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Design and Implementation of a Prototype Electrooculography Based Data Acquisition System

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***Abstract*—For different controlling applications, tracking of eye movements is becoming increasingly popular nowadays. Particularly it is very helpful for the disabled people suffering from Amyotrophic Lateral Sclerosis (ALS) or other illness that prevent correct response of their limbs as well as deprive of their ability to speak. Among different eye movements tracking methods, in this paper Electrooculography (EOG) based system is developed. Electrooculogram (EOG) signals can be used to improve the communication ability as well as the quality of life of the disabled persons. Some devices are made for the purpose of lab experiments to take EOG signal for different patterns of eye movement. A typical EOG data acquisition device or circuit should be developed and compared the data to the standard device one. In this paper a low cost EOG data acquisition system is proposed. Different patterns of eye movement are recorded by the proposed EOG acquisition device and compared them with the standard BIOPAC MP36 system to check accuracy of our designed system. It will play a vital role to develop advanced devices and real life applications for paralyzed or physically disabled persons those who are affected by different diseases of any organ of the body except eye. Compared to standard device, our proposed scheme works very well with less error.**

***Keywords*—electrooculography (EOG), ALS, human-computer interface (HCI), BIOPAC MP36, EOG acquistion, low cost, triangular error, subtractor.**

I. INTRODUCTION

A. Background

Now we live in a technologically developed world. It has blessed us with different advanced technologies to make our life easier and more comfortable. Human Computer Interface (HCI) is one of these. In the whole world there are about few billions of elderly or disabled people. Science and technology must provide them a better quality to lead their life without the help of others. Several research efforts have taken place in recent years to restore functionality of disabled people with severe motor disabilities. HCI has created a new pathway for helping those people by rehabilitative aids. HCI is the study of humans and machines in conjunction. HCI plays a vital role for paralyzed patients those who are affected by some diseases such as Amyotrophic Lateral Sclerosis (ALS), Guillain-Barre Syndrome, quadriplegia and heniiparesis due to which they cannot speak or use hands [1].

Electro-biological signals can be used for the purpose of HCIs to create an alternative way to communicate without speech and hand movements. Generally electrical signal generated from human body is referred to as electro-biological signal. Due to the relative change of concentration of sodium (Na+) and potassium (K+) electro-biological signal is created between any two points in living cell or organism. Some commonly used signals using for HCI are EOG, Electromyogram (EMG) and Electro-Encephalogram (EEG). Here in this study we have designed an EOG based data acquisition device for extraction of EOG signals for helping the persons who can only communicate through eyes [2]. The EOG signal plays a vital role for understanding, characterization, and classification of eye movements which can be applied to variety of applications such as wheelchair control, mobile robot control, cursor mouse control, eye activity recognition and eye exercise recognition. For the purpose of development of eye based assistive devices various technologies such as Video-oculogram (VOG), infrared reflectance, eye gaze, P300 and EOG methods can be applied [3]. The VOG based system with the help uses a video camera to track the user's eye movements [4]. The advantages of VOG based systems are comfort and easy to use, but these systems are costly and require intense training for users [5, 6]. The other technologies such as infrared reflectance, eye gaze and P300 have comparatively more disadvantages compared to the EOG based system for developing EOG based assistive devices. So EOG based system is preferred. EOG signals can be effectively used for distinguishing between different eye movements. For different types of eye movement EOG signals show unique patterns. Those patterns can be used for producing different control signals which can be used in future for different HCI applications, robotics, and automation. In this paper we have extracted EOG data from our proposed data acquisition system and have compared it with the data from BIOPAC data acquisition unit. Here we have used only horizontal eye movements instead of vertical eye movements. BIOPAC data acquisition unit (MP36) can be used for data acquisition, analysis, storage and retrieval. The MP system is a complete data acquisition system which contains both software and hardware. Each MP system (MP36 or MP150) is complete data acquisition system that function likes like an onscreen chart recorder, oscilloscope and X/Y plotter. The MP unit takes incoming signals and converts them into digital signals that can be processed with the help of computer.

