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The Design and Improvement of an Eye-Controlled Interface

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I. Introduction

Recent advances in computer interface design and accompanying hardware, such as menu-based, graphically oriented bitmap displays, mice, tablets, and touch screens have made interacting with the computer less intimidating for casual users and both easier and more efficient for everyone, from novice to professional. The computer's power, versatility, and now ease of use have made its predecessors in almost every field all but obsolete. A misspelled word or other typo in anything from a single business letter to a thousand-page report can now be located in a matter of seconds, and no longer means retyping the entire page; a change in one item of accounting data can not only trigger an automated search and replacement of all occurrences of that item, but the appropriate recalculation of complex formulae involving entire columns of numbers as well. CAD and other specialized software allow quick visualization and analysis of manufacturing or architectural designs, even from perspectives other than that from which the design was created. In brief, electronic data processing allows the update, simulation, or manipulation of information in ways that can only be dreamed of with pen and paper or other traditional methods, with far less effort and time. Computers are idispensible and easy to use for anybody-or are they?

Underlying many hardware and software designs is one fundamental assumption that can not always be taken for granted: "normal" motor function and coordination. Mice and touch screens are a nice improvement over keyboard for some tasks, but can hardly be utilized by those in the advanced stages of degenerative muscular disorders, and much less so by a quadriplegic. 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, or even for the most basic communication needs. Although several hardware and software interfaces have been devised for the handicapped computer user, there are no inexpensive systems that deliver the true power and ease of today's computers.

The immediate goal of this project is the improvement of existing, and/or the development of new, inexpensive hardware and software tools for use in the most challenging cases: the estimated 150,00 severely disabled persons able to control only the muscles of their eyes. This encompasses the construction of the eye-trakcing hardware and its fine-tuning in software, as well as the definition of acknowledgeable eye behavior and establishment of basic protocols governing on-screen object selection and manipulation. It should also include, at the earliest convenience, one or more sample applications, most importantly a text editor. If successful, a much longer term goal will be the creation of entire software libraries built upon the basic interface and operating principles, with possible applications not only for the disabled but in other fields as well; virtual reality and video games are obvious targets, for starters.

II. Electro-oculography

Deliberate eye control actions can convey useful information in basically two independent ways: through the six extra-ocular muscles by absolute eye position, speed and direction of movement, or through the levator palpebrae (eyelid) and other periorbital muscles as unilateral or bilateral blinking and blink duration. Most eye-tracking systems have chiefly addressed the need to measure eye position and/or movement, treating blinks merely as artifact to be discarded. This would be a serious mistake in a practical interface ,as will be discussed later, but fortunately, almost all systems can easily be extended to process blink data. One eye-tracking method in which blink (and in fact all eye movement) data is particularly simple to collect and analyze, even with very modest equipment, is electro-oculography.

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. The actual recorded potentials are smaller, in the range of 15 to 200 microvolts, and are usually amplified before processing. 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 [YaS75].

Somewhat crude electro-oculographic equipment has already been produced in-house from inexpensive, off-the-shelf components, and set up to detect horizontal 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, and the resulting voltage 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 display.

Both accuracy and angular resolution of eye position are currently limited due to signal drift and electrode polarization, but slant towards improvement in future hardware and software revisions. Two additional data channels will also be added, an independent vertical channel for each eye. Only one channel would suffice to determine vertical eye position alone, for such movement is always conjugate; however, to distinguish a deliberate unilateral blink from a routine bilateral blink, which would both appear as a characteristic pulse in the corresponding vertical channel(s), requires separate measurement of each eye.

Electro-oculography has both important advantages and disadvantages over other eye tracking methods. On the positive side, the equipment is cheap, readily available, and can be used with glasses or contact lenses, unlike some reflection methods. The necessary fixtures do not obstruct the visual field, and are completely insensitive to head movement, although significant deviation form the last calibrated position would require the user to repeat a calibration sequence for accurate tracking. On the other hand, the measured signals are subject to drift from several sources: changing skin resistance, electrode slippage or polarization, even a variable corneoretinal potential due to light accommodation and level awareness. Automated gain and zeroing control is a must for the finished product; for development and testing purposes, these are currently under pickup from other electrical devices can be minimized by careful shielding, but action potentials of the other facial muscles can mask the desired signal. The most obvious shortcoming, uncorrectable by its very design, is the need for attachments directly on the user's face - six electrodes under the proposed scheme. Set-up is cumbersome, and although actual discomfort is low, mental and physical awareness can be very high, creating a large long-term "annoyance factor"; this method may be unacceptable to some subjects.

