Eye Movements, for A Bidirectional Human Interface

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Abstract

When we look at a screen, we are unaware of precisely where our eyes are looking, yet our eye movements contain valuable information. An optoelectronic system which monitors our eye movements, may be used to communicate with a machine. Items on a screen may be selected simply by looking at them, and actions initiated by deliberate eye movements. Such a system can also be aware of our interests and difficulties, and may respond to our needs, even those of which we are unaware. This paper describes the techniques of eye movement measurement, possible applications of this information, and several practical demonstrations of an eye-controlled interface.

1 Introduction

Human computer communication is far less intimate than a meeting between two human beings, where eye movements, facial expressions and body language communicate a considerable amount of the information. As a greater percentage of the population becomes involved in the use of computers, it is natural to expect the manner of controlling computers to move away from the programming model and closer to the perceptual process we use to accomplish our goals in the physical world [Krueger et al, 1985]. A more intimate relationship with computers should bring a greater awareness of our real needs. The use of eye movement information is a step towards a closer relationship.

This paper will explain the meaning of eye movements and describe techniques for their measurement. The range of applications of eye movement controlled technology will be presented, and finally details will be given of several practical demonstrations.

2 The Human Eye, its capabilities and limitations

2.1 The Physiology of the Eye

The human visual system is very complex. For the purposes of this paper it is necessary to describe a little of the physiology of the eye. Those who wish greater detail, are recommended to read "Eye and Brain" by Richard Gregory [1966]. The eyeball is approximately spherical, and is rotated within its bearing socket by means of a number of muscles. An optical system images the external view onto the retina which is a dense matrix of light sensitive cells, inside the back of the eyeball (Fig. 1). The dominant imaging component is the bulge in the front surface of the eye, the cornea. The lens within the eye provides some additional focusing which is controllable, enabling the eye to focus on objects at different distances.

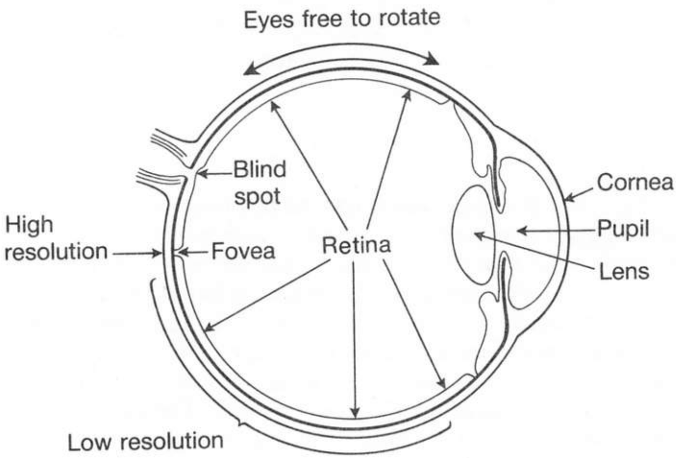

Fig. 1 The human eye. Note, that only that small part of the image which falls on the Fovea, can be seen with high resolution. The rest is "blurred"

Whilst it is attractive to imagine the eye as a sort of camera, this is not an appropriate analogy. Firstly it begs the question "What looks at the picture?". Secondly, the eye is in effect an extension of the surface of the brain, and much signal processing occurs within the back of the retina itself, in groups of cells optimised for specific purposes, such as moving edge detection. The image we see of reality is a software simulation updated by features sensed by our eyes.

2.2 The Resolution (Visual Acuity) of the Eye

The human eye has very high resolution, about one minute of arc, close to the diffraction limit for the size of the optics used. However the eye does not provide high resolution over a wide field of view simultaneously. Central vision is used for the acquisition of fine detail. Only coarse detail is discernible away from the central region (see 4.3.1.1 and [Yager and Davis, 1987]), and peripheral vision is used largely for motion detection. We achieve high resolution perception by sequentially moving the small central high resolution view of the eye, over the scene of interest.

