Retina Based Mouse Control (RBMC)

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Abstract—The paper presents a novel idea to control computer mouse cursor movement with human eyes. In this paper, a working of the product has been described as to how it helps the special people share their knowledge with the world. Number of traditional techniques such as Head and Eye Movement Tracking Systems etc. exist for cursor control by making use of image processing in which light is the primary source. *Electro-oculography* (EOG) is a new technology to sense eye signals with which the mouse cursor can be controlled. The signals captured using sensors, are first amplified, then noise is removed and then digitized, before being transferred to PC for software interfacing.

Keywords—Human Computer Interaction, Real-Time System, Electro-oculography, Signal Processing.

I. INTRODUCTION

PEOPLE with physical disabilities face a lot of problems in communication with their fellow human beings. In this paper, the design of an eye-controlled mouse system with an emphasis on the *Human-Computer-Interface* (HCI) based on *Electro-oculography* (EOG) has been presented. Computers can be used by persons with disabilities for communication, environmental control, source of information and entertainment.

There are a lot of head and eye movement tracking systems for cursor control. Some of them are equipped with sophisticatedly designed systems using complicated concepts or using high quality devices such as high cost 3-D graphical hardware [1].

Head Movement Tracking System is a device that transmits a signal from top of the computer monitor and tracks a reflector spot placed on the user's forehead or eyeglasses. Using only the movement of the user's head, the movement of the cursor can be controlled, allowing 'The Head Mouse' to be used as an ordinary computer mouse [1]. But problem with this technique is that some disabled people cannot even move their head comfortably, also the system becomes inaccurate if user's forehead is not facing the camera.

Eye tracking is a technology in which a camera or imaging system visually tracks some features of the eye and then a computer determines where the user is looking at [1]. Eye tracking technology can be divided into two areas; firstly a remote computer-mounted device, in which an IR camera is mounted on a computer screen, and secondly a head-mounted device, in which an IR camera is placed on user's head. This technique is accurate but expensive.

Electro-oculography (EOG) is a new technology of placing electrodes on user's forehead around the eyes to record eye movements. EOG is a very small electrical potential that can be detected using electrodes. The majority of the people using this setup may have severe cerebral palsy or been born with a congenital brain disorder or suffered traumatic brain injury, for example from automobile or drowning accidents. This technique is adapted because it is inexpensive and accurate

The anatomy of the eye is shown in the Fig. 1. The light entering the pupil, is focused, inverted by the cornea and lens and projected onto the back of the eye (fovea). The fovea defines the center of the retina with the region of highest visual acuity [2]. The retina houses seven layers of alternating cells and processes which convert a light signal into a neural signal (transduction). The actual photoreceptors are the rods and cones, but the cells that transmit to the brain are the ganglion cells [3]. Cones provide the focus on fine detail and distinguish color. They require relatively high levels of illumination to operate. Rods, on the other hand, are much more sensitive to light, providing superior capability to detect movement in low levels of illumination [2]. The axons of the ganglion cells make up the optic nerve, the single route by which information leaves the eye [3].
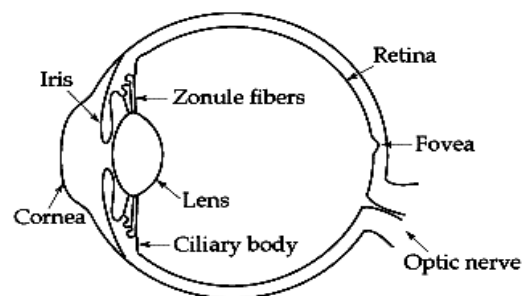

Fig. 1 The anatomy of the eye [3]

II. IMPLEMENTATION

In building this whole circuit, number of components was tried and final component selection was based on optimal performance.

A. Sensing Eye Signals

Due to the higher metabolic rate at the retina compared to the cornea, the eye maintains a voltage of +0.40 to +1.0 millivolts with respect to the retina. This corneoretinal potential, which is roughly aligned with the optic axis and hence rotates with the direction of gaze, can be measured by surface electrodes placed on the skin around the eyes, (see Fig. 2). The actual recorded potentials are smaller in the range of *15 to 200 microvolts* and are usually amplified before processing [4]. With proper calibration, the orientation of the electric dipole can be used to specify the angular position of the eyeball to within 2 degrees vertically and 1.5 degrees horizontally [4]–[5].