III. Design considerations

Although the eye muscles cannot operate on real world objects directly as those in the hand or even the foot are capable, exclusively eye-driven computer interfaces should not be thought of as inherently inferior and casually dismissed, or worse yet, casually designed. While manual dexterity is of prime importance in many real world tasks (which are sometimes executable by "feel" with little or no visual feedback), in the GUI (graphical user interface) computer world this is not usually the case. Here vision alone plays the major role, and the hands act merely as extensions of the eyes, directing a mechanical selection device to that portion of the computer screen already selected by gaze. If this intermediate manual step were eliminated so that the cursor or other on-screen tool responded instantly and precisely according to the user's gaze point, the computer tool could not only be essential to the handicapped, but for some applications , the instrument of choice for the non-handicapped was well. This needs to be kept in mind by the system designers, that minimally correct functionality is necessary but far from sufficient. The interface should be able to provide hours of non-frustrating, continuous use, at least good enough to be used by the system designers themselves for extended periods of time.

The Erica workstation, or eye-gaze response interface computer aid, is an example worthy of study[Hut89]. Erica is based on a standard personal computer specially adapted with imaging hardware and software. Through near-infrared reflectometry, Erica can distinguish up to nine menu boxes arranged in a 3 x 3 matrix, from which the user may select one merely by looking at it for a configurable interval of time, usually two or three seconds. After this time a tone sounds, and the menu box marked; if the user continues to stare at the enabled option, a second tone sounds and the action is performed. This delay allows the user to change or abort the enabled option by altering his gaze. Included application software was obviously well thought out and covers four general areas: control, including environmental control and nonvocal communication of personal needs; communications, including word processing and synthesized speech; recreation, including computer games, digitized music, and educational programs; and text reading, including a small library of books and other texts.

Erica's angular resolution is small, especially given the 1-2 degrees or better accuracy possible with infrared reflectometry, but should be sufficient and quite workable for the limited number of conceivable submenu options in most cases. The major exception and notably the most important function to the severely disabled person unable to communicate in any other fashion, is text entry. In its word processing module, Erica's maximum of nine menu boxes is reduced to only six to leave room for a display area; the user is thus forced to traverse up to four submenu levels before being able to select the desired character key or editing function, yielding unacceptably low input speeds of approximately 85 minutes per page of text-for the *experienced* user. For each agonizingly slow entry, the user must wait not only until he reaches the desired submenu, but until the interface acknowledges and confirms his selection at every stage.

Consider also the Eye Word Processor of Yamada and Fukuda [YaF87]. In this system, which detects only horizontal eye movement, a frame scans over columns of characters at an adjustable speed (usually every one or two seconds). The user selects a column by staring for a moment at a target on the other side of the screen; The characters of the column are then scanned over and the desired one selected in a similar manner. When the frame moves once per second, the rate of input is about 8 letters per minute, even worse than Erica.

Both systems are limited by their low resolution and consequent inability to directly select form a larger, more densely packed menu. The EWP could of course add as many columns and characters as desired, but that would only lengthen the scanning delay between selections; actual resolution would still amount to only two choices: accept the highlighted item, or pass. Erica, as stated above, at best resolves only a 3x3 matrix, so a fuller keyboard arrangement is impossible. With either system, text entry is invariably a tortuously slow affair. To borrow from the introduction to the cited Erica article:

> Imagine yourself the victim of a severely crippling accident. You can no longer move or talk. You're unable to write, to point, or even to nod your head. You communicate solely with your eyes....Your intellectual and creative abilities remain undiminished, in spite of your physical disabilities, yet your thoughts...

are constrained to one "page" of text every 85 minutes! Erica's word processor is just awful, and the EWP seems to have been designed by the Marquis de Sade. Can we do any better?

