that are generated in a muscle during its contraction. A muscle fiber contracts when it receives an action potential. The EMG observed is the sum of all the action potentials that occur around the electrode site. In almost all cases, muscle contraction causes an increase in the overall amplitude of the EMG.

EMG signals can be used for a variety of applications including clinical applications, HCI and interactive computer gaming. They are easy to acquire and of relatively high magnitude than other biosignals. On the other hand, EMG signals are easily susceptible to noise. EMG signals contain complicated types of noise that are caused by inherent equipment noise, electromagnetic radiation, motion artifacts, and the interaction of different tissues. Hence preprocessing is necessary to filter unwanted noise in EMG. The EMG 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 [4].

1.2.2.3 EOG based methods

The Electrooculogram (EOG) is the electrical signal that corresponds to the potential difference between the retina and the cornea of the eye [1]. This difference is because of the fact that occurrence of metabolic activities in the cornea region is higher than that in the retinal region. Usually the cornea maintains a voltage of +0.40 to +1.0 millivolts which is higher than the retina. When the eyes are rolled upward or downward, positive or negative pulses are generated. As the rolling angle increases, the amplitude of the pulse also increases and the width of the pulse is in direct proportion to the duration of the eyeball rolling process.

The EOG is the electrical recording corresponding to the direction of the eye and 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 [2].

1.3 Objectives

The main aim of the work presented in this thesis is to develop a reliable and easy to use biosignal acquisition system and rehabilitation technique: an RF controlled motorized prototype wheelchair model developed as a rehabilitation aid. This work includes:

1. Developing a data acquisition system for acquiring EOG signals
2. Developing a new algorithm for detecting basic eye movements and blinking
3. Implementing rehabilitation devices which can be controlled using EOG.

1.4 Thesis organization

Chapter II – Literature Review discusses the basics of the human visual system and fundamentals of Electrooculography. It also reviews some related works done in this area.

The complete process of research and development is explained in **Chapter III – Materials and Method**. It describes the principle of operation and electronic components used throughout the project.

Chapter IV- Results and Discussion contains organized evaluation and discussion of electronic circuit, DAQ, microcontroller, software devices developed and obtained graphs and results.

The future of the device in terms of improvements and possibility of public release is discussed in Chapter **V - Conclusions and Prospects**.

All related works which have provided some insight into the development of the proposed device are listed in **Reference** section.

Chapter II

Literature Review

2.1 Principle of electrooculography

The eye is a place of a steady electric potential field that is quite unrelated to light stimulation. This field can be detectedeven with the eyes closed or eyes in total darkness. This steady electric potential can be viewed as a fixed dipole 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 butit is due to the occurrence of higher metabolic activity in the retina. For the invertebrates, the polarity of this potential difference is of 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 [2]. 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).

2.2 **Anatomy and physiology of the eye**

Eye is one of the most complex sense 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 helps 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 has to be described.

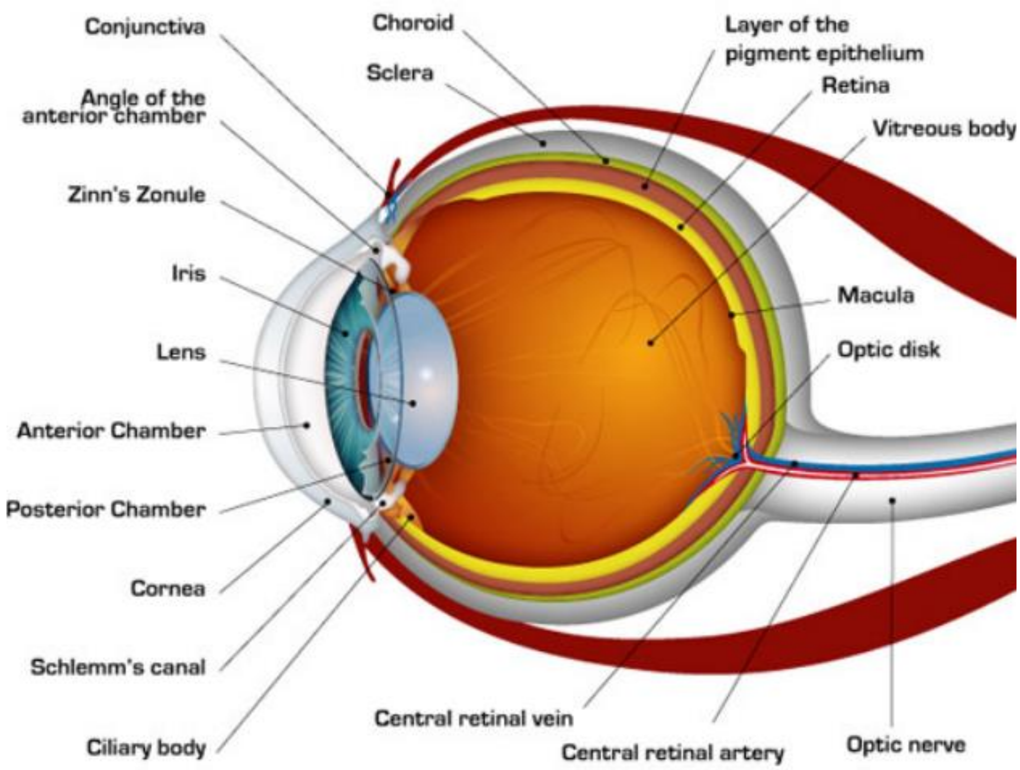

Figure 2.1 anatomy of the human eye [7]

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 colour 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 humour. This fluid contains nutrients which help in the survival of the cornea and the lens. The aqueous humour is constantly replenished for the inlet of fresh nutrient media. 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 jelly like substance known as the vitreous humour. This jelly helps in the refraction of light before it comes in contact with 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 [7, 8].

The functioning of the eye is dependent on its movement and positioning which is controlled by the various muscular systems associated with the eye.

2.3 Types of muscles in the eye

The movement of the eye is controlled by two pairs of rectus muscles 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.

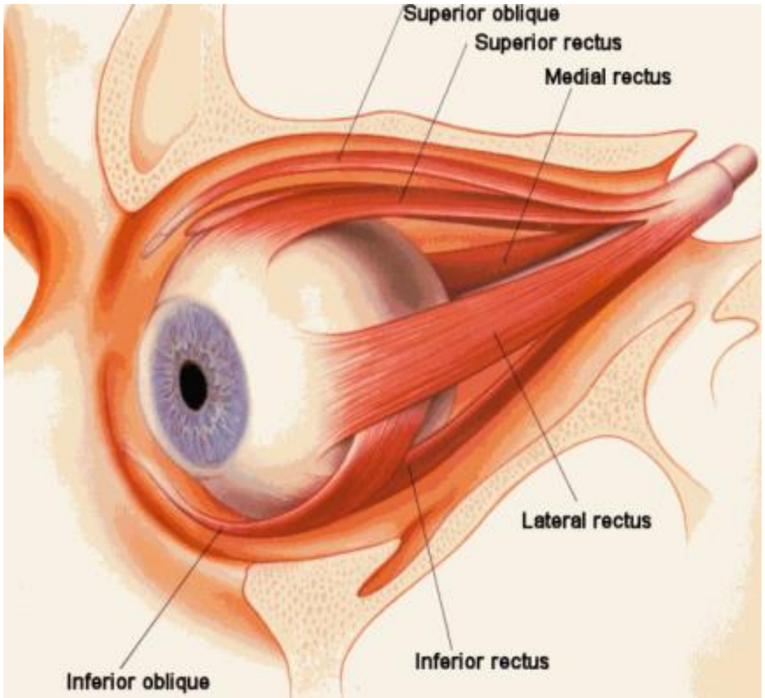

Figure 2.2 Lateral view of extraocular eye muscles [7]

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 intorsion and extorsion 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 [7, 8].

2.4 Types of movement of the eye

The ocular muscles mentioned in the above paragraph work individually or in synchrony to provide the overall motion of the eyeballs thereby positioning the eye in the direction of vision. These movements, which have been deeply studied in neurophysiology and psychology, can be broadly classified into four categories: saccades, smooth pursuit movements, vergence movements, and vestibulo-ocular movements.

Saccades comprise of the short, quick burst of movements that occur in the eye that are associated with the normal functioning such as reading, gazing etc. The Rapid Eye Movement (REM) stage of the sleep which is associated with lucid dreaming also consists of saccades movement of the eye. These movements are mostly reflexive in nature but can also be voluntary.

Smooth pursuit movements are voluntary movements of the eye which are much slower in nature. This movement is associated with the tracking of an object which usually occurs after an initial saccade which is used to locate the object.

Vergence movements are those which help in proper focusing, pupil dilation, convergence and divergence of the eye based upon the distance of the object. Unlike the other muscles which work uniformly for both the eyes, vergence movements function independently for each such that the perception of depth and distance can be well achieved by the superimposition of the two independent images formed by each eye in the brain.

Vestibulo-ocular movements are stabilizing movements of the eye with respect to the movement of the head. These movements prevent in keeping the object under the circle of vision even while the head is moving. [7]

2.5 Generation of EOG

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 [2]. 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 [2].

2.6 Advantages and disadvantages of EOG signal

EOG approach has both advantages and disadvantages when compared to other methods for determining eye movement.

I. The chief application of the EOG is in the detection and measurement of eye movement.

II. EOG based recording techniques are simple and cheaper than other methods and can be recorded with minimal discomfort.

III. The EOG is commonly used to record eye movement patterns.

IV. EOG readings can be measured even when eye is closed, for example during sleep.

V. EOG can be utilized as an influential visualizing parameter to assist the ophthalmologists to diagnose the ophthalmic syndromes in a better way.

VI. EOG can be employed in modeling ophthalmic instruments which are capable of accompanying in disease diagnosis as well as for therapeutic purposes.

VII. In general, fully or partially differentially abled persons have a dominant vision which can be used as a residual influential tool in developingtheir rudimentary works through human-machine interfacing.

Disadvantages of EOG signal

I. The corneoretinal potential is not fixed but has been found to vary diurnally, and to be affected by light, fatigue, and other qualities. Consequently, there is a need for frequent calibration and recalibration.

