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BY- GLASER, ROBERT RAMAGE, WILLIAM W.
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INSTRUCTIONAL AND EQUIPMENT CONSIDERATIONS IN THE DESIGN OF THE STUDENT MACHINE INTERFACE, THE POINT OF CONTACT OF A LEARNER WITH AN EDUCATIONAL SYSTEM DISPLAY, ARE DISCUSSED. INSTRUCTIONAL ASPECTS ARE CONSIDERED WITH RESPECT TO THE REQUIREMENTS FOR THE INDIVIDUALIZATION OF THE LEARNING ENVIRONMENT, THE SEQUENCING OF INSTRUCTIONAL STEPS, AND NONEXPOSITORY INSTRUCTION WHICH ALLOWS THE LEARNER TO DIRECTLY MANIPULATE ELEMENTS OF A SUBJECT MATTER. THE DISPLAY REQUIREMENTS OF INTERFACES ARE INFLUENCED NOT ONLY BY HUMAN ENGINEERING CONSIDERATIONS, BUT ALSO BY ASPECTS OF SENSORY INPUTS THAT FACILITATE OR INHIBIT LEARNING. RESPONSE REQUIREMENTS MUST CONSIDER RESPONSE DETECTABILITY, DEGREE OF SIMULATION, AND LEARNER RESPONSE CAPABILITY. RESPONSE FEEDBACK IMPOSES DEMANDS FOR IMMEDIATELY RESPONSIVE DISPLAYS WITH SHORT LATENCIES BETWEEN LEARNER RESPONSE AND FEEDBACK. EQUIPMENT CONSIDERATIONS EXPLORE THE DEVELOPMENT OF NEW DEVICES AND THE ADAPTATION OF EXISTING TECHNIQUES IN ORDER TO PROVIDE BETTER INTERFACES BETWEEN THE STUDENT AND HIS SUBJECT MATTER. DEVICES AND TECHNIQUES FOR MEETING THE BEHAVIORAL REQUIREMENTS OF THE INSTRUCTIONAL INTERFACE ARE DISCUSSED, AND METHODS FOR ELIMINATING AUXILIARY INTERFERING TASKS ASSOCIATED WITH THE OPERATION OF THE DEVICES ARE INDICATED. FIGURES ARE INCLUDED. THIS ARTICLE IS A REPRINT FROM THE 1967 "IEEE INTERNATIONAL CONVENTION RECORD, PART 10," NEW YORK, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, 1967. (AUTHORS)

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ROBERT GLASER AND WILLIAM W. RAMAGE

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Robert Glaser

and

William W. Ramage

Learning Research and Development Center

University of Pittsburgh

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THE STUDENT-MACHINE INTERFACE IN INSTRUCTION*

Robert Glaser
William W. Ramage
Learning Research and Development Center
University of Pittsburgh
Pittsburgh, Pennsylvania

Abstract

This paper discusses both instructional and equipment considerations in the design of the student machine interface, i.e., the point of contact of a learner with an educ.tional system display. Instructional aspects are considered with respect to the requirements for the individualization of the learning environment, the sequencing of instructional steps, and non-expository instruction which allows the learner to directly manipulate elements of a subject matter. The display requirements of interfaces are influenced not only by human engineering considerations but also by aspects of sensory inputs that facilitate or inhibit learning. Response requirements must consider response detectability, degree of simulation, and learner response capability. Response feedback imposes demands for immediately responsive displays with short latencies between learner response and feedback.

Equipment considerations explore the development of new devices and the adaptation of existing techniques in order to provide better interfaces between the student and his subject matter. Devices and techniques for meeting the behavioral requirements of the instructional interface are discussed, and methods for eliminating auxiliary interfering tasks associated with the operation of the devices are indicated.

Introduction

In the design of new educational systems it is necessary to consider the way in which subject matter is displayed to the student and the means by which he can respond to it. Despite all the service that printed materials and traditional audio-visual aids have provided, it is appropriate in the light of present behavioral science and engineering technology to examine new possibilities for providing interaction between the student and his subject matter environment. In engineering, the term "man-machine interface" has been used to describe the "surface" by which a human comes into contact with a machine. In engineering psychology, much work has gone into the study of the display and response characteristics required in a system to provide an optimal man-machine unit. The purpose of this paper is similar to this in that it examines the student-machine interface in an instructional system. In contrast to other man-machine systems, an instructional system is uniquely designed to educate and hence to change the behavior of a human with respect to some body of knowledge; as a result, knowledge of the learning process becomes especially relevant.