Independent measurements can be obtained from the two eyes, but as the two eyes move in conjunction in the vertical direction, it is sufficient to measure the vertical motion of only one eye together with the horizontal motion of both eyes. To detect vertical motion, one electrode is placed 2cm above where as another electrode is placed 1cm below the left eye. To detect horizontal motion, an electrode is placed on outer side of each eye with 2cm distance from the eye (see Fig. 2). *Ag/AgCl electrodes* are chosen as their half cell potential is closer to zero.

When the eyes look straight ahead, a steady dipole is created between the two electrodes. When the gaze is shifted to the left, the positive cornea becomes closer to the left electrode, which becomes more positive [6], with zero potential at the right electrode, and vice versa. The EOG signal is a result of a number of factors, including *eyeball and eyelid movement, different sources of artifact such as EEG, electrodes placement, head movement and influence of the luminance, etc*. For this reason, it is necessary to eliminate the shifting resting potential (mean value) because this value changes [7]. To avoid this problem, it is necessary to have *ac differential amplifier* that will take the difference of the two opposite electrodes.
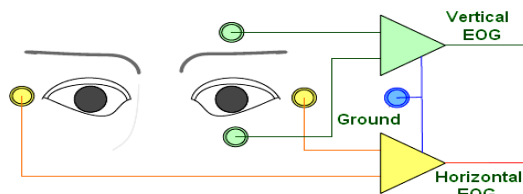

Fig. 2 Correct positions of five electrodes [8]

B. Signal Amplification

Number of devices was considered for signal amplification such as A0401 instrumentation amplifier with built-in filters, EyeSense EOG amplifier, RHA1016, CED1902, but all these devices were very expensive. Some known instrumentation amplifiers were tested such as AD624, INA114, INA118, etc, but all these devices began deviating from their original behavior when applied to such a small range of inputs. There behaviors were verified on Multisim 7.0 Electronics Workbench.

INA126P is an instrumentation amplifier recognized as EEG/EMG amplifier. It is selected as it can handle signals in microvolt range. Gain of 100,000 is achieved by implementing the amplification phase into two stages, each having a fixed gain of 1,000. 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.

As the signal is amplified, the noise may also get amplified. *Radio Frequency (RF) Interference* is a common source having frequency over 10k Hz. Common-mode signals present at the instrumentation amplifier's inputs are normally greatly reduced by the amplifier's common-mode rejection but, at RF frequencies, most instrumentation amplifiers have no common mode rejection [9]. To remove this interference and *Electro-Static Discharge (ESD),* a protection system in the form of an

RC low pass filter with cutoff at 47 Hz is implemented at the INA126p's inputs (see Fig. 3). This cutoff frequency can be calculated using (1).

$$f_c = \frac{1}{2\pi \left(R1 + R2 \right)\left(C3 + C1 + C2 \right)}$$
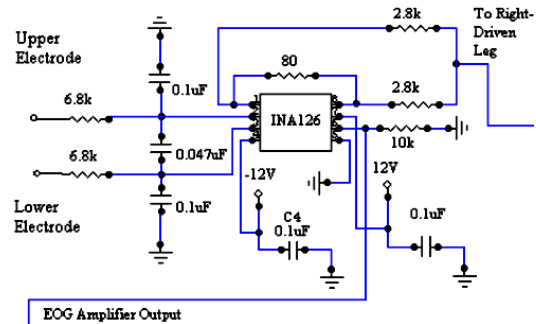
(1)

Fig. 3 INA126 with RFI and ESI protection system

C. Driven-Right Leg

IN126P's Common Mode Rejection Ratio (CMRR) is around 94DB. To improve it, a Driven-Right Leg circuit is implemented (see Fig. 4). This circuit is normally used in medical operations because the devices like INA126P read a very small electrical potential from the body and treat it as the desired one. That may add to the original signal and pollute it. This circuit reads what it believes to be noise and transfers a minute signal back to the body through reference electrode to negate its effect.
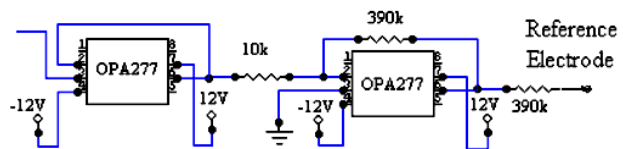

