Proceedings of the 2017 4th International Conference on Advances in Electrical Engineering (ICAEE)
28-30 September, Dhaka, Bangladesh

Hardware and Software Implementation of Real Time Electrooculogram (EOG) Acquisition System to Control Computer Cursor with Eyeball Movement

Zakir Hossain[1], Md. Maruf Hossain Shuvo[2], and Prionjit Sarker[3]
Department of Electronics and Communication Engineering
Khulna University of Engineering & Technology
Khulna-9203, Bangladesh
E-mail: zakirh817@gmail.com[1], maruf.shuvo1@yahoo.com[2], ptsprionjit@gmail.com[3]

***Abstract*—Human computer interface (HCI) is an emerging technology of neuroscience and artificial intelligence. Development of HCI system using bio signal e.g. Electrooculogram (EOG), Electromyogram (EMG), Electroencephalogram (EEG), Functional near-infrared spectroscopy (fNIRS) etc. are attracted more and more attention of researchers all over the world in recent years because through this it is possible to get acquainted with advanced technologies of artificial intelligence. This paper presents the design and implementation of a fully functional Electrooculogram (EOG) based human computer interface. In this work we have designed and implemented necessary hardware and software for EOG signal acquisition along with controlling hardware such as wheelchair, robotic arm, mobile robot etc., and move computer mouse cursor simultaneously using EOG signal. This interface has three portion: EOG signal acquisition and amplification, analog to digital conversion, and real time hardware and mouse cursor movement. Eye movement is detected by measuring potential difference between cornea and retina using five Ag-Agcl disposable electrodes. Frequency range of EOG signal is considered as 0.3 to 15Hz, so this frequency range is taken using an active high and low pass filter so that accurate EOG signal can be achieved. The analog output of the EOG signal from filter is converted into digital signal by using an Arduino. Arduino serialize the EOG data for calibration and provides a threshold reference point which is used for controlling Hardware. The Classification module e.g. Support Vector machine (SVM) and Linear Discriminant Analysis (LDA) classify live data with respect to the horizontal and vertical data. This works as a binary classifier and choose optimal hyper-plane between two variables. According to each update on the eye position, cursor automatically accelerated in particular direction. PyMouse module in python is used for this task. Eye gesture based Hardware like robot, wheelchair etc. control and mouse cursor movement are the principle outcome of this research work.**

Keywords—Electrooculogram (EOG); Human Computer Interface (HCI); Cursor Movement; Support Vector Machine(SVM)

I. INTRODUCTION

Development of Human Computer Interface (HCI) technology based on different bio signal is the new era of Biomedical Engineering. It becomes more and more popular topic in the current research field of neuroscience. Bio-potential such as EOG, EMG, EEG, fNIRS etc. can be used for HCI applications [1-2]. But among them, Electrooculogram (EOG) is much more reliable, cost efficient and non-invasive to implement. Electrooculogram (EOG) is a bio signal which is produced by the potential difference between retina and cornea of the eye [3]. The potential difference is generated because metabolic rate of the retina is higher than cornea which results in a higher potential of cornea than retina. In this way, the eye is modeled as an electrical dipole and this dipole moves with the movement of eyeball [4]. There are many experiments where the corneal part is considered as positive pole and retina part is considered as a negative pole. This two pole is responsible for generating a small amount of electrical field which is detected from the forehead, temple and upper side of the cheek by placing a couple of electrodes. Normally, EOG signal has a differential potential between 0.05-3.5mV of amplitude and frequency range 0.1-20Hz. This EOG signal can be deployed for HCI application to transfer information between human and machine.

Many strategies have already been introduced to implement HCI system based on EOG signal. There are various proposals such as development of HCI technology using EOG where EOG acquisition circuit has been developed and graphical user interface was added for playing game in computer [5]. Some researchers worked on only EOG acquisition portion and they proposed that their low cost system will applicable for implementing HCI system though they didn't implement that on their work [5]. Motorized wheelchair controller was also developed, which is useful for disable person [6]. Another approach was two channel and four-way cursor movement which had an ability to control mouse cursor using EOG signal [7]. Most of the research work tried to focus on the rehabilitation of paralyzed person, but since this is a new technology it should be spread all stages of people by making it less complex, cost effective, available and portable.