The principal communication channels used by human learners involve visual, auditory, and motor responses; this paper will limit its considerations to the requirements placed on these channels by the educational environment and to some of the techniques under development that utilize these channels in an automated instructional system. The scope of the paper also is limited to examples of innovative automated devices that can add new dimensions to instructional techniques and strategies. An automated environment can encompass a wide range of possibilities and in order to establish a reference which can include most technological innovations, the educational system considered will be a computer-based system in which the instructional techniques and their control are programmed on a digital computer.

A major point of view taken in the paper is that automated instructional devices in the future will enable the student to manipulate and operate on the units and elements of a subject matter so that he can, for example, change the character of a displayed mathematical function or match sounds in learning a new language. This view is in contrast to the commonly held notion that computer-assisted instruction serves to implement the traditional student-teacher interaction by simulating a question-and-answer tutorial discussion. The task of new instructional systems is rather to put the student more in direct control of the skills and body of knowledge he is to acquire. If this is indeed a future direction, then the emphasis on interface design becomes increasingly significant.

Instructional Requirements

In an instructional system, learning occurs as a result of the interaction between three components of the student's environment: the stimulus display, the student's response to this stimulus, and appropriate feedback as a result of his response.[1] The display component is concerned with the presentation of information in a manner that is meaningful with respect to the subject matter being taught and with respect to the behavior capabilities of the learner. The response component is concerned with the acceptance of in-

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formation from the learner in a manner appropriate to the subject matter and with a minimum of the auxiliary tasks which are often required by the nature of a response device. For example, the selection of a particular symbol on a display may involve learning the relationship between the symbol and some key on a keyboard or may involve learning to operate a pointing mechanism such as a light pen or spot-controlling lever. The feedback component involves the presentation of information as a function of an associated response. The direction of information flow of this component makes it similar in nature to the display component, but the function it performs dictates characteristics different from that of the display component and requires features that may not be needed in the display component.

Integrally related to the above components of an instructional system are certain instructional strategies which influence the design and operation of interface devices. Major requirements of this kind are individualization, the sequencing of instructional steps, and non-expository instruction. The individualization of learning means that each learner will interact with the subject matter at his own rate, in a manner suited to his learning habits, and along an instructional path that matches his skills and background. The implication of this requirement is that interface devices being used by two or more learners at the same time will need to handle different information and hence will require a certain amount of independence from all other interface devices in the system.

The requirement for sequencing information in appropriate steps means that the amount of information presented before requiring a response may be small. This implies that the material displayed between responses will probably not be extensive; however, a fast learner or just a fast responder may require relatively high rates of access to new material, and with individualized instructional sequences, this access will be on a quasi-random basis.

The non-expository requirement implies a high degree of learner-directed sequences of material. This process of learning by discovery or by induction means that the learner has the ability to explore or to manipulate a particular subject matter, and not only must the instructional program have the logical capability to cope with this requirement, but the interface devices must contain enough alternative states or controllable configuration to allow a wide range of selection of response alternatives.

As has been indicated, the learner learns as a result of certain relationships between a stimulus situation presented on a display, a response to this situation implemented by some control mechanism, and appropriate feedback as a result of this response. Each of these components will now be considered.

Displays

Good display interfaces will present subject-matter stimuli in a form and in a sense modality appropriate to the subject matter. This is a non-trivial statement if one considers that it is not always possible to do this if subject-matter dimensions need to be restricted to static or two-dimensional displays. For example, if one is concerned that students of mathematics should be taught "mathematical imagery" as it may be defined by mathematicians, then it seems appropriate to teach a course in calculus or the theory of functions with an interface which permits dynamic manipulation of oscilloscope displays as a student manipulates the elements of an equation and approximates a solution. All of us can think of a variety of examples where subject-matter dimensions are reduced in their richness as a function of the constriction of presentation through a typewriter or printed page display.

Relevant to display characteristics, work in experimental psychology and human engineering has reasonably well documented existing knowledge about man's capabilities and limitations on receiving stimuli through visual, auditory and tactile channels.[2] For example, with respect to vision, much information is available about the factors affecting visual acuity, depth perception, color discrimination, and brightness-adaptation level. The variables influencing the ability to make visual discriminations such as brightness contrast, ambient light, viewing time, and the movement of objects, have been specified quantitatively; cathode-ray tube visibility has been carefully studied in terms of signal size, brightness, and duration. The design of letter shape and print size has been carefully investigated. The perception of sound signals, auditory displays, and speech communication has been studied with respect to the factors affecting the detection of loudness, pitch and speech intelligibility.

