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Biomedical Instrumentation based on Electrooculogram (EOG) Signal Processing and Application to a Hospital Alarm System

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Abstract—The Electrooculogram (EOG) signal is acquired by a bi-channel signal acquisition system and prominent artifacts and interference are suppressed. It is then processed for use in biomedical instrumentation systems such as eyeball tracking and blink detection. This paper also discusses the application of EOG signal processing to the control of a dual stage hospital alarm system. EOG based bio-control is found to be a suitable alternative to current control schemes, especially for quadriplegics and severely paralyzed patients.

Keywords: Artifact Suppression, Biomedical Instrumentation, Electrooculogram (EOG) Signal, Eyeball Tracking, Eye blink Detection, Inter-channel Interference, Two Stage Hospital Alarm.

I. Introduction

The electrooculogram (EOG) signal 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. The EOG signal is acquired through a bi-channel signal acquisition system, namely, the Horizontal (H) and the Vertical (V) channels. Electrodes placed on either side of the eyes or above and below them pick up the potentials generated by the motion of the eyeballs, as shown in Fig. 1. This potential varies approximately in proportion to the displacement of the eyeballs within the conductive environment of the skull [1]. Saccades inherent in eye motion as well as blinking of the eyelids can produce changes in the EOG signal. The strength of the signal is 10 to 100 μV and the useful frequency component is DC to 10 Hz. This necessitates a careful selection of the Biopotential Amplifier.

The recording of the EOG signal has traditionally been associated with several problems. The signal is seldom deterministic, even for the same person in different experiments. It is a result of a number of factors, including eyeball rotation and movement, eyelid movement, the EMG signal produced by the muscles of the eye, eye blinks, electrode placement, head movements, influence of luminance, etc. For this reason, it is extremely essential to eliminate the shifting resting potential (mean DC value) because this value varies continuously [2].

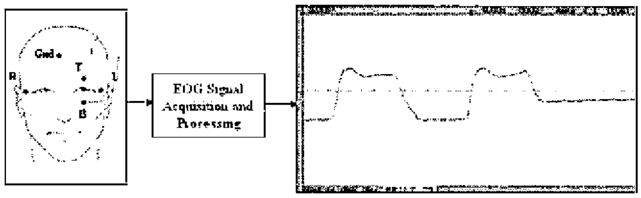

Fig. 1. EOG Signal - Electrode placement and acquired waveform.

The following section describes the instrumentation which has been used to minimize the effect of these factors and aid in obtaining a clean, single ended signal.

II. PrinicipLes of EOG Biopotential Measurement

The unifying principles of any biopotential recording mainly consist of electrode design and attachment suited to the application, amplifier circuit design for suitable amplification of the signal and rejection of noise and interference and finally, good measurement practices to mitigate artifacts, noise, and interference [1].

A. Ag - AgCl Electrodes and Electrolyte Gel

Electrodes for biopotential recordings are designed to obtain the signal of interest selectively while reducing the tendency to pick up artifact. The design should be pragmatic to reduce cost and allow for good manufacturing and reliable long-term use. These practical considerations determine whether high quality but reusable electrodes made of silver or gold, or cheaper disposable electrodes are to be used. Silver (Ag) - Silver Chloride (AgCl) electrodes have been used, which produce low levels of junction potential, motion artifacts and drift in the DC signal [1]. Additionally, an electrolytic gel based on sodium chloride was applied to the skin since the upper layers of the skin are poor conductors of electricity. A gel concentration in the order of 0.1 M (molar concentration) results in a good conductivity and low junction potential without causing skin irritation [3].

B. Minimizing Noise, Artifact and Inter-channel Interference

The frequency content of the EOG signal is very close to DC and hence the separation of DC drifts from the useful signal

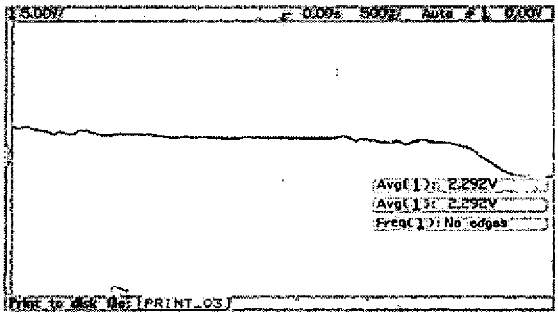

Fig. 2. DC level drift during E●G signal recording.