B. Related Work

For extraction of EOG signals there are different proposed ideas. The extracted EOG signals can be further possessed for HCI applications. An efficient hardware for recording EOG signal is implemented in [7]. They also applied their proposed system for real-time application and achieved the averaged accuracy of 96.2% which is high enough for the feasibility of the system. A system for detecting the possibility of eye dystonia from the analysis of eye movements is proposed in [8]. They extracted EOG signals by using their developed EOG signal acquisition system. They obtain a maximum average accuracy of 93.40% over all classes.

In [9], a new algorithm based on mathematical morphology filtering method is proposed to reduce the interference from noise and baseline drift. Then they recognized 5 types of eye movements by threshold detection and got an average accuracy of about 93%. In [10], user's eye movements are tracked using low cost electrode and the extracted signals are amplified and filtered to get desired voltage to implement communicative devices for disabled persons. In [11], a low cost eye tracking system has been developed to assist physically disabled persons through HCI applications. Different authors in [7]-[11], have used both vertical and horizontal electrodes for extraction of EOG signals. But in this paper we have used only vertical electrodes for that purpose which will be more efficient in future if we can use this single channel EOG signals for HCI applications.

C. Research Scope

The main objective of this paper is to develop an EOG acquisition device and to check its accuracy by comprising with the standard BIOPAC MP36 device. We have collected data for different patterns of eye movement using our proposed EOG acquisition system. We also extracted data using standard BIOPAC MP36 device. Then we have compared EOG data extracted from two different systems.

II. THEORY OF OPERATION

An EOG is the resulting signal of the potential difference caused by the eye movements. The EOG signal ranges between 15 to 200 µV with a frequency range of about 0-30 Hz. EOG signals are extracted by placing electrodes around the eyes [11]. In this paper we have used two horizontal electrodes and a reference electrode to extract EOG signals which is shown in Fig. 1. EOG signal changes approximately 20 µV for each degree of eye movement. There are different types of eye movements (up, down, left, right, up-left, up-right, down-left, down right).

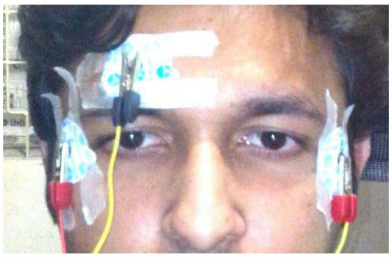


Fig. 1. Placement of horizontal electrodes to extract EOG signals.

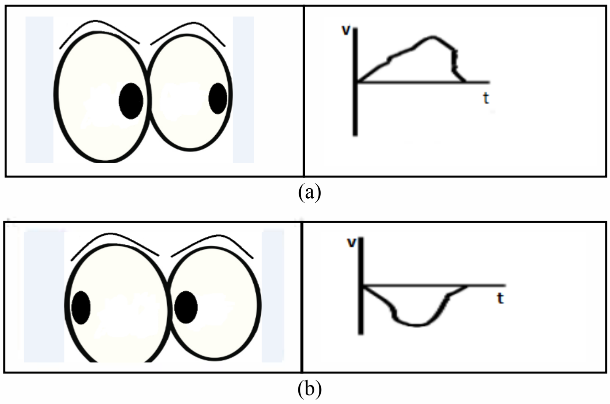


Fig. 2. Horizontal eye movement pattrens (a) for left movement (b) for right movement.

We have assumed that for right eye movement we will get negative peak and for left eye movement we will get negative peak as Fig. 2. All cells in our body have voltages across plasma membrane. The voltage across a membrane is called membrane potential. The inside of cell is negative relative to the outside. When the membrane potential of a cell can go for a long period of time without changing significantly, it is referred to as a resting potential. The eye ball can be regarded as a source of such resting potential. This potential is measured between retina and cornea. Changes in the position of the eyeball cause changes in potential at the skin surface around the eye socket which can be measured by surface electrodes placed on the skin around the eyes.

III. PROPOSED SYSTEM DESCRIPTION

A. Block Diagram

The fundamental components of our proposed system are wet electrode, instrumentation amplifier, filter unit and a voltage subtraction unit. EOG signals are measured by the wet electrodes. Electrodes are connected to the EOG acquisition system by wires. Then the EOG signals are processed by the EOG acquisition system. The processed signals are sent to the computer by a microcontroller unit and the different patterns of EOG signals are recorded by using MATLAB. The whole proposed system is shown in Fig. 3.

