Design of Low cost Data Acquisition Circuit with Feature Extraction

R Archana¹, T Rajalakshmi², P Vijay Sai ³

¹Research scholar (F.T) Department of biomedical engineering, SRMIST, Kattankulathur, Chennai, Tamilnadu 603203, India.
²Assistant professor (Sr.G), Department of biomedical engineering, SRMIST, Kattankulathur, Chennai, Tamilnadu 603203, India.
³Student, Department of biomedical engineering, SRMIST, Kattankulathur, Chennai, Tamilnadu 603203, India.

E-mail: abirajalakshmix@gmail.com

Abstract. Single channel Electrooculogram (EOG) data acquisition system is designed to observe the patterns of signal to confirm the presence of disease or disorder. Tracking the movements of the eyes are done for controlling applications such as wheelchair control, blink detection, word speller, etc for people with complete or partial disability. With the help of signals generated from the eyes, the pattern is studied. This paper lay upon designing of highly precised instrumentation part of single channel EOG with miniaturized circuit and low cost. Different amplifiers are used to remove noise and increase the gain of the signal. Arduino UNO will read the EOG signal as analog input and the signal is recorded using PLX DAQ software which is interfaced with Arduino. The EOG signal is taken for 15 adults and it is tested for the working of the circuit. The signal is further amplified and filtered using MATLAB software and thus the eye movements are visualized. The set of basic mathematical feature are derived for the filtered signal which can be used for future applications for differentiating various eye problems.

1. Introduction

The measurement of electrical potential between the cornea and Bruch's membrane results in EOG. In 1951, Elwin Marg described and named EOG. In 1962, Clinical applications were portrayed first by Geoffrey Arden who understood that the most important data was the examination of the amplitudes under light and dim adjusted states which are known as the Arden proportion [1]. The mean transepithelial voltage of bovine Retinal pigment epithelium is measured as 6 millivolts (mV) [2]. Movement of the eye from left to right or up and down creates an electrical deflection that generates a signal called Electrooculography signal [3].

Detection of horizontal movement is recorded by placing the electrodes on temple of the eyes and vertical movement is recorded by placing the electrodes one above and below the eye [4]. On the off chance that the eye moves from focus position toward one of the two electrodes, this indicates to the
positive side of the retina and the contrary side indicates to the negative side of the retina. Thus the change in voltage is observed when a potential difference occurs between the electrodes [5]. Blink of the eye is recorded with single electrode which is normally used controlling application [6]. EOG patterns are analyzed to understand the function of pigment epithelium and to observe the sleep or awake patterns in conjunction with Electro-encephalogram [7]. Tracking visual targets in order to take over the control of objects in the environment is a further application of EOG.

In the existing literatures, there are several proposed EOG systems for the acquisition and application of biopotential signals. The issues with existing acquisition systems are the use of propriety software, lack of miniaturization and high cost. The self designed board for data acquisition reduces the cost. Lopez and et al. [8] designed an EOG device for simple HCI application and ophthalmological diagnosis. The author proposes the analog front end for system design and comparison of proposed model with existing model is done. Zheng and et al. [9] proposed EOG vigilance estimation system with silver-coated nylon line as dry electrode, a soft dry electrode which is a conductive fabric placed on above the eyes in the form of headband for signal acquisition. Pratomo and et al. [10] developed an EOG system for controlling the prosthetic hand. EOG signal is mostly acquired for Human/Brain computer interface for accessing wheel chairs, for controlling prosthetic devices, for communicating to electronic appliances [11-14]. K.J.Singh and et.al [15] proposed a study that comprises instrumentation Amplifier with driven right leg design for amplifying the obtained EOG signal.

Sanjaya and et.al [16] developed a EOG system with instrumentation amplifier, three staged Low Pass Filter and High pass filter and Level Shifter circuit. Thus the whole gain is made as 1000 greater times than the input signal with 0.5-30 Hz cut-off frequency range with the help of the circuit. The EOG signal property varies accordingly on the electrode placement. The feature extraction of the biological signal will be done and various features are analyzed for the movement of the eyes [17, 18].

