

A REVIEW ON ELECTROOCULOGRAPHY

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Eye tracking based Human Computer Interaction (HCI) systems are becoming more popular day by day. In these systems Electrooculogram (EOG) can serve as primary source of input. The whole process of measurement of EOG is known as Electrooculography. This paper gives a review on Electrooculography and its use in various HCI systems. Detection of eye blinks from EOG signal has also been included in this review work. Finally it gives a light on various issues related to Electrooculography.

KEYWORDS: Electrooculography (EOG), eye tracking, eye blinks, Human Computer Interaction (HCI).

INTRODUCTION

In 1849, Du Bios-Reymond found there was a certain relationship between eye movements and electrode potentials from the skin surface. Medical studies proved that the potential difference, which is commonly called the resting potential, arose from hyperpolarisations and dehyperpolarisations existing between the cornea and the retina. The resting current flows continuously from the retina side to the cornea side, so that an electrical field comes into being with a negative pole at the retina and a positive pole at the cornea. This field changes orientation as the eyeballs rotate. Therefore, a human eyeball can be considered as a spherical battery that the centre of cornea is positive and the retina is negative. It is possible to regard that the battery like this is embedded in an eye socket and rotates around the torsional centre of eye. The micro currents flow radially from the positive pole to the negative pole of the battery through the conductive tissue in the orbit. These currents generate the standing potentials around the eye, and the micro potentials (EOG) can be detected from the skin electrodes pasted on the surface of the canthus.

Electrooculography is a technique for measuring the resting potential of the eye, and the resulting signal is called Electrooculogram (EOG). This signal shows certain patterns for each kind of eye movement (left, right, up, down, blink). These signal patterns can be recognised, and then, the acquired signals can be used for controlling external devices, such as virtual keyboards, powered wheelchairs, movable arms and robots. It is possible to obtain independent measurements from each of the one pair of eyes. The EOG value varies from 50-3500 μ V with a frequency range of about DC-100Hz. Its behaviour is practically linear for gaze angles of $\pm 30^\circ$. The EOG signal changes approximately 20 μ V for each degree of eye movement. The signal is sampled at approximately 10 times per second. The EOG signals are obtained by placing two electrodes to the right and left of the outer canthi to detect horizontal movement and another pair above and below the eye to detect vertical movement. Ag-AgCl floating metal body surface electrodes is used for EOG recording. Silver-Silver Chloride (Ag-AgCl) Electrodes are preferred for EOG measurements. Because silver is a slightly soluble salt, silver chloride quickly saturates and comes to equilibrium. Therefore, Ag is a good metal for metallic skin-surface electrodes. EMG (Electromyogram) and EEG (Electroencephalogram) electrodes can also be used for EOG signal

measurements. Contact impedance should be less than 10 k Ω over the frequency range of 30-200 Hz.

In human computer interaction EOG can be used for eye tracking. The term *eye tracking* as it is used here means the estimation of direction of the user's gaze. In most of the cases the estimation of the gaze direction means the identification of the object upon which the gaze falls.

Eye blinks also play very important role in EOG based Human Computer Interaction (HCI). Sometimes these blinks are required to be used for selection tasks in HCI. It may also be required to remove unwanted blinks from the raw EOG data. Therefore, eye blink detection is also an important part of Electrooculography (EOG).

Eye blinking is the contraction of sets of muscles of eye and produces an electrical activation of eyelid's muscles. The duration of such signals lasts for a fraction of seconds. The eye blinking can be divided into reflex blink (in response to something invading in the eye, this type blink is instinctive response that protects the eye against air puffs and dust, this is also part of scared response to loud noises), voluntary blink (as a result of a decision to blink) and involuntary blink (spontaneous blink without external stimuli, probably controlled by a blink generator in the brain). The spontaneous eye blink is considered to be a suitable ocular indicator for fatigue diagnostics. Spontaneous blinks are typically of a shorter duration than reflexive and voluntary blinks, and voluntary blink show the greatest amplitude in EOG waveform. The range of frequency for blinks is from 1 Hz to 10 Hz.

Other important terms related to eye movements are saccades and fixation. Simultaneous movements of both eyes in the same direction are called saccades. Typical characteristics of saccadic eye movement are 400°/s for the maximum velocity, 20 μ V for amplitude and 80 ms for duration. A fixation is the static state of the eyes during which gaze is held upon a specific location. The term "fixation" may also be referred to as the time between two saccades during which the eyes are relatively stationary.