B. Electrode Selection

The basic requirement for sensing bio-signals is proper selection of electrodes. Generally two types of electrodes are available for sensing EOG signals. One is wet electrode and the

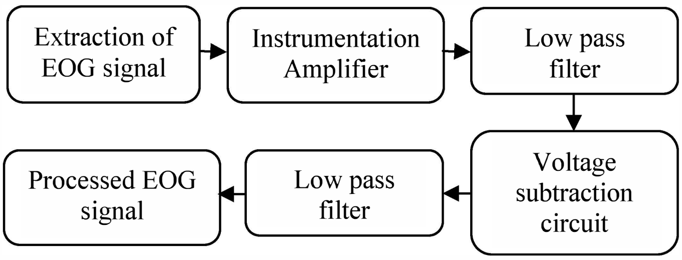


Fig. 3. Proposed system block diagram.

other is dry electrode. Here wet electrodes are used to record EOG signals by using electric gel to improve electric conductivity between electrode and skin. EOG disposable electrodes are easily available. But they cannot be used repeatedly. Ag-AgCl electrodes are chosen here considering low cost, proper signal acquisition, stability regardless of direction of current flow, reliability and accuracy. Since only horizontal eye movement has been detected by our proposed system therefore, only 3 electrodes (two for horizontal movements and one for reference) are used.

C. *Instrumentation Amplifier*

The potential difference for different eye movements obtained from the horizontal electrodes is very small. These very small amplitude signals are amplified by an instrumentation amplifier. In our system AD620 is used as Fig. 4. The AD620 is a monolithic instrumentation amplifier based on a modification of the classic three op amp approach. Absolute value trimming allows the user to program gain accurately (to 0.15% at G = 100). Monolithic construction and laser wafer trimming allow the tight matching and tracking of circuit components, thus ensuring the high level of performance inherent in this circuit. The important features of AD620 are: 1) easy to use, 2) gain range 1 to 10,000, 3) wide power supply range (± 2.3 V to ± 18 V), 4) higher performance than 3 op-amp IA designs, 5) low noise and 6) higher CMRR (100 dB minimum). It is a low cost, high accuracy instrumentation amplifier that requires only one external resistance (RG) to set gain and the gain expression is given in Eq. (1).

$$Gain = \frac{49.4k\Omega}{RG} + 1 \tag{1}$$

We use a 100Ω external resistance and from Eq. (1) the gain of the amplifier was calculated as 495. AD620 has high common mode rejection ratio and for gain 500 it is 130dB. Output voltage is given by,

$$V_0 = Gain \times (V1 - V2) + \frac{1}{2} A_C (V1 + V2) \tag{2}$$

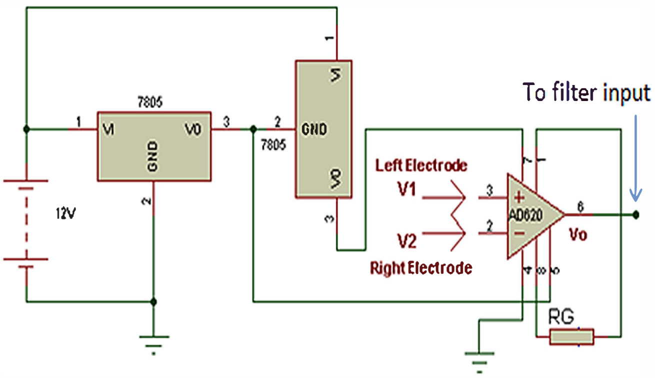


Fig. 4. Schematic diagram of input and amplifier section with dual polarity power supply.

Where, A_C is the common mode gain, V1 and V2 is the obtained voltage from left electrode and right electrode. According to common mode rejection ratio (CMRR) we can write as,

$$\text{CMRR(log)} = 20 \log \frac{Gain}{A_C} \tag{3}$$

$$\Rightarrow 130 = 20 \log \frac{495}{A_C}$$

$$\Rightarrow \frac{495}{A_C} = anti \log(6.5) \approx 316277$$

$$\Rightarrow A_C \approx 0.0001565$$

D. *Filter Design*

Noise reduction is the process of removing unwanted signals from the original signal. A low pass RC filter can be used for this purpose which is shown in Fig. 5. In this paper, filter is designed in two stages. In first stage a low pass filter with 4.82 Hz cut off frequency is used for removing power line noise. During amplification of EOG signals, the instrumentation amplifier output voltage is amplified with some power-line noise that is about 49 Hz to 51 Hz. After passing through the low-pass filter the power-line noise is removed. In the second stage a low pass filter with 3Hz cut off frequency is used after voltage subtraction for reducing the ripple of the output wave shape obtained from the subtractor output. General expression for cut off frequency for low pass filter is given in Eq. (4).

