Preparation of Papers a Cost Effective Prototype for Electrooculogram for Effective Eye Tracking

B. S. Megha Parameshwari, B. S. Madhurya, and K. Uma Rao

***Abstract*—This work presents a neoteric technology to assist disabled people, by tracking eye movement using low cost equipment. Eye tracking has been done using electrooculogram method (EOG), as opposed to traditional methods like video oculography, where a digital video camera is used to record the eye movement, and magnetic search coils, where three dimensional coils are used to track the eye movements. In EOG, the user's eye movement is tracked using a low cost electrode and the signals are suitably amplified and filtered to get a voltage. This is an elementary method to track the potential changes when the subject moves his eye and is a great help for the disabled to access control and communication devices. The design of the amplifier and filter is presented. Open source platforms processing 1.5.1 and arduino 1.0.3 are used for the implementation of the design. The experimental results are presented. It is found that the simple set up presented here, works accurately and can be used to control equipment using eye movement.**

***Index Terms*—EOG, eye tracking, potential, disability.**

I. Introduction

In humans, eye movement recordings are extensively used in behavioural and cognitive neuropsychological experiments. Eye movement recordings are also an important and sensitive tool to diagnose neurologic, ophthalmologic, and vestibular disorders. It is used by psychologists to determine the patient's focus or interest level [1], [2]. There are different systems available that can be used to track eye movement. They can be divided into three main categories - visual eye tracking techniques, the magnetic search coil technique and the electrooculogram. In conventional video oculography (VOG), infrared cameras are used to measure the eye's position. Small cameras, mounted in goggles, track the centre of the pupil to provide the location of the eye. There are many variants of the equipment. Depending on the accuracy of the reading required, the cost of the equipment varies from $1000 to $3000. The scleral search coil method is widely used to measure the position of the eye. Here, the eye position is determined by placing a silicon annulus in the eye.

This annulus contains a coil of thin copper wire. When the patient is placed in an alternate current magnetic field, the position of the eye can be determined from the amplitude of the induction current in the coil. High spatial and temporal resolutions are the main advantages of the method, regarded as the gold standard in oculomotor research However, one of major disadvantages is the invasive nature of this method. Patients cannot bear the coil in the eye for more than 30 minutes, and the eye has to be anesthetized, for insertion of the coil.

This method while, can be used as a diagnostic tool, definitely cannot be thought of as a means to use eye tracking for control of devices!

Elwin Marg described and named the electrooculogram (EOG) in 1951 and Geoffrey Arden developed the first clinical application. The EOG measures the potential that exists between the cornea and Bruch's membrane at the back of the eye. The cornea is approximately 5 millivolts positive compared to the back of the eye, in a normally illuminated room. Movement of the eye produces a shift of this electrical potential. By attaching skin electrodes on both sides of an eye the potential can be measured by having the subject move his or her eyes horizontally a set distance. The EOG amplitude varies as eyeball moves and also depends on many factors like relaxing and tensing the body which activates or relaxes the sweat glands.

In this paper a complete EOG setup is presented and can be easily implemented using low cost components and open source software. The electrodes are placed at the opposite side of the eye and the signal is differentially amplified to obtain a DC voltage. This voltage can now be used to control appliances. The lens directly focuses light coming from the source through the pupil, onto the retina which is light sensitive. The iris controls the amount of light that enters the eye. This is done by contracting the pupil in bright light and expanding the pupil in darker lights.

Light rays that enter the pupil first pass through the cornea and then through the vitreous fluid in the eye where the light is bent and refracted. The image on the retina is inverted. The brain is able to process this image and invert it so that we can see the image in its original form .The boundary between the iris and the sclera is known as the limbus, used in eye movement tracking as shown in Fig. 1.

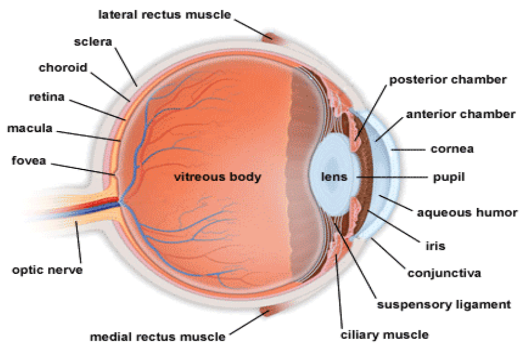

Fig. 1. Anatomy of the eye.