This paper gives an overview on the work done by various researchers in the field of eye tracking using Electrooculography, eye blinks detection, and other eye movements measurement such as saccades, fixations etc.

LITERATURE REVIEW

Ali Bulent and Serkan Gurkan (2010) discussed the design and application of EOG measurement system.

This system is microcontroller based, with CMRR of 88 dB, an electronic noise of 0.6 μV (p-p), and a sampling rate of 176 Hz. The nearest neighbourhood algorithm has been used to classify the signals, and the classification performance is 95%. To reject high-frequency noise, a low pass filter (LPF, $f_c = 16$ kHz) has been used in this research. With this LPF, it is possible to reject high-frequency signals caused by other devices (e.g. fluorescent lamps, PC monitors, etc.). They used IA (LT1167) which has high CMRR (120 dB), input impedance (>1 T Ω), low electronic noise (7.5 nV), and low input bias current (350 pA). An LMC6001 electrometer amplifier is used for other single ended amplifiers and active filters. The input impedance of this chip is >1 T Ω . Having removed the DC level, the signal is applied to fifth order Bessel LPF (with MAX281), and then, it is applied to the amplifier with a gain of 101. The cutoff frequency of the LPF is fixed at 31 Hz, and at the output of this stage, it is possible to pass the 0.15-31 Hz band. Choosing this band, it is easy to remove power line noise, and less memory space is needed.

There are several signal processing techniques such as analysis of variance, and principal component analysis and classification techniques such as kNN, support vector machines, and neural networks. In this paper, because EOG signals are quite distinguishably acquired in time series with less noise, NN technique has been used. It is the job of EOG classification algorithms to give eye gaze position.

A Rajan, Shivakeshavan R G, and V Ramnath J (2006) acquired EOG through a dual channel signal acquisition system and processed for its use for wheelchair control incorporating neural networks. The neural network processor unit learns the eye patterns and helps in minimizing the noise due to the user. Digitisation of the measured EOG signal has been done by the means of commercially available ADCs, with a sampling time period of less than 10ms. This signal is then transmitted to a control unit using FSK modulation technique (400MHz to 950MHz). The neural network used has a simple 5 input, 4 hidden layer neurons and 1 output neuron system. It involves the intelligent judging of absolute direction based on the instantaneous velocity of the wheelchair and a set of raw EOG responses.

Y Kuno, T Yagi and Y Uchikawa (1997) designed an EOG based HCI system. This paper also discusses the feasibility of eye movement related EEG signal to be used in HCI system. As per this paper, EOG has 10-100 μV , provided light adaptation is kept constant, pitch and yaw eye movements can be measured to 0.5-1 degree over a wide range. This accuracy is never inferior to other eye movement detection methods such as IROG, VOG.

In this research, EOG signal is recorded with 20 Hz sampling rate and amplified in an amplifier (EEG-5532) then converted with an A/D transformer (IBX-3133). Generally, EOG has the frequency lower than 15 Hz. Therefore, the higher frequency is cut with a low-pass filter. EOG results obtained were quite appreciable.

In this paper, it has also been tried to predict EEG data according to eye movements. The experiment is performed in an electrically shielded soundproof darkroom, where a small light (LED) was set at the right front and left front of a human subject. The

subject is instructed to look at either of a turned on light. Then, the subject's EEG is recorded with electrodes, which were placed on the subject's head with international 10-20 method. EEG measurement is performed at posterior parietal cortex.

A B Usakli, S Gurkan, F Aloise, G Vecchiato, and F Babiloni (2010) implemented an EOG based Human Computer Interface (HCI) system. The data acquisition system is microcontroller based and has CMRR: 88 dB, electronic noise: 0.6 μV (p-p) and sampling rate: 176 Hz. Five Ag/AgCl electrodes are used for EOG measurement. EOG signals are digitized (10-bit) and processed by a classification algorithm based on the nearest neighbourhood (NN) algorithm. The system's initial circuitry can be used for EOG, EMG and EEG measurements and the system is battery powered. This system types on a virtual keyboard with a speed of 5 letters/25 seconds.