Let's review some simple monitor geometry. Take a 19 inch monochrome display, certainly not an expensive or exotic item. A typical pixel configuration is 1024x768 at 72 dpi, for an active display area of 14.22x10.67 inches. When centrally viewed from a distance of 2 feet, this region subtends an angle of 25 degrees vertically, and 33 degrees horizontally. Maximum EOG or reflectometry resolution is about 1-2 degrees; with menu boxes generously separated by 3 degrees, the 19 inch display still has sufficient room for a 10x4 matrix of directly selectable keys - leaving the entire bottom half of the screen available for a text display area and other menu controls. Better keyboard implementations should definitely be possible.

Before settling on that ridiculous lateral seesaw selection protocol for their EWP, Fukuda and Yamada studied other selection methods, such as focusing directly on the object. Because the eye continually makes fine movements and for other reasons, they concluded that it would not always be possible to determine which letter was selected, and "certain procedures such as averaging the center of the line of sight for a given time will be necessary". I am sure they would also argue that with 40 or more choices dominating at least half the screen, the user would constantly input text accidentally, whether studying the keyboard or through idle, unfocused gazing.

What's really needed is a way to distinguish routine eye function and movement from intentional selection actions. A fast, simple, unmistakably deliberate gesture - something that would not ordinarily occur or interfere with the current task - would be ideal. Perhaps the most significant item in this entire project, unexplicably absent from any other eye-controlled system, is the proposed use of a unilateral blink as that selection action. Blinking normally occurs every few seconds, either consciously or unconsciously - but always bilaterally. Winking only one eye, except as a reflex to a foreign particle on the corneal surface, is *always* a deliberate, very consciously controlled action, yet requires almost no effort and as little as one-tenth of a second to execute, without diverting one's attention or gaze from the area of interest. Blinks are easily detected by EOG as sharp, strong pulses in the vertical channel; since vertical eye movement is always conjugate, a pulse in only one vertical channel is unequivocally a unilateral wink.

Let's return now to the text entry problem. With a 19 inch monitor as described above, a two level keyboard could be layed out in a 10x4 menu box matrix; the bottom half of the screen could display about 25 complete lines of text, and still have additional file, paging, or main menu controls off to the side. The first level of the keyboard would contain all the alphabetic characters, common punctuation, and cursor keys; selecting a special "shift" key would display the second level of the keyboard, with the numbers and less commonly used symbols or editing functions.

The word processor, like all modules of the system, would work as follows. The point of gaze would be instantaneously determined at all times from the EOG signal; this is the most difficult prospect, as discussed earlier. Blinks would be detected, but not allowed to influence the calculated gaze position. Whenever the gaze point coincides with some control or selectable object, that object is highlighted (e.g. displayed in reverse video). The user may stare at any object on the screen for as long as he wants, or even let his eyes wander aimlessly about the room, but no action would ever be taken until a unilateral left (or right) blink is detected, at which point the highlighted command, if any, would be executed immediately; there's no need for a confirmatory delay here. With almost all characters selected from the top level of the on-screen keyboard during word processing, text entry could proceed as fast as the user could look at a character key and blink: at least 60 characters per minutes, with even higher "burst mode" speeds.

Would blinking 60 times a minutes or faster be tiring? Perhaps, but the system would always be in sync with the user and never "scan" any faster than the user himself decided to move his eyes; the system would also wait indefinitely on any selected object, or with no objects selected. If the user so desired, he would not have to blink faster than say, 8 times per minute-but I will bet he would dramatically exceed that rate before the end of the next input word.

Recognizing blinks as legitimate actions distinct from cursor control also allows their use for rapid invocation of important global commands, such as calling an attendant, and in each module as context-sensitive command shortcuts. 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. A particular blink pattern would always have an analogous interpretation in all the control suites; for digital radio or television control (both available in Erica), up/down blink shortcuts could increase/decrease the channel and volume. The blink command language could even be extensible and programmable by the user himself.