II. Additional difficulties arise owing to muscle artifacts and the basic nonlinearity of the method.

III. EOG signals are subject specific. Signal amplitude and duration vary from person to person.

IV. EOG signal amplitude is of microvolt range and highly susceptible to noise.

V. EOG signals are very much sensitive and therefore fluctuate with head movements.

2.7 Related works done in EOG based rehabilitation systems

Arslan Qamar Malik, and Jehanzeb Ahmad (2007) designed and developed an EOG based mouse control device. They used Instrumentation Amplifier INA126P which has a high CMRR (around 94DB) and can handle signals in microvolt range. Total gain of 100000 was achieved by using two amplification stages. A protection system in the form of an RC low pass filter with cutoff at 47 Hz was implemented at the INA126p's inputs to remove high frequency RF interference and Electro-Static Discharge. Common Mode Rejection Ratio (CMRR) was further increased by using Driven-Right Leg circuit. To overcome the problem of 60/50 Hz power line noise, a notch filter with 60Hz cut off frequency was implemented after the first INA126p IA. Another major problem of DC offset was overcome by high pass filter of cut off frequency .14Hz and Roll off of -80DB/Decade. This was implemented by two 2nd order Bessel High Pass Filters in series. One of such 4th order filters was implemented after Notch filter during first phase of amplification. The second one was implemented after second INA126P during second phase of amplification. The high pass filter was followed by a low pass filter of roll of rate -80DB/Decade with cutoff at 30Hz to reduce the power line noise and aliasing effect. Rule used to select cut of frequency is that it should less than a quarter of the sampling frequency. After amplification and filtering the purified EOG signal was digitized using 12 bit ADC ADS7800. ADS7800 was selected since it is fast and can handle wide range of analog data (-10 to 10). Digitized signal was directly interfaced with computer through parallel ports. Two parallel ports were used: one parallel port received digital data of up-down motion from one ADC and another parallel port received digital data of right-left motion from another ADC. Software program was written in visual C++ language [2].

Manuel Merino, Octavio Rivera, Isabel Gómez, Alberto Molina, Enrique Dorronzoro (2010) developed a system to detect eye movement based on the EOG signal. They used Ag/AgCl sensors and BCI2000 and the amplifier g.USB amp for EOG acquisition. Since EOG signal information is mainly contained in low frequencies, band pass filter with a range between 0.1 and 30Hz and sample rate of 128 was used. Noise was further removed by an averaging filter. Developed algorithm for EOG classification depends on derivative and amplitude level of EOG signal. Derivative of EOG signal was used to detect the edges of the signal. This algorithm found out initial edge, final edge, and area between edges. For an up movement and blink, initial edge is positive and final edge is negative. A timer calculated width of area between edges. A pulse was classified as a blink if the width of this area was smaller than 250ms [9].

A.B. Usakli, S. Gurkan, F. Aloise,G. Vecchiato, F. Babiloni (2010) developed and realized a virtual keyboard that allowed the user to write messages and to communicate other needs based on EOG signals.5 Ag/AgCl electrodes are used for EOG acquisition. The data acquisition system was microcontroller based and had electronic noise 0.6Vpp, CMRR 88 dB, and sampling rate was 176 Hz. Differential approach was used to remove the DC level and 50 Hz power line noise. After filtering and amplification EOG signals are digitized and transferred to PC. These signals were then processed by using Nearest Neighborhood algorithm. By using this virtual keyboard user could type with a speed of 5 letters/25 seconds [10].

Patterson Casmir D'Mello, Sandra D'Souza (2012) 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 up on 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 other 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 [11].

W S Wijesoma, Kang Say Wee, Ong Choon Wee, A P Balasuriya, Koh Tong San, Low Kay Soon (2005) developed initial model of a robotic wheelchair system based on electrooculography. 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 [12].

Ali Bulent Usakli and Serkan Gurkan (2011) designed an EOG based HCI. In this system they used 5 Ag/AgCl electrodes. A total gain of 5332(16×101×3.3) and 7595(16×101×4.7) was provided to vertical and horizontal EOG amplifiers. The gain was provided with three cascaded stages. A 16 KHz low pass filter was used to reject the high frequency noise created by other devices like PC monitor, fluorescent lamp etc. They used Instrumentation amplifier LT1167 which provides high CMRR (120dB), high input impedance (>1TOhm), low electronic noise (7.5nV√Hz), and low input bias current (<350 pA). For other amplification purposes and filters, LMC6001 amplifier is used. In order to avoid the signal loss in capacitive coupling or high pass filter they used differential approach to remove DC offset. In this method, the input amplifier output and 0.15-Hz low-pass-filtered signal were added. Since the signals were in opposite phases, they were differentiated. The signal was then applied to 5th

order Bessel LPF (with MAX281) having cut off frequency 31 Hz and then applied to an amplifier having a gain of 101. To provide digitization to the analog signal and to transfer it to the PC, a PIC microcontroller (PIC12F675) was used. PIC microcontroller converts horizontal and vertical analog signals with a 10-bit digital resolution at 176 Hz. Assuming the two least significant bits as the noise, 8 bit data were transferred to the PC. Microcontroller output data were isolated with opto-couplers (PC817). Isolation helps in reducing electronic noise. The isolated data were applied to the PC through a serial communication port. The EOG signals were then processed by using Nearest Neighborhood algorithm [13].

Zhao Lv, Xiao-Pei Wu, Mi Li, De-Xiang Zhang (2009) designed an EOG based HCI system. Three electrodes were used to acquire the EOG signal. One electrode was placed on temple region of head for acquiring horizontal EOG signals and the second electrode was placed roughly above the middle of the eye to obtain vertical EOG signals. Electrode output was given to an emitter follower, followed by a pre amplifier having gain 10. Emitter follower was used to suppress some interference and to isolate that circuit from the other circuits. INA 128 was used as a pre amplifier because it has high CMRR high input impedance. A bandpass analog filter (0.159-10Hz) was used to remove the baseline and higher frequency interference. It was followed by a main amplifier with 800 gain. The amplified EOG signal was then converted to digital signals and transmitted to the computer. The ranges of amplitudes of EOG signals produced by different users are different. To avoid this problem of signal variability, EOG signals were normalized to rectangular square pulses. Dynamic threshold method was used for normalization instead of traditional fixed threshold. To find the number of blinks they found the derivatives of these square pulses and counted the number of positive pulses. For classifying eye movement, the normalized signal was multiplied with certain polarity regulated reference pulses.

This resulted in a new waveform in which up movement was shown as positive pulses and down movement shown as negative pulses. To judge the action of eye movement, an array (EOG_UD[i]) was defined to record the polarity of two adjacent pulses. If the value of the present sample is 0 and the next sample is 1, then EOG_UD[i] =1and the system will judge it as a positive pulse. On the contrary, EOG_UD[i] =-1 and it is a negative pulse. Next, the values of EOG_UD[i] were checked for judging the rolling direction. If EOG_UD[0] and EOG_UD[1] are both 1, that means the user is rolling upward and if both are -1 that means the user is rolling downward. Command signals were generated by following procedure: When the user rolls his eyes upward twice continually, if he observes that the detection is correct in the screen, he just blinks three times quickly to confirm the action. If the detection is erroneous, the user closes eyes for about 3s to restart the system [14].

Divya Swami Nathan, A. P. Vinod, and Kavitha P. Thomas (2012) designed an EOG based typing system. It used a virtual keyboard for typing letters on the monitor using 8 types of distinct EOG patterns. EOG pattern Identification was based on the amplitude and timing of negative and positive components within the signal. Five electrodes were used to measure EOG signals. The reference electrode was placed on the right mastoid. A gUSB amplifier was used in filtering, amplification and analogue to digital conversion of EOG signals. Filtering stage employed a 2 - 30 Hz bandpass filter. Since the inbuilt bandpass filter in the gUSB amplifier is a relatively lower order filter, the attenuation provided by this filter at power line frequency of 50 Hz might not have been sufficient. Therefore, a notch filter was also enabled at 50 Hz to attenuate the power line interference. The sampling frequency was set as 128 Hz.Classification algorithm employed threshold values for both positive and negative components and also employed a time factor to ensure the occurrence of these components within a fixed period.

50µV was used as the threshold. Since specific occurrence of positive and negative components was found in every EOG pattern depending on the type of eye movement, after detecting the presence of positive/negative component that occurs first, algorithm waits for a certain time period to estimate the presence of next component. For example, once amplitude is greater than the threshold, it checked amplitude of the signal within next 0.078s. If the amplitude in this region less than -50 µV it was identified as up movement, and it was the same way for down movement.When signal amplitude exceeds the threshold value, it was considered to be a valid signal for recognition. Usually, the threshold values were determined through trial and error method. They were able to classify EOG patterns corresponding to 8 types of different eye movements and able to employ these eye movements to control a virtual keyboard. A cursor on the letterboxes of the screen keyboard moved step by step in response to the subject's intention. Eye movements operate cursor movements in 8 directions, scanning through one letter for each movement, and a selection was indicated by a voluntary eye blink. Their system achieved typing speed of 15 letters / min and an accuracy of 95.2% [15].

M. Trikha, A. Bhandari, , and T. Gandhi (2007) introduced a new technique for classification of multiple channel EOG. The classifier was based on Deterministic Finite Automata (DFA). The system was capable of classifying sixteen different EOG signals. Five silicon rubber electrodes of impedance below 10KΩ were placed around the eye to obtain EOG signals. Silicon rubber conducting electrode was used because it is able to sense the very low amplitude signals as compared to Ag/AgCl electrodes. By using FFT analysis, it was found that prominent frequency components are up to 40 Hz whereas the maximum frequency components lie around 4 Hz. They used four threshold values THH, THL, TVH, and TVL, which are High/Low threshold levels in Horizontal/Vertical channel EOG signals respectively. These

Threshold levels were +/- 37.5% of the highest positive/negative amplitude of the obtained EOG signal. Symbols [CV+, CV-, CH+ and CH-] are positive/negative region above/below threshold levels in vertical/horizontal channel respectively. Symbols [CV0, CH0] are rest zone area in vertical/horizontal channel respectively. These Signals were fed as primary input to the Peak Detection Deterministic Finite Automata (PDDFA), which identifies positive/negative peaks and rest zone in EOG. The output of PDDFA was mapped onto set P ϵ {V+, V-, H+, H-} used as input by the Movement Classifier Deterministic Finite Automata (MCDFA) to determine which eye movement was performed by the user, from its set of sixteen different eye movements. This output was then used by the O/P module to display which eye-movement was detected, on the LCD display [16].

Jason J. Gu, Max Mag, Albert Cook, M. Gary Faulkner (2001) developed EOG based robotic prosthetic eye system. EOG method was used to determine the real eye position and the signal obtained was used to control the artificial eye movement. Two small electrodes were used for recording contact points around eyes and a reference electrode was located on the midline of the forehead. The potential difference between the two electrodes was amplified and sent to the computer through the AD card with 30Hz sample frequency. A calibration curve was developed to find out the relationship between the output of the sensor and the eye. After the calibration curve was obtained, the eye position signal was fed to the controller to control the artificial eyeball so that the artificial eyeball would have the same orientation as the real eye. Prosthetic eyeballs were mounted on to a servomotor, which was controlled by microcontroller using pulse-modulated signal [17].