This information points to such general conclusions as the following: (1) The range of human senses is remarkably large when compared with electronic or electro-mechanical sensors. In hearing, the range is over 130 decibels and in vision it is over 100 decibels.[3] The regulatory mechanisms of the human contribute to this wide range and the ability for fine tuning. In contrast, the ability of the senses for temporal resolution is limited, and the discrimination of events occuring closely spaced in time may be best done by machine. (2) The input characteristics of the senses are not linearly related to corresponding changes in physical quantities. For example, when a human observer reports that the value of the brightness of a visual display or the loudness of a sound has doubled, his perception of an increase does not correspond to doubling the intensity of the physical stimulus dimension. (3) In man, the ability to make discriminations, that is, the ability to perceive changes and differences between stimuli, is much more acute than the ability to identify items in isolation. For example, a person may hear the difference between tones only one cycle per second apart at a thousand cycles per second, and under certain conditions a person can make some 400 to 500 discriminable steps in frequency. In contrast, when the same individual is asked to assign different identifying labels to tones displayed singly over his range of hearing, he can accurately assign only six or seven identifying categories. Using this differentiating ability in the learning laboratory, it has been found that discrimination training is an especially effective way to teach young children to identify and make fine distinctions between such stimuli as numerals and letter sounds.

Perhaps of even greater importance than these human engineering aspects of the display are the aspects of sensory input that may facilitate or inhibit learning. This can best be illustrated by pointing out that there is apparently an undocumented truism among educators, especially those concerned with elementary education, that multimedia and multisensory stimulation enhances learning by virtue of the fact that the learner experiences the same thing through different sensory channels. While there may be good reasons for presenting subject-matter stimuli in a variety of ways, sheer multiple bombardment is not reason enough. As a matter of fact, there is evidence to the contrary. In contrast to the position usually taken by designers of audiovisual equipment, studies show[4,5] that the human organism at any moment in time is best conceived of as a single-channel system. To date, there is little or no information available which allows us to take the position that the human can receive more information if exposed to two or more sources simultaneously or that he receives more information if transmitted through two sense modalities rather than one. Experiments show that when redundant information is presented over audio and visual channels, there is no facilitation over audio or visual transmission alone; at low transmission speeds, the learner time-shares the channels and at high speeds, he attempts to block out one channel. It should be pointed out, however, that a different effect might prevail when the information presented over the two channels is not redundant, but rather involves a relationship between the auditory and visual stimuli, such as there is in learning the correspondence between printed letters and spoken words. In these cases, the relationship involved must be systematically examined in order to determine the conditions of presentation that are relevant to learning.

Response

In the discussion so far of the stimulus, we have implied some things about the response; however, let us now consider other aspects of the response. As illustration, the following topics can be mentioned: response detectability, artificiality and realism, and learner capability. In designing instruction, stimulus presentations are engineered to guide the responses of the learner in appropriate subject-matter behaviors. If a display permits irrelevant responses or provides opportunity for delay and distraction, other behaviors are learned which may significantly inhibit the attainment of subject matter competence. As a consequence, displays and the instructional stimuli they present must be carefully tested to insure that relevant subject matter activity is encouraged on the part of the learner.

The relevant aspects of these responses need to be detected so that they can be used to guide the future course of instruction. Automated interfaces may offer the possibility of detecting response components which are useful in guiding instruction, but which are difficult for a human teacher to sense or keep track of. For example, the processing unit behind the interface can store the results of a set of responses, and on the basis of this immediate bookkeeping, can prescribe a new learning problem. Furthermore, automated interfaces can detect the speed or latency with which a learner responds; this is extremely difficult, if not impossible, for the teacher to do. This may, however, be a significant response dimension since there is evidence in the experimental psychology of learning that response latency is indicative of the strength of learning. As another example of detection capability, it seems likely that small motor responses such as are involved in the teaching of handwriting, may be detected and acted upon more quickly than in the usual classroom.

In many instances, the nature of the media through which instructional information is presented forces restraints on "realism," realism in the sense of changing the characteristics of the task eventually to be learned. A significant example of a restriction of realism, although no value judgement is implied in these remarks, is the use of multiple-choice responses, which limit other forms of response, so that answers on a test can be automatically detected. The appropriate use of display and response technology can reduce this kind of artificiality, or at least, in interface design, imposed artificiality needs to be considered. Work on the design of simulators has taught us that realism in instructional devices may be a much overemphasized notion.[6] When simulators are used, it is often obvious that to foster learning, effective simulation needs to omit and control aspects of a real situation. In the early stages of learning a subject matter, artificiality may be a necessary requirement; at more advanced stages, the necessity for efficient performance measures may introduce artificiality. What is required is an analysis of the component tasks involved so that behavior is taught which insures transfer to the noisy situations that will be encountered in real life. If anything, insistence on realism too early in learning may be a disservice to the learner.