In this work, we have designed and implemented a prototype low-cost EOG signal acquisition system which is portable, battery powered, include low power consumption equipment and can interface with the computer. Using this method EOG signal will be easy to acquire and can be processed in real time. The main outcome of this work is to control robotics hardware such as a mobile robot, wheelchair, Humanoid robot etc. and real time computer cursor movement using EOG signal with respect to eyeball movement.

This paper is organized as follows: Section II describes the materials and methods of the system emphasizing on EOG

978-1-5386-0869-2/17/$31.00 ©2017 IEEE

acquisition and processing. Explanation of hardware and software implementation are discussed in Section III and IV. Section V shows the experimental results with proper illustrations and discussions. Finally, conclusions are drawn in section VI.

II. MATERIALS AND METHODS

EOG signal acquisition and utilization for HCI system consists of different process. This process is related to both Hardware and Software interfaces. The step by step procedure is described below.

A. System Configuration

The overall block diagram of proposed EOG based HCI system is shown in Fig. 1. Eye movement sensing, amplification, and filtering circuit, Arduino based ADC are included in this system. Ag-Agcl disposable electrode is used for sensing purposes, and acquisition circuit contains instrumental amplifier AD620, operational amplifier LM741, resistors and capacitors for additional gain and filtering operations. These electrodes work based on the capacitive coupling between a conductive material and skin. Analog EOG data is transmitted to Arduino through serial communication where EOG signal is converted into digital signal. This digital data is transferred to PC for calibration and classification in Python programming language.

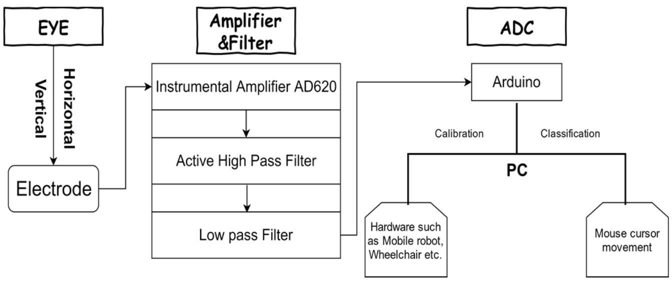


Fig. 1. The Overall block diagram of EOG based human Computer Interface (HCI) system.

The required equipment for this system is shown in Table I. Price also given to get a clear idea about the overall cost of this EOG based HCI system. Overall system costs approximately 26.00USD which is very low and large scale production will further reduce the system development cost.

TABLE I. LIST OF NECESSARY EQUIPMENT

Name of the Equipment	Quantity	Price (USD)
LM7805	2	0.20
9V Battery	2	1.10
AD620 Instrumental Amplifier	2	8.00
Electrode	5	0.35
LM741 Operational Amplifier	2	0.30
Arduino Mega 2560	1	12.28
Resistor	15	0.10
Capacitor	10	0.14
Wire, clip , gel etc.	As required	2.20
Total		26.67

B. Detection of EOG Signal

Horizontal and Vertical movement of the eyeball is detected with the help of electrodes. Two channel data acquisition module is used for acquiring eye movement information such as horizontal and vertical movement. Placement of horizontal and vertical electrode along with their positions are as shown in Fig. 2. Five electrodes are used where two for the Horizontal Channel (A & B) and two for the vertical channel (C & D) and one for reference or ground (G) [8]. The voltage form of eye movement is changed its ionic form to its electron form in the wires with the help of electrode [9]. Voltage significantly changed when eye move right to the left, same case occurs for up and down movement. Since eyes have a sphere shape, the range of horizontal movement of eyes is wider than the vertical movement [7].