The main intent of this paper is to obtain the EOG signal with low-cost miniaturized circuit. The obtained signal is analyzed for various features which can be used for future comparison of the normal signal with abnormal signal. In this paper we minimized the instrumentation part without any compromisation in acquisition of the accurate signal. This paper is assembled into following as Methodology in Section 2 which describes the electrode placement and proposed DAQ system. Section 3 involves in Results of the proposal and the feature sets of 15 adult subjects. Finally, section 4 gives some discussion and conclusions.

2. Methodology

2.1 Schematic Block diagram

The basic block diagram of EOG data acquisition system is mentioned in Figure 1. Signal acquisition is done with specific functioned bio potential electrodes which are having low impedance. Thus Ag/AgCl surface electrodes are used for picking up the EOG signals which is low in cost [19]. Since it is a surface electrode, it can be easily attached and detached from patient’s skin with less or no pain. In our data acquisition system, we are taking EOG signals for horizontal movement. The Ag/AgCl electrodes are placed on the temple of eyes and the single channel output are taken to various stages for filtering the unwanted noised and further amplification. The peripheral units which are used in our data acquisition system are electrodes, EOG designed circuit, Arduino UNO and a Rectifier circuit.
2.2 Electrode placement system
The placement of the electrode depends on the study or the application of the signal. The signal is taken for the person who is not affected by systemic disease. In this study, the electrodes are placed in horizontal position and the signals are picked up. The electrode placement system is displayed in figure 2. Thus in the single channel system, three electrodes are used including one reference electrode. Two electrodes are placed on left and right eye and reference electrode is placed on the forehead [20]. The polarity of the retina and cornea are positive and negative and thus the movement towards left side of eye generates the positive potential and the movement towards right side generates negative potential.

2.3 Circuit diagram of the proposed DAQ system
The circuit diagram of the proposed system is mentioned in figure 3. In the hardware part a low pass filter, High pass filter and twin t notch filter is used and the output signal is sent to microcontroller. The Arduino software is interlinked with PLX-DAQ software which helps in recording the signal in excel. The analog signal is converted into digital format using microprocessor and it is transmitted for further analysis of the signal for several feature sets. EOG is normally used for detecting ophthalmological disorders but it is normal for patients who have optic nerve disorders.
2.4 Calculation for Instrumentation amplifier and filters

The instrumentation amplifier AD620 which is low cost and great accuracy is used. It includes several imperial features such as low power consumption, low noise, High CMRR, great precision and adjustable gain $G$ with one external gain resistor $R_g$ [21]. The electrode which is placed near left eye is connected to the third pin and the electrode which is placed near right eye is connected to the second pin of the AD620 amplifier since the 2\textsuperscript{nd} and 3\textsuperscript{rd} pin of the amplifier represents the negative and positive terminal of the input.

\[ G = 49.4K \Omega(R_g)^{-1} + 1 \]  
\[ R_g = 49.4K \Omega(G - 1)^{-1} \]  

Thus

The gain of the amplifier is made as 500 by adjusting the gain resistor $R_g$ to 100 $\Omega$. The total gain of the circuit, $G$ is 1000. The equations (1) and (2) represent the general formula for calculating gain and gain resistance. Another 500 gain is achieved by adding gain resistors to the filters used in the circuit. The cut off frequency of high pass and low pass filter ranges from 0.5Hz to 25 Hz. The 2\textsuperscript{nd} order low pass filter and 2\textsuperscript{nd} order high pass filter is used. The active low pass and high pass filter is having four resistors and two capacitors. Non-inverting gain amplifier is used where the frequency $f_c$ is determined by using the formula given in equation (3) where $R$ and $C$ is the Resistor and capacitor for the filter. The derivation of low pass and high pass filter is given in equation (4) and (5).