IV. Electro-Oculography: Principles and Practice

EOG is based on electrical measurement of the potential difference between the cornea and the retina. This is about 1 mv under normal circumstances. The Corneo-retinal potential 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 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 toghther with the horizontal motion of both eyes. This gives rise to the three channel recording system shown in Figure 1.

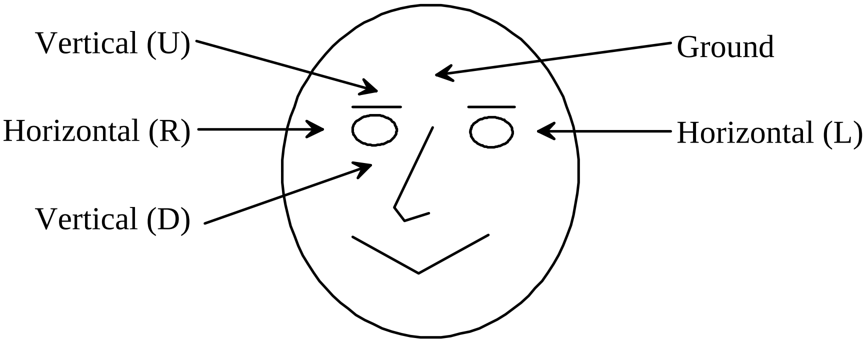


Figure 1: Placement of Transducer Pickups to Measure Eye Movements

Our eyes need to move in order to keep the image of whatever we are interested in at the central part (called the fovea) of the retina. Thus the act of "taking in" a visual scene consists of fixating (moving the fovea to image) all the objects in the scene that interest us. Human ocular movement has been widely studied in neurophysiology and psychology [RGG86, WaB81, ZeP84]. These studies indicate that there are four types of eye movements, called *vestibular, optokinetic, saccadic,*and *pursuit.* The first two have to do with the largely involuntary head motion. The saccadic movement is used to "jump" from one object of interest to another. This is the fastest type of eye movement. The pursuit movement is used to maintain fixation on a moving object.

If the orientation of the eyes are measured, it is possible to locate the 3D position of a fixated target object by triangulation. The accuracy of the location determination depends on the accuracy with which the eye orientation is determined. In this respect, EOG cannot compete with the direct reflectance methods. In OEG, a quantitative estimate of positional accuracy can be based on the observation that there is a change in potential of about 1 micro volt for every degree of change in eye orientation in either direction [YoS75]. Thus accuracy and resolution are determined by the sophistication of the electronic circuitry (and hence also its cost) built to amplify and condition this signal. In principle, however, 3D location can be determined with respect to a "head" frame of reference. In order to determine 3d location with respect to a static environmental frame, the system would also have to measure head movement and incorporate it in the calculations. The EOG technique cannot measure head movement directly. However, using the EOG signal we can estimate the distance of the fixated point from the head of the user. This might enable the system to determine that the user is fixating at a point outside the computer display.

The signal quality of the EOG output data has been well documented in text boots of neurophysiology as well as manuals of Electro-nystagmography (ENG), the study of eye movements [BBT81, Bar82, Coh86, InS85, YaF86]. Straightforward signal processing steps can be devised to condition the data so it can be reliably interpreted by an optical technician. Some of the noise patterns such as the 60 Hz line frequency can be easily removed, using a notch filter. Other noise artifacts are mostly transients caused, for example, by the turning of an electrical swithc on/off in the vicinity of the electrodes, contraction of the facial or neck muscles, slippage of the electrode due to sweat and eye blinking. Eye blinking is considered noise in ENG. However, the signals produced by eye blinks are, in fact, quite regular. This makes it easy to recognize and eliminate them. On the other hand, because this type of signal is quite distinct from the usual data from pursuit or saccadic movements, they can be recognized and categorized as such. In other words, the EOG technique can potentially recognize eye "gestures" such as winking, blinking or a combination thereof.

V. System Design for Location Specification using EOG

The work related to the proposed system involves both hardware and software design and development. The system architecture is shown in Figure 2.