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

E. *Subtractor*

For recording different patterns of EOG signals for different eye movements the output voltage of the acquisition device are sent to the microcontroller unit. If the output voltage is more than 5 volts then the microcontroller cannot sense the voltage and desired output cannot be recorded. So a voltage subtraction circuit of op-amp is used to limit the output voltage within the microcontroller operating voltage as Fig. 6. Here the LM324N is used. The output voltage equation of the subtractor is given in Eq. (5).

$$V_0 = \frac{R6}{R3 + R6} \frac{R5 + R4}{R4} V1 - \frac{R5}{R4} V2 \tag{5}$$

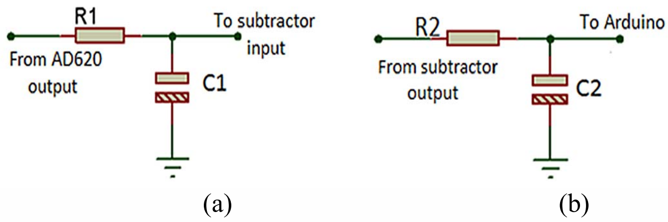


Fig. 5. Low pass filter for reducing noise and ripple (a) before subtractor (b) after subtractor.

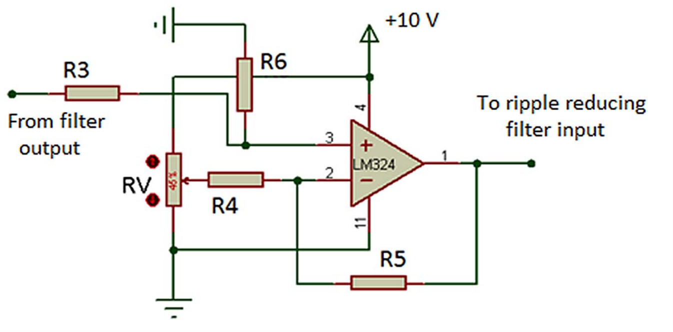


Fig. 6. Subtraction circuit of an op-amp.

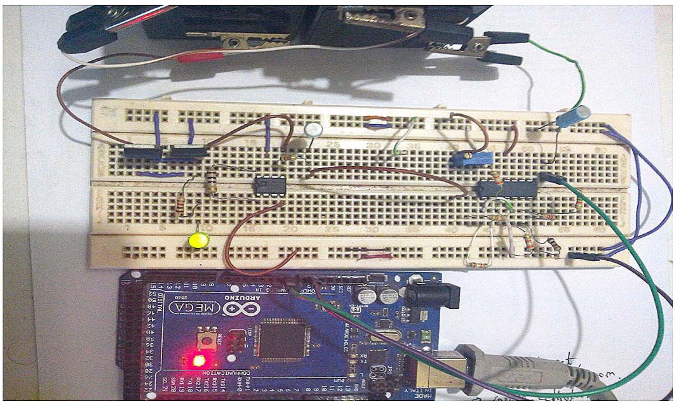


Fig. 7. Pictorial view of our proposed system.

F. Hardware Setup

A prototype model of EOG acquisition system is implemented. Two 6 volt, 4 ampere-hour batteries, connected in series are used as 12 volt power supply. A pictorial view of our designed system is shown in Fig. 7.

IV. Results and Discussion

The output voltage of the EOG acquisition device is sent to the analogue pin of the microcontroller unit. A very special function of a microcontroller is to convert analog signals to digital signals and vice versa. In order to read the EOG signals, the microcontroller should be programmed as an Analog-to-digital converter (ADC). In our proposed system the Arduino Mega2560 is used as microcontroller unit to process the data. Then with a serial communication with computer through USB cable the data is sensed by the MATLAB code and after a certain time the waveform of different patterns for eye movement are obtained. In our experiment we tested four patterns of eye movements by using our designed system and standard bio-signal acquisition device BIOPAC MP36. Total eight patterns are found for a user. For convenience, at every output stage such as at AD620 output, subtractor output and filters output the patterns were also observed. Output wave shapes of left-middle-right-left-middle-right pattern at different stages are shown in Fig. 8 and the corresponding pictorial movement is shown in Fig. 9.

