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SESSION X SYMPOSIUM: ON-LINE EYE MOVEMENT RECORDING SYSTEMS

GEOFFREY R. LOFTUS, *University of Washington, Presider*

General software for an on-line eye-movement recording system

GEOFFREY LOFTUS, PAUL MATHEWS, SUSAN BELL, and STEVEN POLTROCK
University of Washington, Seattle, Washington 98195

A general on-line eye-movement recording system is described which consists basically of (a) some on-line instrument capable of displaying a visual scene, (b) a device to measure eye position and output position information in the form of electrical signals (c) an analogue-to-digital converter, and (d) a computer. General software for such a system is discussed with emphasis on subroutines which perform calibration and which continuously monitor eye position.

A person's pattern of eye fixations over a visual scene may be construed as an overt manifestation of internal cognitive events, in the sense that such patterns constitute a reasonably direct measure of where in the scene an observer is attending and how long he attends to any particular area. Thus, eye fixation patterns provide a useful class of dependent variables in a variety of experimental situations and have been used to explore such cognitive tasks as reading (Tinker, 1955), picture processing (Mackworth & Morandi, 1967), picture memory (Loftus, 1972), decision processes (Russo, Reference Note 1), scanning of short-term memory (Gould, 1973), and linguistic processing (Carpenter & Just, 1972).

A problem which arises with the use of eye-movement patterns as a dependent variable is that they are often somewhat difficult to measure and analyze. Originally, the simplest measurement technique involved having an observer look at a scene with a small hole in the center; a movie camera aimed through the hole could then take motion pictures of the observer's eyes as the observer looked around the scene. Such a technique (and indeed any technique which does not involve an on-line computer) has two major disadvantages. First, data analysis is extremely tedious involving, with the technique described above, waiting for development of the motion pictures and then carrying out a frame-by-frame analysis of eye position. The second disadvantage is that the experiments which can be done are limited in the sense that the experimenter cannot easily alter the display contingent on aspects of the observer's eye-movement pattern.

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Currently, however, there are a number of devices available which are capable of measuring eye position and outputting electrical signals corresponding to the vertical and horizontal coordinates of the eye at any given instant; these signals may then be input to a computer via an analogue-to-digital converter. The present paper concerns such systems and has two purposes. First, a general eye-movement recording device/computer system will be described, noting the capabilities of such a system. Second, general software for an on-line eye-movement recording experiment will be outlined. Subsequent papers in this symposium will describe various types of eye-movement recording devices in some detail.

A GENERAL ON-LINE EYE-MOVEMENT RECORDING SYSTEM

Figure 1 shows a schematic representation of an on-line eye-movement recording system. At the top left corner of the figure is an eyeball looking at a visual scene, and simultaneously some "device" is looking at the eyeball. For our purposes, it is unimportant how the device works; only two characteristics of the device are

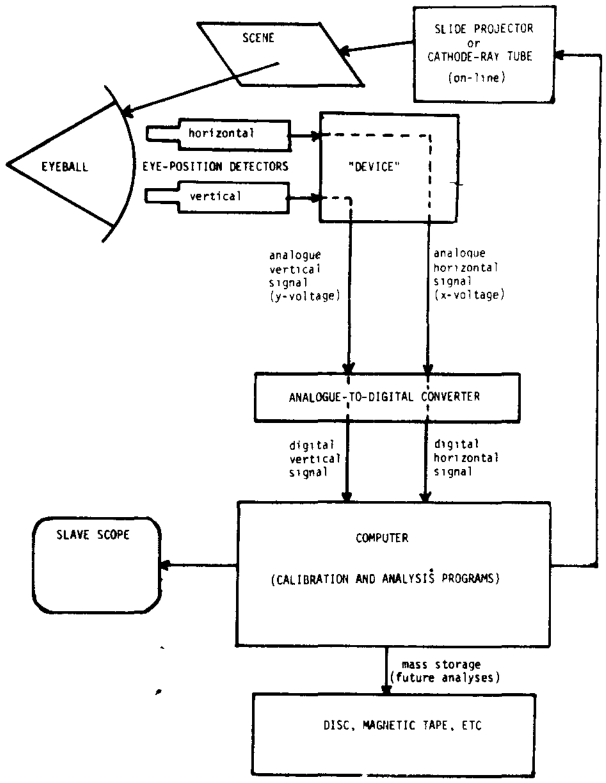

Figure 1. A general system for performing an experiment in which stimuli are controlled and eye movements are recorded on line.

of interest. First, it is assumed that the device includes detectors that in some way acquire information about the vertical and horizontal components of eye position. Second, it is assumed that the device is capable of taking this positional information from the detectors and translating it into two analogue signals which correspond in some systematic way to vertical and horizontal eye position. These analogue signals are then passed from the device to an analogue-to-digital converter which, in turn, relays a digital signal to the computer proper.