In considering the response requirements of an interface, learner capability also should be introduced as a consideration. Young children can speak and point to things before they have developed the fine motor skills for manipulating a pencil or a typewriter key. Much intellectual content might be taught to very young children if an interface device could detect touch positions and a small spoken vocabulary. The limited capacity of handicapped children with muscular disorders is another significant area for interface design which must adapt to learner capabilities.

Feedback

The presentation of information and response detection are of little consequence in insuring learning without the third component of feedback appropriate to and contingent upon the learner's responses. In our concerns with the student-machine interface, an environment highly responsive to and adaptive to the behavior of the learner is a fundamental property of the system. The experimental study of learning has indicated that feedback contingent upon the consequences of the student's response is a powerful force in guiding and maintaining learning. It is the necessary responsive aspect of a learning situation which makes our traditional methods of instruction inefficient and outmoded and it is this responsive aspect of interface devices which is a key notion in considering their design. A demanding requirement on the design of learning environments with their interface devices and associated processors is the necessity for immediate action on the basis of a student input. This immediate action takes the form of a change in the stimulus display or the characteristics of the response device.

The immediacy of feedback is a key factor in increasing the probability that the performance engaged in by the learner will be learned. The absence of immediate feedback will depress the occurrence of behavior. The delay of reinforcing feedback has had extensive study by psychologists,[7,8] and the general evidence is that delay results in less efficient learning. Under certain conditions, delays longer than a few seconds can reduce learning efficiency. In addition, the behavior that occurs during the delay interval may be the behavior that is learned, and we may indeed be reinforcing distraction, lack of concentration, or slow thinking. Extensive experimentation has also been carried out on the pattern and schedule by which reinforcing feedback is provided to the learner. Reinforcing feedback can occur after every response, after a fixed time period of responding, after a fixed number of responses have occurred, in a variable fashion, and in other ways. Each of these patterns of reinforcement results in different response characteristics on the part of the learner.[9]

The nature of the feedback display which leads to the reinforcement of behavior is a matter for study. It can be extrinsic to the subject matter at hand, as when the teacher says "good" or when the student gets an 'A', but what seems most possible in newly designed interface devices is feedback intrinsic to the subject matter and which gives the student a feeling of a high degree of control over the body of knowledge with which he is interacting. He can produce changes in the subject matter as a result of his behavior, and it is these changes that are reinforcing and motivating and which foster effective learning. The effectiveness of stimulus change has undergone an increasing amount of research over the past decade. Highly responsive learning environments can result in highly curious and exploratory individuals.[10] Investigations have repeatedly demonstrated that new behavior is efficiently learned if it leads to a change in the stimulus display with which the individual is interacting. In addition, this stimulus change elicits side effects which can be labelled as curiosity and inquisitiveness. With highly responsive interfaces, it seems that we should be able to add a significant dimension to education.

Individualization

It has been recognized for a long time that instructional systems need to adapt to the requirements of the individual learner. In contrast to this notion is the fact that while the importance of individualization has been recognized, our schools are overwhelmingly geared to mass, group instruction. Automated systems may be one answer to managing the requirements for the individualization for instruction. With respect to the interface, however, it is to be pointed out that mass communication interfaces have been the general rule and the design of motion picture screens, television receivers, and so forth have different design characteristics when they are up close to and are responsive to the inputs of individual learners.

The Subject Matter

Up to this point we have considered interfaces from the point of view of the characteristics of the learner. The other major component involved in interface design is the nature of the subject matter being taught. Quite obviously, different subject matters and different bodies of knowledge have varying stimulus and response requirements which determine the kind of interface suited to them. Some trade-off is involved between the design of general-purpose consoles versus consoles specifically designed for particular instructional topics. For example, a nonexpository system for mathematical problem solving is the Culler-Fried system in which the student can, on an oscilloscope, literally look at the results of his attempts at problem solution.[11,12] Actually seeing how a mathematical function is varying, seeing where it peaks and where it does not, suggests as a result of this visual inspection, certain procedures that are useful in approximating a solution. For problem solving in other subject matters, like qualitative analysis in chemistry and teaching young children to read and to write, interfaces with different characteristics suggest themselves.

Equipment Techniques

Techniques employed in current instructional systems generally make use of techniques and devices developed in other areas such as the military or entertainment fields; however, the functional requirements of instructional systems are unique in some aspects and are not satisfied by the devices developed for other purposes. Investigations concerning the interface requirements between a student and a particular subject matter have suggested that for certain tasks the matching of the student to the subject matter can be improved by the use of electronic devices.[13] There are two techniques that have been developed in direct response to the requirements of the educational need that appear to have real promise in interface applications. These techniques are principally coordinate-detecting methods that are able by one method to identify the location on a given surface of a single arbitrary object and by a second method to identify the locations on a given surface of several unique objects while remaining blind to other foreign objects.