Chapter III

Materials & Methods

3.1 Materials and methods used for EOG based assistive technique

3.1.1 Materials

The ICs AD620 and OP07 were procured from Analog devices, Norwood, USA and Fairchild, South Portland, USA, respectively. Disposable pre-gelled electrodes for signal acquisition were obtained from BPL, Bangalore, India. The Data acquisition device (USB-4704) was procured from Advantech Corporation, Taiwan. Arduino Leonardo and Arduino Uno microcontroller boards were procured from Arduino Corporation Italy. The capacitors, resistors, motors and other parts were procured from local market.

3.1.2 Method used for EOG based assistive technique

Basic Block Diagram of EOG based HMI system is given in Figure 3.1

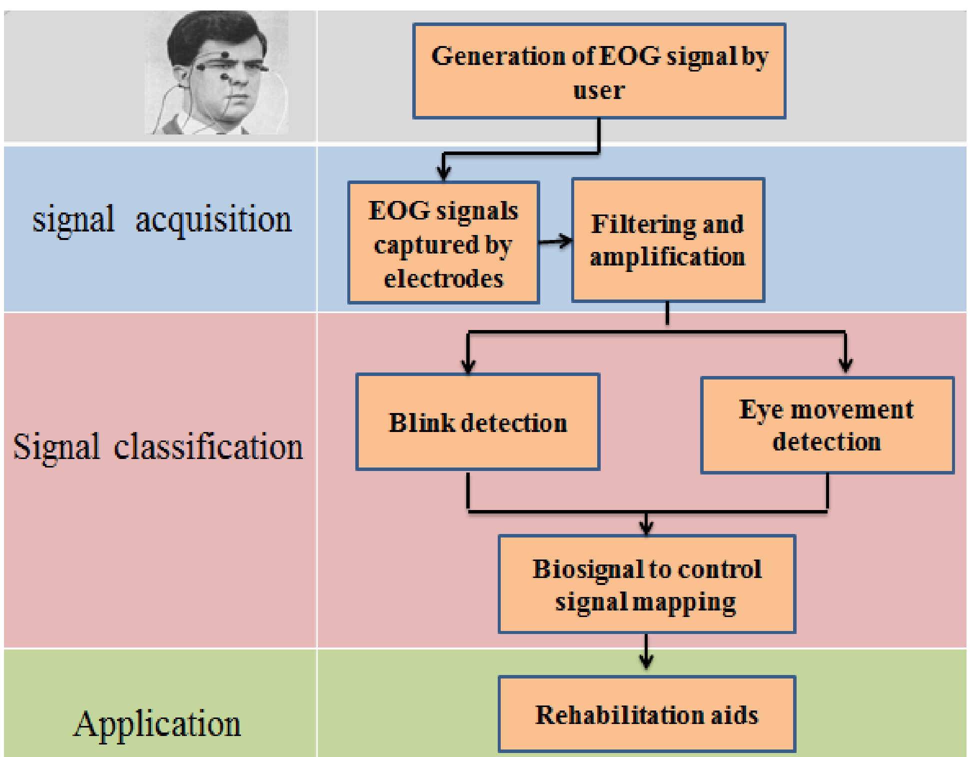

Figure 3.1 Basic Block Diagram of EOG based HMI system

The development work involved three parts:

1. **Signal acquisition part** included development of DAQ.
2. **Signal classification part** included classification of basic eye movement types and blink.
3. **Application part** involved implementation of rehabilitation devices which can be controlled using EOG.

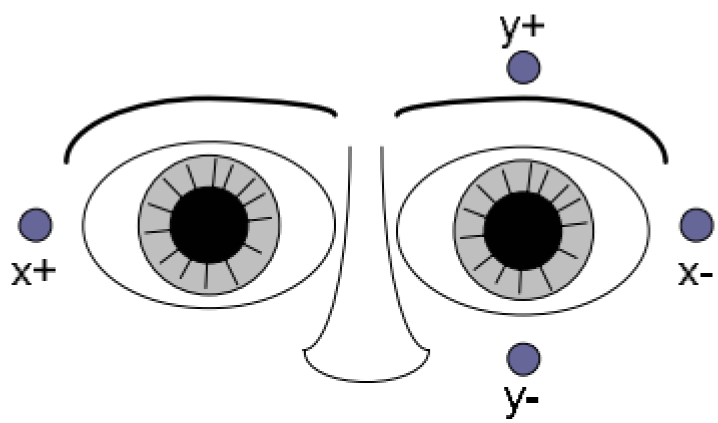

Figure 3.2 Electrooculography electrode placements [18]

EOG signals were measured by placing electrodes on the region surrounding the eye. They were recorded from two separate regions: horizontal and vertical. Horizontal electrodes were for detecting horizontal eye movements (left and right eye movement) and vertical electrodes were for detecting vertical movements (up and down cornea movements) [18].

Three to five electrodes were used to acquire the EOG signals. Figure 3.2 shows the five electrode placement in Electrooculography. Electrodes x+ and x- were horizontal electrodes and y+ and y- were vertical electrodes. The fifth electrode placed on the forehead was for reference [2, 19]. AD620AN was used as the pre amplifier. The AD620 was a low cost, high accuracy instrumentation amplifier. It was used as a pre amplifier because of its high CMRR and high input impedance [19].

The main source of noise present in the signal was power line noise and baseline wandering. Base line wandering was due to the presence of low frequency components in the signal. These two noises were removed by using a band pass filter with cut-off frequency 0.5 to35 Hz. Noise was further removed by implementing filters using LabVIEW.

Separate algorithms were used for identifying blink and eye movements. They were identified by the amplitude, width and timing of positive and negative components within the signal. For eye movements, width of the pulse was more but amplitude was low. For blink, waveform amplitude of the pulse was more but duration was low. This can be identified by using separate algorithms.

This step was followed by bio signal to control signal generation. Separate eye movements and duration between individual eye movements can be formulated to produce individual control signals. These control signals were used to control the movement of a wireless controlled wheelchair. These control signals were parallel in nature; HT12E encoder took parallel data, packaged it into serial format and then transmitted it with the help of the RF transmitter module. At the receiver end, HT12D decoder received the signal through the RF receiver module, decoded the serial data and reproduced the original data in the parallel format. The microcontroller controlled the direction of wheelchair motors depending on the incoming data.

Chapter IV

Results and Discussion

4.1 EOG based motorized wheelchair

4.1.1 System organization

The block diagram representation of EOG based motorized wheelchair system is given in Figure 4.1. The horizontal and vertical eye movements were acquired separately by using DAQ. These signals were displayed and processed using LabVIEW. Depending upon the direction of eye movement, separate control signals were generated. These control signals were parallel in nature; the encoder took parallel data, packaged it into serial format and then transmitted it with the help of the RF transmitter module. At the receiver end, the decoder received the signal through the RF receiver module, decoded the serial data and reproduced the original data in the parallel format. The micrcontroller controlled the direction of wheelchair motors depending on the incoming data. A detailed description of each block and their functions is explained in following sections.

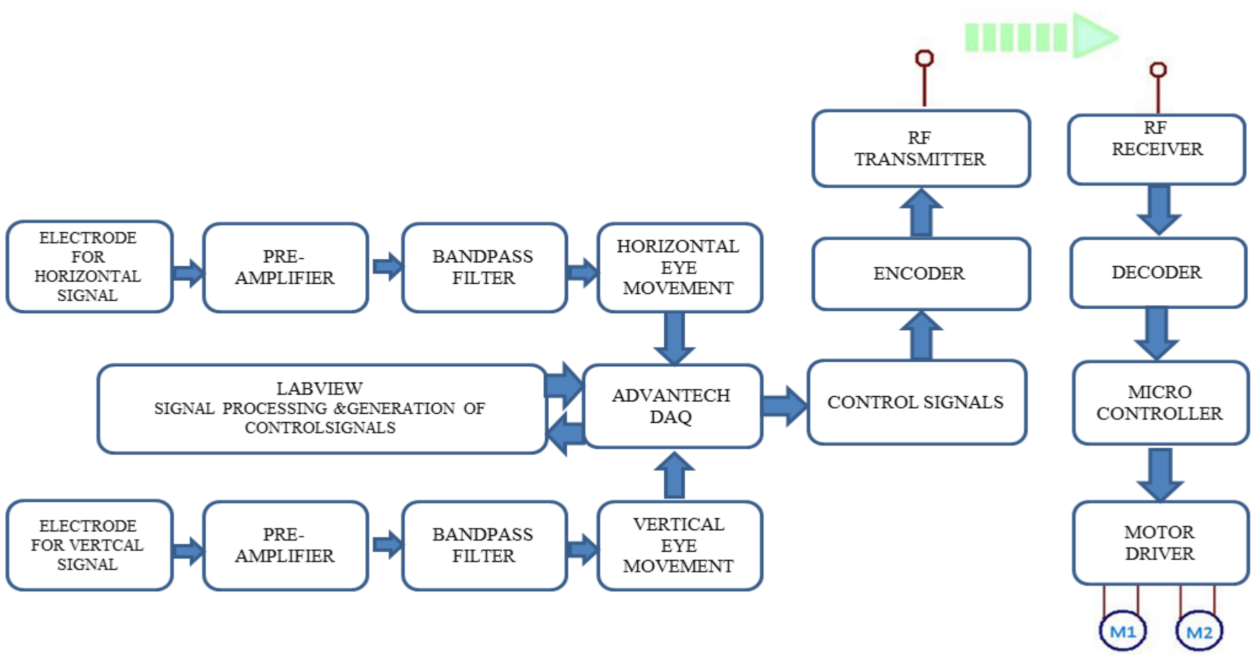

Figure 4.1 System organisation of EOG based wheelchair

4.1.2 EOG signal acquisition system

4.1.2.1 Electrodes and input cables

Disposable pre-gelled Ag/AgCl electrodes were used to acquire EOG signals from the body. Since the EOG signal amplitude range was in microvolts, they were very much susceptible to various noise sources. To overcome the effects of RF noise and electromagnetic interference, shielded wires were used to connect Ag/AgCl electrodes and data acquisition circuits.

4.1.2.2 Safety regards

Since electrical safety of the patients was a major concern for the development of biomedical equipment, the circuit shown above run only using two 9 volt batteries. Apart from that, Advantech DAQ was powered using the USB terminal of a laptop, which was run in the battery powered mode to ensure electrical safety of the patients. Being operated in battery mode also reduced the power line interfaces to a limit.