Zhao Lv, Xiaopei Wu, Mi Li and Chao Zhang (2008) designed an EOG based Human Computer Interface system. It composed of three parts: EOG acquisition and amplification, EOG pattern recognition, and control command output. This paper also declares that the amplitude of the pulse increased with the increment of rolling angle and the width of the positive (negative) pulse is proportional to the duration of eye ball rolling process. The gain of preamplifier used in this system is 10 and of main amplifier is 800. A bandpass filter of 1-100 Hz has been used to remove the base-line higher frequency interference. This paper also provides mathematical expressions for 50 Hz narrow notch filter and algorithms for blink detection and eye movements detection.

As per this paper, to count blinking in a specified time conveniently, normalised signals should be processed derivation first. After derivation, blinking can be recognised easily and counted in a numerical way. The position of the first pulse is named 'start_point'. When the second pulse comes, its position named 'end_point'. If the value (end_point - start_point) which named DIF, is smaller than 1500 (sample at a rate of 1kHz, so the time is 1.5 s), the system will identify the process as a blinking action and the number of blinking adds 1.

S Venkataramanan, P Prabhat, S R Chaudhury, H B Nemade, and J S Sahambi (2005) presented instrumentation for EOG acquisition and signal processing. An AD521 instrumentation amplifier has been used in this system which has proper amplification (25) and bandwidth, high input impedance, high CMRR, low noise, and stability against temperature and voltage fluctuations. After this a non-inverting amplifier with an amplification of approximately 510 is used. Combinational logic system has been used for determining eyeball position. It requires proper threshold values

Andreas Bulling, Daniel Roggen and Gerhard Troster (2009) introduced a novel embedded eye tracker based on electrooculography (EOG). This self contained wearable device consists of goggles with dry electrodes integrated into the frame and a small pocket worn component with a DSP for real time EOG signal processing. It can store data locally for long-term recordings or stream processed EOG signals to a remote device over Bluetooth.

The final design of wearable EOG system consists of two components: Goggles with integrated electrodes and a signal processing unit (called WEPU, Wearable EOG processing unit). The complete system weighs 188g and is powered by a 3.7V/1500 mAh Li-polymer battery. The average power consumption is 800 mW and depends upon the destination where data is to be stored. The electrodes are mounted on spring steel to ensure permanent skin contact and constant contact force. The instrumentation amplifier used has CMRR rating of 110 dB and $10^{10} \Omega$ input impedance. To further increase the CMRR, a Driven Right Leg (DRL) circuit is used. It has a dsPIC microchip and contains dedicated 24-bit delta sigma ADCs for each channel of EOG, a Bluetooth, and an EPROM. The main advantages of dsPIC over other microcontrollers is its suitability for efficient real time signal processing. To achieve a resolution of $2.5 \mu V/\circ$ for EOG signals with a dynamic range of 600 mV the ADCs have to provide a minimum resolution of 18-bit. It allows a sampling rate upto 250 Hz.

In this paper, techniques used for denoising (using median filter), motion artefact compensation (using adaptive filter), blink detection (using template matching technique), saccade detection (using Continuous Wavelet Transform – Saccade Detection), blink removal (removal of Presaccadic blinks, Intersaccadic blinks and Postsaccadic blinks), and eye gesture recognition (template matching technique) are also discussed.

R Barea, L Boquete, M Mazo, E Lopez, and L M Bergasa (2000) presented a new method to control and guide a mobile robot. To detect saccadic eye movements and fixations a neural network (RBF) is used. A Radial Basis Function Neural Network, which has only one hidden layer, is used in this work to detect where one person is looking as a function of detected EOG. The network inputs are the present EOG signal and the last nine delayed because a RBF tapped delay network is used and the network output is the angle of the gaze desired. Finally, the output of neural network is used to control an electric wheelchair by generating various EOG codes.

It is necessary to eliminate the shifting resting potential (mean value) because this value changes with time. To avoid this problem an ac differential amplifier with a high pass filter with a cutoff frequency at 0.05 Hz and relatively long time constant has been used in this paper. The amplifier used has programmable gain ranging from 500, 1000, 2000, and 5000.

Nobuyuki Itsuki, Masashi Yamada, Masanori and Kayo Shinomiya (2004) discussed an improved method for measurement of Electrooculogram (EOG). The method measuring the relative potential between the inner canthus (nasal) and outer canthus (temporal) is described here. In this method total 6 electrodes are used. The plus electrodes put on the inner or outer canthus of the eye and the minus electrodes put on the earlobes as a basal level of potentials. The earth points of the differential amplifier put on the backs of subject's hands.

