Eye Gaze Input Systems for IBC Terminals - The motor handicapped perspective.

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I. Abstract

Access to software and services via modern multimedia telecommunications equipment or microcomputers is for some people with severe motoric or speech disabilities a physical impossibility. For others the use of a hand manipulated pointing device to manipulate a WIMPS interface is a source of irritation and lost productivity as they are required to move from keyboard to mouse and back again.

The measurement of eye movement and tracking of eye gaze have been used for a number of years in fields such as research psychology and military guidance systems. In recent years however attempts have been made to design communications and computer control devices using eye gaze tracking techniques, with a number of products reaching production.

In this paper, the various techniques for measuring eye movements will be outlined, and the work undertaken to date to develop a non-mechanical eye gaze tracking system will be described. This will then be briefly set in the context of the RACE IPSNI project concerned with IBC terminals.

II. Keywords

IBC terminal, eye gaze , motor handicapped

III. Introduction

A. Aim of the project

1. Communication system

There is a trend concerning modern multimedia computers and telecommunications terminals whereby users expect more and more intuitive access to more complex services and applications, and increasing quantities of data. In order to satisfy these demands, increasing use is being made of WIMPS type user interfaces coupled with an array of both general purpose and application specific pointing devices. The majority of these are hand controlled devices, so a keyboard user has to take their hands off the keyboard, find and manipulate the device, and then return to the keys, a process which is frequently criticised by fluent keyboard operators. In addition, some motoric and speech disabled people are completely unable to use the terminals however accessible they are to able bodied users. Examples of this might be those with "locked in syndrome", spasticity, or the effects of a high spinal injury or a nerve or muscle wasting disease such as motor neurone syndrome or multiple sclerosis. It is therefore clear that current user interfaces, whilst a very real improvement on those predominating only a few years ago, are still irritating for some users and completely unusable by others. If a device were available that utilised eye gaze as a way of communicating with a terminal, the problems for all these users would be solved.

To this end, the aim of the project is to develop a communication and terminal interface system based upon a microcomputer driven by the eye gaze of the user rather than a keyboard or currently available pointing device. Assuming the eye gaze detector output obeys the regular pointing device protocols, the pointing device may be replaced and the WIMPS interface driven by the user's eye gaze. In addition, by using such a device in conjunction with keyboard emulation software, it is possible replace the keyboard entirely.

The first application of this system will be for severely disabled people where, the head is also unable to move, so the eyes remain fixed in three dimensional space relative to the computer system.

As a result of the experience gained with this system, it will be refined to allow free movement of the head, initially only in a plane a fixed distance away from the computer system. Eventually the aim is to allow full movement of the head, with the eye gaze tracker being able to find the eye and read its movements, thereby enabling the systems to be used by anyone who wishes to do so. In this way, those people who like the flexibility of a WIMPS interface, but do not like to take their hands off the keyboard will be able to drive the terminal and its applications via eye gaze and continue to use the keyboard for data entry. As an extension of this, there may be many able bodied users that may find that for some tasks, the emulation of keyboard function by an eye driven system would be very attractive.

2. Integrated in terminal

In order for such a system to achieve universal acceptance, it must be completely intuitive to use and require as little familiarisation as a mouse currently does. In addition, no attachments may be made to the user, be they EMG or EOG detectors or reflective pads etc. It is envisaged that the necessary hardware will fit naturally onto the regularly terminal display, and will integrate into the functions of the terminal. This has the implication that all the regular terminal functions, be they the hardware and peripherals or the software and services, may be manipulated and controlled via this device, representing a significant breakthrough for the initial target user group. Not only will they have access to a communication device, but they will also have access to all the power and applications available to a user of a regular terminal.

In addition, once the device has been developed such that it is able to follow eye gaze whilst the subject is able to move their head freely, it may have as significant impact on the human/computer interface as the mouse did when it was introduced in the early 1980's, particularly for those users that are fluent keyboard operators.

