

Design of EOG based Human Machine Interface system

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Abstract— According to study on physically disabled individuals with severe paralysis, it is found that those patients still retain the ability of eyeball movements. Various systems are being developed to assist the mobility of such patients. Electroencephalogram (EEG) based Human Machine Interface (HMI) systems are being developed which not only require high computational complexity but also are not cost effective. In this paper we have discussed a cost effective and reliable approach towards Human Machine Interface using Electrooculography (EOG). EOG is a physiological signal which can be recorded from temple of eyes during eyeball movements. EOG being a voluntary biomedical signal, it can be used in HMI applications which make the desired control of a machine, a reality. In our work, we have designed a signal acquisition and conditioning unit which gives out the filtered and amplified signal used for the demonstration of HMI based on EOG. The designed system is found to showcase reliable performance in terms of obtaining EOG signal, its conditioning and its desired application.

Keywords— Electrooculography (EOG), paralysis, eye movements, electrodes, filters, signal conditioning, Human Machine Interface (HMI).

I. INTRODUCTION

According to world health organization 2-5% of people living in our society are suffering from motor disabilities, they cannot move their hand and/ or leg but they can think or they can move their eyes. [1]. In order to assist them for mobility various systems are being developed. Such systems should possess reliable interface between the disabled individual and the assisting machine. Electroencephalogram (EEG) based Brain Computer Interface (BCI) can be used to cater this need. However, the complexity involved, cost, number of electrodes required and discomfort experienced by the patient makes EEG based HMI rather an unsuitable approach. Then comes an easier and reliable approach, which exploits the fact that even severely paralyzed individuals retain their ability to move their eyes in the desired direction. Thus, in our work we have discussed about EOG based HMI targeted to individuals with motor disabilities. The signal acquisition and conditioning unit has been designed. EOG signal, filtered and amplified is fed to Arduino board. Finally, Light Emitting Diodes (LEDs) are used to demonstrate the interface with the help of movement of eyeballs by the subject.

II. Electrooculogram (EOG)

Various eye tracking methods like video-oculography with pupil and corneal reflection, video-oculography with pupil only and Electro-potential oculography are in practice [2], [3], [4]. The eye is known to have a resting potential and acts as a dipole in which the anterior pole (cornea) is positive and the posterior pole (retina) is negative. The magnitude of this cornea-retinal potential is in the range 0.4-1.0 mV. This difference in potential can be explained by the metabolic activities in the eye. The Electrooculogram (EOG) signal thus is derived from the polarization potential, also known as the Corneal-Retinal Potential (CRP), generated within the eyeball by the metabolically active retinal epithelium. The CRP is produced by means of hyper-polarizations and de-polarizations of the nervous cells in the retina [5]. Electrooculography (EOG) is a technique for measuring this resting potential. The resulting signal is called the "Electrooculogram" [6].

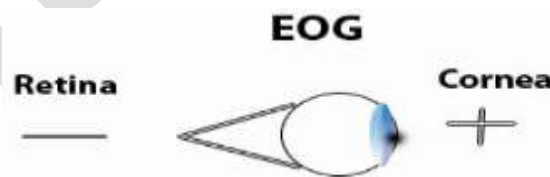


Fig 1. Polarity of Eye

The amplitude of the EOG signal is known to be in microvolt range (15 - 200 μ V) and most of the information is contained in 0 Hz to 38 Hz frequency range with dominant component in 0 to 25 Hz range [7], [8], [9]. Specially designed electrodes for EOG are placed

on the corners (lateral canthi) of both the eyes. When the eyes look left the positive end of the dipole (the eye) comes closer to the electrode on the left canthus and the negative end to the right canthus. The vice versa is observed for the eyes looking towards right. Ideally the difference in potential should be proportional to the sine of the angle the eye produces with respect to the central axis.