From the measurements, it has been observed that the outer canthus potentials of both eyes are larger in comparison with inner canthus potentials. Moreover, the waveform of EOG at the outer canthi invert in phase against inner canthi. As the cornea of the right

eye comes away from the inner canthus electrode when the right eye abduct, the cornea closes in the outer canthus electrode on the contrary. Consequently, the waveform of inner canthus potentials reverses against the outer canthus potentials. The EOG was in proportion to the amplitude of the eye movement within about $\pm 35^\circ$. The small saturation occurs over $\pm 35^\circ$.

R Barea, L Boquete, M Mazo, and E Lopez (2002) designed an eye-control method based on EOG to develop a system for assisted mobility. One of its most important features is its modularity, making it adaptable to the particular needs of each user according to the type and degree of handicap involved. The main functional blocks of this system are power and motion controllers, human machine interface, environment perception, and navigation and sensor integration. It has been proved that the derivative of the EOG signal allows us to determine when a sudden movement is made in the eye gaze and this variation can be easily translated to angles.

In this research, the measured EOG signal has been used for wheelchair control. Important points to be considered for the implementation of this system are guidance strategy, self-confidence, interface comfort, tiredness, comfort for generating trajectory, and degree of concentration. It is observed in this study that as much as bigger is the degree of freedom and movements that the user can carry out, easier and more comfortable it is the guidance of the wheelchair and it is the system preferred by the user.

Antti T Vekhaoja, J A VerNojd, J O Lekkala, and Jari A Hyttinen (2005) discussed a wireless head cap for measurement of EOG and facial EMG signals. The head cap is made of fabric and used to hold the electrodes. A two-way wireless data transmission link operating at licence free 2.4 GHz frequency band has been used for transferring 16-bit measurement data, sampled with 1 kHz frequency. Wireless system provides high noise immunity and user safety. The electrodes are manufactured of conducting silver coated fibers by embroidering. These electrodes require no skin preparation, only the electrodes are to be moisturised with a sufficiently conducting saline solution. The size of each electrode is 20×20 mm.

The total gain of the EOG channels is 40. A low gain value is needed because the measured signal contains a DC-component and a high gain could easily saturate the amplifier. DC-measurement is obligatory to estimate the gaze direction. In an AC-measurement only the movement of eyes (change in direction) could be really measured. The problem in DC-measurement is that the difference in the half cell potentials of the electrodes will also be amplified. This difference may sometimes be quite high especially with fabric type of electrodes. The measured EOG signal is digitally low pass filtered at 10Hz cutoff frequency afterwards with PC by using a 4th order Butterworth filter.

Min Lin and Bin Li (2010) proposed a wireless EOG-based human computer interface. It consists of EOG signal acquisition, EOG filter and amplifier, ARM microcontroller and Zigbee wireless module. In this scheme, an embedded microcontroller is adopted to perform a wireless control of a toy car. On the embedded ARM platform, algorithms are programmed to perform the software filtering, feature

extraction, eye gestures recognition and command encoding. Finally, the control command corresponding to the eye gesture is transmitted to model car by Zigbee wireless communication module. The band pass filter used in this scheme, composed of one second-order high pass filter with variable gain and one fourth order low pass filter. Its bandwidth is in the range of 0.01-42 Hz.

A Bulling, D Roggen and G Troster (2009) presented an embedded eye tracker for context awareness and eye-based human-computer interaction: the wearable EOG goggles. It consists of goggles with dry electrodes integrated into the frame and a small pocket worn component with a powerful microcontroller for EOG signal processing. The system is also used for saccadic eye movements. Simultaneous movements of both eyes in the same direction are called saccades. Typical characteristics of saccadic eye movements are 400°/s for the maximum velocity, 20 μ V for the amplitude and 80 ms for the duration.

To compensate for EOG signal artifacts caused by physical activity and changes in ambient light and accelerometer and a light sensor need to be used. On the wearable EOG goggles, blinks are detected with a template matching approach: using a template created manually from example blinks of different persons, blinks are detected by shifting this template over the vertical EOG signal component. For those segments of the signal where the similarity to the template is higher than a defined threshold, a blink is detected and removed from the signal. Saccade detection is performed using the so-called Continuous Wavelet Transform- Saccade Detection (CWT-SD) algorithm. The CWT-SD first computes the continuous 1-D wavelet coefficients from the signal at scale 20 using Haar wavelet. A saccade is detected for all samples where the absolute value of the coefficient vector exceeds a calibrated threshold.