Adaptation of developments in the fields of audio and video display also holds promise of providing a communication capability that will significantly augment individualization and interaction of a student with his subject matter. Two such developments which were adapted for computer controlled learning environments are mentioned below.

Coordinate Detection

The coordinate detection technique for identifying the location of a single point on a surface is an extension of the work reported on 'lightpen' facilities for direct view storage tubes.[14] This is basically an analogue technique in which the value of a particular coordinate of a point corresponds to the value of a measurable voltage at the location of the point. Figure 1 illustrates one embodiment in which electrical fields can be alternately established in orthogonal directions across a conductive surface to produce unique potentials at a point corresponding to X and Y coordinate values. These potentials can be detected by a high impedance stylus placed against the surface which does not distort the potential field. These potential values may be converted to digital values by an A/D converter if input to a digital device is desired. The conductive surface may consist of transparent conductive glass so that visual displays such as templates or cathode ray tubes may be associated with this surface to provide a highly interactive display and response surface. Scanning rates may be as high as several kilocycles so that normal tracking of a hand-held stylus may be accomplished if desired. Figures 2 and 3 illustrate applications of this technique encompassing the functions of pointing or writing type responses. Figure 2 shows the use of the technique with a transparent conductive surface associated with a cathode ray tube display and Figure 3 shows the technique being utilized with conductive paper as the working surface of a scratch pad type device.

Object Arrangement

Instructional programs in subjects such as geometry and simulation programs or games involving object arrangements require a response surface on which objects may be placed or moved as an indication of input or response to the program. A surface capable of detecting one or more objects of a special set has been described.[15] This surface has the property of being able to detect several objects of the set simultaneously and to provide information concerning their location on the surface. With proper coding (such as size or shape), the information provided is sufficient to identify individual objects and to determine the orientation of the object on the board. The surface has the further desirable property that it is "blind" to almost all other objects such as pencils or fingers which may be temporarily in contact with the surface.

The technique employed is based on the principles of a transformer with a variable reluctance magnetic path. Two wires are placed in a slot of a block of ferromagnetic material. One wire is the drive line and the second the sense line. When the drive line is pulsed by a current source, a signal is coupled to the sense line. The coupling existing between lines and, therefore, the magnitude of the signal generated in the sense line is a function of the magnetic circuit reluctance; the higher the reluctance the less the magnitude of the generated signal. With no magnetic material covering the slot, a large air gap exists in the magnetic circuit and it has a high reluctance. Figure 4 shows an arrangement with seven sense lines and one drive line. When the drive line is energized, those points, such as the one indicated in bold outline, that have objects covering them will produce a detectable pulse on its associated sense line. By sequencing the pulsing of the drive lines, a sequence of groups of points may be scanned to determine whether they are covered or not.

A prototype surface, approximately 10 x 12 inches in area and having a resolution of 36 points per square inch, is presently under construction. This unit will be provided with electronics that can automatically scan the surface and furnish data to a computer at a rate of approximately 10^6 bits per second.

This scan will be initiated by command from an external source such as a computer. Initial work with this prototype will probably involve a set of about ten distinct objects coded such that each can be uniquely identified from other members of the set.

Audio Displays

Audio stimuli are an important component of an instructional system for the teaching of certain types of subject matter or certain kinds of learners. Instruction in new verbal behavior, as in teaching a new language, obviously requires an audio capability, and young children or illiterates may require that instructions be presented through the spoken word.

The technology of speech generation at the present time is such that the creation of natural sounding speech displays are most easily obtained from analogue recordings of speech sounds. It is difficult to juxtapose small units such as syllables or words and maintain a smooth sounding message, and it is unfeasible to store and retrieve in acceptable time intervals the number of possible messages that might be associated with a highly adaptive instructional sequence. It has been estimated that if the basic unit were words, then a vocabulary of 20,000 words would be needed to cover 99% of the requirements of free text (newspapers and similar type material).[16] Although a particular instructional program would not be expected to have the demands of free text, the storage requirements for words, phrases, and sentences can be very large if the program is adaptive to a wide variety of learners.

The access and demand requirements for audio messages used with instructional sequences imply that several categories of audio capability may be needed in an instructional system. The audio messages or phrases might be classified as being universal, general, or special depending upon their application in a given program. Universal phrases are those used many times in various programs to indicate results or give directions. Such messages might include the phrases "correct," "try again," and "go on to the next problem." General phrases will be more specific to a particular program and often may be juxtaposed to another phrase to compose a meaningful message. These phrases will be used often during a program and may include such phrases as "the correct answer is," and "multiply the numbers shown." Special phrases are those phrases which are unique to a particular item in the program and as such will have relatively low demand and can be somewhat linearly ordered if each user has his own source of special messages.