Fig. 4 Driven-right leg

D. Q-Notch Filter

The most critical problem that needs one's attention is the power line noise. It ranges from *50 to 60Hz*. The main source of this is the fact that the subject's head behaves as an antenna allowing a capacitance to be set up between overhead fluorescent lighting and the patient's head, with the air behaving as a dielectric. Similarly nearby electrical equipment induces power line noise, introducing interference [10]. A simple Q-Notch filter with 60Hz cutoff is implemented after the first INA126P to counter this problem (see Fig. 5). In applications where the rejected signal might deviate slightly from the null of the notch network, it is advantageous to lower the Q of the network. This insures some rejection over a wider range of input frequencies [11]. The values of resistors and capacitors are selected according to (2), (3) and (4).

$$R1 = R2 \ \& \ C1 = C2 \tag{2}$$

$$R3 = R1/2 \ \& \ C3 = C1/2 \tag{3}$$

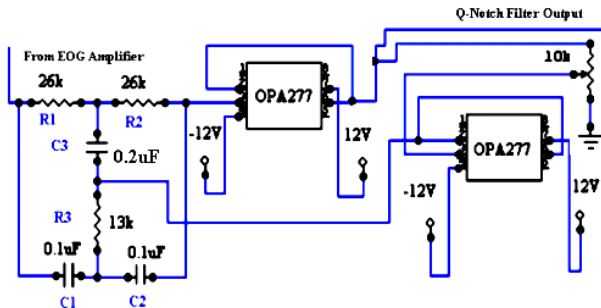$$R = \frac{1}{2\pi f_c C} \tag{4}$$

Fig. 5 Q-notch filter

E. High Pass Filter

Another critical issue in accurately acquiring and amplifying the EOG potential, is overcoming a *substantial DC offset* generated by the potential difference between the reference electrode and each of the active electrodes. This DC potential is due to the *skin impedances* and can be highly variable, due to *skin temperature, skin moisture, the humidity of the air, time of day, etc* [10]. A single stage amplifier with a gain of 1000 or more will amplify a DC voltage to a very large value, thus possibly saturating the amplifier. A high-pass filter with a very sharp roll off (-80dB/decade) and a corner frequency of *0.14Hz*, is used to reject DC. Based on the type of filter that is used (e.g. Butterworth, Bessel, Chebyscheff) the attenuation of the lower frequencies can be greater. This attenuation is also based on the order (e.g. 1st, 2nd) of the filter that is used. Based on the order of the filter, the rolloff of the filter can be calculated using the formula $-n*20$ dB/decade. This means that a first order high pass filter has an attenuation of -20dB/decade, while a second order filter should have -40dB/decade rolloff and on down the list for higher orders [12]. Rolloff of -80DB/Decade is achieved by implementing two 2nd order High Pass Filters in series. The circuit diagram is shown in Fig. 6. Bessel filter is preferred since it has a fast transient response. *One of such 4th order filters is implemented after Q-Notch filter during first phase of amplification. The second one is implemented after second INA126P during second phase of amplification.* The values of resistors and capacitors are selected according to (5).

$$R_1 = \frac{1.1017}{2\pi f_c C} \ \& \ R_2 = \frac{1.4688}{2\pi f_c C} \tag{5}$$
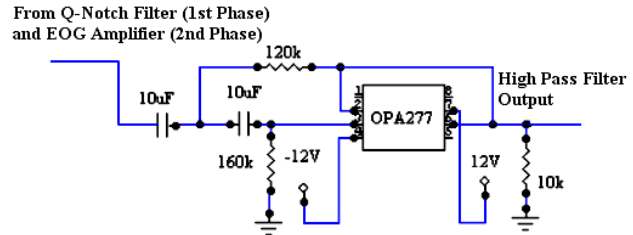
Fig. 6 2nd order Bessel's high pass filter

F. Anti-Aliasing Filter

Having passed through second INA126P, the power line noise may again come into play because this noise is always present. So whenever the signal is amplified, this noise may also get stronger. This noise can be removed by implementing a second Q-Notch filter with the same cutoff as before. But another problem that may occur is *Aliasing*. Aliasing may occur if the input signal has the frequency components that are greater than the half of the sampling frequency. *The sampling frequency that is achieved through custom software is 100Hz.* Since power line noise has frequency components that are greater than the half of the sampling frequency i.e. 50Hz in Pakistan, there is a need to implement an anti-aliasing filter. The power line noise and the aliasing effect can both be greatly reduced by implementing a sharp rolloff low pass filter (-80DB/Decade) with cutoff at 30Hz (see Fig. 7). The cutoff frequency of the filter should be no higher than about ¼ of the sampling rate. If the sampling rate is 400Hz, for example, then set the filter's cutoff frequency to below 100Hz. Although the required cutoff frequency was little shorter than 30Hz such as 25Hz, cutoff frequency of 30Hz is selected due to bandwidth of the EOG signal (1~25Hz). The values of resistors and capacitors are selected according to (6).