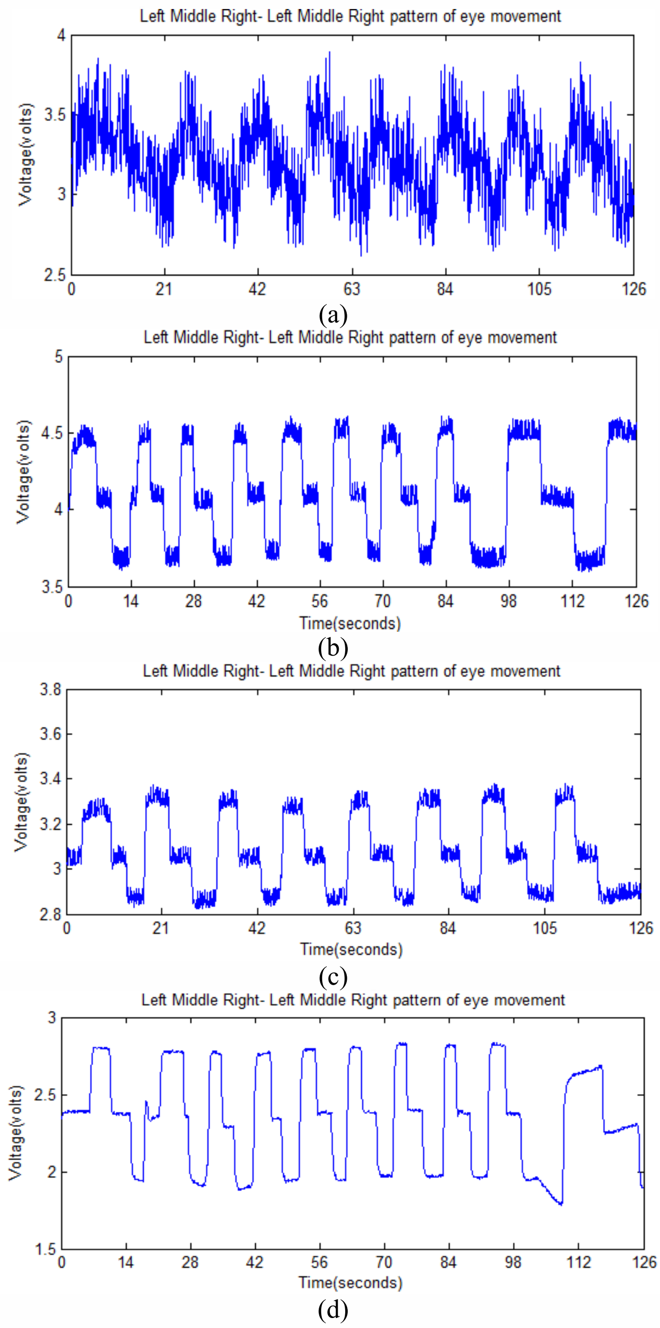


Fig. 8. Output waveform patterns of EOG signal of proposed approach. (a) output at instrumentation amplifier AD620, (b) output at low pass filter with 5 Hz cut-off frequency, (c) output form at voltage subtraction circuit (d) Output voltage waveform of processed EOG signal after gain and filtering by a low pass filter with 3 Hz cut off frequency.

