A cost-effective EOG acquisition system for laboratory exercises

Milica Stojanović, Jelena Djordjević-Kozarov, Jelena Anastasov, Dejan N. Milić and Emilie Avignon-Meseldzija

***Abstract*—Electrooculography (EOG) is a non-invasive technique used to measure eye movements by detecting corneo-retinal potential differences. In addition to its wide application in medicine, EOG is increasingly used for practical applications such as assistive device control (artificial arms, wheelchairs, virtual keyboards, etc), driver monitoring (fatigue and sleepiness detection, pilot training, etc), and gaze-based human–computer interaction (HCI) systems. We have devised a system for acquisition that is cost effective, and hardware lightweight, and could be used for student laboratory exercises for education and training, as well as for further research and development. In this paper, we propose a model of such an acquisition system that fulfills the requirements. We show the results obtained so far and propose directions for further research.**

***Keywords*— Electrooculograph, eye movement, acquisition system, signal processing.**

I. Introduction

The electrooculogram (EOG) is a bioelectrical signal generated by the potential difference between the corneal (positive) and retinal (negative) surfaces of the eye. This potential varies with eye movements, allowing the EOG to be used as an indirect method for tracking ocular position and motion. The changes in potential are typically recorded using a pair of surface electrodes placed around the eye, either horizontally or vertically, enabling real-time monitoring of gaze direction and eye movement.

Given that the EOG signal is low-frequency and low-voltage, the precision of EOG acquisition is critical, as it directly influences the reliability and validity of the derived data, particularly in applications requiring high temporal and spatial resolution.

In [1], authors present a cost effective bioelectrical signal acquisition system for real time biomedical applications, consisting of an op-amp-based bio-amplifier, data acquisition board and a laptop. In order to test the proposed system, the acquisition of ECG, EMG, EOG and EEG signals was conducted. The paper incorporates active filters and does not use active feedback of any kind.

Another EOG data acquisition system is proposed in [2] for detecting horizontal eye movements and it was compared with the standard BiopacMP36 [3] system to check its accuracy. The fundamental components of the system proposed in this paper are wet electrodes, an instrumentation amplifier, filter unit and a voltage subtraction unit. As a microcontroller unit, the Arduino Mega 2560 was employed.

In [4], the EOG acquisition system for detecting eye movements that can restore communication abilities to patients who have nonfunctional limbs and facial muscles was presented and an accuracy of 78 % was achieved. This acquisition system consists of JFET input operational amplifiers, second order low pass filter and second order high pass filter, followed by pre-processing and converting signal to digital data.

A biosignal based HCI that can quantitatively estimate the horizontal position of eyeball was developed in [5]. A signal acquisition system that can measure EOG and EMG independently at the same time by frequency division and signal processing, with only two electrodes, was designed. Unlike traditional systems, a pre-processing filter is applied instead of a ground electrode.

The complete design of an analog front-end for EOG systems was presented in [6], considering most important issues such as possible sources of noise, interference and motion artifacts and ways to minimize them. Two approaches of the acquisition of the EOG signal are suggested, AFE based on low-resolution ADCs which requires more analog signal processing and limited flexibility, and AFE based on high-resolution ADCs which is associated with a higher power and a higher area.

In [7], an EOG acquisition system using an ATmega AVR microcontroller was developed for vertical and horizontal eye movement detection. The signal is processed using high-pass and low-pass filters after amplification, then digitized via Arduino Mega 2560. The system enables hardware control (e.g., LEDs, wheelchairs, robot arms).

In [8], a MEMS-based multisensor platform with a commercial QVAR electrostatic sensor was proposed for long-term biopotential monitoring, demonstrating high accuracy in eye movement detection.

Similarly to the presented research, we develop a cost-effective analog front-end for acquiring EOG signals. Our focus is aimed at using single-supply compatible with USB voltage levels, active feedback to improve common-mode

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interference rejection, optional power-line filtering of the signal, and use of low-cost components.

