An Eye Tracking Computer User Interface

Arie E. Kaufman, Amit Bandopadhay, and Bernard D. Shaviv
Computer Science Department
State University of New York at Stony Brook, NY 11794-4400

Abstract

We describe an inexpensive eye movement controlled user interface for 2D and 3D interaction. It is based on electro-oculography (EOG) rather than the very expensive reflectance based methods. We have built the hardware and software to demonstrate the viability of EOG for human-computer communication. Our experiments indicate that EOG provides the basis for an adequate input interaction device. Being very inexpensive, the system is applicable for many virtual reality systems and video games as well as for the handicapped.

1. Introduction

Many computer interface hardware and software designs, such as mice and touch screens are a nice improvement over keyboard for some tasks, but cannot be utilized by quadriplegics. Yet, it is the physically disabled that have the most to gain from and the greatest dependence on computer and electronic aids for work, recreation, environmental control, and even for the most basic communication needs. Although several computer interfaces have been devised for the handicapped (e.g., Erica [Hut89], EWP [YaF87]), there are not any inexpensive and non-intrusive systems that deliver the true power and ease of today's computers.

Our main goal is to develop an inexpensive hardware-software system for use in the most challenging cases: the estimated 150,000 disabled persons able to control only the muscles of their eyes. This encompasses the construction of an EOG eye-tracking hardware and its fine-tuning in software, as well as the definition of acknowledgeable eye behavior and the establishment of basic protocols governing on-screen object selection and manipulation. Such a device can also be used for many virtual reality systems and video games.

Electro-oculography depends on the corneoretinal potential that creates an electrical field in the front of the head. This field changes in orientation as the eyeballs rotate. The electrical changes can be detected by electrodes placed on the skin near the eyes. In clinical practice, the detected voltage changes are amplified and used to drive a plotting device, whereby a tracing of eye position is obtained.

It is possible to obtain independent measurements from the two eyes. However, the two eyes move in conjunction in the vertical direction. Hence, it is sufficient to measure the vertical motion of only one eye and the horizontal motion of both eyes. If the orientation of the eyes is measured, it is possible to locate the 3D position of a fixated target object by triangulation.

The signal quality of the EOG output data has been well documented in neurophysiology and in electronystagmography (ENG), the study of eye movements [Coh86]. Straightforward signal processing steps have been devised to condition the data so it can be reliably interpreted by a technician. Some of the noise patterns, such as the line frequency, can be easily removed using a notch filter. Other noise artifacts are mostly transient, caused, for example, by the turning of an electrical switch, contraction of the facial or neck muscles, slippage of the electrode due to sweat and eye blinking.

Our research has been focusing on creating a workable eye controlled user interface. In a 19" monochrome display, a typical pixel configuration is 1024×768 at 72 dpi, for an active display area of 14.22×10.67 inches. When centrally viewed from a distance of 2', this region subtends an angle of 25° vertically, and 33° horizontally. Maximum EOG or reflectometry resolution is about 1-2 degrees [YoS75]. With menu boxes generously separated by 3 degrees, the 19 inch display still has sufficient room for a 10×4 matrix of directly selectable keys – leaving the bottom half of the screen available for a text display area and other controls.

Recognizing blinks as legitimate actions distinct from eye movement would also allow their use for rapid invocation of important global commands, such as calling an attendant, and in each module as context-sensitive command shortcuts. The EOG system can potentially recognize "eye gestures," such as left and right winking and blinking, or any combination thereof. The eye gesture command language could even be extensible and programmable by the user himself. For example, during text entry or while scanning read-only text, a left blink rapidly followed by a right blink could be a page-up command; right followed by a left would be a page-down, etc.

2. System Design

We have produced in-house electro-oculographic equipment from inexpensive, off-the-shelf components, and set up to detect horizontal and vertical eye movement. The potential across two electrodes placed posteriolaterally to the outer canthi is measured relative to a ground lead strapped around the wrist or clipped to the auricle. The resulting voltage is amplified and sent though a custom-built, 8-bit analog to digital converter filtered to remove high-frequency electrical noise. The converter fits into an IBM PC expansion slot, and transmits the digitized data through the PC serial port to a SUN workstation for X window based display.

The principal software modules in the system and their functions are:

1. Signal smoothing and filtering to eliminate noise. Calculation of quantitative parameters from the signal channels (two for horizontal movements, one for each eye, and one for vertical movement of the eyes). These parameters are angular positions, angular velocities, and angular accelerations of the eyes.

2. Extraction of symbolic tokens from the signal. These tokens indicate the direction of the movement of the gaze (e.g., North, South, NE, etc.), the magnitude of the move, and the type of eye movement, such as smooth pursuit, saccade, or a blink.

3. Graphical user interface. This includes control algorithms to manipulate cursor motion and decision algorithms to drive the overall interface. It automatically decides when the user is actually engaged/disengaged in interacting with the system. The graphical user interface has been developed within the framework of our Cube 3D user interface [KaY90].

3. Experimental Results

The experiments were performed using a 3×2 boxed menu driven by eye selections. We experimented with a two level menu. There are several parameters which give the software the ability to make a correct choice: number of calibration repetitions, number of data samples necessary for absolute choice determination, different thresholds, etc. The above parameters can be set manually, or "automatically" by an auto-calibration mode. Once the parameters are set, a second calibration mechanism is invoked before a menu selection. The user follows a box which horizontally moves back and forth on the screen, until calibration occurs.

The following performance measures of correct selections have been recorded after repeated use of this program by two experienced subjects (accuracy within 5%):

• Menu selections:	73%
• Menu selections (4 corners only):	90%
• Horizontal detection:	75%
• Horizontal detection (4 corners only):	99%
• Vertical detection:	92%
• Vertical detection (2 centers only):	92%

Although accurate results are difficult to achieve (73%), many of the errors are tied to each other. When a wrong choice is made, there is a high tendency for both a horizontal and vertical selection error. Note that results improve when only the four corner squares are looked at, as opposed to only the two center squares.

There are several problems, related to head and muscle movement interference, signal drift, and channel crosstalk, which must be overcome to improve the performance measures reported above. Whether the user makes a choice or sits idle, there is always some unavoidable minor head movement. In applications where only a rough resolution is used, such as in driving a wheel-chair (e.g., forward, left, right, stop), or when gazing at the computer screen, head movements are negligible. However, in other applications head tracking can be incorporated into the system to compensate for the head movement.

4. Conclusions

There are many ways to measure eye movement, some far more accurate than EOG, but these are expensive. Furthermore, the eye tracking method is just a means, one in which pinpoint accuracy is not really necessary; the provided service and ease of use of the eye-controlled interface is the true goal. Our experiments have shown that EOG is a viable and inexpensive method for human-computer interaction.

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