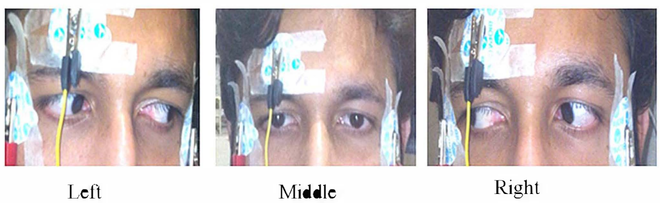
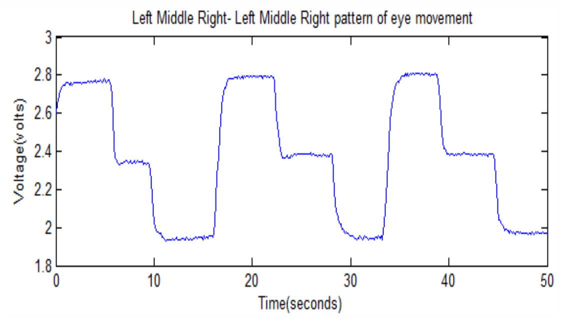


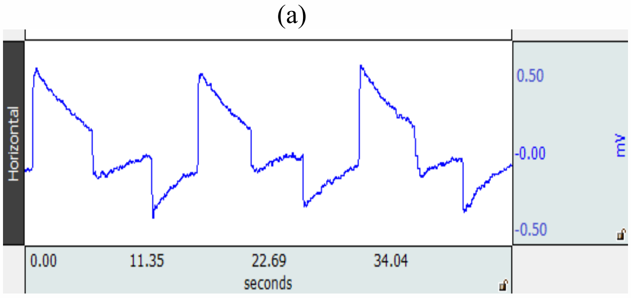
Fig. 9. Pictorial view of left, middle and right movement of eye.

The recorded signals of MP36 are shown in AcqKnowledge software. Comparisons between EOG data, extracted from our proposed data acquisition system and standard BIOPAC MP36 device are given below.

A. Left-middle-right-left-middle-right Pattern



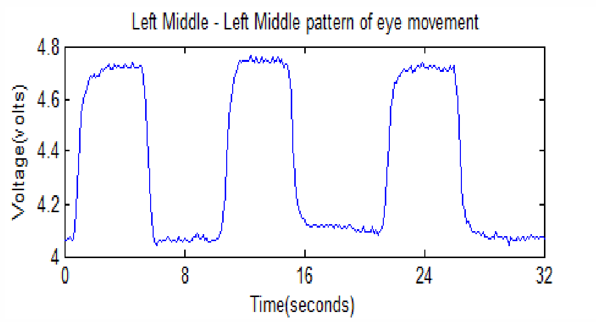
(a)



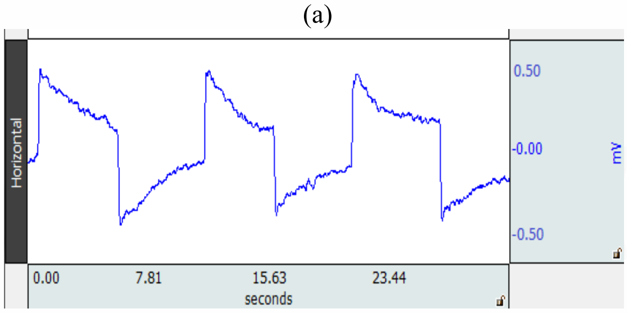
(b)

Fig. 10. Output signal after eye movement of left-middle-right-left-middle-right pattern (a) recorded signal obtained by the designed system (b) recorded signal obtained by BIOPAC MP36 system.

B. Left-middle Pattern



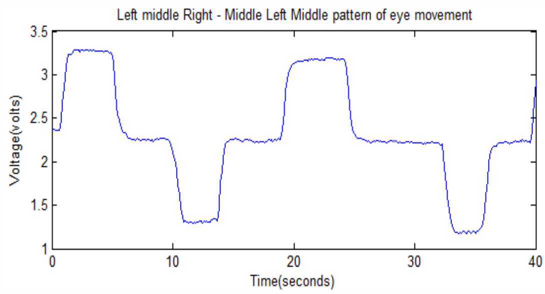
(a)



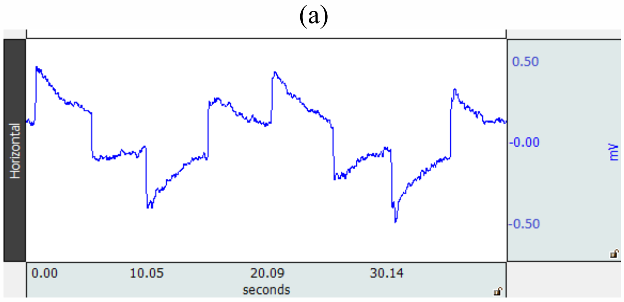
(b)

Fig. 11. Output signal after eye movement of left-middle pattern (a) recorded signal obtained by the designed system (b) recorded signal obtained by BIOPAC MP36 system.