The above categorization of audio messages implies that an automated instructional system may need two or more types of audio storage media. The universal phrases will need a fast access (within one second) device with modest capacity (100 phrases) to provide fast system response when these phrases are used for the feedback function. The general phrases probably do not functionally require the access speed of the universal phrases, but if several general phrases are to be juxtaposed, the access must be fast enough to prevent disturbing pauses within the message. Special phrases are probably best linearly ordered on an individual transport for each student, so that as the student progresses through the program, the transport is positioned in such a way that access time to the next special phrase is relatively short (5 seconds or less).

Equipment having the characteristics outlined above is certainly within the state-of-the-art. The fast access transports can be belt-driven devices that are designed to accommodate speech recordings. Transports of this type have already been designed for digital applications for use as storage media for computers.[17] These transports should be two speed (access and play) and designed for digital or programmed control The slow access units can probably be any one of the existing designs of cartridge or reel loading transports modified to accept digital control and positioning.

Visual Displays

Research and development of techniques for generating visual displays on cathode ray tubes is a fairly well advanced art with most computer manufacturers and others who now offer displays capable of generating symbols or simple black and white line drawings. The engineering challenges occur when instructional programs require pictures that may require color or motion. Slides and movies accomplish both features, but both are predetermined and, hence, limited in adaptability and if large numbers of scenes are desired, the access times become unacceptable.

Storage of video information can be a problem if more than simple text or line drawings are to be displayed. Pictures and photographs contain millions of bits of information, and although much of this is redundant, we do not yet know of efficient coding methods that will greatly reduce the storage requirements and still allow the scene to be regenerated. The Plato system[18] at the University of Illinois has for some years been combining the advantages of film storage and computer-generated information by multiplexing onto a common display the outputs of an optically scanned slide and an electronic storage tube containing computer program generated information. This technique of combining th advantages of an economic storage medium such as film for background information and superimposing the adapted program information still seems to be the practical answer to handling large amounts of video information.

Recent developments in video storage on magnetic discs have created the possibility of having large libraries of stored television type pictures accessible in a few seconds. A picture from this library might be copied into a given user's buffer and the signal from this buffer multiplexed with user created information that is unique to the particular user's program and his particular responses. This approach is functionally equivalent to that of the Plato system, but may hold promise of larger libraries on-line and the advantages of the economics and facilities of the already existing TV industry. Figure 5 shows a monitor displaying one of 500 pictures previously recorded on a magnetic disc.*

Conclusion

The design of the student-machine interface requires detailed analysis of the psychological requirements of the learning environment, the structure and characteristics of the subject matter, and the adaptation of display and response engineering techniques which may not have been orginally intended for educational use. Two aspects are of prime importance in facilitating the learning process: one is the availability of immediate feedback on the basis of student activity; the second is the availability of equipment to enable the student to directly manipulate the units and elements of the subject matter. The implementation of these two aspects in instructional in-

*Disc manufactured by MVR Corporation.

terface design can add a significant dimension to education. This dimension consists of highly responsive learning environments which facilitate learning through reinforcing feedback as well as providing the degree of stimulus change necessary in an educational situation to develop curiosity and exploration.