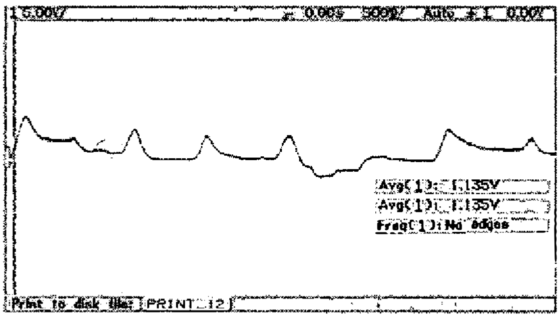

Fig. 3. Interference observed in the V Channel due to the H Channel signal.

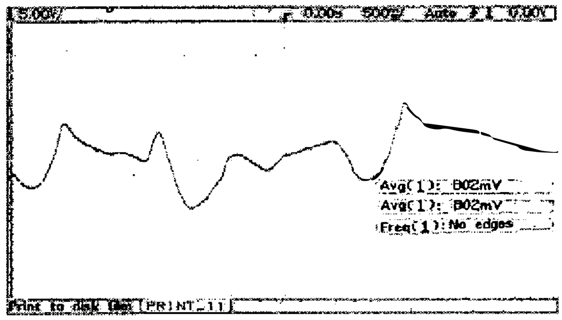

Fig. 4. Neck movement artifacts in the EOG signal.

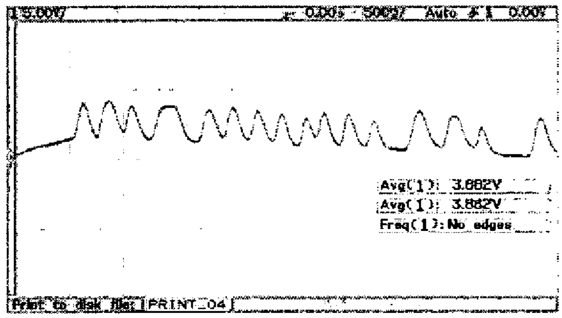

Fig. 5. Effect of eye blinks on the recorded EOG signal.

content is a difficult task. The shift in the DC level during EOG signal recording is shown in Fig. 2. Dual channel acquisition of the EOG signal has been employed and considerable inter-channel interference was observed. This interference arises because of two factors, namely, small deviations of the eyeball position towards the other channel during motion and improper alignment of the electrode pairs. The effect of the horizontal movement of the eyeballs on the recorded V channel signal is shown in Fig. 3. In our system, appropriate thresholds have been set to counter this effect and aid in correct determination of the eyeball position.

Skin Preparation and winding of the electrode leads helped to mitigate the effect of artifacts and noise. An emery paper was used to remove the poorly conducting dead skin layer before the placement of the electrodes. Electrode lead pairs were wound together (Top-bottom and Left-right) in order to prevent interference such as the power line signal from being magnetically coupled with the circuit [2]. The common artifacts that mingle with the EOG signal recorded are neck movement artifact, EMG signal of the muscles around the eyes and blink artifacts. Neck movement artifacts in the recorded EOG signal is shown in Fig. 4 and eye blink artifact is shown in Fig. 5. The effect of the artifacts can be considerably minimized with appropriate filtering.

C. *The Biopotential Amplifier*

The design considerations for the biopotential amplifier ought to include proper amplification and bandwidth, high input impedance, high common mode rejection ratio (CMRR), low noise and stability against temperature and voltage fluctuations [4]. An AD521 instrumentation amplifier was used to meet these requirements. The required low frequency response might make the amplifier susceptible to shifts in the junction potential at the skin-electrode interface. A drift cancellation circuit may be necessary, if required by the application.

D. *Ensuring Patient Safety*

Electrical isolation limits the possibility of the passage of any leakage current between the patient and the instrument. This can be done electrically by inserting a transformer in the signal path or optically by introducing an optocoupler [5]. Since we have processed the EOG signal to obtain digital signals, the response of the isolation device did not have t● be linear. Hence optocouplers were employed for the purpose of electrical isolation.

III. EOG BASED EYEBALL TRACKING SYSTEM

The position of the eyeballs can be approximately determined from the processed EOG signal. This has been indicated in a $3 * 3$ Light Emitting Diode (LE●) array.