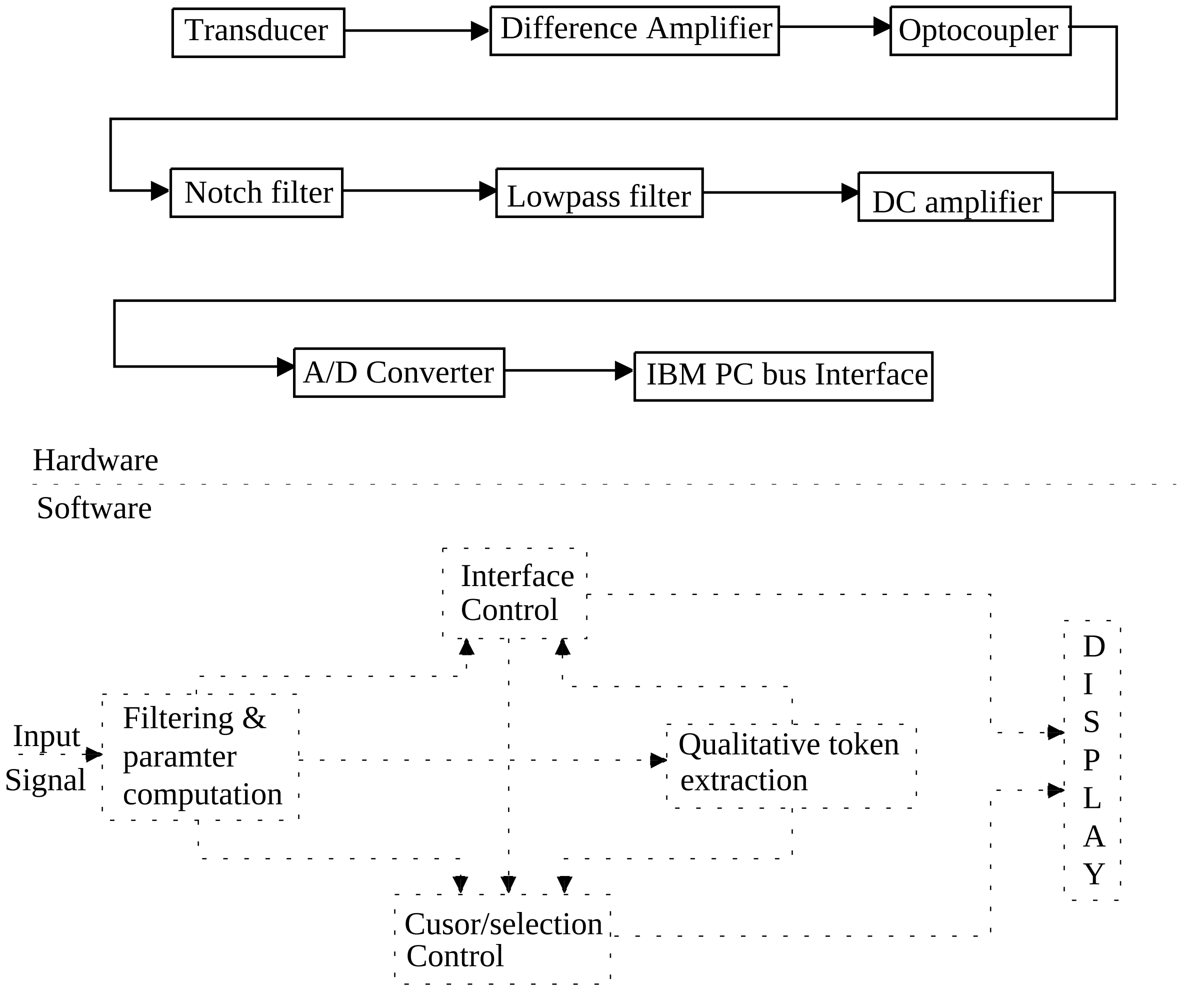
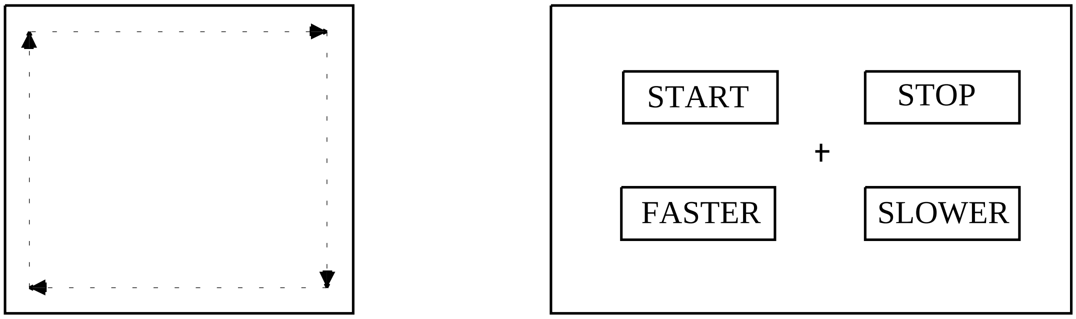