4.1.2.3 Amplifier circuitry

In general, the EOG signal amplitude and bandwidth varies in the range of 50-3500 µV [2]. USB-4704 is a 12-bit analog-to-digital converter. Hence, care had to be taken to design a bio potential which would amplify the signal in such a way that the digitization of the EOG signals result in minimum quantization error. To ascertain this, the gain of the bio potential amplifier should be adjusted so that 100 µV EOG signal is amplified above 1.4 mV [20]. Also, the characteristics of AD620 suggest that as the gain of bio-potential amplifier is increased, there was a subsequent increase in the common-mode rejection ratio (CMRR). Taking the above facts into consideration, the bio potential amplifier was designed with a gain of 1500. Circuit diagram of vertical EOG signal acquisition system is given in Figure 4.1. Same circuit can be used to acquire vertical EOG signals.

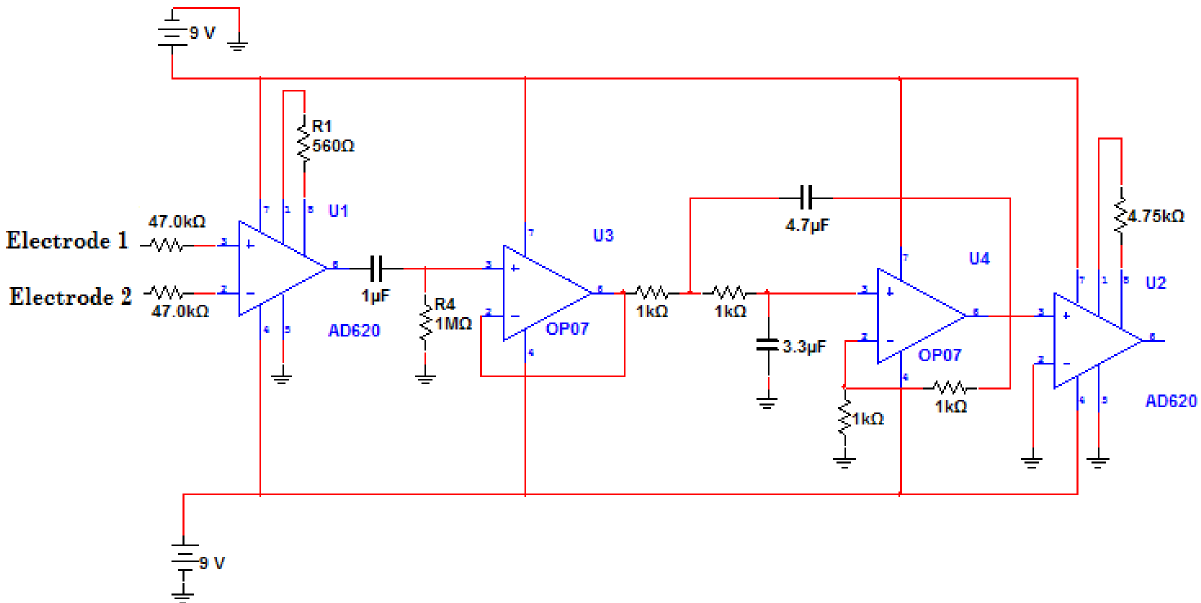

Figure 4.2 Circuit diagram of Vertical EOG signal acquisition system

4.1.2.4 Pre-amplifier

Low cost high precision instrumentation amplifier AD620AN was used as front end amplifier. It provides high CMRR (around 100 DB) and can handle signals in microvolt range. Differential amplifier in the instrumentation amplifier allows subtraction of the common or unwanted signal from the actual signal. High common mode rejection ratio indicates better subtraction and the CMRR of the AD620 at a gain of 1000 is about 130 dB, which is more than sufficient for this project. A single external resistor sets the gain of AD620 from 1 to 1000; the resistor is connected between the 1st and 8th legs of the op-amp. The gain can be calculated by the following equation

$$G = \frac{49.4\Omega}{Rg} + 1$$

Where, Rg was the resistor connected between the 1st and 8th legs of the opam [18].

Rg = 560 Ω.

When, Rg = 560 Ω Gain will be approximately 89.

4.1.2.5 Band pass filter

Chance of generation of substantial DC offset due to the potential difference between each of the active electrodes and the reference electrode was observed. This DC potential was due to the skin impedances and varied substantially depending on parameters like skin moisture, skin temperature, the humidity of the air, etc. [2]. Front end amplifier AD 620 with high gain amplified this DC voltage to a very large value, thus possibly saturating the amplifier. This was overcome by introducing a high pass filter with a corner frequency of 0.15Hz. It rejected DC and prevented the noises amplified by the preamplifier circuit. It also rejected motion artifacts and baseline wandering but at the same time allowed the lower end of the frequency band of interest to pass.

$$f = \frac{1}{2\pi RC}$$

R = 1MΩ and C = 1μF   gives f = .156 Hz

Most of the EOG signal information lies in the frequency range 1-25 Hz [2]. So the high-pass filter was followed by a Sallen-Key 2 Pole Butterworth Low Pass Filter with a 40Hz cut-off frequency [2].Selecting a cut-off frequency in the range 30-40Hz helped in overcoming power line noise. Low pass filter also acted as an anti-aliasing filter. [2] The gain of low pass filter was set as 2.

Transfer Function:

$$G(s)=\frac{64474.532}{s2+425.531914894s+64474.5325596}$$

Cut-off frequency: f_c = 40.41Hz

Quality factor: Q = 0.59670

Damping ratio: ζ = 0.8380

In order to obtain a total gain above 1500, the filtered signal was again amplified by using a second AD620 with Rg = 4.7k Ω. When, Rg = 4.7 kΩ gain will be approximately 89 and total gain of EOG acquisition system was 89*2*11 = 1958.

4.1.3 LabVIEW analysis of EOG signals

Amplified and Filtered EOG signal obtained from final AD620 output was fed to Advantech USB4704 for interfacing with laptop working on battery mode. These signals were then subjected to a band pass filter with cut off frequencies 0.5 and 35Hz. For better analysis, the envelope of EOG signal was obtained by subjecting the input signal to a low pass filter of cut-off frequency 3Hz. An original EOG signal and corresponding enveloped signal obtained from a blink operation is shown in Figure 4.3.

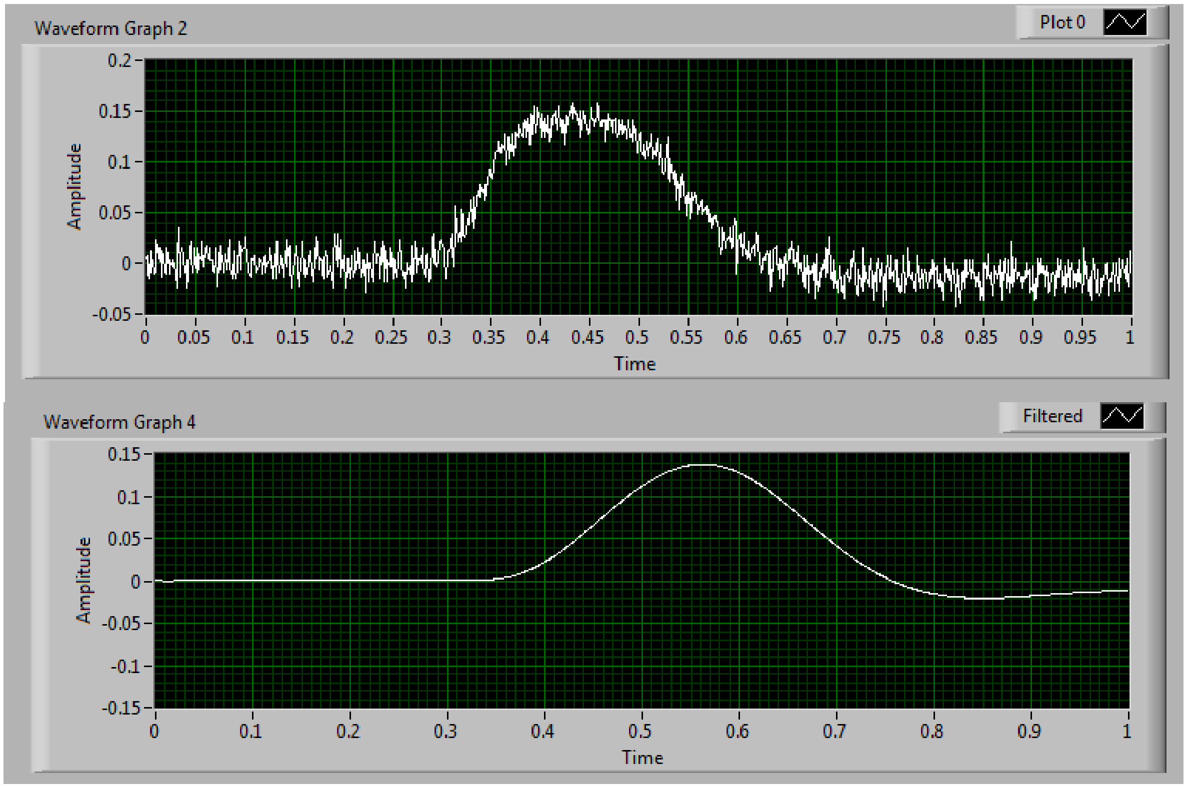

Figure 4.3 Original EOG signal and corresponding enveloped signal from a blink operation

4.1.3.1 EOG waves corresponding to different eye movements

Waveforms corresponding to six distinct basic eye movements have been acknowledged during the course of the project development, viz. blink, rest, up eye movement, down eye movement, left eye movement and right eye movement. This can be extended by the combination of basic eye movements like up-right, up-left etc.

4.1.3.2 Blink

Blink EOG signal was obtained from vertical channel. Highest peak in the vertical channel was obtained from blinking. Time span of blink waveform was short compared to other eye movements. This quick span of the signals was due to the high-velocity of an eye blink [18].

Figure 4.3 was obtained while doing a single blink. Blink can be voluntary or involuntary. Involuntary blink was considered as a motion artifact or noise. From observations, it was found that the amplitude and duration of involuntary blink was much less than voluntary blink which was used as a condition to eliminate involuntary blink. Figure 4.4 shows the differences between voluntary and involuntary blinks.