A. *Signal Acquisition*

An instrumentation amplifier has been used since it reduces the effect of common mode signals like power line interference, electrode movements and skin-muscle artifacts, which affect the electrode pairs almost equally [6]. We have used AD521 Instrumentation amplifier (IA) and the amplification is approximately 25. The signal from the electrode leads is observed to contain a sizeable DC offset and therefore the first stage gain has been kept low to prevent amplifier saturation.

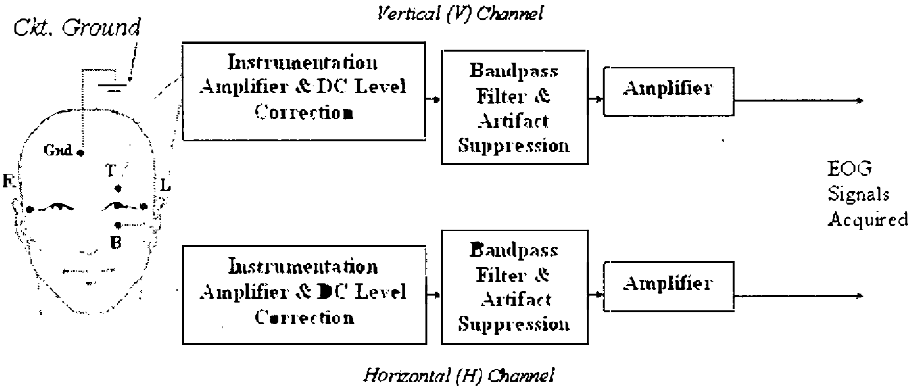

Fig. 6. Block diagram of EOG signal acquisition system.

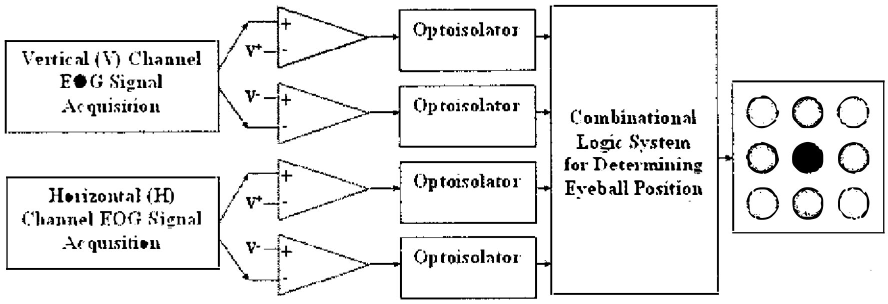

Fig. 7. Block diagram of the eyeball tracking system.

The block diagram of the EOG signal acquisition system is shown in Fig. 6.

B. Filtering and Amplification

After the EOG signal has been acquired and amplified, the next stage is the passive bandpass filter and a second stage of amplification. The useful EOG signal content varies between DC to 10 Hz. A bandpass filter with a passband of 0.1 - 10 Hz is used to pass the relevant signal content and attenuate the DC offset. Noise, as well as the power supply interference (50 Hz in India) are also suppressed. A second stage of amplification follows the bandpass filter, since the gain of the IA is not sufficient to amplify the EOG signal to useable levels. This is achieved by a non-inverting amplifier with an amplification of approximately 510. Since the overall system amplification is over 12750, the attenuation provided by the first stage of high pass filtering is insufficient. Hence, we require a second stage of offset removal, which is provided by a first order passive high pass filter with a cutoff frequency of approximately 0.1 Hz.

C. Thresholding

The optimal reference voltages for the two comparators of Fig. 6 were empirically determined in order to minimize the effect of inter-channel interference. The comparator outputs are hence two mutually non-overlapping binary signals that are high when the eyeball moves in a particular direction, i.e. either left or right.

TABLE I
WORKING OF THE COMBINATIONAL LOGIC BLOCK

Left Sig	Right Sig	Top Sig	Bottom Sig	LED Lit
0	0	0	1	Bottom
0	0	1	0	Top
0	1	0	0	Right
1	0	0	0	Left
0	1	0	1	Bottom Right
0	1	1	0	Top Right
1	0	0	1	Bottom Left
1	0	1	0	Top Left
0	0	0	0	Center

D. Optical Isolation

The binary signals are then optically isolated using an Opto-coupler chip. This ensures patient safety and device protection as explained in the previous section. A pair of optocouplers is used for each channel of the EOG signal acquired. This produces two mutually non-overlapping digital signals as the