Figure 2: Architecture of the Proposed System

The hardware part of the system is fairly straightforward. We have completed the design of the amplifier and filter sections and assembled a crude circuit for testing and data collection. Our overall design philosophy has been to keep the actual add-on hardware (i.e., in addition to the computing hardware) as simple as possible. Thus we have chosen to do most of the filtering and noise removal in software. The actual hardware fabricated amplifies the voltage picked up by the transducer, removes the electrical line frequency (60 Hz notch filter), and removes high frequency noise (120 Hz low pass stage). Subsequently, the analog signal is converted to digital form and the data samples are sorted in an IBM PC and finally transferred to a UNIX based workstation, where all the software processing will take place.

The behavior of the system is derived from software algorithms that operate on the digitized eye movement signals. The system interacts with the user in two modes. The graphics displays in these two modes are shown in Figure 3. In the synchronizing mode, the system displays a moving cursor and the user is asked to follow the cursor. The cursor follows a fixed path and the user's eye movements are analyzed to verify that the pattern of movement and the cursor motion is the same. This enables the calibration algorithm to calculate the idiosyncratic signal parameters associated with this particular user, for instance, the amount of voltage fluctuation in the signal corresponding to the leftmost and rightmost eye position, the velocity for smooth pursuit motion, and so on. This calibration establishes signal parameter ranges that are to be used in later classification and symbolic token extraction from the signal.



Synchronizing Screen
(User tracks cursor motion)

Interaction Screen
(User selects operation)

Figure 3: Screen Layout for the Interaction Modes

The second interaction mode is the command mode, where the cursor is moved by the system to track the user's gaze. In our example interface, shown in Figure 3, we show four command "buttons." The cursor is at the center of display (the cross). Imagine that this command system controls a machine, whose speed can be changed. So when the user looks at the start button the cursor follows his or her gaze. Then the command is activated by the user winking twice - i.e., the machine is started. In this way the user can communicate control commands to the computer by guiding the cursor to the appropriate button and making an actuating gesture (i.e. eye blinking or winking).

The problem with using the eyes as a pointing device is that humans also use the eyes for other purposes. Thus during the interaction episode the user might blink naturally, turn his or her head to look at someone or something else, or quickly dart a glance away and then back to the screen. The system must recognize such irrelevant signals and discard them. Natural blinks cause low voltage blips that do not occur in rapid succession. On the other hand, valid blinks for the registration of commands must be vigorous and in rapid succession, and thus can be distinguished from natural blinks. Another technique would be to require winking (or single eye blinking) for transmitting commands. This too should be fairly easy to distinguish from natural eye blinks. Since we measure eye signals from both eyes, we can obtain a rough estimate of the distance of the fixated point from the center of the forehead. When the head is turned away from the screen, the system will be able to detect this because the fixated distance changes from the "norm" recorded during calibration. This will cause the system to disengage and freeze the cursor on the screen. To re-engage the user should perform a gesture such as fixating on the cursor and winking twice. When the user looks away from the screen by performing a saccade, the system will recognize the irrelevancy of the motion by comparing it with the classification range of velocities calculated during calibration. Again, this should cause the system to disengage.

The system we have proposed communicates location interactively without having independent head position measurements. This lack of information is overcome by a synchronization step before actual interaction. We assume that during an interaction "episode," the user's head will not move appreciably.