$$C_1 = \frac{0.9076}{2\pi f_c R} \ \& \ C_2 = \frac{0.6809}{2\pi f_c R} \tag{6}$$
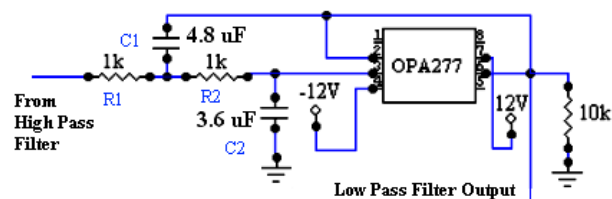
Fig. 7 2nd order Bessel's low pass filter

G. Data Acquisition

After all amplifications and filtrations, the purified signal must get first digitized so that it can be transferred to PC. Analog to Digital Conversion (ADC) could be done using MAX182 or ADC0808. PIC series microcontrollers could also be used since they have built-in ADC module, but for the signal to be a valid input into the PIC, MAX182 and ADC0808, it has to be in the range from 0V to 5V [13]. The summing amplifier would be needed in that case because the EOG signal has a natural offset that varies each time the

electrodes are hooked up. This summing amplifier will take average of the input signal to limit its range. But this summing amplifier or simply stating a voltage range shifter will definitely increase the complexity of the circuit.

ADS7800 is chosen as it is a fast (333 KHz Sampling Frequency) analog to digital converter and has the ability to handle wide range of input analog signals (-10V to +10V). With the help of this converter, 12 bits are directly interfaced with computer through parallel port, thus there is no need to have Programmable Peripheral Interfaces (PPI) such as 82C55. Also interfacing with microcontroller does not have much significance in this regard. Least significant 8 bits are interfaced with parallel port's 8 bit DATA register. Most significant 4 bits are interfaced with parallel port's 8 bit STATUS register. ADS7800 starts its conversion when falling edge occurs at its CONVERT pin. This CONVERT command is controlled by a 3rd pin of CONTROL register of Parallel Port. By default, the parallel port is configured as a unidirectional (output) data pins, unidirectional (input) status pins and unidirectional (output) control pins. *To make data pins bidirectional, set 6th pin of Control register designated as Direction pin.* One of the advantages of this ADC is that there is no need of summing amplifier over here since it can handle a wide range of inputs.

One parallel port receives digital data of up-down motion from one ADC and another parallel port receives digital data of right-left motion from another ADC. The circuit diagram is shown in Fig. 8.
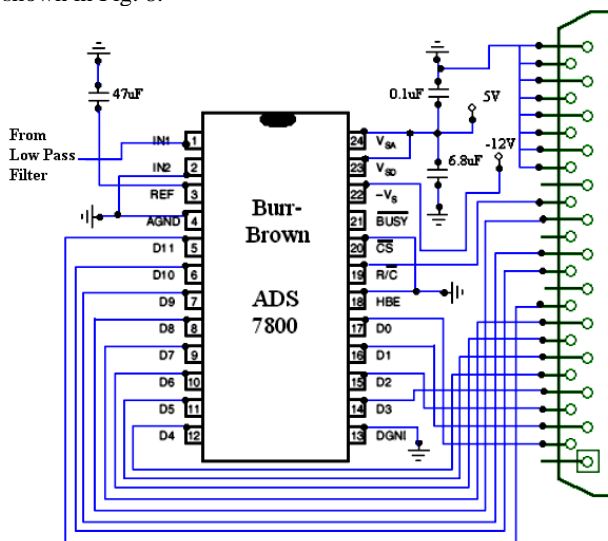

Fig. 8 The data acquisition system

H. Software Interfacing

The software has been written down in Visual C++ environment. It will receive digital information from two parallel ports, one after the other and then that information would be mapped onto a real-time graph.

The software has the resolution of 10msec limiting the sampling frequency of 100Hz which rightly follows the *Nyquist Rate*, which means the sampling frequency, should be more than twice the original frequency.

III. RESULT

The final output is shown in Fig. 9 for continuous up-down movement. The greater value will be achieved for larger displacement of eyes and vice versa. The output shown in figure 10 is calculated when eyes do sudden up movement. Figure 11 shows the response of continuous blinking of eyes.