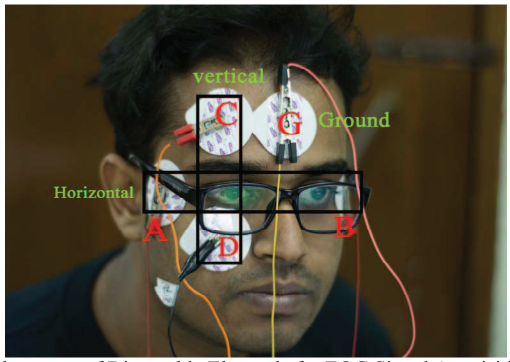


Fig. 2. Placement of Disposable Electrode for EOG Signal Acquisition.

C. Methodology of EOG signal acquisition

Electric potential is produced between cornea and retina for left, right, up, and down action which are captured through electrode and sends to AD620 instrumental amplifier. Entire circuit diagram from acquisition to HCI implementation is shown in Fig. 3. Both vertical and horizontal signal acquisition use similar circuitry. Since EOG has a small range of amplitude, the signal needs to be amplified by adjusting the gain value. This gain can be set by using various resistor value in between pin 1 and 8 of AD620. The EOG signal taken into the circuit and associated noise is removed by the filter circuit. Active High pass and Low pass filter acted as a band pass filter where the frequency band of EOG signal 0.3-15Hz is maintained, and it also removes the unwanted frequency component from raw EOG signal as well. Acquired EOG signal shows a positive peak for right and up eyeball movement and a negative peak for left and down eyeball movement.

This analog EOG signal is converted to digital using Arduino board. Arduino and Python program receives data and perform calibration and classification on that data which calculate a threshold value. The threshold value is stored in EEPROM of Atmega328P micro controller in Arduino. Depending on the threshold value Arduino program sends command to hardware (mobile robot, wheelchair etc.) attached to the Arduino board. Thus Hardware is controlled by EOG signal. On the other hand, there is another calibration program in python which produce a reference dataset. Using this reference dataset SVM and LDA classifier classifies left, right, up, and down events which then used to control live mouse cursor movement.

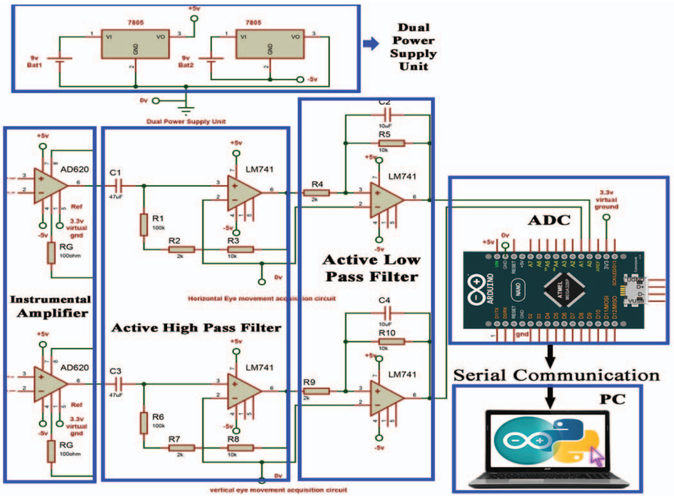


Fig. 3. Two channel EOG data acquisition circuit.

SVM and LDA are two classifiers which are very little in common. They are both tremendously useful where a separation between two classes are mandatory. LDA tries to maximize the distance between the means of the two variables, while SVM tries to maximize the margin between the two variables. Here horizontal and vertical eye movement data need to be separated for specifying accurate eye position. An optimal hyper plane between these two data are created at the point of execution starts, and it is illustrated in Fig. 4. The algorithm of SVM and LDA is developed in Python with Scikit-Learn module.

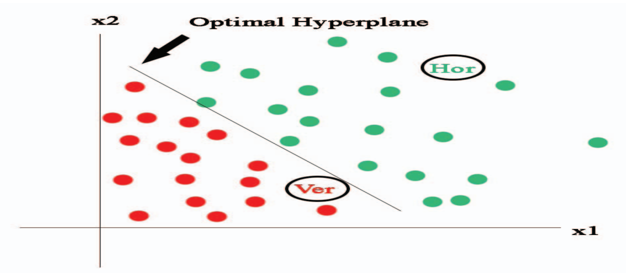


Fig. 4. SVM and LDA classification of EOG data.

