

tion. It was assumed that each student might possess unique learning problems; thus, flexibility was another watchword.

Rewards were built into the degree of success the user had on his or her level of difficulty. Short games or visual displays provided the maximum incentives for the student's success.

Another item that was given considerable attention was the security of the program. A difficult situation could arise if a student tried to break out of the program, thus erasing his poor performance. Limitations and checks on input statements, on error commands, and on masking of keys were used to eliminate many of these areas of concern.

MOVEMENT

THE EYETRACKER COMMUNICATION SYSTEM

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Mark B. Friedman (standing), Mark Dzmura (left), and Gary Kiliany.

Our EyeTracker Communication System allows a physically handicapped person to use eye movements to control high-quality speech output efficiently. A teaching system has been in use for over six months. We are currently developing a portable, personal communication system whose main features are ruggedness, convenience, safety, and portability. The

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system consists of three main modules, each of which is independently useful. The video-based sensor module determines the direction of eye gaze under most indoor lighting conditions. The dynamic display module incorporates a hierarchical data base that allows quick access to a large amount of data. The accessible data include not only letters and words but also full phrases and sentences. The output module allows the data to be output in a sex- and age-identifiable voice or printed on paper.

Introduction

The EyeTracker Communication System has been designed to aid severely physically impaired children. It is currently in classroom use as a teaching aid. We are developing it to be used as a portable, personal communication system.

The system features safety, ruggedness, portability, and convenience. There is no physical contact with the user. The device is all solid state, powered by low-voltage direct current, and there are no moving parts or critical alignments. User control of the device is rapid and nonfatiguing. Printed and high-quality vocal outputs are available. The handicapped user can use the EyeTracker Communication System without supervision.

Modular Organization

The EyeTracker system consists of three related modules, all of which are controlled by the same microprocessor. The sensor module allows the Eye-

Tracker to sense remotely which one of up to nine display areas a user is looking at. The display module, with an integral, hierarchical data base, facilitates the communication function of the EyeTracker. Finally, the output module incorporates high-quality speech generation and, optionally, printed copy.

The remote eye direction sensor module, which costs less than \$1500, uses an infrared video camera and a digital preprocessor. This economy was achieved by using a conventional, infrared-sensitive, commercial surveillance camera. For extra safety and ruggedness, an industrial solid-state automation camera can be substituted.

A sharp image of the user's eye is maintained by an ultrasonic-ranging and automatic-focusing system. Direction of gaze is computed from the relative positions of a corneal reflection and an image of the pupil.

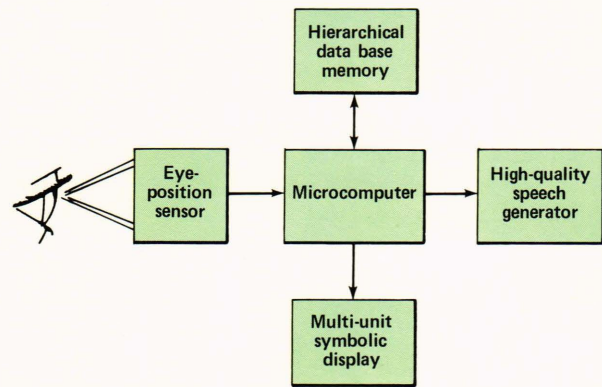
The display module currently consists of eight solid-state alphanumeric display regions arranged on the perimeter of a 3×3 matrix. Initially, the display presented to the user consists of up to eight subject headings. Gazing at one of these areas results in the presentation of up to eight subject-related words or phrases. This process of presenting successively more specific subject choices continues until the final level of specification is achieved. In practice, a specific word, such as a name or place, is inserted into a general phrase, such as a greeting or request, and the resulting sentence is sent to the output module.

The output module produces high-quality, concatenated speech, which can be specific to the age and sex of the user. In order to achieve age- and sex-identifiable speech quality, compressed speech is encoded digitally and reproduced using a continuously variable-slope delta-modulation technique. If desirable, the output can be reproduced on the on-board printer.

Features

There are two main reasons for using eye-movement-based communication aids over more conventional limb- or body-movement-based devices. First, two substantial groups of handicapped children (severely spastic and paralytic) do not have any other reliable body movements under voluntary control. Second, even among children with other reliable body movements, eye movement control is much more rapid and less fatiguing. This latter factor, ease and rapidity of encoding a message, often makes the difference between whether a person will voluntarily use a communication aid or will use it only when obliged to, under supervision.

We are still selecting and organizing the vocabulary data base while we finish the hardware support. We anticipate that most of the "small talk" of daily living will be encodable with two passes through the hierarchical data base (in two sets of four glances), because some of the lowest levels of the data base include phrases (for instance, greetings or requests) that lack only a word or phrase to make



EyeTracker Communication System, high-level conceptual diagram.

them specific. For instance, after one pass through the data base (four glances), a phrase such as "please give me" or "I would like to go to" is stored in a sentence buffer. Another pass completes the sentence with a phrase such as "a drink of water" or "the toilet."

The hierarchical, tree-structured organization of the speech data base in conjunction with the dynamic display provides a very efficient means of accessing the large number of phrases and sentences available. The philosophy of frame-oriented menu selection used in the EyeTracker was developed as PROMIS at the University of Vermont and as ZOG at the Carnegie-Mellon University. Using this system, five eye movements, taking less than a minute, enable a user to choose from among over 4000 phrases; adding one more level to the hierarchy would expand the possible choice list to over 32,000 phrases. Such a large data space allows for a high degree of redundancy, which greatly facilitates inexperienced users' mastery of the system.