Dinesh Kumar (2002) determined the reliability and limitations of EOG signal for determining the angle of eye gaze for controlling a computer. In this work, for EOG acquisition Nessler Med – Technin Austria universal Ag-AgCl electrodes, Ref 1066 are used. The acquisition system has been programmed to sample at 1000 Hz with the anti-aliasing filter at less than 500 Hz. The AC coupled amplifiers has been programmed with a time constant, T_c of 15s – an effective 0.01 Hz high pass filter.

To determine the bandwidth of EOG useful for HCI, the power spectral densities of several EOG traces from each subject are analysed to determine frequency content. The EOG data is initially decimated and passed through a 12th order 5 Hz Butterworth LP filter and histograms of the unfiltered and filtered data are plotted.

The change of voltage for each step of eye movement was determined by calculating the mean and median of the initial level and final level for each EOG transition. The absolute difference of the means and the medians were tabulated. A linear region was indicated between +45° to -45° for horizontal eye movement and -38.7° to +30.7° for vertical eye movement.

From this study, it has confirmed that it is possible to derive signals for the generation of spatial controls from EOG recordings and to have confidence in the

reliability when used in a HCI. It has been found that for restricted ranges of eye gaze angles that EOG and eye gaze are related by a simple linear mathematical expression.

rikha, A Bhandari, and T Gandhi (2007) introduced a simple and novel technique for classification of multiple channel EOG. The classifier is based on Deterministic Finite Automata (DFA). The system is capable of classifying sixteen different EOG signals. Five silicon-rubber electrodes of impedance below 10 Kohm, placed around the eye to obtain EOG signals. To find out frequency contents present in the EOG signal, its FFT is obtained which shows that the prominent frequency components are upto 40 Hz where as the maximum frequency components lie around 4 Hz.

Four threshold levels (THH, THL, TVH, and TVL) have been used for classification EOG signal in this paper. Two threshold levels are for horizontal EOG and two are for vertical EOG signal. Symbols [CV+, CV-, CH+, CH-] are positive/negative region above/below threshold levels in vertical/horizontal channel respectively. Symbols [CV0, CH0] are rest zone area in vertical/horizontal channel respectively. These signals are fed as primary input to the Peak Detection Deterministic Finite Automata (PDDFA), which based on these signals identifies positive/negative peaks and rest zone in EOG signals obtained from horizontal/vertical channel. The output of PDDFA is mapped onto set $P \subseteq \{V+, V-, H+, H-\}$ used as input by the Movement Classifier Deterministic Finite Automata (MCDFA) to determine which eye movement is performed by the user, from its set of sixteen different eye movements. A scheme for EOG signal classification is proposed in this paper which can be used as a mathematical model for development of EOG based medical instrumentation where device control is the main objective. The sixteen classified signals provide a large range of input signals, enabling EOG to serve as a primary source of input to many multimode controllers. The proposed scheme can be universally applied for development of embedded systems requiring real time EOG signals as primary input.

B Nouredin, P D Lawrence, G E Birch (2007) presented a new time-frequency analysis of ocular artifacts found in the EOG. This paper provides a time-frequency analysis of blinks and eye movements (specifically large, rapid movements or “saccades”) in an EOG signal measured at a very high sampling rate. For EOG measurement, electrodes are attached at the right outer canthus and nasion for horizontal EOG (HEOG) measurement, and above and below the right eye for vertical EOG (VEOG). Both signals are amplified with an amplifier having a nominal gain of 1100, equipped with a second order Butterworth low-pass filter with a cut off frequency of 12 KHz. The data is sampled at 24.5 kHz using a PC and 12-bit A/D convertor board.

Each subject is instructed to perform four tasks. During the first task, a 4×4 grid of numbers are displayed on the computer monitor. Each number is sequentially highlighted for two seconds, and the subject is instructed to follow the highlighted number. During the second, the grid is shown, but this time the subject is instructed to blink at least once during a two second interval. During the third task, a small red dot

was shown sequentially on each corner of the computer monitor, and the subject was instructed to follow the dot. During the final task, the subject is instructed to look at the ceiling, at the floor and back up at the ceiling five times in a row, and then to look at the far left, the far right and again the far left five times in a row. Each eye movement is guided to last about two seconds.