III. Hardware Implementation

A. Electrode

For sensing purpose Bio Protech T716 electrode was used. It is a commercially available low-cost electrode and can be used to sense ECG, EMG, and EOG signal as well.

B. Power Supply Unit

Two LM7805 voltage regulator is used for supplying 5V. LM7805 is equipped with two commercially available 9V Lithium battery. It provides short circuit protection and safety for all other circuit components as well. Ground electrode for this system must be connected to the 0V of dual power supply unit [9].

C. Amplifier and Filter Design

Signal acquisition must require Instrumental amplifier, op-amp, and filter which is shown in the top of Fig. 3. AD620 commercially available low-cost instrumental amplifier is used for this system, which provides Common-mode rejection ratio (CMRR) greater than 100dB at nearly 1 kHz. There are three amplification stages for data acquisition unit. First raw EOG signal amplification is done by AD620 and gain was set to 495. Since EOG contains a very small range of amplitude, it requires very high amplification and so gains 495 is chosen for the first stage of amplification. The gain of AD620 is depended on R_g resistor of the following expression in (1).

$$Gain = \frac{49.4\ K\Omega}{R_g} + 1 \tag{1}$$

Where, $R_g = 100\ \Omega$

$$Gain = \frac{49.4\ K\Omega}{100} + 1 = 495$$

Second and third amplification is done by an LM741 operational amplifier. The total gain of the second and third stage was 12. Non-inverting configuration was chosen for both stages of amplification which is shown in Fig. 5. The gain of both amplifiers was set by using following (2) and (3).

For second stage amplification,

$$A_{v1} = 1 + \frac{R8}{R7} \tag{2}$$

Where, R8=10KΩ and R7=2KΩ

$$A_{v1} = 1 + \frac{10\text{K}\Omega}{2\text{K}\Omega} = 6$$

For second stage amplification,

$$A_{v2} = 1 + \frac{R10}{R9} \tag{3}$$

Where, R10=10KΩ and R9=2KΩ

$$A_{v2} = 1 + \frac{10\text{K}\Omega}{2\text{K}\Omega} = 6$$

Three stage of amplification is done for avoiding amplifier saturation. When electrode offset voltage mixed with bio signal the saturation of amplifier occurs. For removing this dc offset as well as low-frequency noises first a high-pass filter of 0.03 Hz cut-off frequency is used after first stage amplification. A band pass filter is implemented using an active high pass and a low pass filter in cascade which is shown in Fig. 5. Since the frequency band of EOG signal is in between 0.3-15 Hz, cut off frequency of High pass filter was set to 0.3Hz and cut off frequency of Low pass filter was set to 15 Hz. The following (4) is used to determine the cut-off frequency of the filter,

$$f_c = \frac{1}{2\pi RC} \tag{4}$$

Where, for HPF, R=100KΩ and C=47μF for LPF, R=10KΩ and C=10μF.

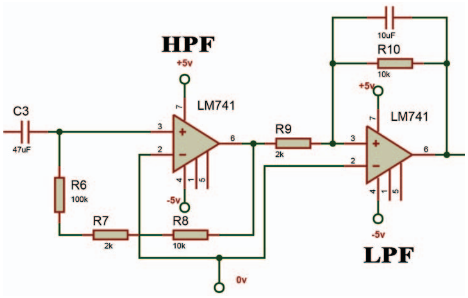


Fig. 5. Design of Active High and Low Pass filter.

D. Micro Controller Unit

As a micro controller unit Arduino Mega 2560 board was used which consist of ATmega2560. The speed of serial communication was 9600bps which take 320 samples per second. Larger sampling rate can be taken by choosing high baud rate or clock speed [10]. It is important to isolate signal acquisition circuit from AC mains for reducing noise and power line interference. A virtual ground of 3.3V is used as a reference of the AD620 instrumentation amplifier. This makes the bipolar EOG signal to Unipolar. Two separate Horizontal and Vertical channel circuit is shown in Fig. 6. The similar configuration makes this EOG acquisition circuit easier to understand.