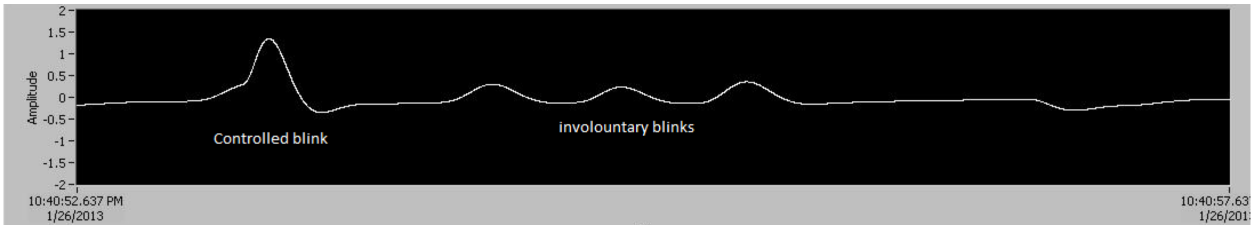

Figure 4.4 Voluntary and involuntary blinks

4.1.3.3 Up – down eye movements

EOG signals corresponding to up – down eye movements are dominant in vertical channel. From the observations, it was found that EOG signal due to up eye movement consists of a positive peak followed by a negative peak and the amplitude of positive peak was much higher than that of the negative peak. In the case of down movement, it was exactly the opposite. Figure 4.5 indicates EOG signal waveforms corresponding to vertical eye movements obtained from DAQ.

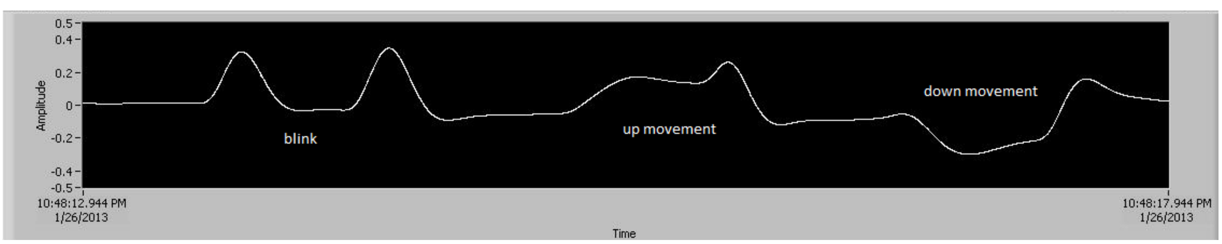

Figure 4.5 indicates EOG signal waveforms corresponding to vertical eye movements

EOG signal of an up movement was similar to blink signal but there was significant difference between amplitude and duration. Amplitude of blink EOG signal was slightly more than that of the up signal and duration was lesser.

4.1.3.4 Left – right eye movements

EOG signals corresponding to left –right eye movements were found to be dominant in Horizontal channel. Their EOG Waveforms were similar to that corresponding to up – down movements. Figure 4.6 and 4.7 indicate left and right eye movements.

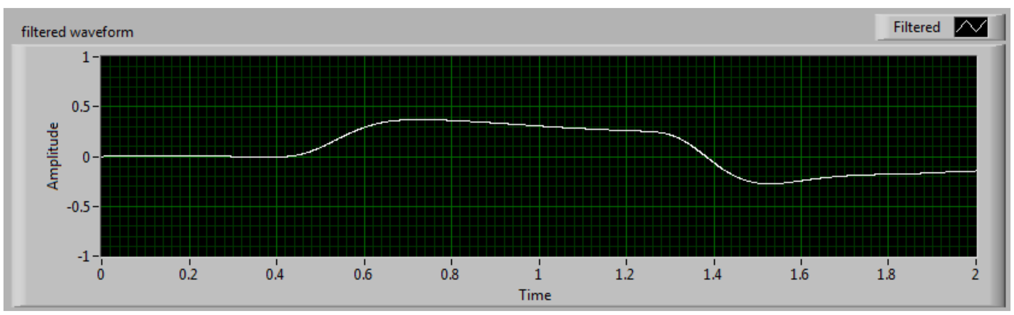

Figure 4.6 EOG corresponds to eye movement towards right

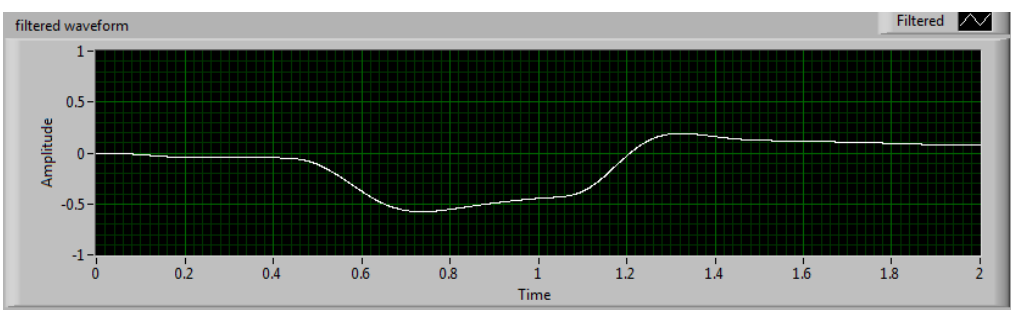

Figure 4.7 EOG corresponds to eye movement towards left

4.1.4 Classification and control signal generation

4.1.4.1 EOG classification algorithm

From the EOG signals obtained, which are mentioned in Figures 4.3 to 4.7, it is clear that each eye movement follows a unique pattern. There are different algorithms for classifying EOG signals. Among them the most common algorithms compare the obtained EOG signal's amplitude with a predefined threshold. When signal amplitude exceeds the threshold value, it is considered to be a valid signal for recognition. This method is very simple and easy to implement, but is not without drawbacks. Generally, EOG signal is very sensitive. It fluctuates with respect to the head movement or even with the slightest displacements in electrode position. So these algorithms produce erroneous outputs in these conditions. This can be overcome to an extent by a new algorithm, in which, along with the threshold the amplitude duration of signal in which it keeps the amplitude above threshold, was also calculated.

The flowchart of detection algorithm is shown in Figure 4.8, which describes the sequence of steps to identify horizontal EOG signals (right and left eye movements). The same algorithm was used to classify up and down movement, introducing a slight modification made to classify between up and blink action.

From EOG signal analysis done on voluntary candidates it was found that the peak of amplified EOG outputs is around 0.5V for right movement and -0.5V for left movement. It also keeps the amplitude high for duration 500ms to 900ms.

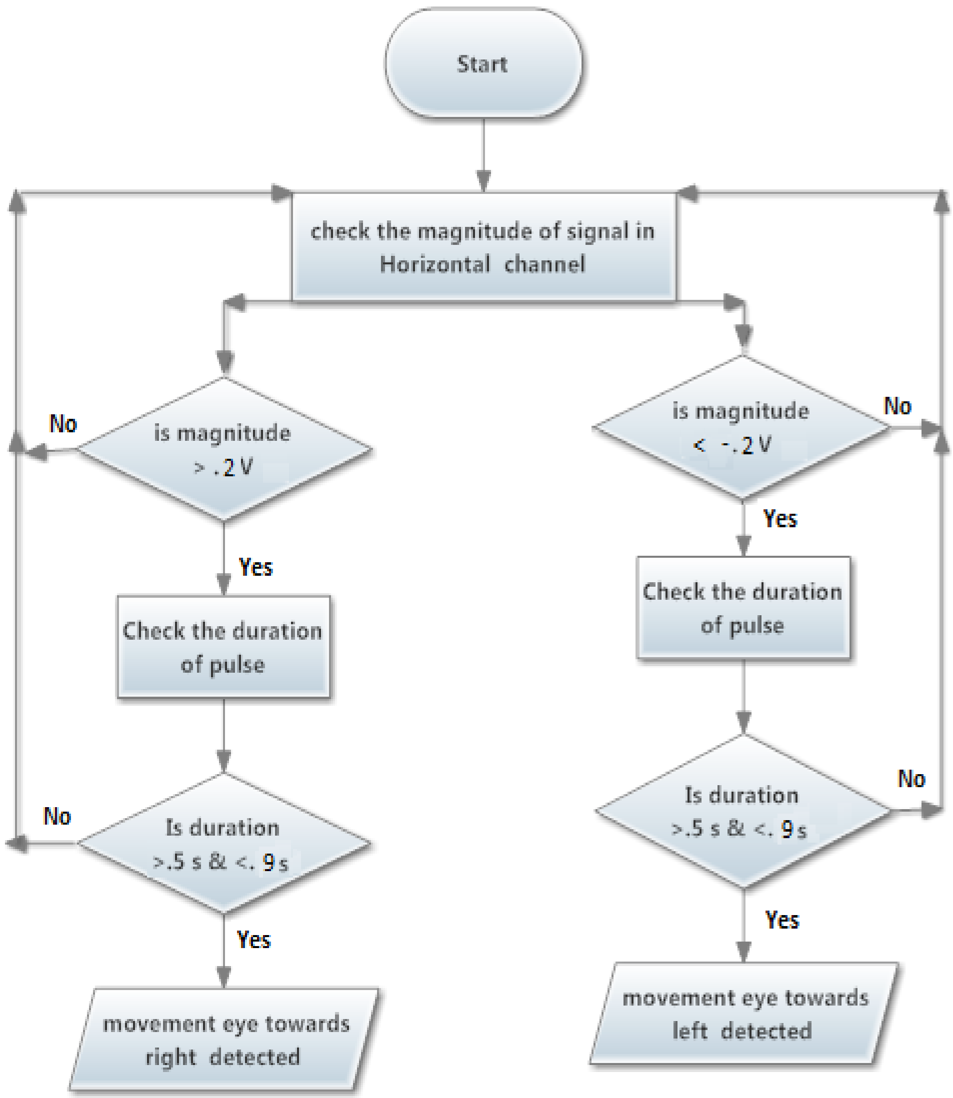

Figure 4.8 Flow chart for detecting right – left eye movements

Further, for Up and Down movement we experienced almost the same amplitude and duration. EOG signal of an up movement was similar to the blink signal but there was a significant difference between amplitude and duration. Amplitude of blink EOG signal was around 0.75v to 1V, which was more than the up signal (0.5V) and the duration is only 200 to 450ms.