II. EOG Signal Characteristics

A. *Characteristic phenomena in EOG signals*

There are several characteristic phenomena in EOG signals that are directly related to eye movements:

Blink is a contraction of a group of eye muscles and causes activation of the eyelid muscles (Fig. 1). The average duration of a blink is between 100 ms and 400 ms [9]. Eye blinking can be divided into reflex blinking (in response to some condition in the eye, this type of blinking is an instinctive response that protects the eye from wind and dust), voluntary blinking (as a result of the decision to blink), and involuntary blinking (spontaneous blinking without external stimuli, controlled by the brain). Spontaneous blinks are usually shorter than reflex and voluntary blinks, and voluntary blinks show the highest amplitude in the EOG waveform. The frequency range of blinks is from 1 Hz to 10 Hz.

Saccades are rapid, simultaneous movements of both eyes in the same direction, which abruptly change the point of fixation during viewing. Typical values of saccade eye movements are: maximum speed 400 °/s, amplitude 20 ° and duration is from 10 ms to 100 ms [10,11]. Saccades can be caused voluntarily, but they also occur without the influence of the will, whenever the eyes are open, and even when they fixate on a certain point.

Microsaccades are a type of fixational eye movements. These movements are like twitches and do not depend on the will of the person. Such eye movements occur during longer fixations of a target, i.e. when the same point is viewed for more than a few seconds. Microsaccades move the eye by a maximum of 0.2 ° in adults.

Fixation is a static state of the eyes during which the gaze is held at a specific location. The term fixation can also refer to the time between two saccades during which the eyes are relatively still. The average duration of fixations is between 100 ms and 200 ms [10,12].

Rapid eye movements, abbreviated REM (Rapid Eye Movement), refer to the stage of sleep during which dreams occur. In this stage, the eyes move rapidly. Involuntary rapid eye movements that occur during sleep are also saccadic movements.

Smooth eye movements represent the tracking of a moving stimulus, by maintaining the stimulus at the point of clear vision, the fovea. These movements are much slower than saccades and are under the direct influence of the human will, that is, the observer can choose whether to follow the stimulus with the eyes or not. Smooth tracking movements in adults can reach 100 °/s.

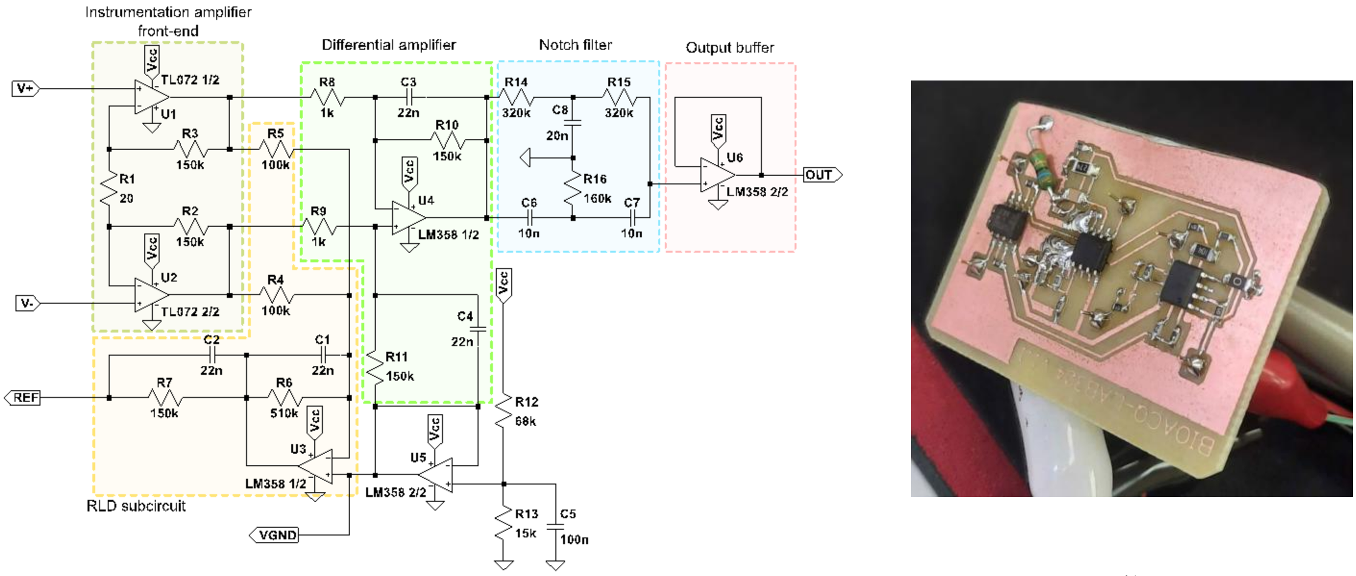
The optokinetic reflex is a combination of saccades and smooth tracking movements. It is a reflex that allows the eye to follow moving objects while the head is stationary.