B. Current work available

The techniques and concepts upon which this work is based have been established over a number of years from the two following perspectives:-

1. Psychology research

Research into the understanding of attention and reading have, for more than 20 years, studied the eye movements associated with these activities in the hope that this will reveal more about the processes involved. Highly sophisticated equipment is now available to track eye movements to an accuracy of better than 3 minutes of arc of movement of the eye. The movement is then translated into gaze direction, enabling the gaze point to be superimposed onto a video film of the field of the view of the experimental subject. For our purposes, the principles involved in the equipment provide techniques that may be used in the proposed system. The equipment itself however often achieves its remarkable accuracy through highly complex and delicate optical machinery, which is not suitable for mass production and installation in domestic and commercial environments.

2. Communications aids

A number of dedicated communications devices have been made based upon eye gaze detection techniques. These include devices such as ERICA [1] and the EyeTyper® 300. The former is a an eye gaze communication system that runs in a microcomputer and allows access to all the functions and software of the computer. The latter is essential a stand alone eye gaze communication device that may be used as a keyboard emulator. The incentive for continuing to work in this field comes from the recognition that due to the increasing power available within microcomputers today, solutions are potentially available for such devices to be made such that the eye need not be tracked mechanically but rather the images over a wide field of view may be analysed to extract the data. This would reduce the cost and make the devices more robust and reliable.

IV. **Methods**

A. Measurable effects of eye movement

There are a number of measurable features of the eye which alter as it moves and hence provide a way of measuring the movement and determining the gaze direction. These may be divided into those which measure the effect of the working of the muscles that move the eye, those that measure movements of features of the eye, and those that measure reflections off surfaces of the eye.

1. Muscle movement detection

a) EOG

Eye movements are measured by detecting the eye muscle activity that corresponds to the eye movement. Electrodes are placed on the skin around the eye, and these measure the potential changes produced by the muscles. This method is unacceptable in this project due to the discomfort felt by the subject wearing the electrodes, and yields little data that is of relevance to our work.

2. Movement detection

a) Search Coil

Small coils built into rings that are placed on the surface of the eye produce an induced voltage as the eye moves when the wearer is sitting within the effects of two much larger coils. This system is clearly unusable in practical applications as it is extremely uncomfortable to wear, but it does yield valuable data about the nature of eye movements as it measures the movements entirely independently of head movements.

b) Pupil Tracking

As the eye moves, the center of the pupil follows the line of gaze. This movement may be recorded by a video camera, often working in the IR region. The image is analysed to reveal the edges of the pupil, from which the center may be calculated. This method is generally used in conjunction with another to enable the gaze direction to be found independently of small head movements.

c) Limbus Tracking

This method is a variation of the one above. Because there is a large contrast on colour between the coloured iris and the white sclera of the eye, and consequently a difference in the amount of light reflected, the edge between them is relatively easy to detect. The movement of this edge gives a measure of relative movement, initially from a reference point. This method is successful for horizontal movement, but less so for vertical movement because the eyelid shields the iris/sclera edge for most of the vertical arc.

3. Detection of reflection

a) Corneal Reflection

A light source in the visual field produces a reflected image on the front surface of the cornea, and due to the fact that the corneal bulge has a different radius to the main body of the eye, this reflection moves at a different rate but in the same direction as the eye movement. In conjunction with a method such as pupil tracking therefore, a system may be devised to follow eye gaze direction independent of head movement. In practice IR light is generally used to produce the reflection as this allows the system to be used independent of ambient light. This combination represents a good possibility in practical systems provided that the arc of view is not so great that the reflection point moves off the corneal bulge, as the geometry at the bulge edges becomes very difficult to predict. By employing modern image processing techniques the variations in pupil diameter with changing ambient light levels should not be a problem.

b) Retinal Reflection

This method depends on the reflection of light off the retina, and is also known as the Red Eye Effect. It is a very visible effect, but may in practice be available for only a limited arc of view. It may be suitable in applications similar to those for the corneal reflection.