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Eye tracking is an important research field because of its varied applications in many fields. Some of the traditional methods applied to implement this are given below.

A. Visual Eye Tracking System

Visual eye tracking technique is also referred as videoculography. The position of the eye is observed using a camera. Here light is shone directly at the eye usually infra-red light is used, as it is invisible and does not make the subject close their eyes. The light reflects back when it is shown directly on the pupil along the optic axis due to refractive property of the retina. A camera is used to detect these reflections which is then used to detect eye position.

B. Magnetic Search Coil

The Magnetic Search Coil technique was developed in the 1960's by Robinson, and has been used as a method of eye tracking by Skalar Medical under the name Scleral Search Coil (SSC). An induction coil, encased in a suction ring of silicone rubber, is affixed onto the eye's limbus. After which a high frequency horizontal and vertical magnetic field is generated around the subject. This induces a high frequency voltage in the induction coil. As the subject moves his eye, the voltage with the sclera position changes, and therefore the eye, can be tracked.

II. Disadvantages of Traditional Systems

In magnetic search coil method a local anesthesia must be applied before inserting the coil into the eye. The subject can only wear the search coil continuously for 30 minutes only.

The subject must also stay in the centre of the magnetic field during the recording period which may cause health issues. Videoculography is not suitable to track vertical eyeball movement because the eyelid covers a part of the limbus when the eye is looking up or down. This system requires the subject's head to be stationary. To overcome this disadvantage we see that the preceding method is of great importance, while not compromising on the stability of the output.

III. Electroocculography

Electrooculography [3] is the most popular method to measure the electrooculogram, more known as the potential of the eye. The advantages of these methods over traditional methods are

1) Larger range than visual methods.
2) Linearity.
3) Head movements are permissible
4) Non-invasive.
5) Obstacles in front of the eye.
6) Variable lighting conditions.
7) Cost effective.
8) Closing eye is allowed.

In order to devise a system protocol which performs the required action in an efficient and cost effective manner, the implementation described in the following sections has been used to develop a prototype. The functional block diagram is shown in Fig. 2.

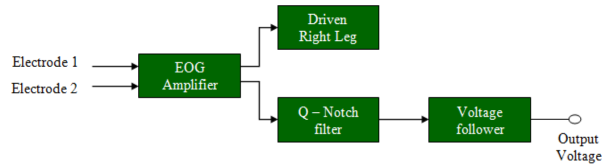

Fig. 2. Functional block diagram.

A. Implementation

Fig. 3 shows a pair of electrode is placed either above and below the eye or to the left and right of the eye. If the eye is moved from the centre position towards one electrode the potential at this electrode becomes more positive than the other electrode. Thus a potential difference is seen between the two electrodes. The recorded potential gives the eye position [3]. The human eye is capable of moving in a number of different manners like saccadic movement, conjugate movement, smooth pursuit movement, compensatory eye movement.

All these movements can be tracked [4]. This is done using disposable ECG electrode that are highly cost affective. Since the two eyes move in conjunction in the vertical direction, it is sufficient to measure the vertical motion of only one eye rather than both the eye. To detect vertical motion, one electrode is placed 2cm above where as another electrode is placed 1cm below the eye. To detect horizontal motion, electrodes are placed on outer side of each eye at a distance of 2cm from the eye. When the eyes look straight, the potential difference is almost zero at the two electrodes. When the subject looks to his left, the cornea is closer to the left electrode thus the electrode has more positive potential with respect to the other electrode and vice versa. The EOG signal is influenced by a number of factors, such as position of the eyeball, electrodes placement, head movement, luminance and skin conductance (which itself depends on many factors). To avoid these problems we have used a differential amplifier that will take the difference of the two opposite electrodes.

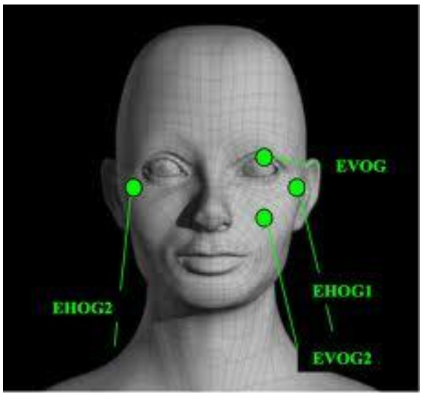

Fig. 3. Electrode placement.