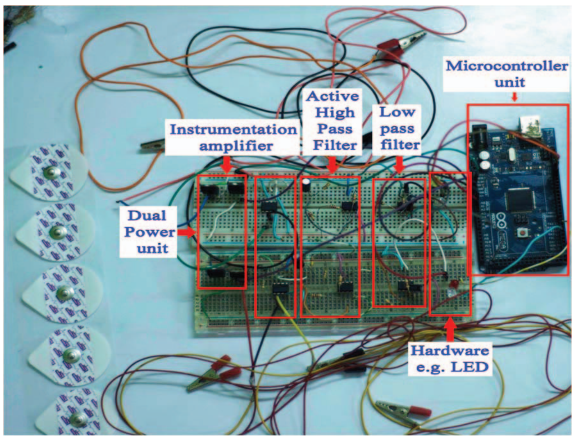


Fig. 6. Experimental Setup of acquisition system.

IV. SOFTWARE IMPLEMENTATION

A. Arduino Platform

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards can read inputs from the sensor and turn it into an output for activating a motor, turning on a LED etc. The micro controller on the board take instruction and perform various controlling task. There is 16 channel 10-bit analog to digital converter (ADC) in Arduino. EOG data come to Arduino via this ADC channel but there is negative peak for Left and down movement of eye which can cause damage to Arduino whereas it works only between 0V to +5 V. To remove this problem 3.3V virtual ground is used instead of 0V ground. ADC returns a linear value from 0 to 1023 corresponding to 0V and +5V respectively. Two string take that serial data and make calibration to find the threshold value. Depending on that threshold value atmega2560 send command instruction to Hardware. In this program, Baud rate was taken 9600bps for communication between Arduino and acquisition circuit.

B. Python Platform

Calibration and Classification for Mouse cursor movement fully done in python platform. Since computer screen is 2D, mouse cursor control must require two value. After attaching the electrode, python calibration code generate a reference dataset where two data exist as (x, y). SVM and LDA classifier works as binary classifier and outputs an optimal hyper plane for two values. Scikit-Learn module is used to perform Classification on that dataset. This dataset contains of vertical and horizontal data. PyMouse module has move (x, y) function which is finally called to control mouse cursor live. The step by step process of cursor movement is shown in Fig. 7.

