A real-time control system for CAI and prosthesis

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An integrated hardware and software system was used for the real-time control of text display in a CAI environment. Reliability and cost considerations led to the development of a digital EOG transducer, which was used in conjunction with a KIM-1 microcomputer. This paper traces the development of that system from a complex and expensive PDP-11-based system to a microcomputer firmware approach. Such a system could, in real time, accomplish a similar display task for severely handicapped nonvocal individuals.

The purpose of this paper is to describe a system for detecting eye movement for the control of computer processes, and to trace its development from an expensive limbus-tracking minicomputer approach to a relatively inexpensive electrooculogram microcomputer method.

Initially, we adapted a PDP-11/40, which had a limbus-tracking interface, for the real-time control of text displays. The objective was to use measures of eye fixation to select frames of text to be displayed by slide projector. Cost and reliability considerations led us to explore electrooculogram (EOG) measures as an alternative approach, and a digital transducer was developed, which was free from a number of constraints imposed by the limbus-tracking system. For detecting eye movement and fixation, the digital EOG device was then interfaced to a KIM-1 microcomputer, and the microcomputer replaced the PDP-11/40.

The use of biophysical measures in the control of real-time systems is an area of current research interest. In computer-assisted instruction and prostheses, these applications involve the real-time processing of either bioelectric potentials, or other, indirect, measures of physical movement.

In humans, one of the physiological systems that has been used in the control of prosthetic devices is the oculomotor system. Eye movement appears to be a useful source of biological signals, since the detection

of specific eye movements can be used as "logical states" in the control of communication or prosthetic applications. There are a number of methods for transducing these eye movements. (For reviews, see Tursky, 1974; Young & Sheena, 1975.) These range from infrared tracking of the margin of the iris (limbus tracking) to recording the electrical signals associated with the movement of the eye itself (EOG).

In many severe physical disabilities and degenerative neurological diseases, the neuromuscular control of eye movement is either unimpaired or is among the last of the human organ systems to be degraded. This suggests that such motor control processes can be used for prosthetic applications. In support of this suggestion, Rinard and Rugg (Note 1, Note 2) have controlled an electric wheel chair by eye movements using limbus tracking methods.

THE APPARATUS AND CIRCUITRY

Limbus/PDP-11

The radiology research group of Temple University Health Sciences Center generously made available their eye movement laboratory. The laboratory is equipped with a PDP-11/40 minicomputer with the laboratory peripheral system (LPS-11), a random-access carousel projector with special interface to the PDP-11, designed by Edwin Wells, and a pair of infrared limbus-tracking spectacles produced by Narco-Bio-Systems, Inc. Existing software, operating in conjunction with the limbus-tracking system, was modified to determine the duration of time that a subject fixated upon a text displayed in one of four quadrants on a video display unit. Depending upon the quadrant fixated, a text passage was then selected by the program for display by the random-access projector. The system, while functional, is expensive and requires a high level of sophistication to operate. The desire to have available a portable and

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DIGITAL EOG TRANSDUCER
BLOCK DIAGRAM

Figure 1. Block diagram of a digital electrooculogram transducer. The amplifiers are AD521s, and both the filters and the comparators are 741s. The 240K and 365K resistors provide the ability to distinguish the vertical and horizontal components of the EOG.

relatively simple device prompted us to explore other eye movement measurement techniques.

EOG Apparatus

The corneo-retinal potential of the eye can be detected by skin electrodes around the orbit. When the eye rotates, shifts in the associated electrostatic field are recorded. The dc recording method used for such detection is called electrooculography. A number of technical problems are associated with this method, including amplifier drift and electrode polarization. To avoid these difficulties, we developed a digital transducer employing operational amplifiers and band-pass filter techniques.

The apparatus is designed for easy interface with the laboratory peripheral system of the PDP-11 (LPS-11). A block diagram of the digital EOG transducer is illustrated in Figure 1. Four Beckman Ag-AgCl recording bioelectrodes are attached via two phonojacks to the circuit. The electrode outputs are then fed through two integrated circuit (IC) instrument amplifiers having a variable gain of 200-400. The signals are then high-pass filtered (3 dB, .5 Hz). The filtered signals are passed to two adder comparators, utilizing $\pm$ hysteresis (horizontal and vertical components are distinguished by slightly different resistor values). This yields four discrete signal levels (one for each quadrant) to be forwarded to the LPS-11. Two light-emitting diodes (LEDs) are triggered in binary fashion to indicate the quadrant being fixated.

To test such practical issues as reliability and portability, the EOG transducer was interfaced to a TV pong game. The "eye-pong" was controlled by the filtered vertical components of the EOG signal, produced by our configuration. Using a photomodulated

potentiometer, we bypassed the typical joystick controls, permitting a subject to play the game by merely scanning the place on the TV set where he wanted to place the "pong paddles."

This provided a means of investigating the control of a video display by means of an ocular transducer. A similar system was constructed and evaluated by Rinard and Rugg (Note 1, Note 2) to assess patient acceptability of the device, system speed, and fine-grain control. The TV game was reported to have been "enthusiastically received by . . . high-level quadriplegics who were helping with clinical evaluation of the control."