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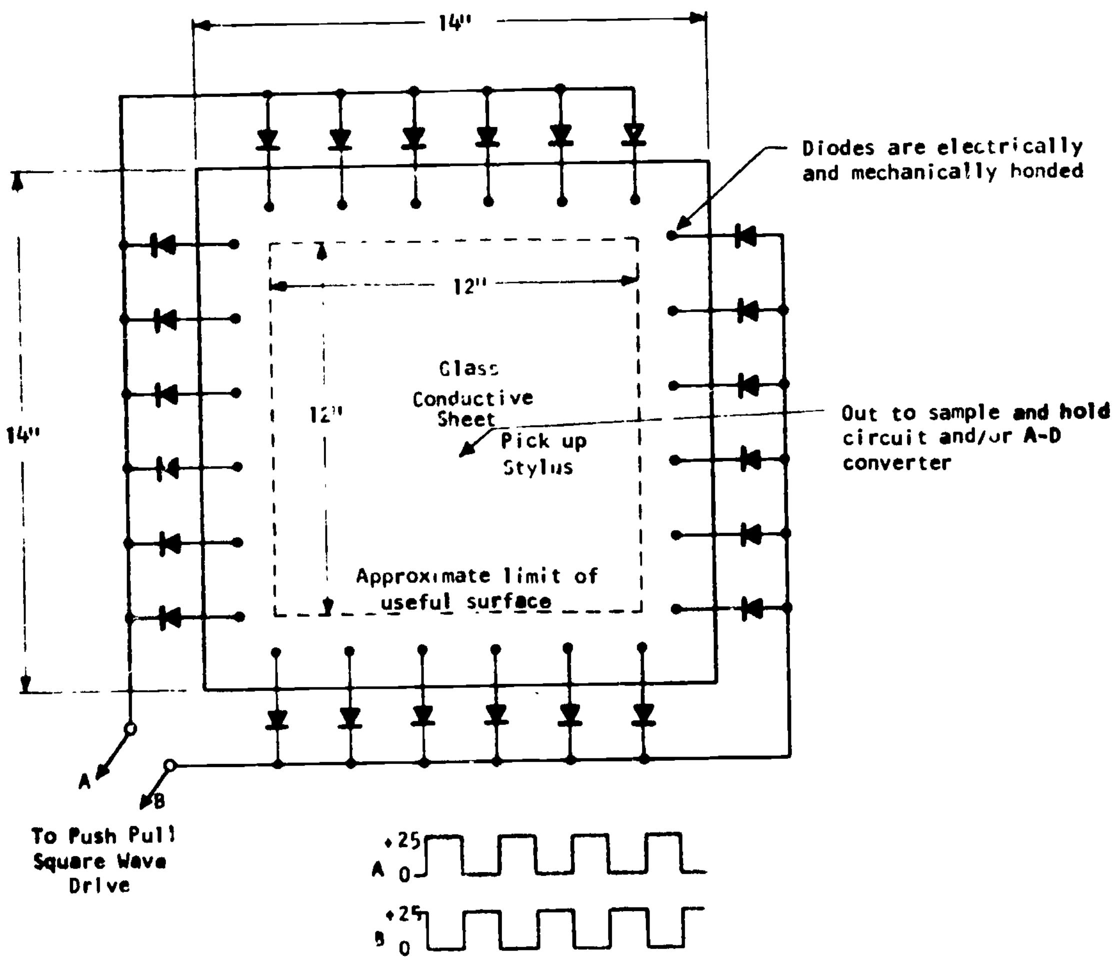

Fig. 1. Coordinate detection technique.

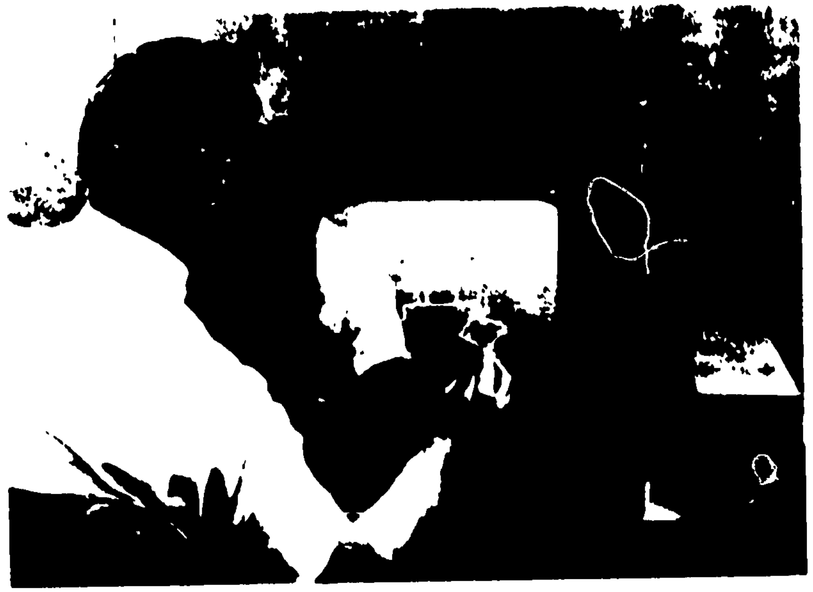

Fig. 2. Coordinate detection device with transparent conductive surface associated with a cathode ray tube display.

