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Eye Tracking in HCI and Usability Research

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INTRODUCTION

Eye tracking is a technique whereby an individual's eye movements are measured so that the researcher knows both where a person is looking at any given time and the sequence in which the person's eyes are shifting from one location to another. Tracking people's eye movements can help HCI researchers to understand visual and display-based information processing and the factors that may impact the usability of system interfaces. In this way, eye-movement recordings can provide an objective source of interface-evaluation data that can inform the design of improved interfaces. Eye movements also can be captured and used as control signals to enable people to interact with interfaces directly without the need for mouse or keyboard input, which can be a major advantage for certain populations of users, such as disabled individuals. We begin this article with an overview of eye-tracking technology and progress toward a detailed discussion of the use of eye tracking in HCI and usability research. A key element of this discussion is to provide a practical guide to inform researchers of the various eye-movement measures that can be taken and the way in which these metrics can address questions about system usability. We conclude by considering the future prospects for eye-tracking research in HCI and usability testing.

BACKGROUND

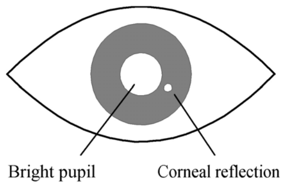
The History of Eye Tracking

Many different methods have been used to track eye movements since the use of eye-tracking technology first was pioneered in reading research more than 100 years ago (Rayner & Pollatsek, 1989). Electro-oculographic techniques, for example, relied on electrodes mounted on the skin around the eye that could measure differences in electrical potential in order to detect eye movements. Other historical methods required the wearing of large contact lenses that covered the cornea (the clear membrane covering the front of the eye) and sclera (the white of the eye that is seen from the outside) with a metal coil embedded around the edge of the lens; eye movements then were measured by fluctuations in an electromagnetic field when the metal coil moved with the eyes (Duchowski, 2003). These methods proved quite invasive, and most modern eye-tracking systems now use video images of the eye to determine where a person is looking (i.e., their so-called *point-of-regard*). Many distinguishing features of the eye can be used to infer point-of-regard, such as corneal reflections (known as Purkinje images), the iris-sclera boundary, and the apparent pupil shape (Duchowski, 2003).

How Does an Eye Tracker Work?

Most commercial eye trackers that are available today measure point-of-regard by the corneal-reflection/pupil-center method (Goldberg & Wichansky, 2003). These kinds of trackers usually consist of a standard desktop computer with an infrared camera mounted beneath (or next to) a display monitor, with image processing software to locate and identify the features of the eye used for tracking. In operation, infrared light from an LED embedded in the infrared camera first is directed into the eye to create strong reflections in target eye features to make them easier to track (infrared light is used to avoid dazzling the user with visible light). The light enters the retina, and a large proportion of it is reflected back, making the pupil appear as a bright, well defined disc (known as the bright-pupil effect). The corneal reflection (or

Figure 1. Corneal reflection and bright pupil as seen in the infrared camera image



first Purkinje image) is also generated by the infrared light, appearing as a small but sharp glint (see Figure 1).

Once the image processing software has identified the center of the pupil and the location of the corneal reflection, the vector between them is measured, and, with further trigonometric calculations, point-of-regard can be found. Although it is possible to determine approximate point-of-regard by the corneal reflection alone (as shown in Figure 2), by tracking both features, eye movements critically can be disassociated from head movements (Duchowski, 2003, Jacob & Karn, 2003).

Video-based eye trackers need to be fine-tuned to the particularities of each person's eye movements by a calibration process. This calibration works by displaying a dot on the screen, and if the eye fixes for longer than a certain threshold time and within a certain area, the system records that pupil-center/corneal-reflection relationship as corresponding to a specific *x,y* coordinate on the screen. This is repeated over a nine- to 13-point grid pattern to gain an accurate calibration over the whole screen (Goldberg & Wichansky, 2003).

Why Study Eye Movements in HCI Research?

What a person is looking at is assumed to indicate the thought "on top of the stack" of cognitive processes (Just & Carpenter, 1976). This eye-mind hypothesis means that eye movement recordings can provide a dynamic trace of where a person's attention is being directed in relation to a visual display. Measuring other aspects of eye movements, such as fixations (i.e., moments when the eyes are relatively stationary, taking in or encoding information), also can reveal the amount of processing being applied to objects at the point-of-regard. In practice, the process of inferring useful information from eye-movement recordings involves the HCI researcher defining areas of interest over certain parts of a display or interface under evaluation and analyzing the eye movements that fall within such areas. In this way, the visibility, meaningfulness, and placement of specific interface elements can be evaluated objectively, and the resulting findings can be used to improve the design of the interface (Goldberg & Kotval, 1999). For example, in a task scenario where participants are asked to search for an icon, a longer-than-expected gaze on the icon before eventual selection would indicate that it lacks meaningfulness and probably needs to be redesigned. A detailed description of eye-tracking metrics and their interpretation is provided in the following sections.

EYE TRACKING AS A RESEARCH AND USABILITY-EVALUATION TOOL

Previous Eye-Tracking Research

Mainstream psychological research has benefited from studying eye movements, as they can provide insight into problem solving, reasoning, mental imagery, and search strategies (Ball et al., 2003; Just & Carpenter, 1976; Yoon & Narayanan, 2004; Zelinsky & Sheinberg, 1995). Because eye movements provide a window into so many aspects of cognition,

Figure 2. Corneal reflection position changing according to point-of-regard (Redline & Lankford, 2001)