B. *Technical standards*

Electrooculography is a method used to record eye movements by measuring the corneal-retinal potential, which exists between the front (cornea) and the back (retina) of the human eye [13]. The technical principle of EOG is based on the fact that the eye behaves as an electric dipole between a positive corneal potential and a negative retinal potential [14]. This corneal-retinal potential is in the range of 0.4 mV to 1 mV, is oriented along the line of sight (electrical axis) and changes with eye movement.

III. Analog Front-End

Building on the previously reviewed papers, this paper propose new cost effective EOG data acquisition system. Schematic of our proposed analog front end is shown in Fig. 3. It consist of an instrumentation amplifier realized using FET input operation amplifiers, followed by a differential amplifier, and active feedback to control the common mode.



a) b)

Fig. 3. Schematic of the proposed acquisition front-end a), and realized prototype b)

This sub circuit is similar to one that is commonly used in ECG acquisition systems.

Output signal of the differential amplifier is fed into a passive notch filter designed to suppress power line interference. Output signal from this filter is buffered using a unit gain operational amplifier to provide low output impedance and provide separation of filter and output of the front end. Power supply is envisioned as standard USB power supply of 5 V.

The passive notch filter has the following theoretical transfer function:

$$G(s) = \frac{as^3 + bs^2 + cs + 1}{ds^3 + es^2 + fs + 1}, \quad (1)$$

where the coefficients are connected to element values using following expressions:

$$\begin{aligned} a &= C_7 C_8 C_9 R_{14} R_{15} R_{16} \\ b &= C_8 C_9 (R_{14} + R_{15}) R_{16} \\ c &= (C_7 + C_8) R_{16} \end{aligned} \quad (2)$$

$$\begin{aligned} d &= a \\ e &= b + C_7 R_{14} [C_8 R_{14} + C_9 (R_{15} + R_{16})] \\ f &= c + C_7 R_{14} + C_8 (R_{14} + R_{15}) \end{aligned} \quad (3)$$

Filter elements have been chosen to provide notch at 50 Hz, while also having realistic values that are easily obtainable. The values are listed in Table I, together with measured values that differ somewhat from the declared values.

In order to provide testing facility for the front end we have used input stage that provides a suitable interface between single ended function generator and our differential input acquisition system. Principal of the input stage is shown in Fig. 4. Further testing results are discussed in the following section.

TABLE I
PAGE LAYOUT DESCRIPTION

Element	Designed value	Measured value
C_7	10 nF	12.30 nF
C_8	10 nF	11.85 nF
C_9	47 nF	50.30 nF
R_{14}	200 kΩ	200.22 kΩ
R_{15}	200 kΩ	199.10 kΩ
R_{16}	270 kΩ	266.45 Ω