For low pass filter,

\[ f_c = (2\pi RC)^{-1} \]  

by substituting $f_c$ and C value,
Thus Resistor value of low pass filter is 6.3KΩ

For High pass filter,
The cut off frequency of 0.5, a fixed value of capacitor is kept as 0.1uF and Resistor R will be calculated by substituting the values in equation (3)

\[ 0.5 = (2\pi R \times 0.1 \times 10^{-7})^{-1} \]

Thus Resistor value of low pass filter is 3.3MΩ

Gain of the filter \( Av = 1 + \left( \frac{R_2}{R_1} \right) \), we want to adjust the resistors according to the gain for low pass and high pass filters. The twin t notch or band stop filter helps in reducing the 50Hz interference noise [22]. The entire circuit is powered with the help of rectifier circuit which helps in conversion of 230V AC to 9V DC.

2.5 Data collection

The data is taken for 15 subjects for persons who are not blind and who are not having any other eye related problem. Patient who is affected by systemic disease are also not tested as EOG signal will be abnormal for these patients. The electrode placement is shown in Figure 1. The output of notch filter is given to the analog sensor of Arduino UNO in which the potential ranges between 0 to 5v. The output will be alternating voltage which is read by the circuit inside microcontroller which is known as analog-to-digital converter or ADC. The analog sensor of Arduino is taken as input and converts it to a digital value. The program is fetched in the Arduino software to read the signal from the analog pin A0. The signal cannot be stored in arduino, thus it is interfaced with PLX-DAQ software which helps in recording of the signal in excel sheet [23]. Thus the data from excel sheet is fed into MATLAB for further analysis and feature extraction.

2.6 Feature Extraction:
The data from excel sheet is fed into MATLAB for further analysis and feature extraction. In MATLAB, the raw signal is further filtered with Low pass filter and High pass filter with same cut off frequency which is used in the hardware part. This filter program which is coded in MATLAB removes the excess noise which is failed to be removed by hardware filter circuit. The filtered signals are taken for feature extraction.

The features that are extracted for this article are explained below:

- Maximum of the amplitude
  Maximum of the amplitude is defined as the highest amplitude of the EOG signal
  \[ \text{Max} = \text{max} (\text{signal}) \]

- Minimum of the amplitude
  Minimum of the amplitude is defined as the lowest amplitude of the EOG signal
  \[ \text{Min} = \text{max} (\text{signal}) \]

- Mean is the mean value of the EOG signal which is represented in equation (6)
  \[ \sum_{i=1}^{n} x_i [n]^{-1} \]

- Median absolute deviation(MAD)
  \[ \text{MAD} = \text{median}(|X_i - \bar{X}|) \]

  The average distance between the mean and the other data set value is represented by MAD. The variation in the data set is described by MAD.

- Variance of the amplitude
  It is the squared standard deviation which is also useful for measuring the scatterings in the data
  \[ \sum_{i=1}^{n} (x_i - \bar{x})^2 [n - 1]^{-1} \]
• Skewness
In the distribution of data the asymmetry of it is measured for a real value random variable about its mean
\[
\sum_{i=1}^{n} (x_i - \bar{x})^3 \frac{(n - 1)^{-1}s^{-3}}{n}
\]  

(9)

• Mode – It is the highest number of the repeated amplitude value in the EOG signal
Mode= mode (signal)

• Standard deviation
The scatter or distribution of the data set is calculated by Standard deviation.
\[
[\sum(x_i - x)^2 N^{-1}]^{-\frac{1}{2}}
\]  

(10)

• Trim mean
The trim mean or truncated mean is the more accurate form of mean after discarding the higher and lower value.
In MATLAB trim mean is expressed as trimmean(signal,percent)

• Kurtosis
It is the level of focus that presents the estimations of a variable about the focal zone of the frequencies conveyance
\[
\sum_{i=1}^{n} (x_i - \bar{x})^4 \frac{(n - 1)^{-1}s^{-4}}{n}
\]  

(11)