The EOG data contains transient noise, which must be removed. The process by which this is done can be termed contextual filtering. Such filtering will ensure that once a pattern of movement has been established, transient deviations from the pattern will be ignored. In our development of noise filtering algorithms for the EOG data, we will draw upon the literature on signal processing and digital filtering techniques [BaB82, Coh86, JJP85]. In contrast to most expensive commercial systems, our proposed system will minimize the electronic signal processing hardware. This approach distinguishes our proposed method from existing commercial products. 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 directions of the movement of the gaze (e.g. North, South, NE, etc.) and also the type of eye movement - such as smooth pursuit or saccade.
3. Graphical User Interface. This includes interface control algorithms to control cursor motion and decision algorithms to drive the overall interface system. This module will automatically decide when the user is actually engaged in interacting with the system and when she is disengaged. The graphical user interface will be developed employing our tools for the interactive prototyping of 2D and 3D user interfaces [Gik90] and within the already developed framework of our Cube 3D user interface [Kau89, KaY90, KYB90, KaY89].

VI. Current Eye Track System

Our objective in this project was to build a 2D point-of-regard controlled spatial locator system and demonstrate its feasibility in a computer graphics environment. The system block diagram is shown in Figure 2 and discussed in Section 5.

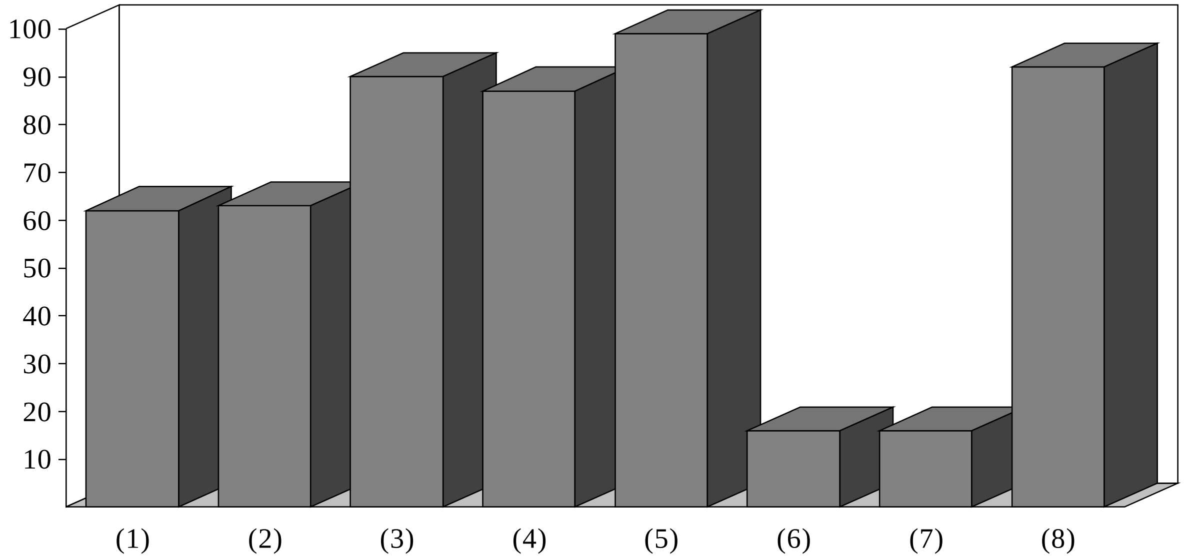
We acquire data using an IBM compatible PC and perform software development on a SUN workstation. This decision was based on convenience. Hardware prototyping is inexpensive and quick on the PC bus because of the wide availability of components and printed circuit boards available in the market specifically for this purpose. On the other hand, the window based user interface software (based on X windows) is at present better supported on the SUN and other UNIX based workstations. We chose X as our window environment because it is rapidly evolving into an industry standard. In the future, production systems based on our research can easily be wholly resident in the PC, since X products for the PC have already appeared in the market, and we expect such products to dominate window system development within the next few years.