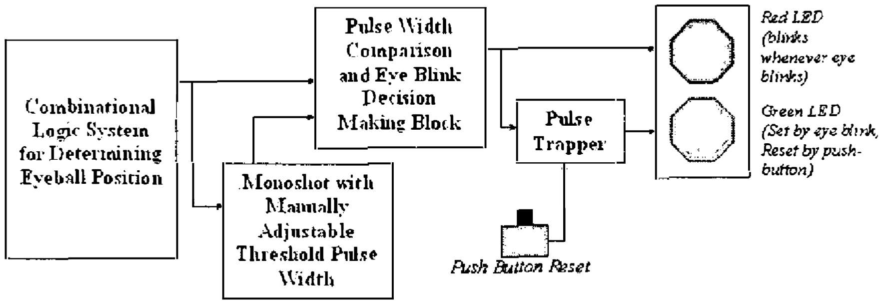

Fig. 8. Block diagram of the eye blink detecting system.

input to the decision making combinational logic block, which processes these inputs and controls the LED array.

E. Decision Making Logic Block and LED Array

This block receives the two mutually non-overlapping digital waveforms from the top/bottom channel and the two mutually non-overlapping signals of the left-right channel as inputs. It consists of a combinational circuit, that controls the $3 * 3$ Light Emitting Diode (LED) array, based on the logic shown in Table I. This LED array consists of nine segments (listed in Table I) and represents the displacement of the eyeballs from its central resting position. The block diagram of the eyeball tracking system is shown in Fig. 7.

IV. EOG Based Eye Blink Detection System

Eye blinks are either the reflex of the eyes to sudden movements near them or are involuntary actions. They cause the eyelids to cover the eyes as a means of protecting them from harm. It is well established, that during an eye blink, the eyeballs shoot upwards and this should therefore result in some potential difference being generated across the V Channel electrodes [7]. We have used this principle to devise our eye blink detection circuitry, which takes the vertical channel EOG signal as the input. This is processed to differentiate between sudden movement of the eyeballs from the center towards the top position and normal gazing towards the top direction, which is generally a slower action. The threshold pulse width can be set by the user according to the slowest rate of his eye blinks. In case a sudden movement of the eyeballs towards the top position from the center occurs, then a pulse trapping circuit is activated which then lights the green LED, until this is reset by the user. The red LED glows as long as no eye blink occurs and the glowing of green LED denotes that an eye blink had just occurred previously [2]. Fig. 8 shows the block diagram of our eye blink detection system based on the processing of the EOG signal.

V. Application of EOG Processing - Dual Stage Hospital Alarm System

There are over 4 million disabled people in India according to the 2000 census, most of whom live below the poverty line. Indian hospitals, both rural and urban, usually have no facility for a convenient switch that can be operated by disabled people as an alarm. Patients who are admitted to hospitals often have problems in operating devices manually. This may be due to immobility caused by accidents and amputation, or body ailments such as paralysis and polio. As a result, these patients require an easy to operate and completely secure switching system for the devices in their immediate environment like the lights, fans, bed pillow rise and alarms. A few of the presently existing, popular control schemes for hospital alarm systems are Electromyogram (EMG) based switching, contact based switching by limited body movement and speech based switching. The EMG is the biosignal associated with the muscles of our body. Flexing and relaxing of the muscles results in an increase or decrease in the amplitude of the EMG signal and this is processed to work as a switch. Contact based switching involves the use of body parts such as the neck or head, which can be moved relatively freely. A set of push button contact switches are placed around the head or neck and the user operates them by the limited movements which are available to him. Numerous hospital alarm systems based on user voice commands exist in the commercial market today, owing to the ease of operation of the system as well as the relatively noise free environment of hospitals, which drastically improves the reliability. Such systems have to be customized for individual patients based on the various traits of speech such as pitch, tone, volume and frequency.

Switches based on the EOG signal offer a safe, reliable and cost effective solution, since even patients with extreme paralysis generally have control over the movement of their eyes. This section deals with one such hospital alarm system, which is to be activated in two stages. Extensive analysis of the V and H channel EOG signals has shown that the reliability of the V Channel signal is inferior to that of the H Channel, owing to its sensitivity to eye blinks, neck motion artifact and offset drift. Hence, the H channel EOG signal was chosen to operate the hospital alarm system.