Once the two EOG signals are digitized, two digital filters were applied to each signal: a 60Hz notch filter to remove the line noise, and a 1000 Hz 2nd order Butterworth low-pass filter. The spectrogram of each signal is then calculated using a Hanning window. After visual section of several trials, it has been determined that no significant power existed beyond 200 Hz for any of the collected data. Thus, for each time epoch in the spectrogram the power in the 0.1-200 Hz range is examined. On average over all subjects, frequencies up to 54 Hz for blinks and up to 13 Hz for saccades must be considered to account for 95% of the power at any given time.

Y Kim, N Doh, Y Youm, and Y K Chung (2001) proposed an ideal Velocity Shape signal processing algorithm to extract position data where the eyes are focusing on from the noisy and drift included EOG signals. Additionally, an efficient algorithm for the detection of various eye-lip movements such as blink and wink is suggested. EOG signals are in micro order voltage level and include non-linear drift and various external noises. To circumvent these, a signal processing algorithm based on "ideal velocity shaped" is proposed in this paper. The algorithm detects rapid eye movements and eye-lip movements (for the detection of left/right blinks and winks).

The point where the eyes are focusing on can be extracted from the eye rotation angle data. This angle data normally detected by saccadic signal or its velocity profile. Yet the saccadic data includes non-linear drift. The non-linear drift consists of hardware noise, external noise and muscle fatigue noise. This drift makes it difficult to estimate accurate eye angle data. To remove its effect, the ideal velocity shape algorithm, which minimizes the error between actual and ideal velocity profile, is proposed in this paper. Ideal velocity profile can be constructed from the definition of saccadic motion. It can be calculated as six order polynomial equation. This paper also explains characteristics of wink and blink signals and velocity profiles of left and right wink signal.

K Yamagishi, J Hori and M Miyakawa (2006) developed a communication support system controlled by eye movements and voluntary eye blinks. Horizontal and vertical electro-oculograms were measured using two electrodes attached above and beside the dominant eye and referring to an earlobe electrode and amplified with AC coupling in order to reduce the unnecessary drift. Eight directional cursor movements and one selected operation were realised by logically combining the two detected channel signals based on threshold setting specific to the individuals.

A device is proposed in this paper which outputs nine kinds of intentions: movements in 8 directions (up, down, right, left, up right, up left, down right and down left) and one selection, by transforming two channel AC-coupled EOG signals detected by three electrodes. Eye movements operate cursor in eight

directions and a selection is indicated by a voluntary eye blink. A quick and simplified selection can be done by cursor movements alone, without the need for automatic scanning selection. The paper also includes logical combinations using EOG signals for eight different eye movements. A sequence of voluntary eye closing and opening used to indicate selective intentions. EOG peaks are detected using upper and lower thresholds of the vertical channel V (V1 and V2) and the upper and lower thresholds of the horizontal channel H (H1 and H2). These thresholds should be determined beforehand. When the EOG potential exceeds one of these thresholds, the output assumes ON. The setup time is the time interval between the first and second peak of EOG signals. All thresholds automatically switch to OFF after intention is output. The optimum values for the thresholds and the setup time are determined by trial experiments. The thresholds and the setup time of EOG signals should be used for distinguishing the intentional signals from artifacts such as eye blink and ordinary saccade eye movements.

A cursor on the letterboxes of the screen keyboard moved up step by step in response to subject's intention. The low-cut and high-cut frequencies of the analog bandpass filter built in EOG system were 0.53Hz and 5 Hz respectively. The sampling frequency is set at 100 Hz. In this system, thresholds play an important role in improving system performance. When the threshold is set high, few of the detected signals exceeds the threshold, resulting in poor accuracy. In contrast, when the threshold is set low, the error rate increases due to unintended output. In particular, the potential change observed during involuntary eye blink intended to be misconstrued as up direction output.

A bhandari, V Khare, M Trikha, and Sneha Anand (2006) presented a novel and simple technique for signal conditioning of EOG signals which primarily involves denoising corrupted signals and post-processing for signal enhancement. The non-stationary and time-varying EOG signals are processed using methodologies anchored on multi-resolution analyses and the Wavelet Transform theory. Coiflet wavelets are used for subsequent removal of noise from the corrupted EOG signals using the concept of coefficient thresholding. SURE (Stein's unbiased risk estimate) is used for threshold selection. Haar based wavelets of higher orders are used for post-processing of EOG signals. This research shows that SURE based threshold selection for de-noising the EOG signals improves the SNR by 49.65%.