The initial work involved hardware equipment setup so that real time signal acquisition could take place. This involved assembling the electrodes, constructing the analog and A/D circuits on a PC form factor board, and interfacing and installing it on the PC bus. The PC was then linked to the SUN via a serial (19.2 Kb) line. Routine software has been developed to enable a program running on the SUN to access the eye movement data captured on the PC and transmitted on the serial line.

The research and development on the software part of this project has been done concurrently with the hardware development. This project is carried out under the joint direction of two faculty members of the Computer Science Department, SUNY at Stony Brook, Dr. A. Bandopadhay and Dr. A. Kaufman, who serve as the principal investigators. The project required the recruitment of three student research assistants. Once of them worked on the hardware setup. Two have worked on software, once on the signal processing and extraction of symbolic tokens, and the other on the graphical human-computer interface. We also have plans of porting the software onto other UNIX-based workstations running the X window system (we have HP and SGI workstations in our lab, that can be used for this purpose). This will strengthen the commercial viability of the product.

The above discussed software is a 3 x 2 boxed menu driven eye selected interface. This menu has two levels, thus enabling a choice of any letter in the alphabet, as well as some additional punctuation characters. When the program is run, there are several parameters which need to be defined to 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. The user follows a box which horizontally moves back and forth on the screen, until calibrated. This mechanism is invoked at this experimental stage every time before the software is ready to attempt a menu selection determination.

After a subject has used this program several times, he becomes experienced and tends to yield better results. The following performance measures have been recorded after repeated use of this program by two experienced subjects (note - accurate to within 5%).



(1) Correct Menu Selections	62%
(2) Correct Horizontal Detection	63%
(3) Correct Vertical Detection	90%
(4) Correct Menu Selections (Four Corner Squares Only)	87%
(5) Correct Horizontal Detection (Four Corner Squares Only)	99%
(6) Correct Menu Selections (Two Center Squares Only)	Random (approx. 1 / (3x2) %)
(7) Correct Horizontal Detection (Two Center Squares Only)	Random (approx. 1 / (3x2) %)
(8) Correct Vertical Detection (Two Center Squares Only)	92%

Note that Although accurate results are difficult to achieve (62%), many of the errors are tied into each other. When a wrong choice is made, there is a high tendency for both a horizontal and vertical selection error. Also notice that results improve radically when only the four corner squares are looked at (87%), and drop drastically when only the two center squares are looked at (Random number of correct selections).

There are several problems which must be overcome in order for the above mentioned errors to be eliminated. Most of these errors are generated systematically due to one or more of the following reasons:

a. When the user makes a choice or alternately just sits idle, there is always some unavoidable minor head movement. This head movement generates a signal which is sometimes picked up and misinterpreted by the program. Blinking, breathing and talking generate similar signals as well, which at times are also mistaken for a legitimate choice.

b. There is an ever existing drift in the signal pickup (electrode slip, sweat, etc.) which forces us to average the signal over time. Due to this, the system detects only relative signals and can not make any absolute eye position determination.

c. There is a substantial amount of interference within the experimental board itself (which is wire wrapped). A signal in the horizontal channel will generate a small signal in the vertical channel and vice versa.

VII. Possible Near Future Improvements

The first and most important change needed by the above described system is a new board. The experimental board contributes to wrong box selection due to erroneous signals resulting from wire wrapping. A new board which is being designed now will have better isolation and more importantly four channels (two per eye) instead of two. This will enable the software performance improvement, as well as some additional features which will be added (e.g. processing of a one eyed wink). This improved board will eventually drive to finer resolution on the screen. The software is being revised to enable better results as well. This will take form in the way of defining optimal parameter choices for the various thresholds and sampling rates, as well as some other minor software improvements.

Also needed is a better input device. Attaching electrodes to the skin one by one is cumbersome and annoying for the user. What we need is some device which can be put on by the user himself with ease. Such a device is not yet in planning, but once performance improves, it will be of high priority.

VIII. Conclusion

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. I aim to improve the existing eye-tracking system; I will attempt to resolve the current faults and weaknesses, and implement the eye-tracking device in the most user friendly and efficient interface I can devise.

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