EYE GAZE FOR COMPUTER CONTROL

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Abstract: This paper reports the results of experiments that were conducted with five subjects to determine the reliability of the use of Electro-ocular gram (EOG) for controlling computers. Experiments included vertical and horizontal eye motion. Consideration was given to identify a relationship between the angle of the gaze and signal that could be applied to cover all test subjects and generate the required spatial control signals. The results obtained are encouraging. An assessment of the data has concluded that the EOG can be successfully utilised for spatial control applications. The study recommends the choice of bandwidth for the recording, inter and intra subject reliability and difference between the vertical and horizontal movement control.

1 INTRODUCTION

There has been extensive research in the field of developing control systems for improved man machine interface to assist the entry of computers in all gadgets and equipments. This has resulted in the development of a variety of systems that have applications in fields such as robotics, defense, computer games and medicine. An important part of these systems is the front-end module that accepts the command from the human operator. Improved and natural 'Man Machine Interface' (MMI) systems can open the world of virtual reality, control of machinery without physical contact and increased independence from disabilities.

Human have an extremely well developed vision control system that can track an object with the help of dynamic corrections and feedback. This is a result of movement and shape change of the eye.

Electro-oculargram (EOG) is the electrical recording from the outside of the eye and corresponds to the direction of the eye. There have been attempts by researchers to use EOG as a means for the user to control the machine. While the basic system is extremely simple, the difficulty is in the lack of reliability of such a system where there often is a large variation with time.

It is important to realize the limitations, potential errors and possible techniques to improve the system for identifying applications of EOG based computer control systems. There are several possible sources of error that affect the accuracy of the HCI using EOG signals. The angular displacement between head and torso, physiological disorders, an individual perception of gaze point, and movement of the individual relative to a known reference point are some of these. While a system level approach to identify the system reliability provides the users with simple answers, it is not possible to identify individual sources of error and determine ways of improvement. It is important to determine the effects of error for static positions and dynamic movement of an individual's gaze with and without visual feed back. With suitable controlled experiments with pre-defined gaze targets for test subjects to fix their gaze on, the errors can be investigated.

This paper reports the work conducted to experimentally determine the sources of error and effect of these in EOG recordings for determining the suitability of the use of EOG for MMI. The aim was to determine the limitations of the use of EOG for developing a system that would enable the disabled to control machines and computers with the help of their eye movement.

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2 METHODOLOGY

Experiments were conducted where EOG data was acquired from various test subjects while they fixated their gaze on specific target points. Specific features of the recorded EOG were extracted during analysis to assist with the selection of a method to classify the angular movement based on EOG and to generate an output that is representative of the required movement.

The test environment was modeled as a series of target points in 3D space. Each target point was on the surface of a sphere with the human subject effectively at the centre of the sphere. The spatial orientation of the subject's eyes, as they fixate on a specific target point, could then be determined using the detected EOG relative to the origin of the sphere.

2.1 Apparatus

Nine (9) target points were positioned on the circumference of a circle of known radius, as shown in Figure 2 using firm vertical supports. A reference target point was positioned directly forward of the test subject's eyes, at a specified eye height, allowing a known starting point for all EOG measurements in the horizontal and vertical planes.

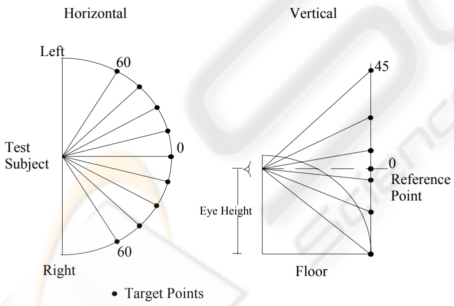

Figure 1: Configurations of Targets

For monitoring the horizontal movement, the targets were located 15 degrees apart relative to the center of the circle and located on the horizontal plane at a specified eye height. The target points at the extremes were located at 60 degrees either side of the reference center target point. Vertical test points were positioned on the reference pole to give five (5) equally spaced sections between 45 degree above eye level and the target point at floor level, below the reference pole as shown schematically in Figure 2. To maintain commonality of test target angles, test subjects were seated so that their eye height from the floor was approximately the same.

2.2 Signal Acquisition

EOG signals were recorded from five subjects, consisting of four males and one female. The eye physiology of each subject was not considered for this investigation and therefore any effects can only be surmised.