Once in the computer, there are three major paths that may be taken by the eye-position information: to a slave scope, to mass storage, and to a scene-displaying instrument.

Slave Scope

It is often useful (although typically not necessary) to have a slave scope that the experimenter can monitor during the course of the experiment. A "fixation spot" can be displayed whose position on the scope corresponds to the location in the visual scene the computer "thinks" the observer is fixating at any given time. A slave scope has two advantages: first, it provides the experimenter with an "intuitive view" of what the observer is doing; second, it alerts the experimenter to unanticipated disasters that may occur (e.g., if the fixation spot were to disappear, the experimenter would realize that the observer has fallen asleep or some such thing, and that corrective action should probably be taken).

Mass Storage

Eye position information can be shipped off to a mass-storage device such as a disk or magnetic tape for future analysis. Depending on the nature of the intended analyses, the information can be stored either in raw form or in "crunched" form (e.g., each time a saccade is made, information about the position and length of the previous fixation could be stored).

On-Line Display

Finally, as noted above, an important class of experimental procedures requires that the display be altered contingent on some aspect of the observer's eye-movement pattern. For example, it might be desirable to turn off or change the scene or to change some aspect of the scene when a certain number of fixations have been made or when a particular location in the scene has been fixated. Accordingly, in Figure 1, eye-position information is depicted as being transferred from the computer to whatever instrument is displaying the scene (e.g., a slide projector or a cathode-ray tube).

GENERAL SOFTWARE

Figure 2 shows, on a very general basis, the minimal software necessary to run an on-line eye-movement experiment. On the left is the main or executive routine responsible for overseeing everything. Under control of the executive are three main subroutines. The first is a calibrating subroutine, essentially responsible for establishing the relationship between known eye position (e.g., in centimeters or degrees of visual angle) and the corresponding electrical signal (voltage) input from the recording device. This calibration routine is called prior to the start of the experiment proper and

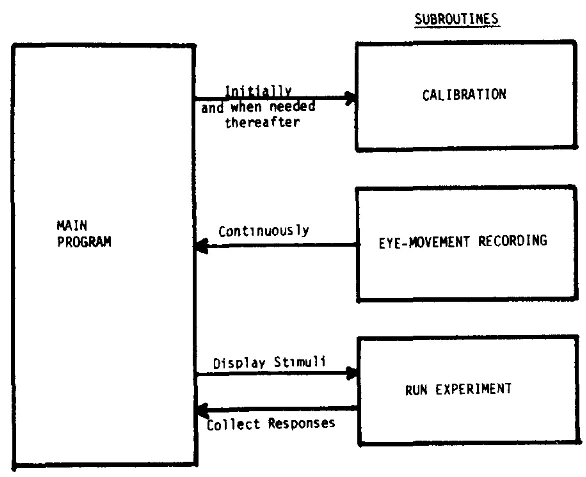

Figure 2. General software for an on-line eye-movement experiment.

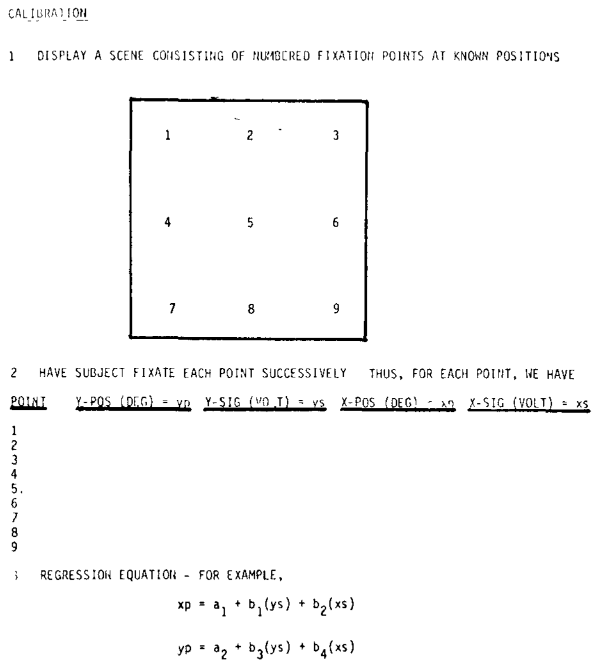

Figure 3. A typical calibration routine.