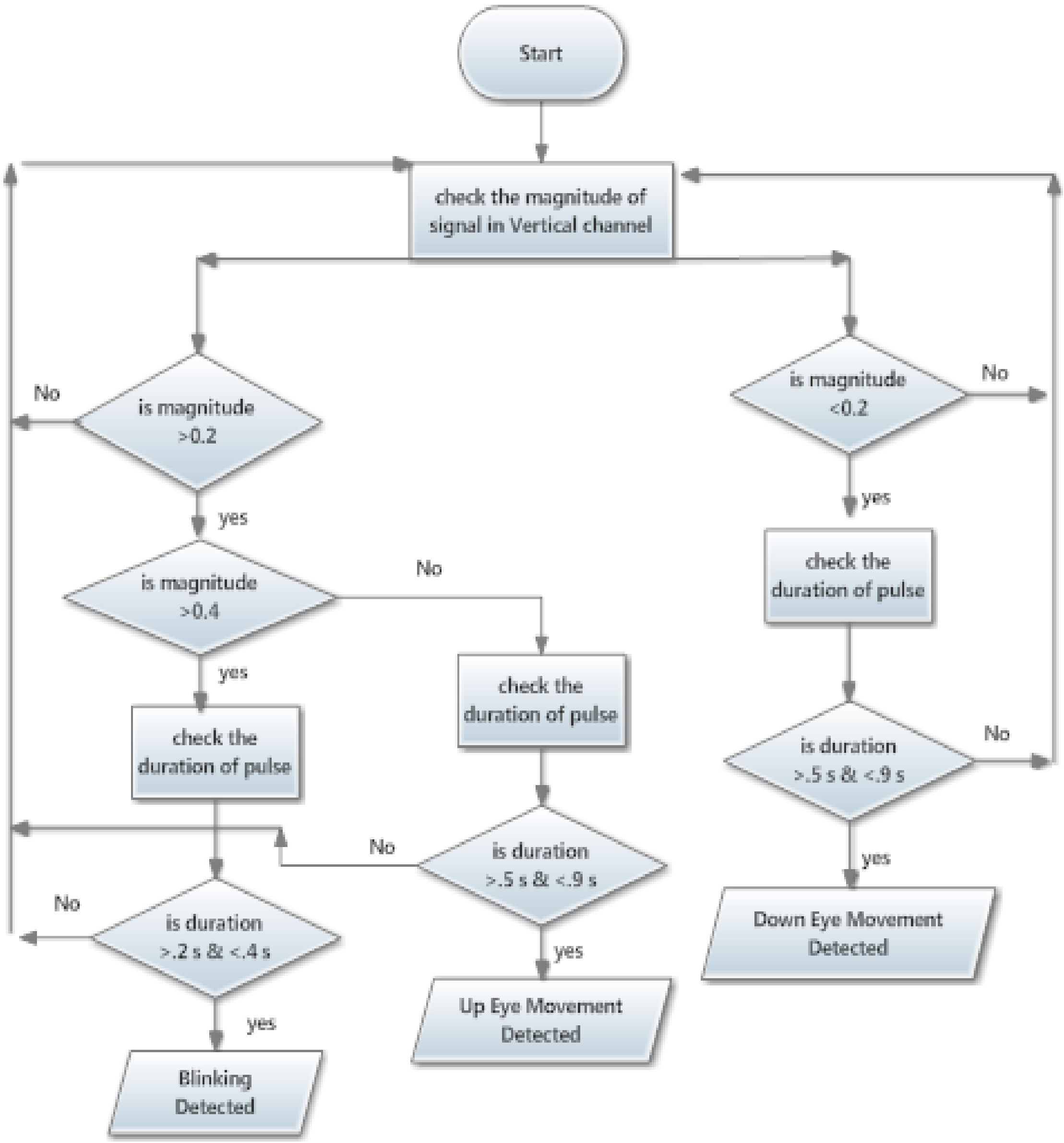

Figure 4.9 Flow chart for detecting up – right eye movements and blink

An EOG signal corresponding to up–down eye movements was dominant in vertical channel. Hence for easy analysis, up–down and blink classification algorithm was applied to EOG signals from vertical channel. Similarly for classifying right – left eye movementsthe algorithm was applied to EOG signals from horizontal channel. Both algorithms were carried outsimultaneously and in parallel.

4.1.5 Control signal generation

Vertical EOG signals and horizontal EOG signals were processed in parallel.Signal amplitudes were compared with the corresponding threshold values. Once it crossed the threshold, the duration for which it holds the threshold value was calculated. If both duration and amplitude condition were satisfied, it generated one control signal. Control signal was generated in such a way that it remained high for the next 2 seconds. Even though the input signal changed, its values did not vary during this time. This kept the system in minimum error and maximum control. The generated command signals were used to drive the LED panel comprising of the 5 LEDs.

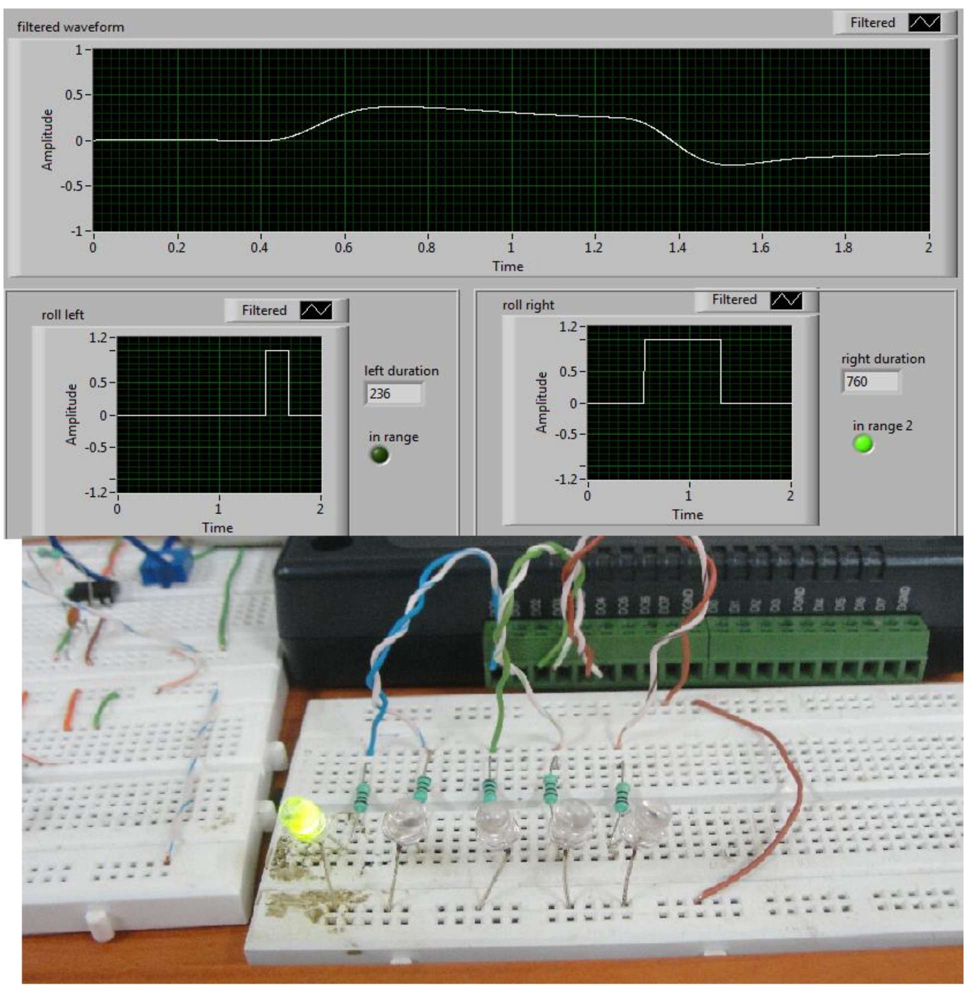

Figure 4.10 Right movement of eye was detected and corresponding output LED glows

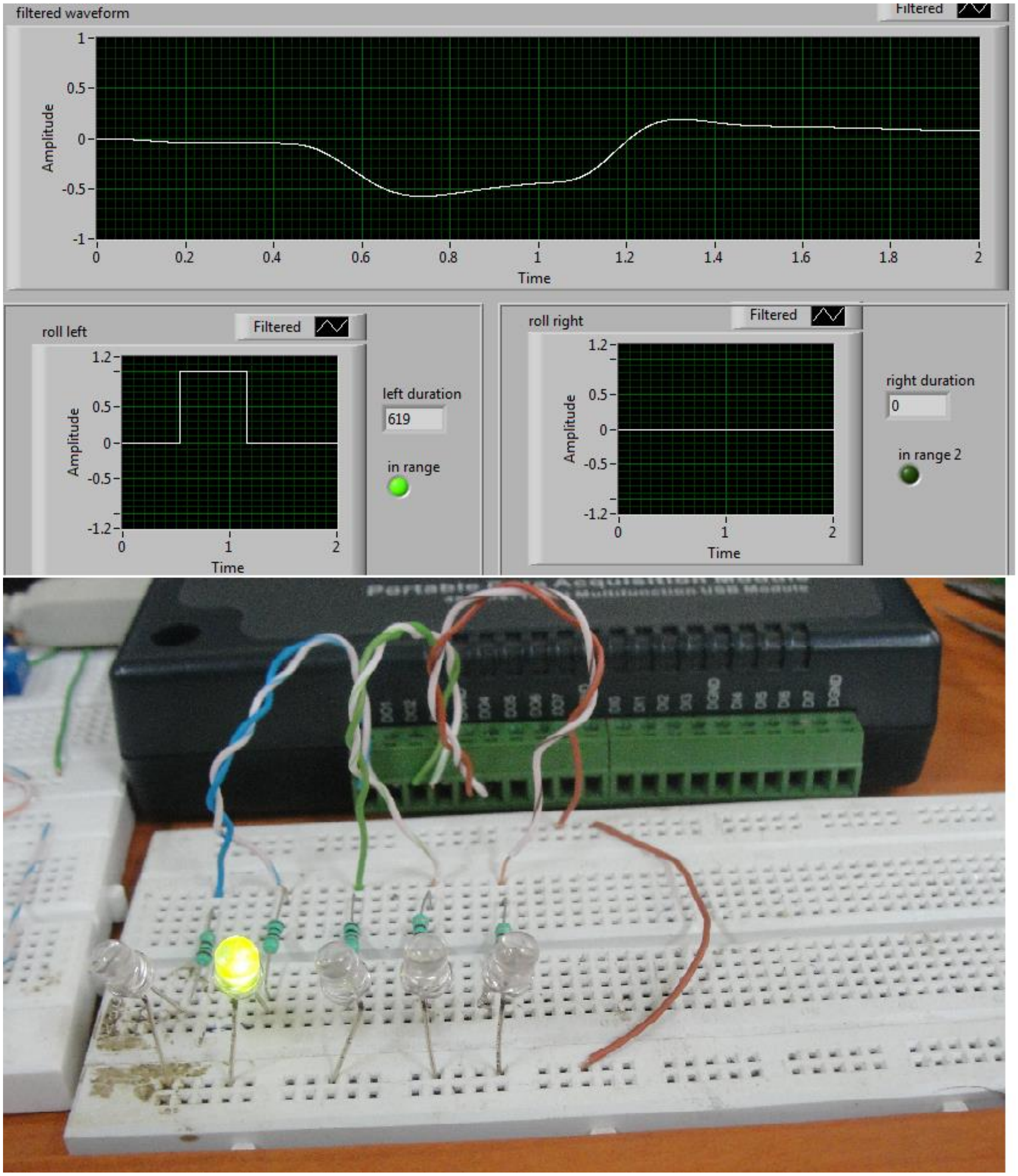

Figure 4.11 Left movement of Eye was detected and corresponding output LED glowed.