B. Eog Amplifier

The signals received from the brain are weak and needs to be further amplified to convert it into a usable voltage. The amplifier shown in Fig. 4 continuously reads the DC potential on the skin surrounding the eyes, which is proportional to the degree of eye movement in any direction and amplifies it. Signals of microvolt range can be handled well. Gain of 1000 is achieved at the end of each stage. This can help in reducing DC offset which may be added due to the skin temperature, the humidity of the air and the skin moisture, etc. At RF frequencies the instrumentation amplifier does not have common mode rejection. Hence to rectify the interference caused by the noise and electrostatic discharge (ESD) we use an RF low pass filter at the INA126's input.

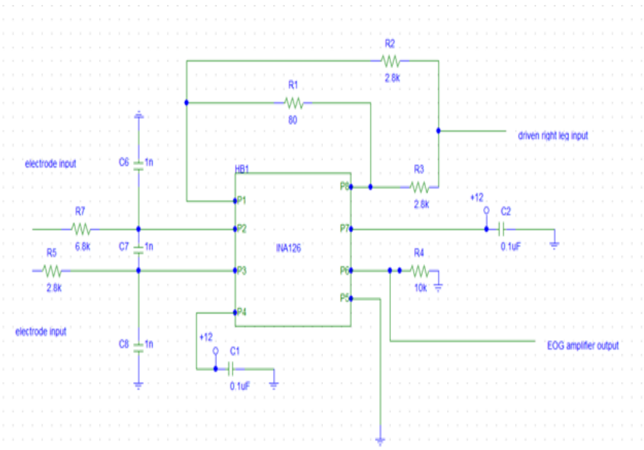

Fig. 4. EOG amplifier.

C. Driven Right Leg

Ideally, a differential amplifier takes the voltages *V+* and *V-*as its two inputs and produces an output voltage

$$Vout=Ad\ (V+ - V-)+ 0.5Acm\ (V+ + V-)$$

where *Acm* is the differential gain.

A high CMRR is important in applications where the signal is very small. IN126P's Common Mode Rejection Ratio (CMRR) is around 94DB. To improve it, a Driven-Right Leg circuit is implemented like in fig.5. This circuit is used in medical fields because devices like INA126P read a very small electrical potential from the body, this may add to the original signal and pollute it. The circuit reads the signal which it assumes to be noise and transfers a minute signal back to the body through reference electrode to negate its effect.

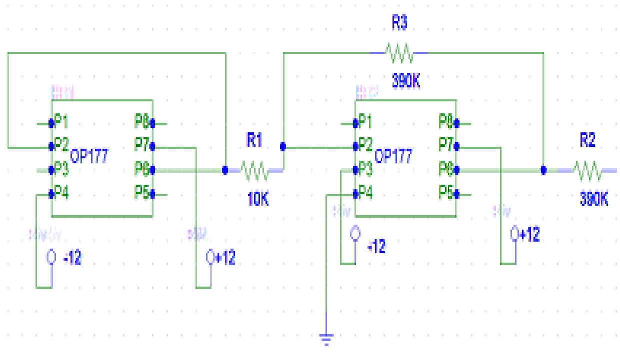

Fig. 5. Driven right leg.

D. Q-Notch Filter

The subject's head is like an antenna allowing a capacitance to be formed between overhead light source and the subject's head. The air between them acts as a dielectric. The nearby electrical equipment also induces some power line noise thus causing interference. A simple Q-Notch filter as shown in Fig. 6 with 60Hz cut off is implemented after the first INA126P to recover the losses.

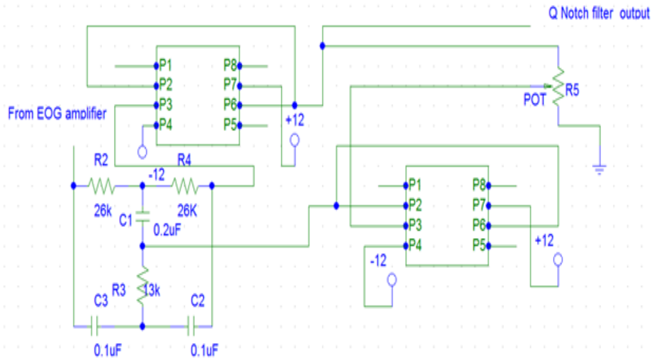

Fig. 6. Q-Notch filter.