c) Purkinje Images

The corneal surface is the first surface of the eye at which reflection occurs, and is also known as the first Purkinje Image. The others are the rear surface of the cornea (2nd), the front surface of the lens (3rd) and the rear surface of the lens (4th). Practical systems have been demonstrated using the 1st and 4th images as there is a difference between the movement of the reflected images as the eye rotates. In practice IR light is generally used to produce the reflection as this allows the system to be used independent of ambient light. This system is by far the most accurate to date, but requires high IR levels in order to bring the 4th image above the noise level. In addition, it is unclear as to the effect that the changing shape of the lens as it focuses will have upon the practical suitability of this method.

B. Application

As indicated above, there are a variety of possible features or effects that may be used to measure the movements of the eye, and from that deduce the line of gaze. Many of them are currently applied in experimental or research systems rather than practical equipment, and as such avoid some of the simple but fundamental barriers to widespread application. These include the necessity to provide a method for determining the distance between the subject and the object of the gaze in order to provide free head movement, and the siting of the IR source and camera to avoid the problems caused as the top eyelid closes when the gaze rotates down. In addition, many of the systems depend on mechanical tracking of the eye in order to optimise the images obtained. One of the essential aims of this work is that the system does not depend on mechanical tracking of the head movement, but rather the image that the camera captures is analysed and the image of the eye and the other necessary data is extracted from the picture, wherever this is in the field of view.

C. System components

The proposed system utilises the reflection of Infra Red light off surfaces of the eye, and compares the movement of these against each other and against other features such as pupil center. The system is made up of the following components

1. Infra Red Source

One or more IR sources are placed adjacent to the terminal screen in such a way that the IR emitted is able to fall on one of the user's eyes. The source is chosen to have a wavelength much higher than visible light in order to make the system independent of ambient light conditions.

2. Camera

An IR sensitive camera is trained on the face of the user, and it is used to capture images of the eye, including any reflected IR.

3. Gaze Analysis

The images are analysed by software that looks for the various features of the eye and the reflections. The distances between the centers of the reflections or features are measured, and then used to determine the direction of the gaze. This is then compared with the map of the screen that the user is looking at, and the action appropriate to the visual cue at that point is executed.