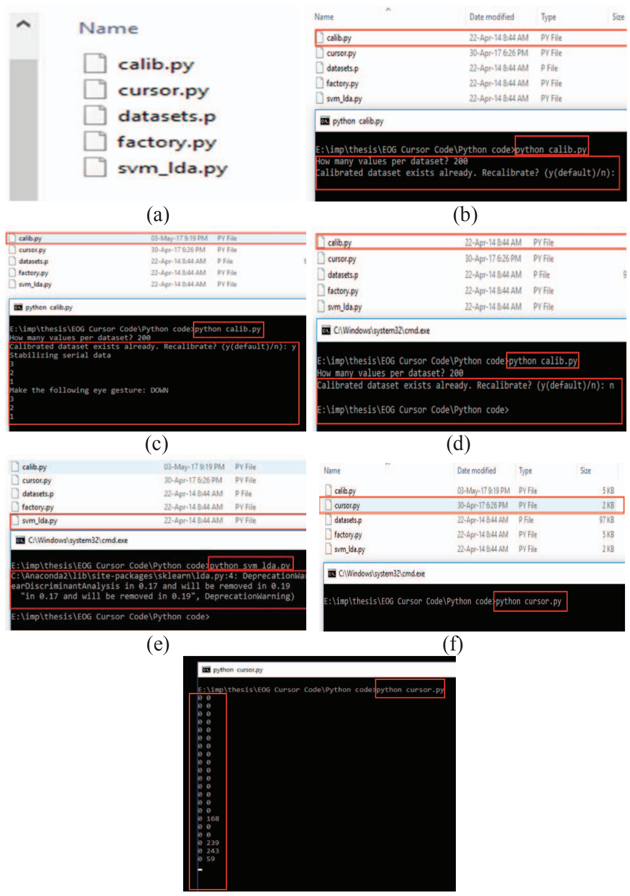


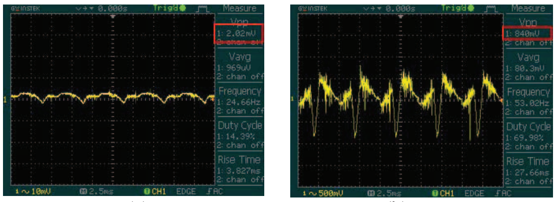
Fig. 7. Step by step process of controlling mouse cursor (a) Python Program Folder, (b) Start calibration, (c) Recalibration for new user, (d) Write 'n' if there is already calibrated dataset exist, (e) Executing svm_lda classifier,(f) Executing cursor movement code, (g) Cursor is moving with respect to(vertical, horizontal) values.

Fig. 7 (a) shows the Python programs which need to be executed for cursor movement. For running .py file, Python software must be installed with appropriate environment settings. At first calib.py code is executed to calibrate the EOG data, and this calibration is required for every new user. Every time calibration code asks user whether calibration requires or not, the screen shots of command prompt is showed in Fig. 7 (b), (c), and (d). After calibration, svm_lda.py code gets executed for classifying vertical and horizontal eye movement. At the end when cursor.py get executed, move (x, y) function in cursor.py code gets live data from eye movement and provides a decision based on classification result. Screen shots of classification and cursor movement are shown in Fig. 7 (e), (f), and (g) where cursor is moving based on classified data.

V. Result Analysis and Discussions

A. *Data acquisition result*

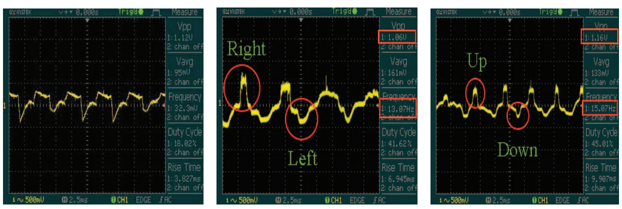
1) Instrumentation amplifier output: In acquisition part, two things are observed for EOG signal, one is without amplification, and another is with amplification of gain 495. Waveform characteristics are shown in Fig. 8 (a) and (b). As we can see in (a) when AD620 has no resistor (Rg) 2.02mV EOG signal is obtained. This signal is amplified into 840mV by using 100Ω resistors as shown in Fig. 8(b). Horizontal movement was recoreded for this output.



(a) (b)

Fig. 8. Instrumentation amplifier output (a) without amplification (b) with amplification.

2) Filtering output: At First, the raw EOG signal was filtered by an active High pass filter of cut-off frequency 0.3Hz. The Filtered output is shown in Fig. 9 (a). As we can see from waveform that low-frequency component was almost removed. Fig. 9(b) and (c) shows the EOG signal for horizontal and vertical eye movement output. Positive peak was found when eye moves right, and Negative peak was observed when eye moves in left direction. The frequency of the EOG signal ranges from 0.3-15Hz was also obtained. Power line interference does not exist because of using 15Hz low pass filter.



(a) (b) (c)

Fig. 9. Characteristics Waveform (a) Output of Active High Pass filter (b) Horizontal movement output (c) Vertical Movement output.

3) EOG signal acquisition with BIOPAC MP36: EOG signal acquisition was done in BIOPAC system which was processed in acknowledgement software and showed in Fig. 10. EOG signal from both systems has almost similar characteristics such as detection of positive and negative peak for horizontal and vertical eye movement as well as their amplitude is in millivolt range. The peak to peak voltage range for EOG signal was measured approximately 1.1mV which was also found in acquisition output of proposed method which described in Fig. 9 (b) and (c).Comparison shows that EOG signal from proposed method is absolutely similar to that obtained from BIOPAC system.