C. Left-middle-right-middle-left-middle Pattern



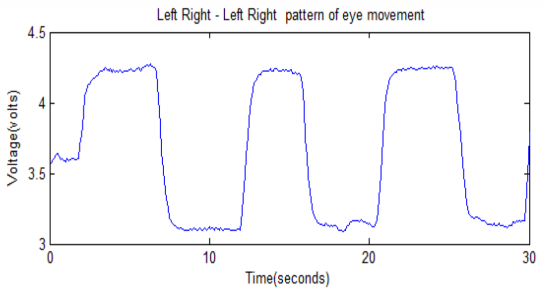
(a)



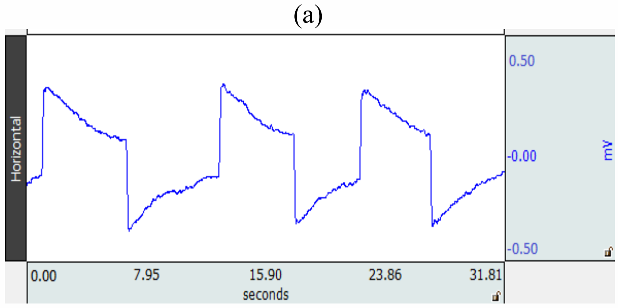
(b)

Fig. 12. Output signal after eye movement of left-middle-right-middle-left-right pattern (a) recorded signal obtained by the designed system (b) recorded signal obtained by BIOPAC MP36 system.

D. Left-right Pattern



(a)



(b)

Fig. 13. Output signal after eye movement of left-right pattern (a) recorded signal obtained by the designed system (b) recorded signal obtained by BIOPAC MP36 system.

From Fig. 10 to Fig. 13, the tested four patterns of eye movement, both for our proposed EOG acquisition system and BIOPAC MP36 system are shown. Two or three cycle of each patterns are shown here. During experiment, the user was asked to change his eye movement after every finite time interval and after few seconds experiment this duration was increased according to certain pattern. It was done so that we can analysis either the signal amplitude remain same or change during keeping the eye movement in same direction for some times. From these figures, it can be seen that when user keep his eye position in a certain direction (left, middle, right) then the signal amplitude remain almost constant for our desgined system. Whereas, in BIOPAC MP36 system the signal amplitude do not remain in same value and always the signal amplitude has a tendency to move towards the zero level which can be compared with the centripetal force. Actually the cause of this tendency is removing dc component of signal. This tendency to move towards zero level may be considered as a error if the device is appliead for any useful application. As the shape of this error is almost like a triangle, so it can be defined as triangular error. From the figures (Fig. 10 to Fig. 13) it is seen that this triangular error has been almost removed in our designed system.

The figure of different patterns of eye movement indicates that our proposed system give the almost same shape of wave forms as like as that was obtained from BIOPAC MP36 system . From this point of view, our designed system can be used for acquisition of EOG signal accurately. The difference of the signal amplitude between left and right eye movement is obtained about 2 volts. This voltage difference can be helpful to a programmer for designing many useful real life applications, as the greater voltage difference can make a scope to detect eye movement precisely and easily. Thus, our proposed system provides a good EOG acquision system. The approximate cost of the system is US$50.00.

V. Conclusion

In this paper, we designed and implemented a prototype low cost EOG acquisition system. In our system we use only three electrodes for detecting horizontal eye movements. Though by using horizontal and vertical electrodes more directional eye movements can be detected but if we can complete same task only by using horizontal movements then we should use only horizontal electrode which can provide more cost effective system. For vertical eye movement detection additional instrumentation amplifier and other extra components will be needed so our cost will be almost doubled. Dual polarity power supply for operating instrumentation amplifier is provided by using only two LM7805 ICs which reduce the cost comparatively. A wide range of voltage difference between maximum and minimum view angle of eye is obtained by this system. Thus, our designed EOG acquisition system will be useful for different real life applications like implementation of virtual keyboard, cursor mouse control and wheelchair control for handicapped persons.

Acknowledgment

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