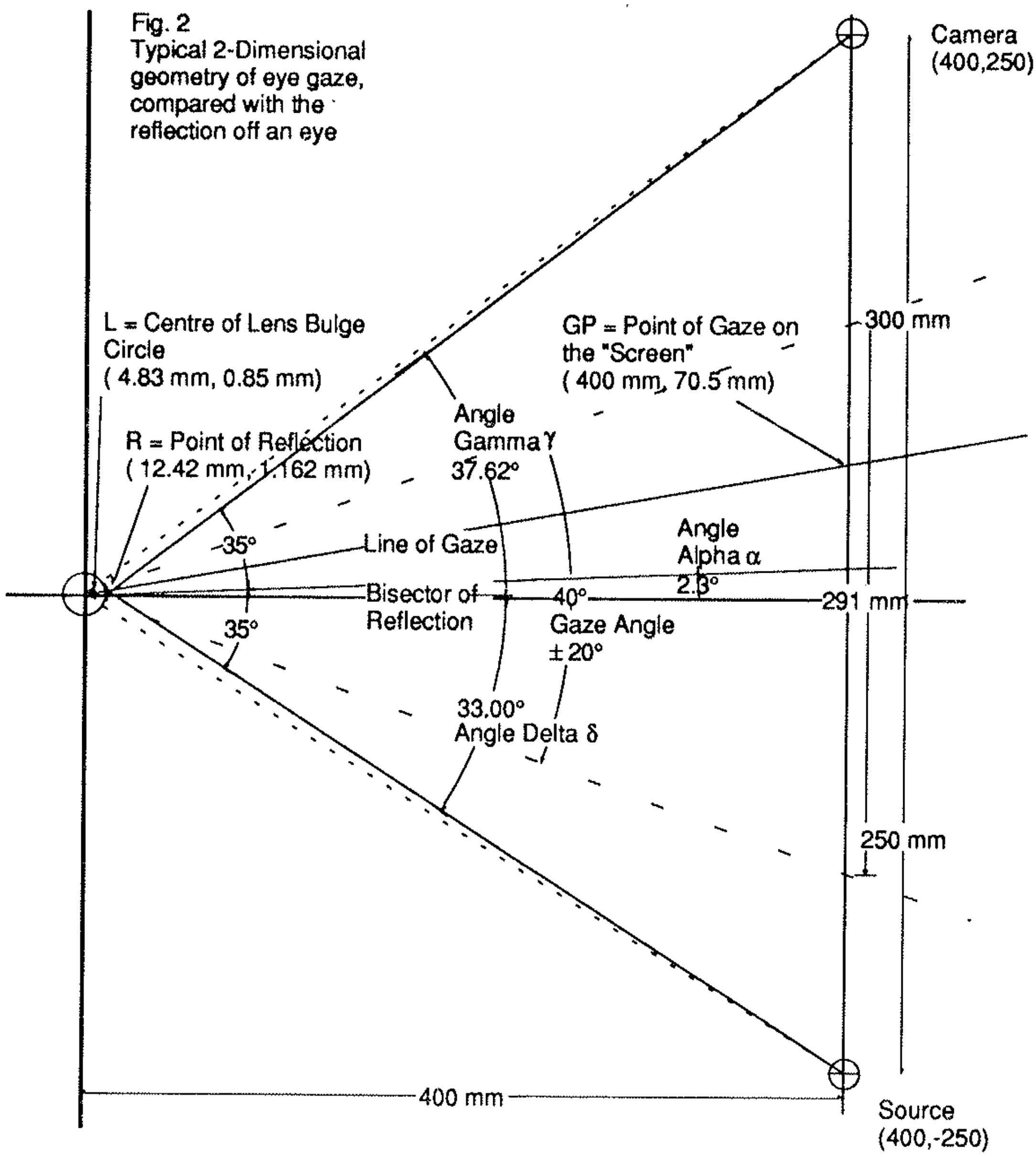
V. **Results**

Work on this project has progressed in a number of foundational areas that will provide the background knowledge necessary to enable us to build the prototype systems. These areas include:-

A. Model of eye

A comprehensive model of the eye has been constructed based upon the geometry of a typical application situation, and comparing the pupil center and corneal reflection to give the angle of gaze as shown in Fig 2 below.

Fig. 2
Typical 2-Dimensional geometry of eye gaze, compared with the reflection off an eye



The dimensions of the eye are entered, as are the coordinates in three dimensional space of the "screen" (in the x,z plane) that the subject is looking at and the locations of one IR source and one camera. The source and the camera may be place in any position, independent from each other in the same x,z plane as the screen.

A table is then generated of the x,y,z, coordinates of a matrix of 21 by 21 points on the screen. From this is calculated the horizontal and vertical angle that the eye must be rotated in order for it to look at each point on the screen. As the eye rotates, the point of the light that comes from the IR source is seen to move as observed by the camera. This movement is in the same direction as the rotation, but the angle of reflection (the angle from the center of the eye through the reflection point) changes in the opposite sign to the angle of gaze. That means the more the eye rotates in one direction, the more the reflection angle changes in the opposite direction.

Because of the corneal bulge, it is difficult to calculate the reflection point directly so an approximation is made of the angle of reflection, using the following equation:-

(Angle between Camera and Source)/2 + Sin(Angle of Gaze)

This introduces the possibility of a negative sin value to pull the approximation in the correct direction depending on the line of gaze. This approximation is checked by using that angle to give a reflection point, and then seeing if the angle between the source, reflection point and camera is bisected by the angle of reflection, according to the following equation:-

$$(\delta - \alpha) - (\alpha - \gamma) = 0$$

The error is divided by two, and added to the angle of reflection to bring it closer to the true angle of reflection, and the check is repeated. This iteration is repeated 4 times, at which stage an accuracy of better than 10E-8 is achieved for every point of gaze on the 21 by 21 matrix.