In left- right movement detection, two comparators were used to check amplitude. The first comparator makes sure the amplitude was above the positive threshold and second one checks whether it was below the negative threshold. Both comparators work in parallel.

Comparator produce a positive pulse output. Pulse amplitude remains high until the signal amplitude crosses the threshold in the opposite direction. If the signal satisfies both the conditions, the system generates a control signal corresponding to thetype of eye movement. Figure 4.13, 4.14 and 4.15 control signal generation for up, down and blink eye movements.

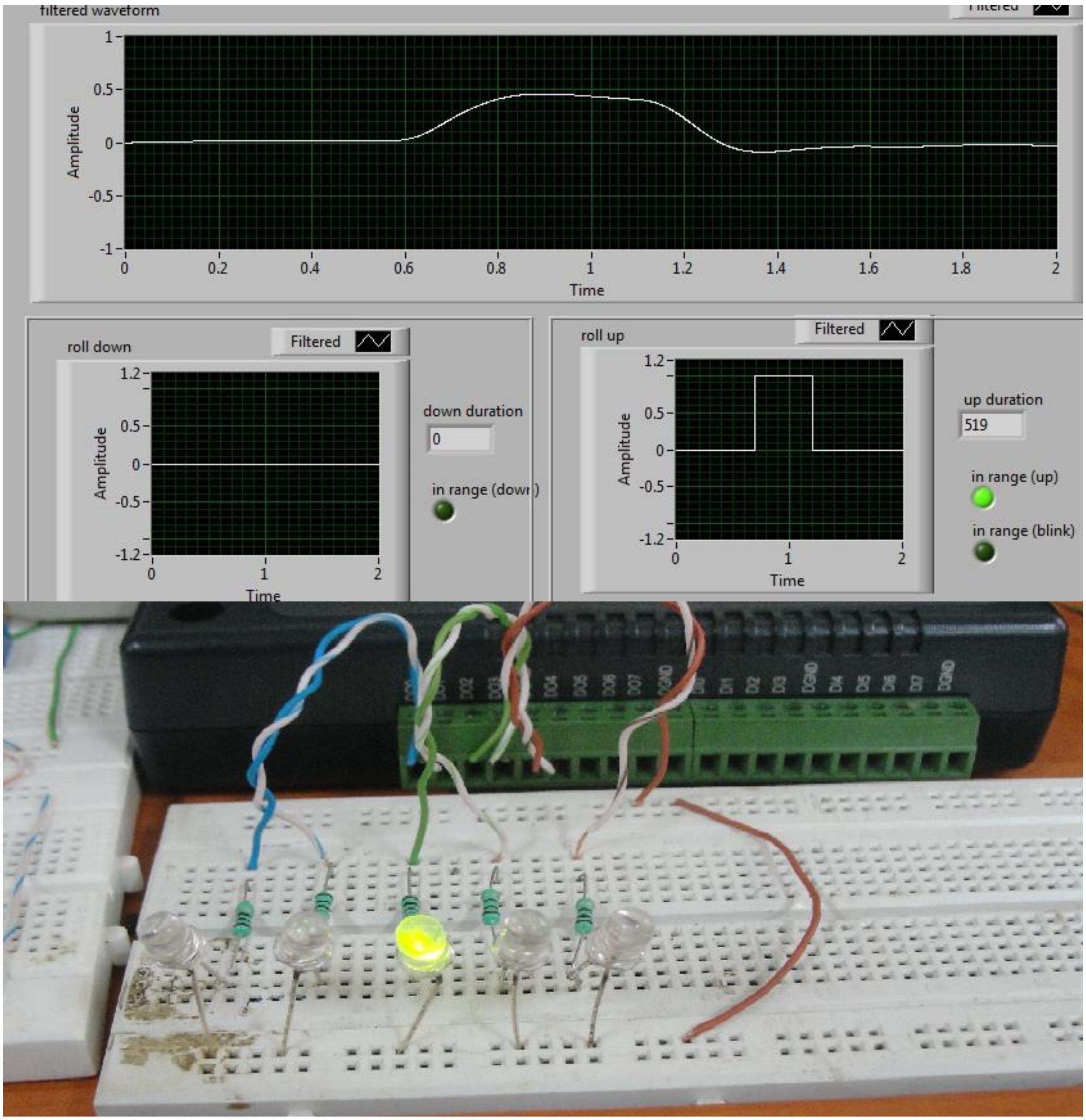

Figure 4.12 Up movement of eye was detected and corresponding output LED glowed

In up – down and blink detection, three comparators were used. Negative comparator was used to detect the down movement. Positive comparator was used to detect up movements and blinking action. If amplitude of the signal was above 0.2V and pulse duration was in the range of 500 to 900ms, it detected up movement. Similarly, if input signal amplitude was above 0.5V and duration was in the range 200 to 450ms the input signal was detected as blinking.

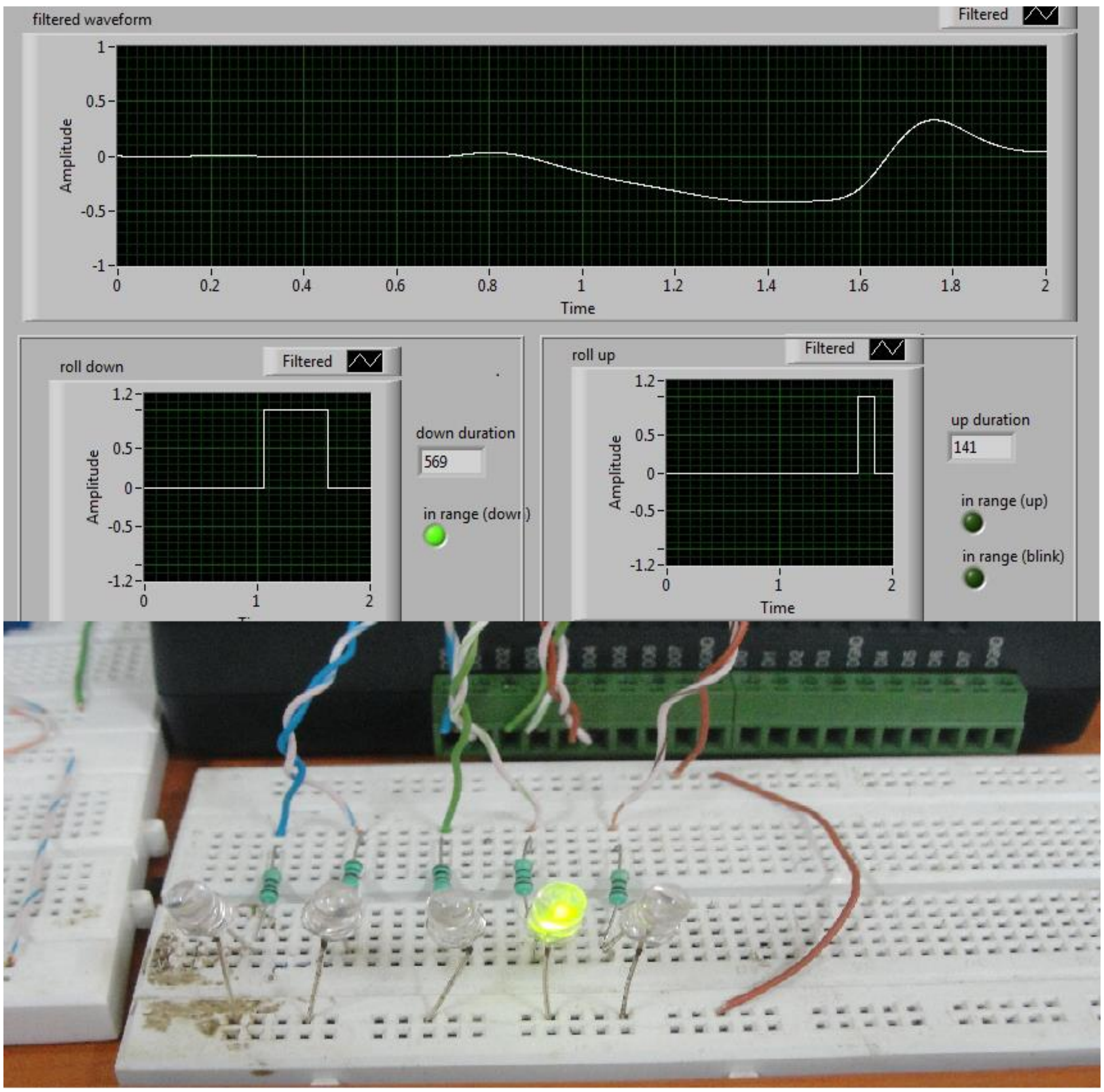

Figure 4.13 Down movement of eye was detected and corresponding output LED glowed