then can be recalled whenever it is desired (e.g., after slight head movements, electrical drifts, etc; or alternatively, at periodic intervals during the course of the experiment). The second subroutine is the eye-movement routine which is responsible for continuously monitoring eye position. Finally, there is a subroutine which is responsible for displaying the stimuli and collecting any non-eye-movement responses (decisions, reaction times, etc.). For the purposes of the present paper, the first two subroutines are of primary interest and will be described in some detail.

Calibration

Figure 3 depicts a typical calibration routine. Initially, a scene consisting of numbered fixation points is displayed, and the subject is asked to successively fixate each point. The spatial coordinates of each point are assumed to be known a priori; thus, for each point, four values are obtained: the known horizontal and vertical coordinates (in degrees or centimeters) and the obtained horizontal and vertical input signals (in voltages). Finally, the known coordinates and the obtained signals are correlated with each other in a regression equation. The nature of the regression equation will depend on the characteristics of the eye-movement recording device—particularly on the degree of linearity between position and signal and on the amount of vertical-horizontal crosstalk. The regression equation shown in Figure 3 is a typical example[1] that assumes reasonable linearity but some degree of crosstalk; hence, both vertical and horizontal positions (yp and xp, respectively) are assumed to be linear functions of both the vertical and horizontal input signals (ys and xs, respectively). Thus, in the calibration routine, the parameters a_1, a_2, and b_1-b_4 are estimated. Naturally, to the degree that the amount of crosstalk is small, b_2 will be larger than b_1 and b_3 will be larger than b_4.

Eye-Position Subroutine

Finally, Figure 4 shows a typical example of a subroutine which is responsible for sampling and monitoring eye position. It is assumed that the analogue-to-digital converter may be set to sample and convert the vertical and horizontal signals every n milliseconds (a typical value for n might be 1). The sampling process occurs continuously and independently of all other software events; and the converted digital signals are assumed to be stored directly in core via a DMA process. Every k conversions (e.g., k might be 16), an interrupt is generated and control is handed to a signal-averaging routine. Several processes occur in this routine. First, the averages of the k vertical and horizontal signals are obtained. Second, these average values are entered into the regression equation to obtain the estimated vertical and horizontal components of eye position. Third, the position data are stored, either in core or on a mass-storage device. Fourth, the position information is used to update the slave-scope display. And finally, if the observed scene is being controlled on line, a check is made to see whether some event (e.g., a saccade) has occurred which may require updating the scene. In all cases, control is ultimately returned to the executive routine.

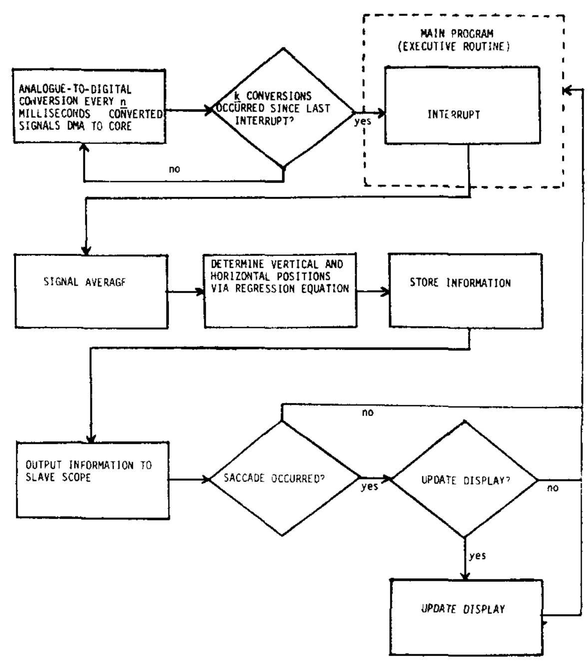

Figure 4. A typical eye-position monitoring routine.

REFERENCE NOTE

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NOTE

1. This equation was described to the first author by Steven Reder who used it in conjunction with a Biometrics SG recorder at Rockefeller University.