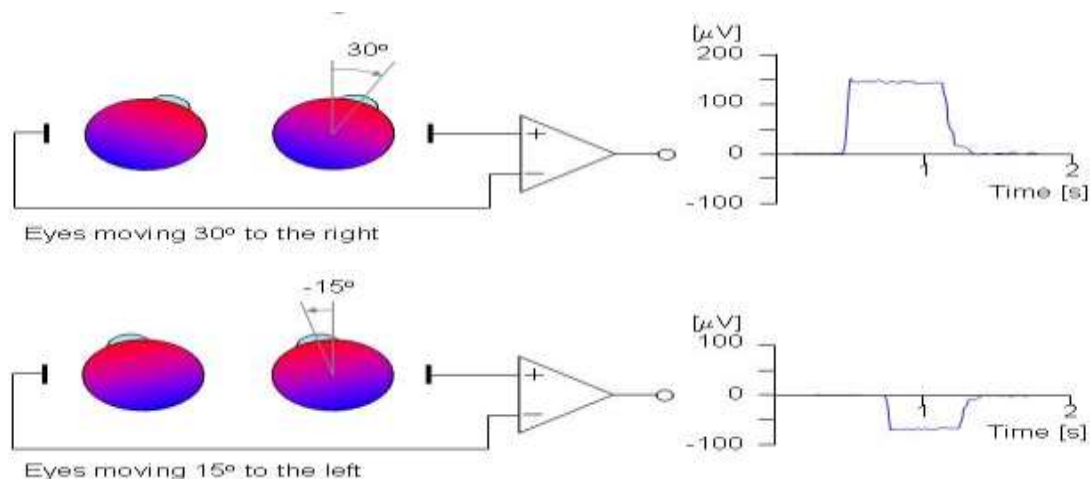


Fig 2. EOG signal based on eyeball movement

Silver/Silver Chloride (Ag/AgCl) Electrodes

These are specialized bio potential electrodes which are mainly used for bio signal acquisition. The signal from the eye is of low magnitude and is acquired through low impedance electrodes which minimizes signal attenuation. Non-invasive surface ECG Ag/AgCl electrodes were used for picking up EOG signals in our project. These electrodes are attached to the patients' skin and can be easily removed. The signal from the lateral canthi of the eyes is converted into voltage by electrodes. In our case, we have used only one pair of ECG surface electrode on the lateral canthi of the eyes. The system developed gives a single channel output to detect lateral eye movements. However, placing the same set of electrodes above and below the user's eye, vertical movement and blink of eyes can be detected.



Fig 3. Ag/AgCl electrodes

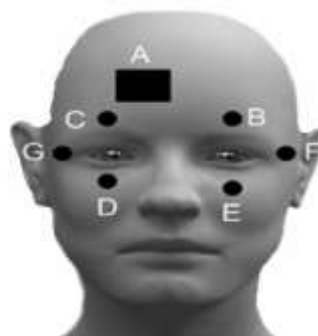


Fig 4. Placement of electrodes

III. Literature review

Satish Kumar et.al, 2015[1] have proposed a low-cost Electrooculogram (EOG) acquisition system that can be used efficiently in Human Machine Interface (HMI) systems. The proposed system consists of an Op-Amp based EEG/EOG amplifier circuit and ATmega8 microcontroller for analog to digital conversion and transferring of acquired data to PC. In this system five electrodes are used to acquire eye blinking, horizontal and vertical eye movements. In this system, the signals are first captured using EEG surface electrodes, amplified, filtered and then converted into digital form before stored into PC. The acquired EOG signal provides different eye related activities. Depending upon these eye related activities various systems can be developed to perform different tasks in real world, which provides a degree of independence to the user.

Kousik Srathy Sridharan, 2012[10] in his thesis work has built a portable system to acquire and analyse electro-oculographic (EOG) signals in real-time. The system contains two sub-systems; a hardware sub-system that consists of the filters, amplifiers, data acquisition card and isolation and the software sub-system that contains the program to acquire and analyse the signal and present the results to the observer. In his work, one paradigm records only normal blinks while the other records long blinks and the results showed differences in detection and error rates. The observations made from performance tests at various levels gave satisfactory results and proved the usefulness of the system for sleep state and drowsiness detection.