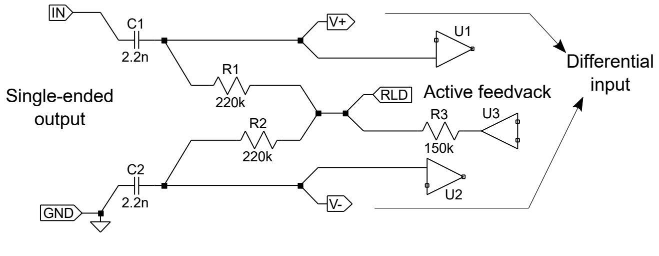


Fig. 4. Single-ended output to differential input interface for test signals

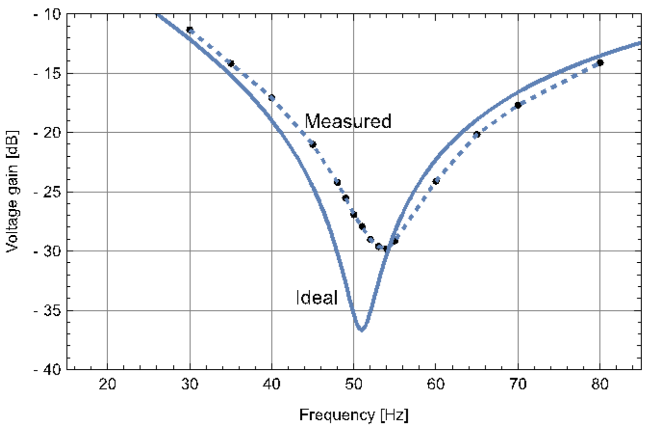
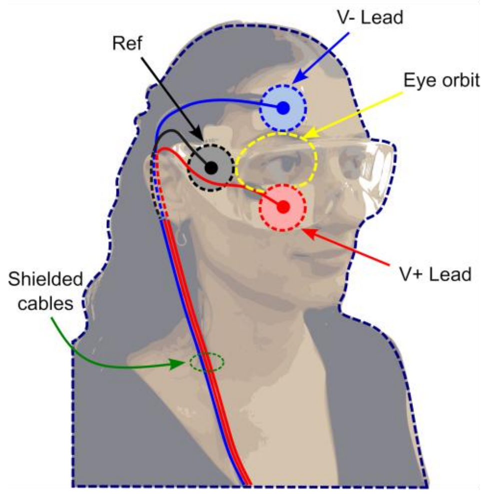


Fig. 5. Transfer function of the system near the frequency of 50 Hz, using proposed passive notch filter.

a) b)



c)

Fig. 6. Electrode placement on test subject: disposable adhesive electrodes are first attached a), and then cables are connected to the electrodes b). Connections are shown schematically in c).

IV. RESULTS

First we show the results of testing the system using deterministic signal from function generator. Fig 5. shows transfer function of our acquisition system. Notch of the filter is clearly visible at 50 Hz. In comparison to theoretical results measurements show significantly less suppression at exact notch frequency. We attribute this difference to non-ideal

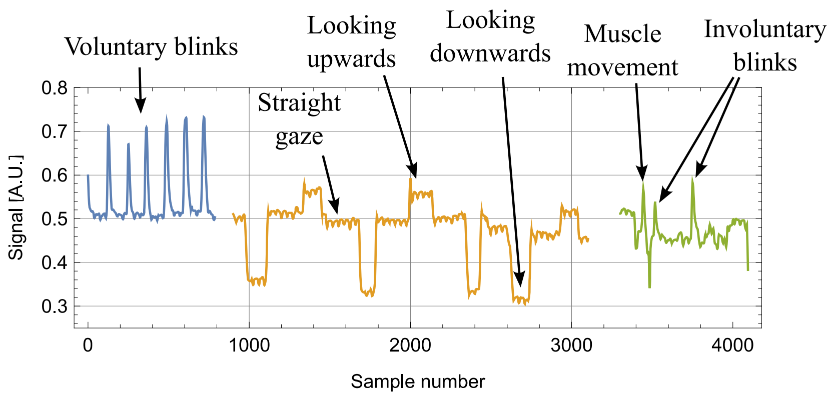


Fig. 7. Example of recorded artifacts during an acquisition session with electrodes positioned for vertical direction channel

characteristics of filter elements, and the signal crosstalk. With this information taken into account, the characteristics of theoretical analysis could be even more closely matched during the future development. Also, better suppression can be achieved using carefully chosen capacitors and switching to active filtering.

Realistic signals can be acquired using electrodes connected to the living subject as shown in Fig. 6. We have tested the system for vertical direction eye movement, blinks and other artefacts. Obtained signals are shown in Fig. 7. The figure shows that our system is able to detect voluntary blinks, eye movement in vertical direction, involuntary blinks and muscle movement artefacts.

V. CONCLUSION

Electrocoulography allows us to detect eye movements by measuring the potential between the cornea and the retina, and is one of the most widely used methods for detecting eye movements. In addition to the clinical applications, electrooculography is also used in various research directions. EOG signals have been increasingly used recently to control external devices such as virtual keyboards, electric wheelchairs, artificial hands and robots, and alarm systems based on the human-computer interaction system - HCI.

We have proposed and built a prototype of the acquisition system that fulfils initial requirements, which are the use of low-cost components, standard USB voltage as single-supply, active feedback for improving common-mode interference rejection, and power-line interference filtering. The prototype has demonstrated good characteristics, and its adequacy for acquisition of EOG signals.

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