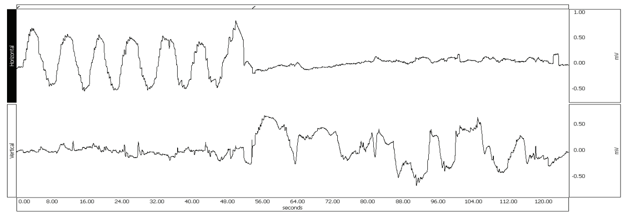


Fig. 10. EOG signal from BIOPAC system.

4) Analog to Digital Conversion: To read the analog data from acquisition circuit analogRead () is used in Arduino code and then digitalRead () is called to read that analog data and convert it into digital data. analogRead() and digitalRead() are two built in function where ADC pin A0, A1 are passed as parameter. Analog and digital output for both eye movement is shown in Fig. 11 which represents conversion waveform of EOG signal.

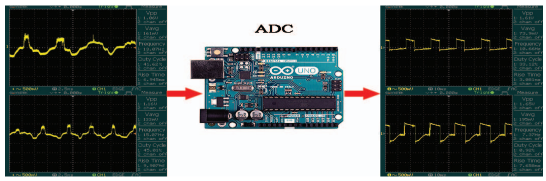


Fig. 11. Analog to Digital Conversion output.

B. *Hardware Control & HCI system Implementation output:*

1) Hardware controlling: The hardware device such as LED control scenario for four basic eye movement e.g. left, right, up and down are shown in fig. 12.

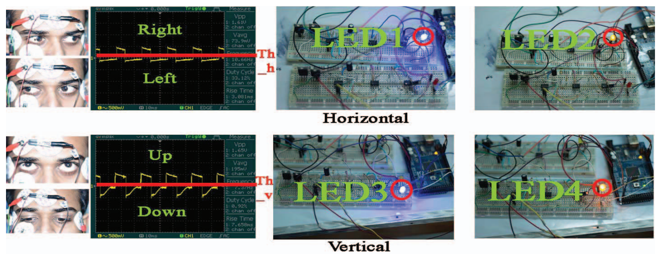


Fig. 12. LED blinking operation for Different eye position.

At the time of horizontal and vertical eye movement there is a positive peak and a negative peak. For horizontal context, only right and left movement of the eyeball is possible which generate positive peak and negative peak respectively. Similarly, up and down movement in vertical context produce positive and negative peak respectively. When calibration program executed, a threshold point is determined which differentiate positive and negative peak. LED1 turns on while eyeball is moving in right direction from straight position. LED2 turns on, and LED1 turns off while eyeball moving from right to left direction as indicated in fig. 12. Similarly, LED3 and LED4 turn on and off for up and down movement of the eyeball.Basically, a comparison occurs between eye movement data from acquisition circuit and threshold point which results in LED turns on or off. Any robot, wheelchair or mechanical hand can be controlled in this way using eye movement.

2) Mouse Cursor Movement: Microsoft hook function defined the cursor movement in windows Operating System. This hook function must need to be called for accessing cursor functionality. Pyhook package in PyMouse module can do similar task of Microsoft hook to access cursor functionality. In cursor.py program there are two essential functions screenResolution (x, y) and move (x, y). Both functions took the parameter values as pixel when code get executed. screenResolution (x, y) function decide the current screen size of the device in pixel and move (x, y) function converts horizontal and vertical data into pixel and used as the parameter in cursor.py program. Both functions are defined in Pyhook package. Fig. 13 shows the cursor position with respect to eye position. Cursor position gets updated each time when eye position changed. For each eye position, the updated cursor position is showed in Table II.

TABLE II. CURSOR POSITION WITH EYEBALL MOVEMENTS.

Eye Position	Cursor Position
Straight	Middle
Straight to Right	Middle to Right
Straight to Left	Middle to Left
Straight to Up	Middle to Up

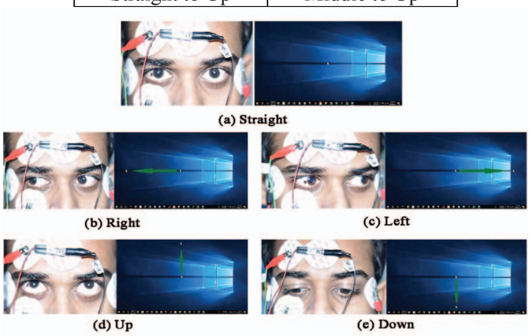


Fig. 13. Mouse cursor control scenario.