A Saravanan et. al, 2015[11] have designed a system which incorporates Texas embedded processor, wireless communication solutions and highly-customized analog front ends. As a demonstration of concept, this technology uses instrumentation amplifiers as analog front end and further single supply quad op-amp for analog signal processing in an effective manner.

W S Wijesoma et.al, 2005[12]. In this paper a complete system is presented that can be used by people with extremely limited peripheral mobility but having the ability for eye motor coordination. The Electrooculogram signals (EOG) that results from the eye displacement in the orbit of the subject are processed in real time to interpret the information and hence generate appropriate control signals to the assistive device. The effectiveness of the proposed methodology and the algorithms are demonstrated using a mobile robot for a limited vocabulary.

Ali Marjaninejad, Sabalan Daneshvar, 2014 [13]. In this paper an EOG based low-cost real-time wheelchair navigation system for severely disabled people is presented using signal processing techniques, bio-amplifiers and a microcontroller driven servomotor. All the digital signal processing and execution of commands were performed utilizing a microcontroller which drastically reduced the total cost of this project. The servomotor has been synchronized with the computed eye direction resulted from processing the horizontal EOG signal. The speed of the wheelchair was also regulated with the same EOG signal. Performed tests indicated that in 98.5% of trials, subjects could navigate to their targets in presence of simple obstacles in their first attempts which confirm the feasibility of the proposed system.

IV EOG acquisition and conditioning unit

EOG signal picked by the surface electrodes is in microvolts range and also contaminated by various noises eg. high frequency noise, junction potential noise between skin and the electrodes, etc. In order to extract essential features from the EOG signal proper signal conditioning is required. EOG acquisition and signal conditioning circuit has two main objectives: 1) To amplify the signal to necessary level and 2) Filter the signal to eliminate noise. Figure 5 depicts the components that were designed to achieve this purpose.

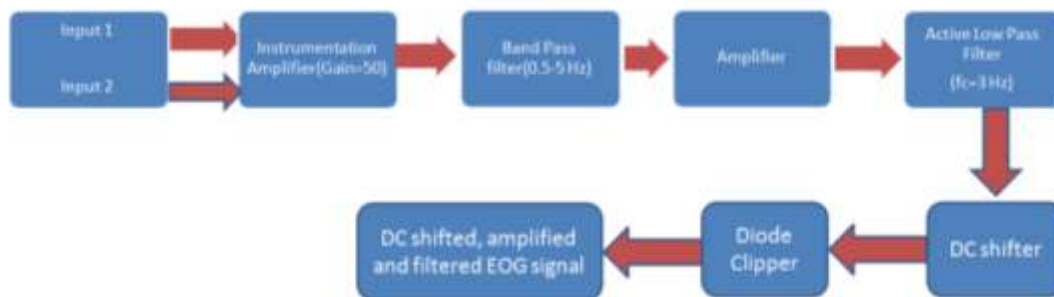


Fig 5. System block diagram of EOG acquisition and conditioning circuit

1. Instrumentation Amplifier Stage

An important stage of all bio-potential amplifiers is the input preamplifier which substantially contributes to the overall quality of the system. The main tasks of the preamplifier are to sense the voltage between two measuring electrodes while rejecting the common mode signal, and minimizing the effect of electrode polarization over potentials. Crucial to the performance of the preamplifier is the input impedance which should be as high as possible. Such a differential amplifier cannot be realized using a standard single operational amplifier design since this does not provide the necessary high input impedance. Hence, instrumentation amplifiers were used to meet the desired requirements.