When we were assured of the reliability of the digital EOG device, it replaced the limbus-tracking system. System operation is described below.

System Description

Figure 2 shows a flow diagram of the computer program used in conjunction with the digital EOG device. Initially, as each of the four distinct levels that relate to the four visual quadrants is present, a computer cursor is used to select the threshold for each level. These four levels are stored in an internal table for subsequent comparison during sampling. The time of fixation in one quadrant, in seconds, which will cue the display selections is specified from the operations terminal.

The first text display is presented by starting the VR-11 display processor. (The real-time clock is programmed to initiate sampling, upon clock overflow, of Channel 0 in the laboratory peripheral analog-to-digital unit.)

The clock interrupts at a 10-msec rate, and transfers processor control to the sampling routine. As soon

Figure 2. Flow diagram of sampling and display logic for EOG computer interface.

as the digitized value is available, it is compared with each of the four levels stored in the internal table. Another look-up table is consulted to determine which visual quadrant is associated with the identified level. A tally is maintained of time of fixation in the particular quadrant. When an eye movement to a different

quadrant occurs, the count is reinitialized and the process resumes.

After each interrupt, the tally is compared with the maximum time allowed in any quadrant. When the fixation time limit is exceeded, a new display is generated, based on the quadrant upon which the subject's eyes were fixated. Following a 10-sec delay, the sequence is repeated.

INTERFACING DIGITAL EOG WITH MICROCOMPUTER

With the development of the digitized EOG device, we considered the feasibility of producing a microprocessor firmware-based device that could accomplish quaternary choice tasks for communication prostheses with severely handicapped nonvocal individuals.

One of the advantages of the four discrete signal levels produced by the EOG transducer is that the need for an expensive A/D peripheral system (such as the LPS-11) is eliminated. A simple logic design, employing amplitude comparators and a 74148 priority encoder, was interfaced with the I/O port of a KIM-1 microcomputer (see Figure 3). Alternate microprocessors may be interfaced by either a 4-bit latch or peripheral interface adaptor (PIA) (if an interrupt driver is desired). However, a device-polling procedure seems to be generally preferable to interrupts in most microprocessor systems.

Employing the amplitude comparator logic shown in Figure 3, we used the KIM-1 microcomputer to monitor the output of the 74148 encoder. Table 1 displays the voltage levels, or logical values, at each stage of the system shown in Figure 4. The microcomputer tallies the dwell time of the EOG fixation and, upon determining that fixation time has been met, selects the appropriate code (1-4) to be placed on an output line for a display driver. Although we have yet to develop the display driver for the digital EOG microprocessor system, the KIM-1 essentially replaces the PDP-11/40.

PROSTHESIS APPLICATIONS

The current digital EOG microprocessor appears to have a number of prosthetic applications. First, using an adequate number of successive quaternary

Table 1
Logic Table for Digital EOG Transducer/KIM-1 System

Eye Position	Trans- ducer (mV)	Outputs					KIM- 1
		311s			74148		
		C1	C2	C3	A1	A0	
Upper Right	450	H	H	H	L	L	4
Lower Right	155	L	H	H	H	H	3
Upper Left	-82	L	L	H	H	L	2
Lower Left	-430	L	L	L	L	H	1

DIGITAL EOG/KIM-1 MICRO COMPUTER INTERFACE LOGIC

Figure 3. Interface logic for digital EOG/KIM-1 microcomputer control system. See Table 1 for logic table.

choices (i.e., successive choices selected from one of four quadrants), one can easily conceive of a system that provides environmental controls such as locomotion, turning lights on and off, adjusting room temperature, selecting TV channels, and so on. Second, interfacing the system with a device such as the VOTRAX® speech synthesizer, a nonvocal individual should be able to generate fully intelligible speech by appropriate eye scanning in conjunction with suitable microprocessor software. The availability of relatively inexpensive programmable read-only memory (PROM) makes these flexible applications quite feasible.

The current EOG microprocessor system represents a hardware cost of approximately \$500. A total system, including display and necessary PROM should be less than \$3,000.

CONCLUSIONS

We have recounted the development of an eye-tracking system from a relatively expensive (\$50,000) limb-tracking minicomputer configuration to a relatively inexpensive (\$3,000) digital EOG micro-

processor configuration. There are a number of theoretical limitations to the approach we have taken for EOG transduction, but the ease of use for a prosthesis system seems to outweigh the theoretical objections.

REFERENCE NOTES

1. Rinard, F. A., & Rugg, D. G. *Current state of development and testing of an ocular control device*. Paper presented at the Fourth Annual Conference on Systems and devices for the disabled, Seattle, Washington, 1977.
2. Rinard, F. A., & Rugg, D. G. *Communication/control applications of the ocular transducer*. Paper presented at the Communication Workshop, University of Ottawa, Ottawa, Canada, 1977.

REFERENCES

- TURSKY, B. Recording of human eye movements. In R. F. Thompson & M. M. Patterson (Eds.), *Bioelectric recording techniques, Part C*. New York: Academic Press, 1974.
- YOUNG, L. R., & SHEENA, D. Survey of eye-movement recording methods. *Behavior Research Methods & Instrumentation*, 1975, 7, 397-429.