Since EOG signal is generated from eyeball movement, Classifier used these movement features as numerical values to decide the optimal hyper plane and classify the horizontal and vertical data. The modified algorithm and coding format of the classifier was made ideal so that an acceptable cursor movement output was observed while taking real time EOG signal.

VI. CONCLUSIONS

For HCI application, acquisition of EOG signal is obvious which was done so precisely in this work that it was possible to obtain four basic eye position correctly. EOG acquisition data from this system is very similar to standard BIOPAC system. So this circuit can be used for only acquisition purpose too. Another important advantages is the computation time from acquisition to HCI implementation is also very small with low power consumption capability. Most existing methods used passive filter where in this work using active filter to ensure exact cut off frequency point as well as good noise reduction ability. 50 Hz power line noise was isolated by using LM7805 voltage regulator which was another important modification brought in this system. This modifications made the performance of this circuit so smooth that real time hardware and accurate mouse cursor movement is possible. Paralyzed patients can control their wheelchair by just moving his or her eye through this system. It will be so interesting when people able to move various robots and mouse cursor by using this EOG based controlling device. By this way, this system took modern technology in such a level where every walks of people will be benefited.

REFERENCES

[1] B. Champaty, D. Tibarewala, B. Mohapatra, and K. Pal, "Development of eog and emg-based multimodal assistive systems," Springer Medical Imaging in Clinical Applications, vol. 651, pp. 285-310, 2016.

[2] J. Yu, K. K. Ang, C. Guan, and C. Wang, "A multimodal fnirs and eeg-based bci study on motor imagery and passive movement," in Proceedings of IEEE/EMBS Conference on Neural Engineering, pp. 5-8, 2013.

[3] R. Barea, L. Boquete, M. Mazo, and E. López, "System for assisted mobility using eye movements based on electrooculography," IEEE transactions on neural systems and rehabilitation engineering, vol. 10, no. 4, pp. 209-218, 2002.

[4] A. B. Usakli, S. Gurkan, F. Aloise, G. Vecchiato, and F. Babiloni, "On the use of electrooculogram for efficient human computer interfaces," Computational intelligence and neuroscience, vol. 2010, pp. 1-5, 2010.

[5] S. Kumar, A. Dash, and M. K. Mukul, "Design and development of low-cost eog acquisition circuit for hmi application," in Proceedings of International Conference on Signal Processing and Integrated Networks (SPIN), 2015, pp. 192-197,2015.

[6] A. N. Rajesh, S. Chandralingam, T. Anjaneyulu, and K. Satyanarayana, "Eog controlled motorized wheelchair for disabled persons," International Journal of Medical, Health, Biomedical, Bioengineering and Pharmaceutical Engineering, vol. 8, no. 5, pp. 302-305, 2014.

[7] H. Tamura, M. Miyashita, K. Tanno, and Y. Fuse, "Mouse cursor control system using electrooculogram signals," in Proceedings of World Automation Congress (WAC), pp. 1-6, 2010.

[8] S. Aungsakun, A. Phinyomark, P. Phukpattaranont, and C. Lim- sakul, "Development of robust electrooculography (eog)-based human-computer interface controlled by eight-directional eye movements," International Journal of Physical Sciences, vol. 7, no. 14, pp. 2196- 2208, 2012.

[9] M. A. Ahamed, M. A.U. Ahad, M. H. A. Sohag, and M. Ahmad, "Development of low cost wireless biosignal acquisition system for ecg emg and eog," in Proceedings of International Conference on Electrical Information and Communication Technology (EICT), pp. 195-199, 2015.

[10] D. Wheat, "Arduino software," Arduino Internals, pp. 89-97, 2011.