The delta-encoded speech of the output module approximates the tonal quality of good telephone voice transmission. We use high-quality compressed speech components rather than totally synthesized speech because it is better accepted by handicapped children. In pilot studies, we found that normal nursery- and elementary-school-aged children enjoyed making a computer generate its typical monotonous, synthetic speech (which they characterized as sounding like Darth Vader of *Star Wars*). In contrast, speech-impaired, handicapped children did not like to use "machine-sounding" speech and much preferred to use speech communication that was sex- and, roughly, age-specific. They wanted their communicator to sound the way they thought they should sound.

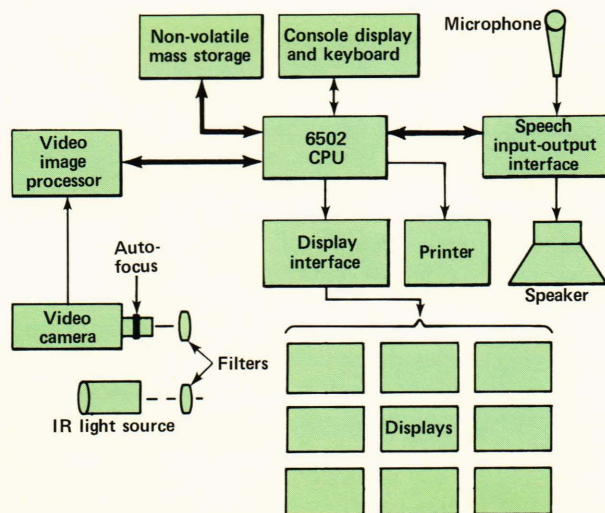
Currently, in a classroom at the Rehabilitation Institute of Pittsburgh (formerly the Pittsburgh Home for Crippled Children), our device is in almost daily use aiding the teaching of a severely movement-impaired child. In response to a teacher's or therapist's question, the child uses her gaze to reply. The child's possible responses are limited to four words, which

are preselected for that trial by the teacher or therapist from a large, precomposed menu presented by the computer. The EyeTracker is used both for vocabulary building (testing word recognition) and concept testing.

In addition to allowing the child to use gaze for selection, another virtue of the EyeTracker Communication System in this application is patience. Whereas a teacher or aide may easily become impatient with the slow decision time of some handicapped children, the EyeTracker will wait indefinitely for the child's response. It will then clearly say the word, which calls the teacher's attention to that student, thus enabling the teacher to work with several disabled children simultaneously.

Hardware

This teaching system is based on an Apple II microcomputer donated to the Rehabilitation Institute by the Alcoa Foundation. To make a practical personal communication aid, we are building our communication systems using another 6502-based microcomputer, the Rockwell AIM-65 single-board computer with built-in printer. Our goal is to have a rugged, portable, battery-powered communication system about the size of a portable black-and-white TV set. For ruggedness and compactness, we have replaced the Apple floppy disk drives with solid-state Magnetic Bubble Memory from National Semiconductor (for which we have written our own operating system). Although bubble memory is expensive now, we anticipate large price reductions in the next few years. Ultimately, any field-modifiable, nonvolatile memory technology will suffice, for instance, battery backed-up CMOS RAM or EEPROM. Throughout our design process, we have written PROM firmware to replace dedicated interface logic.



Current EyeTracker implementation hardware block diagram.

“... we have tried to maintain the principle that, wherever possible, we should use the “intelligence” of the personal computer to minimize the physical and mental effort that handicapped users must expend to use our communication aids.”

Software

The software for the AIM-65-based EyeTracker prototype is stored in PROM and was written entirely in 6502 assembly language. Much effort was made to code the system in a modular fashion; consequently, a software module is associated with each distinct hardware subsystem. Each module output calls for a well-defined set of operations on its associated hardware. This policy has helped make the coding of the abstract, higher level routines as straightforward as if they were written in a high-level, compiled language. Further, as good practice dictates, all software at the user interface level is “friendly;” that is, an inexperienced user can do nothing to destroy data or otherwise compromise the system, and the system attempts to present reasonable error messages on invalid user entry or failure of a system component.

Conclusions

The hardware and software modularity of the EyeTracker Communication System is such that each of the major modules can be incorporated as an independent entity into other aids for the handicapped. The EyeTracker sensor module could be adapted for virtually any control function where it is advantageous to use eye-movement control rather than gross motor movements. It would be practical to implement a physical switch-based communication system using our dynamic display and hierarchical data base. This hierarchical data organization allows for phrase- and sentence-oriented communication without the need for expert knowledge of the system or reference to external manuals.

We have built a limited-vocabulary EyeTracker system based on Apple II that has been in daily use for over six months in a classroom for young physically handicapped children. During this time, we have been developing hardware and software to extend the teaching system into a less expensive, portable personal communication system. Throughout our work, we have tried to maintain the principle that, wherever possible, we should use the “intelligence” of the personal computer to minimize the physical and mental effort that handicapped users must expend to use our communication aids. To the extent that children voluntarily use the EyeTracker Communication System, we will feel that we are successful in our efforts.