$$\text{Design: } G = \frac{49.4K}{R_g} R_g + 1$$

For Gain=50, $R_g=1K \text{ ohm}$

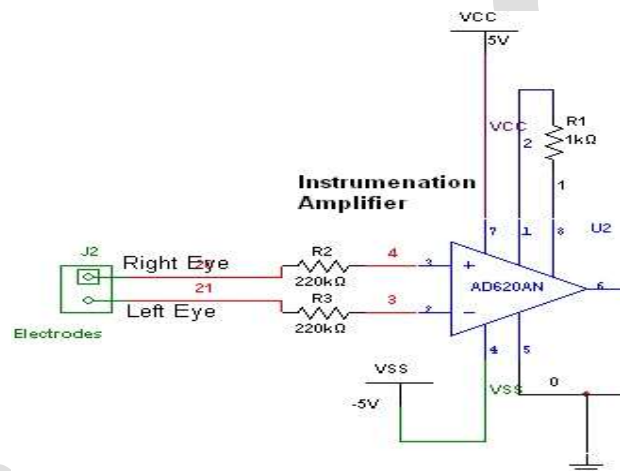


Fig1. Instrumentation amplifier designed

2. Active Band Pass filter:

The output obtained from first stage preamplifier has to pass through a band pass filter to remove the unwanted high and low frequencies from the desired EOG signal. Band pass filter used is the combination of a low pass filter (cut off frequency, $f_c=4.5 \text{ Hz}$) and a high pass filter ($f_c=0.5 \text{ Hz}$). Band Pass Filter used here is an active band pass filter. High pass filter removes any DC offset at the output of the preamplifier. It means necessary gain can be included in the pass band of the filter while attenuating out of band frequencies. A 100 K ohm potentiometer was used to adjust the gain required. (Filter Design equation: $RC=\frac{1}{2\pi f}$)

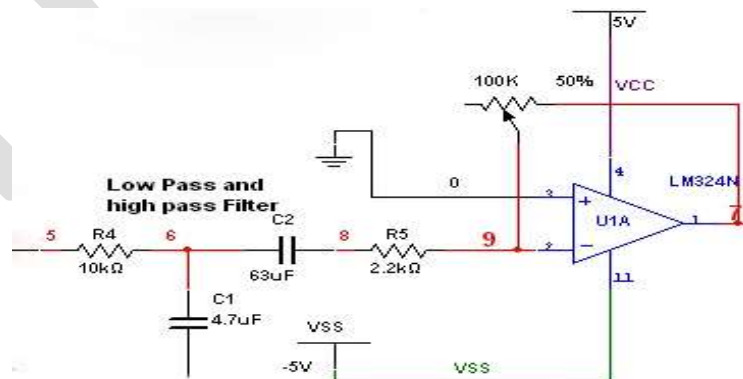


Figure 7. Band Pass Filter

3. Fixed Gain Amplifier

A fixed gain amplifier was used after the band pass filter amplifies the signal with the necessary gain. Inverting amplifier configuration in an op amp was used to achieve this fixed gain amplification.

$$\text{Gain} = \frac{R_2}{R_1}$$

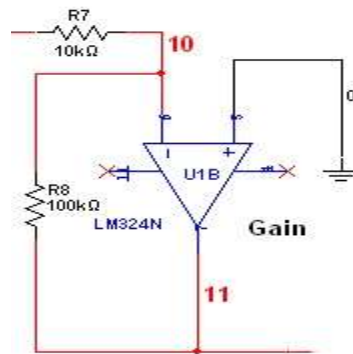


Fig 8. Fixed gain Amplifier

4. Active Low Pass Filter

While amplifying the signal using a fixed gain amplifier, there is a chance for unwanted high frequency noise getting amplified. Therefore, it became necessary to make use of an Active Low Pass filter which not only attenuates the high frequency components but also provides substantial gain to the signal within the required bandwidth. A variable gain can be implemented in the Low Pass Filter by making use of a potentiometer on the feedback path. A 100K potentiometer is used for adjusting required variable gain.

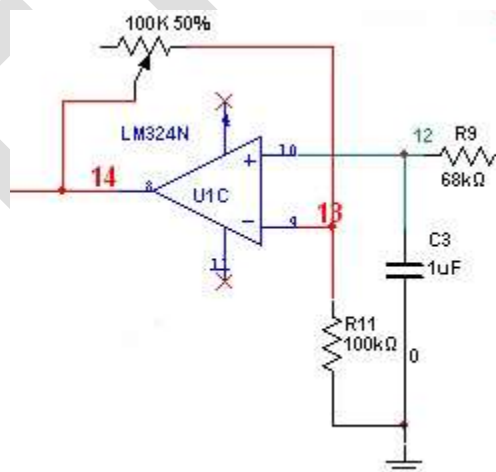


Figure 9. Active Low Pass Filter

5. DC Level Shifter

The EOG signal obtained after above signal conditioning steps is bipolar in nature, i.e. the signal has positive and negative peaks corresponding to the eyeball movements. However, in order to use the signal further into microcontroller we require to level shift the signal in such a way that no negative peaks are present in the signal. For this reason a DC level shifter was used followed by a negative voltage clipper (using a diode). This ensures the EOG signal have both the peaks above 0 V reference.