Yingxi Chen and W S Newman (2004) discussed the design and implementation of an electrooculography based gaze-controlled robotic system. It consists of signal acquisition, pattern recognition, control strategy and robot motion modules. The user's eye gaze movements are reconstructed from EOG signals, which are recorded from the face in real time. The eye movement patterns, e.g. saccades, fixations and blinks are detected from the raw eye gaze movement data by a pattern recognition module. The control strategy module interprets the user's intention from the eye movement patterns based on predefined protocols. A horizontally mounted robot, emulating skeletomuscular configuration of the human arm, is

controlled by the robot motion module to execute the interpreted user intention. In this experiment, disposable EOG electrodes are used and a pair of CED 1902 amplifier modules (high resolution, good CMRR) are used to amplify electrode signals. The amplifiers included options for gains, biases and filtering. The amplified analog EOG signals were sampled at 2 kHz and were processed to reconstruct the subject's eye gaze. Experiments showed that when the gaze vector was within the angular range of $\pm 50^\circ$ horizontally and $\pm 30^\circ$ vertically, the recorded EOG signals were almost proportional to the eye gaze displacements. Additional experiments showed that cross-talk effects were stronger at higher and lower elevation angles.

Incoming data is processed within a moving window of a duration threshold (100 – 200 ms). Initially the window is empty. The data stream goes through this window as a queue. The dispersion of the points in the window is calculated using the given formula. If $\text{dispersion} < \text{threshold}$: a fixation point is found.

Else: a saccade point is found.

The algorithm detects fixations and transforms the continuously changing waveform into several discrete fixations and saccades. Two parameters used in this algorithm, dispersion threshold and duration threshold, are highly interdependent. Therefore, the dispersion threshold and time threshold should be adjusted and tested carefully for a specific application. Also, Amplitude of various blinks viz unconscious blinks/blink reflex, normal blinks, strong blinks and intentionally strong blinks is defined in this paper. If we can distinguish intentional blinks, we can use such cues within a control algorithm. Therefore, to recognize blinks from the eye movement data stream, a moving window, of spike height (σ) and maximum width at 10% of height (ω), is defined in this paper.

In this experiment, two controller schemes (position and velocity based) are devised based upon EOG. To enter or exit a particular mode, intentional blinks and fixations are used. The controller was interfaced to a Kawasaki JS-10 robot for its evaluation.

K Takahashi, T Nakauke, and M Hashimoto (2007) presented a simple gesture recognition algorithm to estimate the user's thinking from EOG and EMG signals, and a control method that combined EOG gesture recognition result and EMG gesture recognition result multimodally is considered to achieve a hands free manipulation system. Algorithms to transform EOG signal into a rectangular signal of amplitude A, to recognize eye movement direction (left or right), to find wrinkles in the forehead (from EOG), and to find jaw gestures from the EMG signal have been discussed in this paper. In order to achieve the hands-free manipulation using the gesture recognition results of the bio-potential signals obtained by the HCI, it is important to consider the combination of the EOG and EMG signals. By using the gesture recognition result of EOG signal four states (left/right, on/off) can be controlled. Although two states (on/off) can be controlled by using the gesture recognition result of EMG signal, a gesture of twice jaw closing as a double click motion is introduced to increase the degree of freedom in control. To investigate the effectiveness of utilizing the proposed interface system, it is applied to control a moving application in

3D virtual space on the hands-free manipulation system. Experimental results confirmed the feasibility and usefulness of the interface system.

T Pander, T Przybyla and R Czabanski (2008) presented a new method for eye blink detection based on detection function. Parameters of eye blinks which can be extracted from EOG signal are for example blink frequency (blinks/min), amplitude or eyelid opening level and duration. It was reported that blink latency, the time interval between stimulus onset and blink onset, was delayed by cognitive processes and motor responses.

EOG signal can be recorded in a horizontal and a vertical direction of eye's movements. This requires nearly six electrodes which are placed in front of a human face. This system is based on the BIOPAC MP-35 unit. Blink detection using detection function follows (a) a low pass filtering is realized with the 32 order low pass FIR filter and the cut off frequency is 30Hz. (b) signal is filtered by the high pass FIR filter and the cut-off frequency is 1.5 Hz. The Chebyshev window with 20 decibels of relative sidelobe attenuation is also used. The order of the filter is 62. (c) A low pass filtering is implemented, the order of filter is 60, the cut-off frequency is 8 Hz, and the Chebyshev window with 20 decibels of relative sidelobe is also used.