Five disposable electrodes (Nessler Med – Technin, Austria, universal Ag/AgCl Ref 1066) were attached as shown in Figure 3 were put on each of the subjects. Two electrodes were attached to the outer canthi of each eye and formed a differential electrode pair for horizontal movement. Two electrodes were placed above and below the right eye to form a differential electrode pair for vertical movement. A fifth electrode was place at the centre of the forehead as a common. Prior to attachment of the electrodes, the skin was cleaned to remove contaminates and improve signal reception.

The integrity of the acquisition system was checked prior to recording using, sinusoidal signals of known amplitude and frequency from a signal generator. A short circuit was used to determine offset levels. The signal generator and the short circuit were interfaced to a, MR01B, analog to digital acquisition card that was installed as part off an AMLAB system (a Computer Based Instrument Emulator).

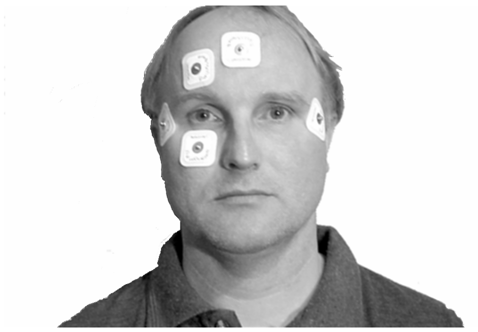

Figure 2: Placement of Electrodes on Test Subjects

Amplifier gain and offset settings were determined for each subjects after consideration of expected full-scale levels recorded during preliminary testing. During recording sessions, test subjects were instructed to minimise the relative movement of the torso and head, as well as other facial movements. To determine the relationship of EOG with the angular displacement of the eyes, eye movements relative to the reference point were conducted. To ensure stable data, a minimum of 5 seconds of EOG signal was recorded while fixating on the reference target. At other target points, the EOG was recorded for approximately 2.5 seconds.

The system was programmed to sample at 1000Hz with the anti-aliasing filter less than 500Hz. The AC coupled amplifiers were programmed with a time constant, T_c of 15 seconds - an effective 0.011Hz high pass filter. The EOG data along with the eye movement data were recorded onto a file.

3 ANALYSIS

The data files were read into MATLAB version 6 for analysis. To determine the bandwidth of EOG useful for HCI, the power spectral densities of several EOG traces from each subject were analysed to determine frequency content. The EOG data was initially decimated and passed through a 12th order 5Hz Butterworth LP filter and histograms of the unfiltered and filtered data were plotted. The filtered data was differentiated to determine the accuracy of the initiation and end of eye movement

The filtered EOGs for each subject were analysed to extract statistical data as an indicator of the reliability of the EOG. 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. The respective means derived from the EOG signals were divided by the expected angular displacement of the eyes producing a pseudo system resolution, in Volts/Degree.

The cumulative amplitude {histograms} sets were statistically analysised (mean, median and standard deviation), to assist with the study of EOG reliability as eye an gaze indicator while determining the reliability of EOG for HCI. Linear regression was applied to determine a suitable mathematical expression. The deviation of the EOG from the mean were plotted against the angle of the eye gaze. This was repeated for vertical and horizontal movements.

The analysis was repeated after filtering the recorded data using a 2nd order 1H z Butterworth LP filter and then using no filter.

Table 1. Linear Regression Analysis – Horizontal Eye Movement

	Eye Gaze Range	
	±60º	±45º
R squared	0.9788	0.9921
$R^2_{adjusted}$	0.9782	0.9918
standard error (σ_{model})	0.5423	0.2902
F computed	1751.022	3512.485
Intercept	0.0111	-0.023
Angle/ V of EOG	0.0873	0.0969
Data Points	40	30

Table 2. Linear Regression Analysis – Vertical Eye Movement

	Eye Gaze Range	
	$-40.9 \leq \theta \leq 30.7$	$-38.7 \leq \theta \leq 30.7$
R squared	0.9796	0.9884
$R^2_{adjusted}$	0.9787	0.9878
standard error (σ_{model})	0.3672	0.2507
F computed	1105.35	1613.72
Intercept	0.0424	-0.0221
Angle	0.1002	0.1060
Data Points	25	21

4 RESULTS

From the data (Figure 3 and 4) it is observed that there is a region where the eye gaze angle and the value of EOG are directly related. In this region, the angle of the gaze can be estimated from the EOG with good reliability. A linear region was indicated between ±45 degrees, for horizontal eye movement, and between –38.7 and +30.7 degree for Vertical eye movement. The data for eye gaze angles versus measured EOG are plotted in Figures 4 and 5. The figures show the standard deviation bounds on specific EOG data points and show increasing variance as eye gaze angle approaches its limits.