2.3 Fovea Fixations and Point-of-Gaze

The fovea is the small, roughly disc shaped area on the retina, which provides the highest visual acuity. It is located close to the central optic axis (the line through the centre of the eye, lens and cornea). The diameter of the fovea corresponds to about 1 degree visual angle. In other words if a person looks at a disc whose diameter subtends one degree visual angle, the image of the disc that is focused on the retina will cover an area about equal to that of the fovea. The word is sometimes used as a verb, to "foveate" meaning to position the eyes so that the image of a certain target or element of the visual scene falls on the fovea. To "fixate" a point in the visual field, implies foveation of that point. In this paper, when we talk about the "point of fixation" or "point-of-gaze" we are indicating the part of the scene being imaged on the fovea.

2.4 The Blind Spot

The normal eye has a region which has no response to light, known as the "blind spot". This is where all the connections are made to the eye, i.e. where the blood supply enters and leaves, and where the optic nerve leaves the eye, carrying the visual information to the brain. What is intriguing about the blind spot is that we do not normally know it is there, we are blind to its blindness. It is not perceived as a hole in the visual field, but instead appears to be filled with a stimulus similar to whatever surrounds it. Blind spots caused by damage or disease also fill-in in this way. The blind spots are offset horizontally from our centre of vision by about 15 degrees. The blind spots of left and right eyes are displaced to the left and right sides of our centre of vision respectively, so that the image from one eye provides details of the image missing from the other. However, the fact that we are ignorant of our loss of information when using one eye alone suggests that vision (and in fact all our perception) is in effect an ongoing simulation of reality, which is continually updated by our senses. In Reference 2, Gregory writes: "The large brains of mammals, and particularly humans, allow past experience and anticipation of the future to play a part in augmenting sensory information, so that we do not perceive the world merely from the sensory information available at any given time ...". In other words, what we are familiar with, influences what we actually see.

3 Eye Movements

3.1 Point-of-Gaze as an Indicator of Point of Attention

When performing a visual task, the point-of-gaze is a reliable indicator of where our attention lies, especially when the task involves resolving some visual detail. It has been shown that, in the absence of peripheral stimulation, it is not possible to make an eye movement without making a corresponding shift in the focus of attention [Shepherd et al, 1986]. Conversely however, it is possible to shift one's attention without making an eye movement, for example one might start thinking about something else while staring at a word in this piece of text. To summarise, an eye movement usually indicates a shift of attention to that new location.

3.2 Types of Eye Movements

Because of the intimate connection between eye and brain, the study of eye movements is now providing a unique insight into human information processing [Groner et al]. There are two distinct types of eye movements, first a jerky motion jumping from one fixed pointing direction to another, and second a smooth tracking motion [Yarbus, 1967], [Carpenter, 1989]. These may occur independently or simultaneously, and perform very different functions. In addition, eye movements when reading text are highly distinctive.

3.2.1 Fixations and Saccades During normal scanning of a visual scene, eye movement is characterised by a series of stops and very rapid jumps between stopping points. These stops, which normally last at least 100 milliseconds, are called "fixations", and it is during these fixations that most visual information is acquired and processed. The rapid jumps or flicks between fixation points are called "saccades". Saccades are conjugate eye movements (both eyes move together) that can range from 1 to 50 degrees visual angle. They generally have durations from 30 to 120 milliseconds, and achieve angular velocities as high as 600 degrees per second [Carpenter, 1989]. Very little visual information is acquired during saccades, mainly due to blurring caused by the fast motion of the image across the retina, and because the brain partially suppresses information just prior to and during a saccade. When our gaze is attracted to a new spatial location, our gaze jumps towards the new location, but typically undershoots by about 10%, followed by a second or even third corrective saccade (see Fig. 2). Each of these jumps takes time, and delays the moment when any high resolution detail from the scene can be perceived. This highlights the need to reduce the number of events which cause eye movements if the speed of performing a task is important.

This jerky motion of the eye can be felt by placing ones fingers on the closed lid of one eye, whilst looking around with the other. Except for unusual mental states such as unconsciousness, the eyes are rarely completely still for more than a few moments. When we are thinking, we do fixate for quite long periods, but even then the eyes are not completely still. The eye exhibits "micro-saccades", tremor and drift, all of which maintain the image in motion on the retina. This motion is necessary for image perception, for if the image is perfectly stabilised on the retina, it will fade totally within a few seconds [Tulunay-Keesey, 1982]. It is possible to observe this fading, by staring fixedly at a scene which contains only low spatial frequencies.

The reason for this surprising fact can be traced to our evolutionary past. Early creatures used their eyes simply as motion sensors, they lacked the