The block diagram of the hospital alarm system which we implemented is shown in Fig. 9. A digital monitoring circuit detects if the correct sequence of eye movements is performed for the correct durations. The sequence of eye

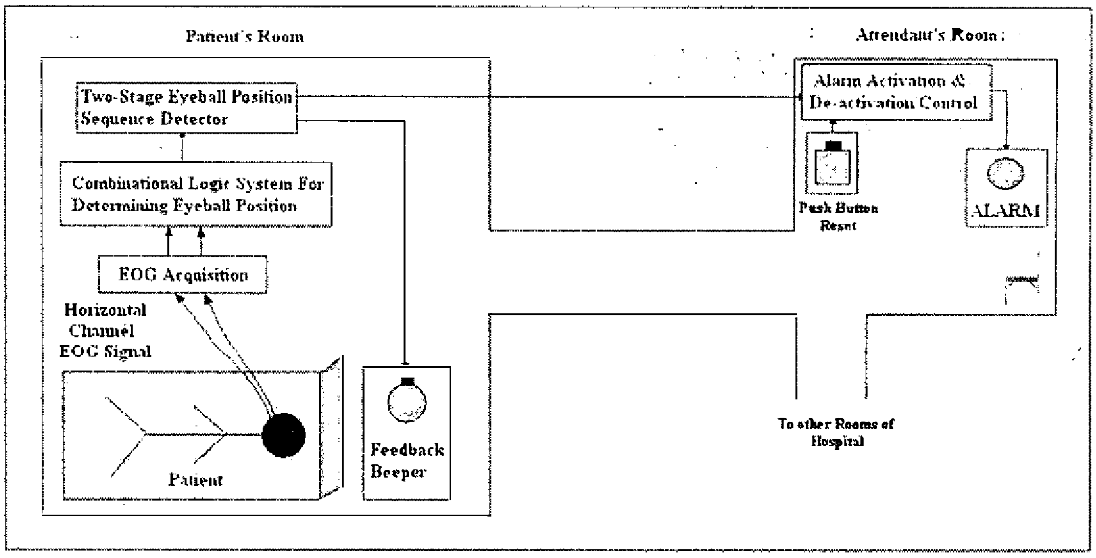

Fig. 9. Block diagram of the two stage hospital alarm system controlled by processed EOG signals.

movements is chosen such that it minimizes the probability of accidental triggering of the alarm and is also convenient to remember and use. The duration for which each eyeball position is maintained can be adjusted to suit the patient. This provision for customization of the duration and sequence of eye movements makes the alarm system user-friendly. The alarm devised has two stages, with provision for cancellation of the activation process, in case of accidental triggering. A beeper is used to warn the patient about the start of the second stage of the alarm activation procedure. In case the patient has accidentally triggered the beeper, he may subsequently cancel the activation process. Hence, this beeper provides audio feedback to the patient. If the patient has intentionally started the alarm activation procedure, a buzzer positioned in the vicinity of the attendant's room is enabled. This buzzer now remains on, until it is manually switched off by the attendant or nurse.

VI. Results and Discussions

It is observed that the V channel is more prone to interference, artifacts and drifts than the H channel. Hence, the H Channel is more suited to operate hospital alarm systems. The typical EOG amplitude was observed to range from 10 μV to 100 μV and the frequency between DC and 10 Hz. Eye blink, neck movement and head motion were observed to be major sources of artifacts and these have been recorded and studied for possible minimization. Inter-channel interference was also observed and it was found that this can be significantly reduced by precise positioning of the electrodes and careful selection of the threshold voltage levels. Effective filtering of the acquired EOG signal has yielded us around 60 dB attenuation of the 50 Hz power line interference. The recorded EOG signal reflects the well established biological fact that the eyeballs shoot upwards during an eye blink and this has been used to devise an eye blink detection system.

VII. Conclusion

The EOG signal has been acquired through a bi-channel acquisition process and common artifacts and inter-channel interference have been suppressed. It was suitably processed and used in applications such as the eyeball tracking system, eye blink detection system and the dual stage hospital alarm system. With careful acquisition, additional processing and precise modeling, the EOG signal can offer a viable replacement for the currently popular bio-control schemes based on signals such as the EMG and EEG, especially for immobile and paralyzed patients.

Current EOG Research Work at IIT Guwahati

Analysis of the EOG signal has revealed some hitherto unnoticed characteristics and the effect of factors such as eyeball velocity and previous position of the eyeballs is being studied. This will facilitate accurate modeling of the EOG signal, accounting for the suppressed artifacts, DC level drifts, saccades and eye blink effects as well.

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