$$\text{DC Offset} = V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

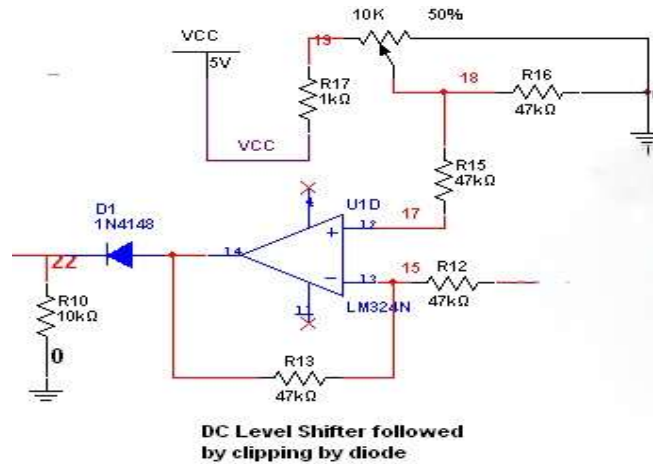


Fig 10. DC Level Shifter

To implement all the above circuit components after the pre amplification provided by an instrumentation amplifier, a Quad-Operational Amplifier (LM324) was used.

The overall EOG conditioning circuit was designed and simulated to get the desired frequency response as shown in the figure 11.