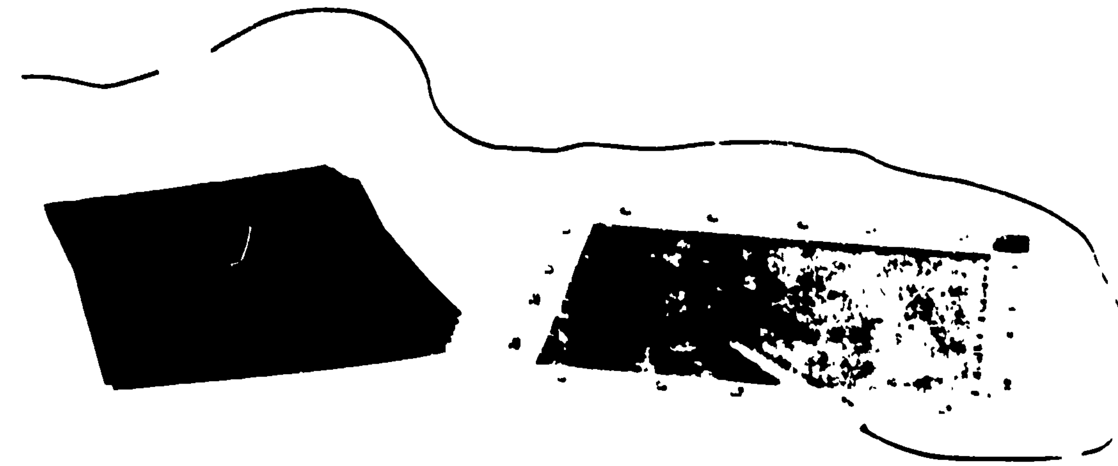

Fig. 3. Coordinate detection device utilizing paper as a working surface.

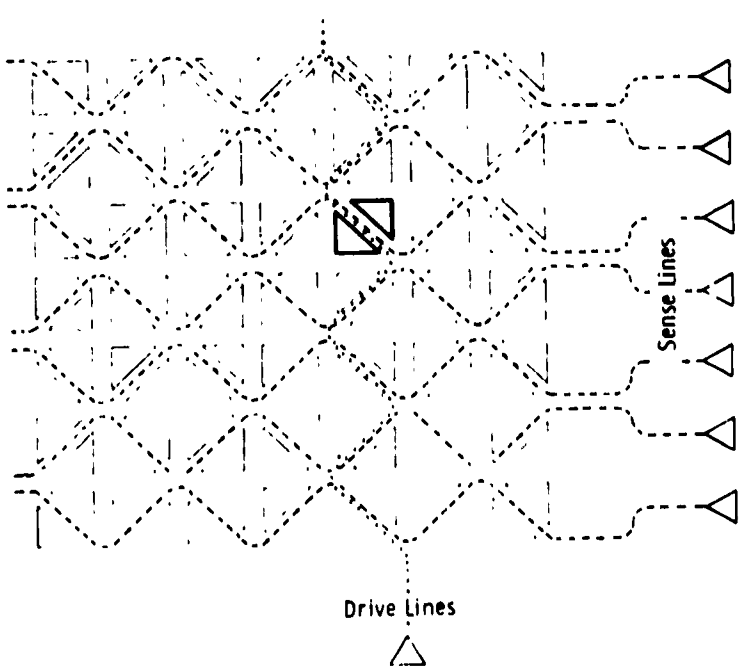

Fig. 4. Object detection technique.

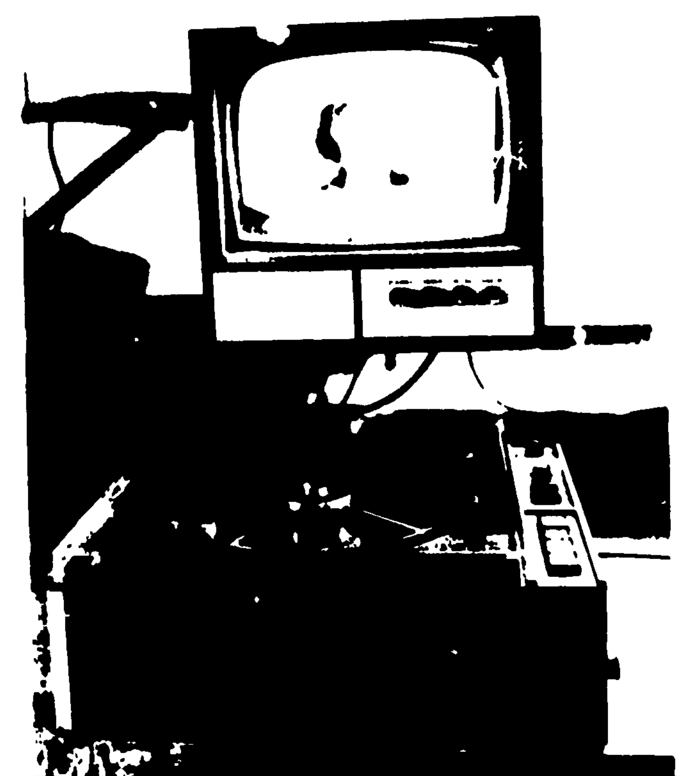

Fig. 5. Video disc storage and monitor.