A comparison is then made between the point of the reflection and the center of the pupil as observed by the camera. The distance and angle between them correlates directly to the direction of gaze, and therefore in practice an image of the eye with these two features on may be compared to the table and the gaze point deduced from measurements of the distance and angle between the points on the image.

This model forms the control against which measurements can take place, and some initial experiments have been conducted to find suitable IR sources and cameras, and a realistic geometry for detailed analysis of the model to begin.

B. Rate of communication

In a parallel investigation being undertaken in order to investigate the user issues associated with the application of the technology, a NAC V Eyemark recorder was used to follow the eye movements of a subject looking at a grid of 54 letters or numbers on a board simulating a terminal screen. This eyemark recorder is a head mounted system that uses the corneal reflection method of eye movement detection. This reflection point is presented, by virtue of a system of mirrors, as a symbol superimposed on a video film of the field of view. In addition the X,Y coordinates of the eye marks are recorded for both eyes, and it is possible to record pupil images for more accurate calculation of eye gaze direction.

The particular issue of interest was the communication rate available by gazing from letter to letter, and the errors that occurred whilst trying to communicate. Calibration was achieved by gazing at the centers of the four borders of the grid. In the first test, subjects were required to fix their gaze on symbols as they were dictated. In the second, they were required to "spell" a sentence, and to verbally indicate the symbol that they were selecting. Following analysis of the results it was found that untrained subjects can point to the 54 characters of the grid freely with an accuracy of 98.7%. Considering the various factors such as symbol layout and learning, a communication rate of 85 characters or 17 words per minute could be predicted, which compares favourably with that reached using a "one finger typing" technique.

VI. Discussion

A. Detecting Reflection

Following the limited success that we have experienced in detecting reflection in a situation that simulates the proposed system configuration, the decision has been taken to utilise equipment used for following eye gaze as part of research in perception and learning. A careful practical comparison will be made of the various detection methods, and the issues that will limit their application in equipment outside a psychology laboratory. The data received will be used to update the mathematical model of the eye, as this will be needed in the subsequent processing of the images.

B. Image processing

Current eye movement detection equipment available to us that provides image processing in real time is based on mini computers. With a trend towards more powerful micro computers and the associated image grabbing and processing software, a system will be set up that will perform the necessary computation to extract the data associated with the features of the eye and the reflections, and from these calculate the direction of gaze. This will then be used to derive the point on the "screen" that the subject is gazing at.

C. Human Machine Interface

By mixing the data gathered using the Eyemark recorder, and good human factors practice, an interface will be constructed to enable the user of the system to interact with the terminal or computer. In the initial application this will involve the display of a keyboard to emulate the hardware keyboard function, and the interfaces required to hook the eye gaze system into the operating system, thereby making available all the standard software running on that terminal.

VII. Conclusion

A. People with Special Needs

This work is an example of a potential solution for a severely disabled user that is embedded in the philosophy that is the basis of the work of the RACE IPSNI project, in that it is a proposal for a practical system to make available to all users the services and facilities available via an IBC Terminal. If this potential is to made available, particularly in the complicated environment of a multi-media terminal, innovative solutions must be found on behalf of those with special needs. This system proposes to do that, in conjunction with terminals that are easily adapted as a result of modular design following clear design specifications.

B. All users

Although the motivation for this work comes from seeking to meet the needs of the disabled so that they will be able to take advantage of the new telecommunications facilities as soon as they become available, the results are likely to be attractive to many able bodied users who seek an intuitive alternative to the mouse or rollerball pointing devices. In this way the WIMPS interfaces will become completely natural with the control being effortless, allowing the user complete freedom to concentrate on the communication task.

VIII. References

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