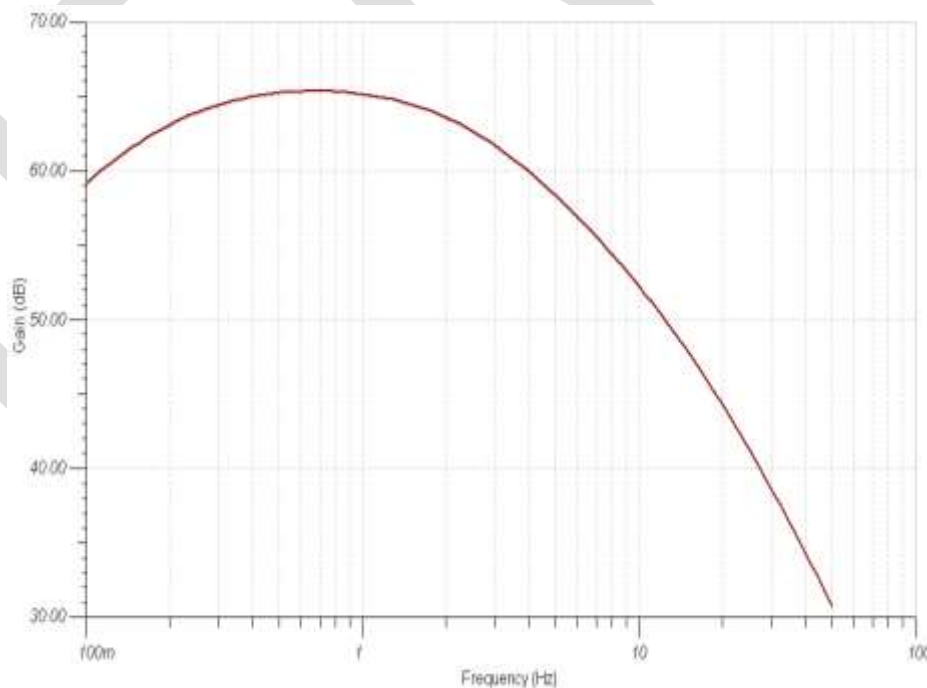


Fig 11. Frequency response of the EOG conditioning circuit

V Demonstration of EOG based HMI

The amplified and filtered EOG signal obtained from the designed signal conditioning circuit was sampled by using Analog to Digital Converter (ADC) which is already inbuilt in most of the available development boards. For the type of electrode placement used during our project, it was quite evident that the magnitude of the signal increases above the reference level as the subject moves his eye toward right direction. The signal reaches its positive peak when the eye is at the extreme right position. If the eye is not moving or at the center position the signal comes back to the reference level. Here the magnitude of reference level can be varied by making use of potentiometer available for the DC level shifter in the signal conditioning circuit. Similarly, if the eye ball moves towards the left direction, the signal drops below the reference level and reaches to minimum when the eye is at extreme left. The information about the magnitude of the EOG signal during the eyeball movement can be easily utilized to generate the necessary control signals. Thus, this demonstrates a cost effective, simple yet reliable solution for Human Machine Interface based on eye ball movement. The algorithm to extract the signal features for the eyeball location makes use of simple thresholds. Three thresholds are arbitrarily set for a center, extreme left and extreme right location of the eye. (Say $th1$, th , $th2$ respectively).

- If $signal_sample > th1$ this indicates eye movement towards right
- If $signal_sample < th2$ this indicates eye movement toward left
- Else, this indicates eye ball is located at the center.

However during the implementation of the crude algorithm above, care should be taken that the decision of the generation of control signals is due to the real movements. There can be sudden momentary peaks occurring in the signals that cross the above mentioned thresholds, in such cases a concept of counter can be implemented in the algorithm, i.e. if the signal meets the threshold condition, counter for that particular case is increased. If both the conditions, the amplitude threshold and the counter number threshold, are met the decision is made and a control signal is generated according to that. In our case, for the idea demonstration we have used simple inexpensive LEDs (Light Emitting Diodes). Three LEDs are connected to output pin of the microcontroller used, one each for the three cases of the eye ball movement, LEFT, CENTER and RIGHT.

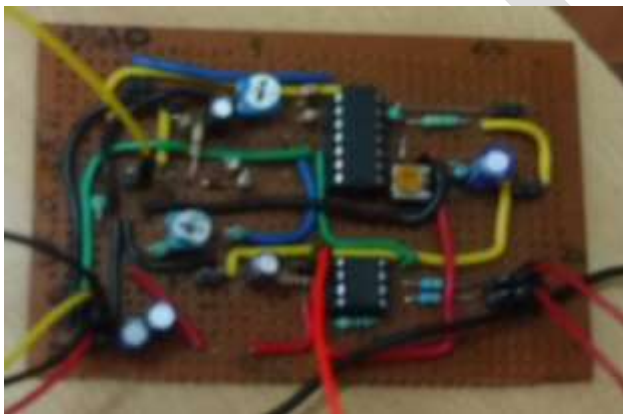


Fig 12. EOG conditioning unit designed



Fig 13. Demonstration of EOG based HMI

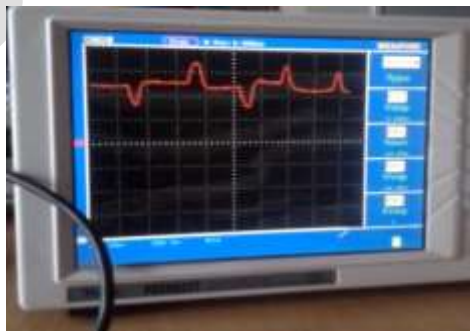


Fig 14. EOG signal displayed in DSO

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CONCLUSION

The frequency response of the designed EOG conditioning circuit clearly shows that there is a significant gain provided to signal within the desired frequency range (0.5 to 4 Hz) while attenuating the other high and low frequency components. The EOG signal acquired from eye using the designed conditioning circuit was found to be good enough, which was further used to generate control signals to demonstrate led blinks in accordance with eyeball movement. The approach was simple, inexpensive and yet so effective. This meets the objective of our project which aimed at utilizing a biomedical signal for Human Machine Interface targeted for physically disabled individuals. The performance of this approach was really promising in terms of its simplicity and reliability.

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