The next step is a non-linear operation and smoothing of the obtained signal with a moving average filter.

$$y(n) = \frac{1}{2N+1} \sum_{i=-N}^{+N} (x_f(n+i))^2$$

where: $x_f(n)$ is the output signal of bandpass FIR filtering, $2N+1$ is a length of the moving average filter. Proper selection of value of N guaranties that detection function has only one peak. In order to avoid fluctuations in the detection function the first derivative of the detection function waveform is smoothed by moving average (MA) filter. The detection of double blink is performed as follows: (a) creation of the detection function for EOG signal. (b) Location of blinks in time domain. (c) Checking, does in short time interval (0.6s) exist one blink or two, fast blinks?

DISCUSSION

Several practical devices use eye movements as communication support. Eye movements can be obtained by different methods such as EOG, InfraRed OcculoGrapy (IROG), VideoOcculoGraphy (VOG), scleral coil (SC) etc. The video-oculogram, which detects eye movements from pictorial images of the eyeball, is expensive because it requires a video camera to film eye movement in real time. Eye movement detection using infrared reflection of the cornea is difficult to use over a long period because the eyes tend to become dry and fatigued. The sclera reflection method detects eye movements using the differential reflectivity of eyes, but its accuracy is not sufficient for practical application. In this method, a part of looking is prevented by the devices. Also, Search coil method is an invasive technique.

Several methods have been proposed in the literature that uses EOG occurring as a result of eye movements. Electrooculographic (EOG) method is preferred for eye tracking because of the following features of EOG: (i) EOG signals can be acquired using cheap and simple electrodes. (ii) Experiments showed that when the gaze vector is within the

angular range of $\pm 50^\circ$ horizontally and $\pm 30^\circ$ vertically, the recorded EOG signals are almost proportional to the eye gaze displacements. (iii) EOG signals are very fast, thus real time implementation is possible. (iv) The system is operated by human's eye signal command, which contains human decision i.e. intelligence. (v) In comparison to VOG, cameras and other associated devices are costly as compared to devices required for EOG. (vi) The eyes are the origin of a steady electric potential field, which can also be detected in total darkness and if the eyes are closed. (vii) Measurement and processing of the EOG signal are easier than other biological signals like EEG ($<100\mu\text{V}$) signals, because, compared with EEG signal, EOG signals have greater amplitude. (viii) Horizontal and vertical eye movements and eye blinking generate easily distinguishable EOG signals, even in time series, without performing processing. Hence, they do not need to be averaged or to use other sophisticated signal processing methods and classification algorithms, which EEG signal processing requires.

Different researchers define different amplitude and frequency ranges of the EOG signal. The broad range of magnitude of EOG signal is in the range of 50-3500 μV , useable frequency range is DC to 40 Hz, with 4Hz as peak frequency.

The record of EOG signal has several problems too. (1) The signal is seldom deterministic, even for the same person in different experiments. It is a result of 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 luminance etc. (2) Another factor affecting the response of the system is saccadic eyeball motion. It describes the quick jumps of the eye from one fixation point to another. The speed may be 20-700°/s. This problem is taken care by the neural network. (3) The subject may also feel uncomfortable if the EOG electrodes are used continuously for a long time. (4) Also during an eye blink, the eyeballs shoot upwards and this should therefore result in some potential difference being generated across the Vertical (V) channel electrodes. Therefore, V channel signal is more affected by eye blinks.

Following measures can be taken to get relief from the above mentioned problems involved in Electrooculography: (1) Shifting resting potential (mean DC value) can be removed by using Silver-Silver Chloride electrodes, which produce low level of junction potential, motion artifacts and drift in DC level. (2) Skin preparation and winding of the electrode leads also help to mitigate the effect of artifacts and noise. An emery paper can be used to remove poorly conducting dead skin layer before the placement of the electrodes. (3) Electrode lead pairs are bound together (top-bottom and left-right) in order to prevent interference such as the power line signal from being magnetically coupled with the circuit. (4) An ac high-gain differential amplifier (1000-5000) is used, together with a high-pass filter with cutoff frequency at 0.05Hz and relatively long time constant and a low pass filter with cutoff frequency at 35Hz. The design consideration for this amplifier ought to include proper amplification and bandwidth, high

input impedance, high CMRR, low noise and stability against temperature and voltage fluctuations.

Electrooculography has wide range of applications like wheelchair control, video games, rehabilitation, driving simulation, fatigue detection, cognitive science, marketing research, eye typing and many more.

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