3. Results
The acquisition is done with the help of Ag/Agcl wet electrodes and the design setup is shown in Figure 4. When the person is moving their eyes, a consistent and uniform signal of horizontal movement is obtained. The obtained waveform is denoted in 5mV corresponding to the time in milli second. The Arduino UNO which is used for recording the signal makes the setup to easily portable instead of using other commodities of recorder such as cathode Ray Oscilloscope, DAQ system, etc., the Arduino software is easy to code and the processing of the signal is achieved without any difficulty.
The acquired EOG signal through Arduino UNO is recorded through PLX software and processed in MATLAB to analyze the features. The data acquisition system can be used for wide range of eye displacements, and most importantly it is cheaper. The EOG signal is taken for one minute for the person without any distortion or artifacts. The acquired signal is processed in MATLAB and filtered again to remove the unnecessary noisy signals. The Figure 5 shows the raw signal obtained from MATLAB which is containing some noise, Figure 6 shows the final output of high pass filtered and low pass filtered signal. All unwanted noisy signals are filtered through MATLAB. The graph is shown in amplitude versus time in seconds. These signals are further filtered and analyzed for several features.

![Figure 5. Raw signal obtained from EOG](image)

![Figure 6. MATLAB output after filtering](image)

### Table 1. Features extracted from the obtained EOG signal

| S.No | Feature sets                  | Mean ± S.D     |
|------|-------------------------------|----------------|
| 1    | Maximum of amplitude          | 5.1756 ± 0.9024 |
| 2    | Minimum of amplitude          | -0.6268 ± 0.3565 |
| 3    | Mean                          | 1.9679 ± 0.4397 |
| 4    | Median absolute deviation     | 1.7145 ± 0.4806 |
| 5    | Variance of the amplitude     | 2.9763 ± 1.2546 |
| 6    | Skewness                      | 0.3295 ± 0.2653 |
| 7    | Mode                          | -0.6268 ± 0.3565 |
| 8    | Standard deviation            | 1.6853 ± 0.3821 |
| 9    | Kurtosis                      | 1.8904 ± 0.3595 |
| 10   | Trim mean                     | 1.9360 ± 0.4536 |

The time domain features are correlated and the values are displayed in Table 1. The filtered signal output from the MATLAB is taken and the various mathematical features are correlated by coding in MATLAB. These feature sets represent the characteristics of the obtained signal and in future these
feature sets can be compared with the abnormal signal to find the attribute of normal and abnormal signals.

4. Discussions
Clive and et al. [24] proposed a kurtosis based algorithm for EEG (Electroencephalogram) artifact removal. The EEG is taken with 10-20 electrode system and VEOG and HEOG are acquired. The author correlated kurtosis values for both EEG and EOG signals and the tabulated kurtosis value for HEOG signal is similarly converging with the values proposed in the Table 1. In the proposed method, the circuit is miniaturized without compromising the accuracy of the signal. The number of important mathematical features are added and analyzed in this paper than in the experiment conducted by [25]. The different features are taken for entire saccadic movement. These values can be compared with lateral studies for abnormal signal of EOG [26]. The low cost Ag/Agcl wet electrodes are used for data acquisition. In the article Sanjaya and et al. [16] three differential amplifiers are used for amplifying the signal whereas in our proposed method, one instrumentation amplifier is used. Ag/Agcl electrode which is used in the proposed method reduces the motion artifact. Natasha and et al. [27] proposed a three sensor eye tracking system where electric potential sensor is used along with the EOG machine. In our proposed system the eye tracking is possible for future application with less than 1/100th of the cost of the existing methods. Isuru and et al. [28] proposed a bio signal interfaced wheelchair for persons with disability where EEG and EOG signals are combined to access the wheelchair, whereas only EOG signal can be used to control the directions. The EEG cap is used for picking the signals whereas EOG sensors attached to goggles will be cost effective. Kristie and et al. [29] proposed a system to classify the movement of the signal using BIOPAC MP36. This system comes with inbuilt feature classification technique with higher cost.

5. Conclusion
In the proposed method, the EOG signals are acquired through our designed circuit and the processing of the signals are done. The experimental results of the eye potential and the feature values are observed. With these features and signal we can classify the normal and abnormal signal in future. The Feature extractions are carried out on filtered data which will be useful for classification of signals as a future work. The same person in the different environment may give the different results. The horizontal EOG recording is done in this experiment and for future work the vertical readings can be recorded for further analysis. The saccadic reading of the eye helps in focusing the deformity of the eyes and thus these data used in our work can be used as extended work in future for classifying the normal and abnormal data for patient with deformities.

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