A Q notch filter possesses a very selective magnitude response and a transient response of short duration. However, increasing the quality factor also increases the duration of the transient process in the filter. Power line losses can be a major problem.

E. Voltage Follower

The output voltage obtained from the Q-notch filter has both positive and negative voltages. We know that an ADC can only take positive values, so to overcome this we use LM358 dual operational amplifier as a voltage follower as shown in Fig. 7. It is operated by a single power supply, one terminal is given to Vcc and the other is grounded. It has a wide range of supply voltages ranging from +3v to +32v. Therefore the Op-Amp offsets the negative signal to a positive signal above the ground which can be given to ADC.

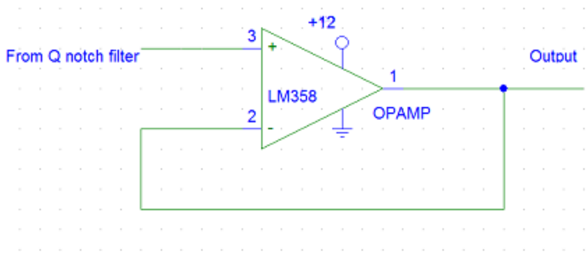

Fig. 7. Voltage follower.

IV. Results

TABLE I: Voltage Readings from Left to Right Movement of Different Subjects

Test subject	EOG output range (volts)	Q-notch output range (volts)	Voltage follower output range (volts)
1.	13.6 -0- 15	1.5 -0- 2.5	2.5 -0- 2.8
2.	12.8 -0- 15.2	1.04 -0- 2	2.5 -0- 2.8
3.	12.2-0- 14.23	1.51 -0- 1.73	2.1 -0- 2.5
4.	13 -0- 15.4	1.45 -0- 2.2	2.3 -0- 2.7

The variations in the results of different people are due to a number of reasons like

1) Improper electrode contact.
2) EMG interference when the subject frowns or speaks.
3) Bioelectric signals due to skin potential, sweat and emotional anxiety.
4) Base line drift.

From Table I, it can be observed that the voltage for a complete movement of the eyeball from left to right, a potential in the range of 12-15V is obtained at the EOG amplifier output and a potential in the range of 1.5-3V at the end of the circuit. The results are consistent and show repeatability.

Fig. 8 and Fig. 9 show the eye-ball movement towards right and left with corresponding voltage values shown in I. Fig.10 shows one of the applications of eye tracking.

Fig. 8. Right movement.

Fig. 9. Left movement.

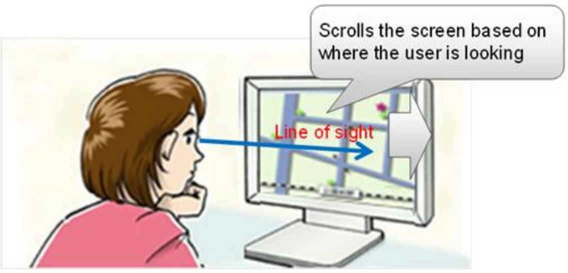

Fig. 10. Eye tracking mouse.

V. Applications

1) The EOG has been used as a controller for a wheelchair which uses ultrasound, infrared sensors and cameras to create information about an environment and help in a safer wheelchair movement. The implementation discussed in this paper provides a very low cost option.
2) A highly accurate product can be developed that can be used in fighter planes. The pilot's eye movement can be used to point to the target when the target is within the range because the movement of eye is more accurate and fast.
3) The signals from the eye can be harnessed and used to control the clicking of a mouse [5]. This can further used to search information on internet etc.
4) Eye movement can be used by paralysis patients and armless patients to perform simple tasks such as human machine interfacing.
5) EOG signals can also be used as a vital sign in some of the neurological disorders.

VI. Conclusions

In this paper a simple, low cost, prototype has been designed to track the eye movement. The potential in the range of mV developed in the initial stages are suitably amplified with a gain of thousand to give a voltage level of 0 to 2.8V. The hardware uses freely available components and can be fabricated by anybody with a total expenditure less than 10$ while the existing systems available in market costs from 70 to 100$.The prototype is tested and found to give consistent and an efficient result over varied spectrum of people. This model can be effectively used to control gadgets and needs further improvement in accuracy if used for medical applications.

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