Results from linear regression analysis, support the reliability of EOG to estimate eye gaze angle for horizontal and vertical eye movement. Tables 1 and 2 tabulate specific results of the linear regression analysis of the EOG amplitude, after filtering by a 1Hz 2nd order Butterworth low pass filter. Similar data was obtained, not tabulated, after linear regression analysis was conducted on EOG data filtered by a 5Hz 12th order Butterworth low pass filter and using no filter. The 95% confident interval for the predicted eye gaze angles were observed to be improved when analysis of the vertical and horizontal eye movement EOG data was restricted to the apparent linear region.

5 OBSERVATIONS AND DISCUSSION

Linear regression analysis of the EOG data resulted in good correlation supported by F-test confirmation, that the mathematical expression adequately modelled the relationship between eye gaze angle and EOG. As this occurred with out the use of visual feedback by the test subjects to adjust their point of eye gaze, improved reliability can be expected when feed back is implemented.

A finite intercept from the linear analysis has indicated that either experimental or physiological artifacts were present during the acquisition phase. These artifacts can be manifested in various ways. From the results of analysis it was observed that:

- There was a small DC drift when the subject is at reference point.
- There was a degree of hysteris in the EOG recording when the eye gaze shifts from right to left, or top to bottom extremes to the reference point.
- The variations of the EOG increased at large angles - where the vision boarded the peripheral vision.
- Differentiation of EOG signals shows distinct pulses where voltage transitions occur on the EOG trace. It was however observed, that if transitions were to close they tended to merge.
- Independence of distance from a target was assumed for this study, this may not be the case. A target may not be precisely at the center of an individual's eye gaze, center of FOV, when fixating on a target.
- A high order LP Butterworth filter reduces the confidence intervals. A low cut off frequency reduces signal information.
- The existence of a linear region in the relationship between eye gaze angle and EOG, confirmed during linear regression analysis, ensures that a simple relationship can be implemented. The size of the linear region also ensures that a usable range of eye gaze angles can be utilized in a HCI. The simple linear relationship also ensures that confidence can be assured in the reliability when implemented in a HCI.

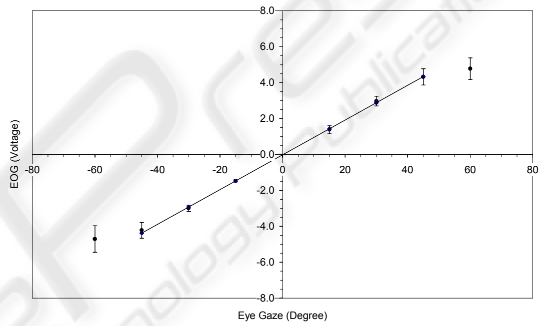

Figure 3: EOG Horizontal Movement versus Eye Gaze Angle

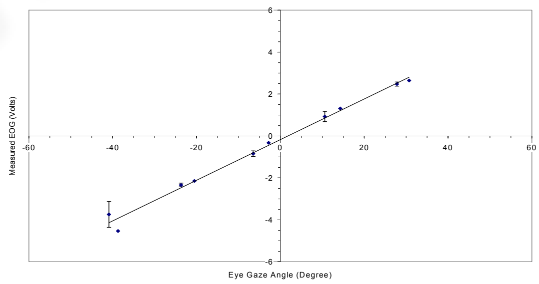

Figure 4: EOG Vertical Movement versus Eye Gaze Angle

6 CONCLUSIONS

Based on this study, it The current study has confirmed that it is possible to derive signals for the generation of spatial controls from electro-oculography 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. It was also found that 95% confidence intervals and the correlation between EOG and Eye Gaze angle were improved.

Greater confidence in the reliability of an HCI utilizing EOG data is assured with further reduction of system artifacts that result in errors and appropriate methods of calibrating the HCI system for individuals. Improved reliability of the HCI system would also been obtained by implementing visual feedback allowing fine adjustments to target position.

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