A. Discussions

When eyes move in continuous vertical fashion, the variations in the output can be seen accordingly (see Fig. 9). Because of the positive and negative nature of the instrumentation amplifier's input channel, *higher value is achieved when eyes move upward and lower value is achieved when eyes move downward*. Similar would be the case for right-left movement.

Some variations are also detected in the output when eyes are still (see Fig. 10). The reason is that the eyes still do some movements known as *stabilizing movements* to remain focusing the image onto the retina when at rest. This portion can be neglected by implementing a software based Band Reject filter. The white doted lines in the figure 10 show the range of this filter.
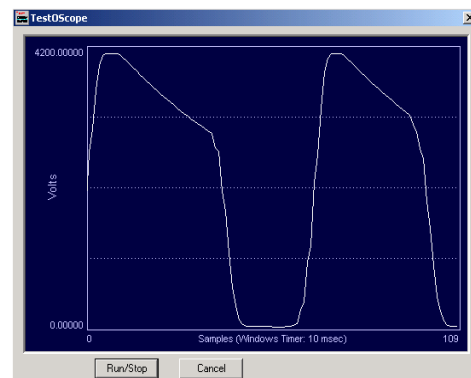
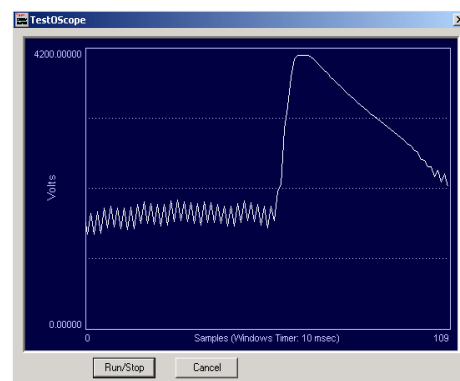

Fig. 9 The response when eyes do up-down movement

Fig. 10 The response when eyes suddenly go up

A particular pattern can be seen with the intentional blinking of eyes (see Fig. 11). *Intentionally strong blink can result into a strong response*. Similarly, a weak response can be noticed with normal blinks.
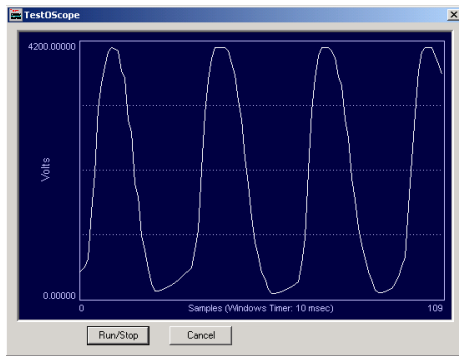
Fig. 11 The response when eyes blink in continuous fashion

B. Comparisons

The challenge we faced with amplification of the signal is the selection of the correct amplifier. With contrast to [14], the actual recorded potentials are in the range of microvolts, so INA103 would start malfunction when applied to such small strength of inputs.

The designs implemented in [10] and [14], have flaws as there is no protection system installed at amplifier's inputs to handle RF interference, so it would be difficult to obtain exact signal.

Expensive equipments such as CED-1902 used in [8] are rejected to reduce the overall cost of the product.

Reference [4] employed software filtering with little concern to hardware filtering, but it will significantly affect on the real-time nature of the system, as the software like MATLAB takes heavy time to process and filter the digital data.

Reference [10] does not implement any filter in the first phase of amplification to handle power line noise as this noise is always present. Also, as the frequencies of required signal and present noises are very near to each other, implementation of a higher order filters is required rather than a first or second order filters as in [10].

IV. CONCLUSION AND FUTURE DIRECTIONS

A human computer interface with basic functionality is successfully implemented and demonstrated. The final application consisted of:

- *An eye controlled cursor providing control over left, right, up and down.*

A. Future Directions

Human Computer Interfaces have an enormous scope in near future. There are four aspects as far as future enhancements are concerned.

- Making a model that can do clicking as well. By clicking, the user can search directories, write notes and browse internet pages etc.
- Making of Sophisticated Software by which one can paint, chat and play virtual games.
- Use of other areas of scalp for EOG acquisition.
- Make a sophisticated product that can be implemented in fighter jets. Pilot just has to point the target with the eyes and press the trigger when target

becomes under the range. It will be highly appreciated since the eye movement is more fast and accurate than just the hand movement.

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