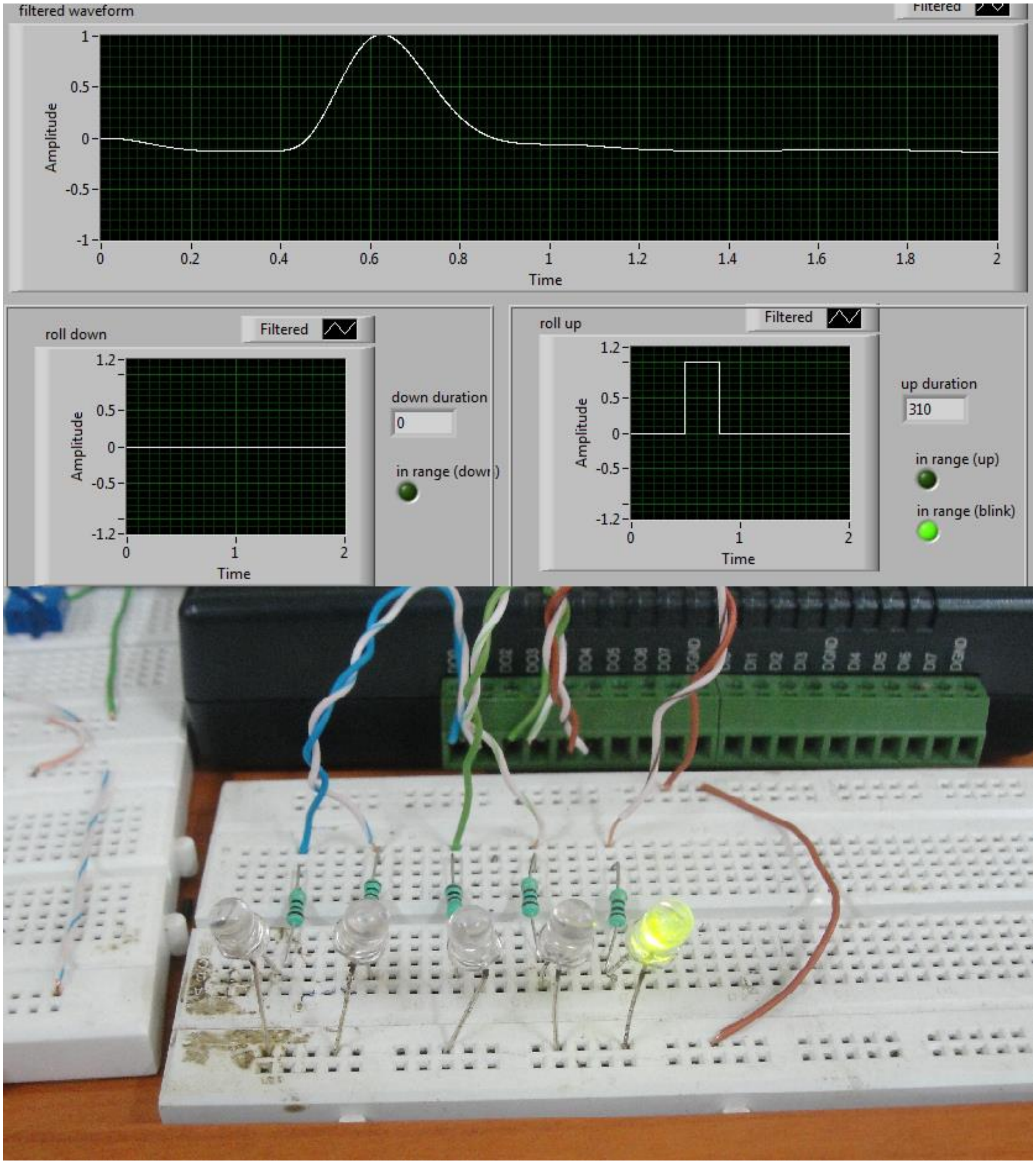

Figure 4.14 Blinking of eye was detected and corresponding output LED glowed

These control signals can be used to control and guide rehabilitation aids. As a part of the project these control signals were used to control and guide a motorized wheelchair. Operation and working of motorized wheelchair is described in section 4.2.

4.2 Controlling motorized wheelchair

Generated control signals can be used to guide and control rehabilitation aids. Hence, as a part of the project, a microcontroller-based wheelchair demo model was developed and implemented. Figure 4.15 shows the schematic block diagram model of the wheel chair control module.

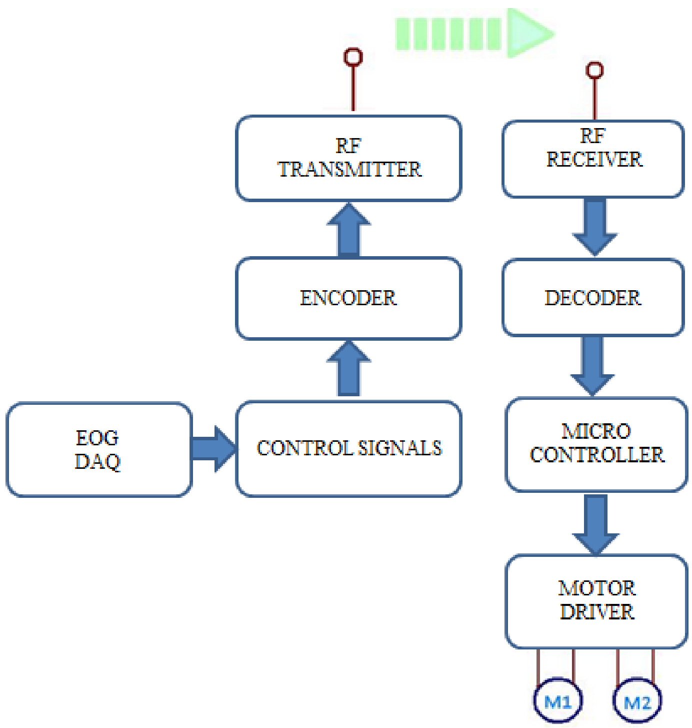

Figure 4.15 Schematic block diagram model of the wheel chair control module.

A radio-frequency transmitter was used to transmit the command signal to the wheelchair module having a radio-frequency receiver. RF transmitter received serial data and transmitted it wirelessly using RF through its antenna. Since obtained control signals were parallel in nature, the parallel data was encoded to serial data by using a HT12E encoder IC. The transmitter/receiver (Tx/Rx) pair operated at a frequency of 434 MHz. The transmission occurred at the rate of 1 Kbps – 10 Kbps. The transmitted data was received by an RF receiver operating at the same frequency as that of the transmitter. Received data was in serial mode. It was again converted back to parallel data by decoder IC HT12D. Figure 4.16 shows RF transmitter receiver module.

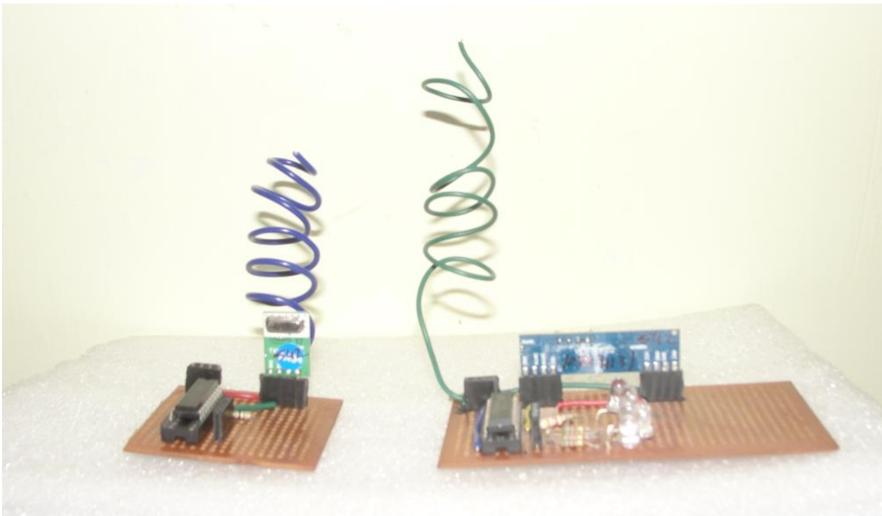

Figure 4.16 RF transmitter and receiver module

Data was then processed by the Arduino Leonardo microcontroller to govern the direction of the wheelchair model. High torque DC motors were controlled by motor driver IC L293D.

Connection diagram of L293D is given in Figure 4.17. A, B, C and D were various microcontroller outputs generated as a result of different eye movements. Behavior of left and right motors for various microcontroller outputs is given in table 4.1.

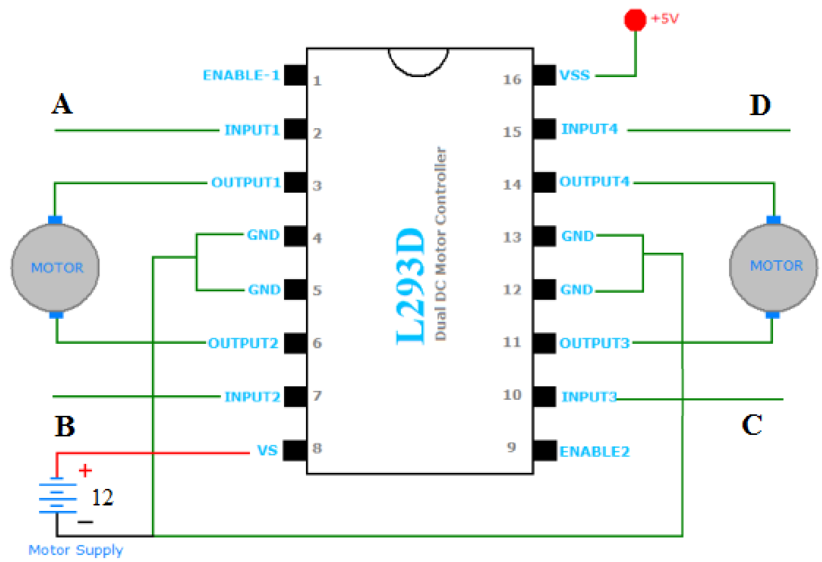

Figure 4.17 Motor controller using L293D chip

Table 4.1 Behavior of left and right motors for various microcontroller outputs

Eye movement	**Microcontroller O/P**				**Motor Direction**		**Wheel chair direction**
	A	**B**	**C**	**D**	**Right motor**	**Left motor**	
Up	1	0	0	1	Clock wise	Anti clockwise	Forward
Down	0	1	1	0	Anti clockwise	Clock wise	Backward
Right	1	0	0	0	Clockwise	Stop	Right
Left	0	0	0	1	Stop	Anti clockwise	Left
Blink	1	1	1	1	Stop	Stop	Stop

Most of the electric wheel chairs available in the market need some kind of motor activity for controlling the movement of the wheelchair. This is not possible for the paraplegic or quadriplegic patients. Developed EOG command based systems may be effectively employed with proper training. Figure 4.18 shows the developed motorized wheel chair which can be controlled by EOG signals.

Figure 4.18 Developed motorized demo wheelchair

Chapter V

Conclusion

5.1 Conclusion

In the present work, an EOG signal acquisition system has been designed and implemented. Additionally, a new algorithm for EOG classification and control signal generation was also developed. This algorithm required much less user training than other classification algorithms. Hence it is very much useful for the implementation of rehabilitation aids. As a part of this project, an EOG based Human Machine Interface has also been developed. This HMI was able to generate control signals during various eye movements and blinks. These control signals were used to control a wireless prototype motorized wheelchair model by various eye movements and blink. This EOG based HMI control system for motorized wheel chair will be a good assistive technique for people suffering from extremely limited peripheral mobility. From the application point of view, control signals generated can be used to control HCI systems or other communication devices. As a whole, great prospects lie ahead for the current project which can be implemented with some further modifications.

5.2 Future work

The future prospects of current project are vast. In this project, only five control signals were generated and transmitted. This can be extended to eight with a little modification in the algorithm. Range of operations can also be increased from 100m to a much wider range if RF module is replaced by GSM module. By using PDA in place of computer the system can be converted to a wearable device. Accuracy of the circuit can be improved by using electronic components with high precision and less tolerance. The EOG based HMI technique discussed in this thesis, can be developed as a practical solution by performing these changes.

Chapter VI

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