GREGG VANDERHEIDEN
Director
TRACE Research and Development Center
University of Wisconsin

Modifying and Designing Computer Terminals to Allow Access by Handicapped Individuals

INTRODUCTION

For handicapped individuals, the primary problems in dealing with computer terminals fall into two categories: manipulation of the keyboard, and dealing with the information displayed. Manipulation problems are usually experienced by individuals with physical handicaps, including the elderly. The second category, dealing with the information presented on the tube, is a problem for both blind individuals and individuals who may have trouble dealing with more complex information. For blind individuals, the problem is primarily one of presenting information in the wrong sensory mode. The complexity of the information display, however, may also be a barrier to some sighted users, such as young children, people with low vision, some elderly individuals, and individuals with varying degrees of language or cognitive disability. Deaf persons generally do not experience any difficulty in dealing with terminals unless there is significant and nonredundant information presented auditorially, either with speech or through beeps and other audible cues. With systems designed to function in libraries these are generally not significant problems, since the systems are usually designed to operate silently or with a minimum of auditory cueing.

In this paper, each of the three areas of handicap—visual, physical and cognitive—will be explored, along with the different approaches which have been used to provide access to textual information. Some of the approaches are simple; others are complex. The following section of the paper will then examine the practical constraints to be considered in designing public access data processing terminals. These include considerations and constraints experienced by both the user and the manufacturer. Finally, the paper will reexamine the various solution strategies presented in the first section in light of these practical considerations and constraints. Practical, low-cost, minimum modification approaches which best meet the constraints of manufacturers and users will be identified.

Strategies for the Visually Impaired

Solution strategies for individuals with visual impairments fall into three basic categories: (1) visual enlargement; (2) tactile displays; and (3) auditory displays. There are several ways of visually enlarging the output display. One technique is to expand the visual image on the display electronically. This gives a "zoom" effect, making the images on the screen larger, but means that a smaller portion of the screen is seen at any one time. A second approach is to use a separate magnifying lens. This solution has the advantage that the display itself does not need to be modified in any special fashion. The magnifying lens can be positioned in front of the display either mechanically or manually, and moved by the individual to scan the information on the page. This same effect can be achieved at a much higher cost by using a magnifying lens on a closed-circuit television camera.

The second approach for visually impaired individuals is a tactile display. While the first approach is intended mostly for individuals with impaired vision, the second approach is intended primarily for individuals with no vision. Tactile displays take basically two forms. The first is an actual representation of the characters themselves. The Opticon is an example of this approach. The Opticon is an aid which has a small camera, about the size of a pack of gum. This camera is connected to the main unit of the Opticon, which is about the size of a cassette tape recorder. The individual moves the camera over the printed letters or the characters on the television screen, and the Opticon reproduces, on the fingertips of the individual's other hand, the shapes of the letters or characters being scanned by the camera. In this way, the individual actually "feels" the various printed characters, and can read them directly. This approach has the advantage that an individual trained in the use of the Opticon can read most types of printed or displayed materials without special adapters. The second form of tactile display involves use of the Braille system. With Braille, each character or group of characters is represented by a pattern of raised dots. These can be punched into paper or presented using dynamic Braille displays, which have little pins that move up and down. Dynamic Braille displays are usually single-cell or single-line displays, since a full-page dynamic Braille display would be extremely expensive.

The third approach to information display for visually impaired individuals is the use of auditory displays. This approach can be used with both blind and visually impaired individuals. With this approach, the information displayed visually is also spoken. Talking terminals of this sort are most effective for transferring bulk text. Selection menus and complex visually oriented displays are more difficult to comprehend if simply read from the screen. This is particularly true when two or three columns are displayed. Therefore, special processing of the information is usually required, rather than simply having the user read the information off the screen one line at a time (which would give the first entry on each of the three columns, then the second entry on each column, etc.). This approach is almost useless with graphic or charted information, as is the dynamic Braille approach. The only approaches which are useful at all for graphic or charted information are the enlarged screen and the direct tactile translation (i.e., Opticon).

Strategies for Physically Handicapped Individuals

For physically handicapped individuals the problem is more complex, due to the greater variety of physical disabilities. As a result, a wide variety of approaches exists to match not only the varying needs and disabilities, but also the varying residual control these individuals may have. This section provides an overview of some of the basic and more applicable approaches for use with data terminals.

All of the techniques can be broken down into two fundamental approaches. The first approach is *direct selection*. Any technique where the individual directly points to the various choices (e.g., using a typewriter keyboard or pointing to selections directly on the terminal screen) is an example of direct selection. The second basic approach is *scanning*. The scanning technique is used wherever the individual is unable to point for himself. With this approach, items are presented sequentially to the individual. When the desired item is reached, the individual signals by operating some type of switch. Thus, the scanning approach is essentially "selection in time," while the direct selection approach could be called "selection in space." The scanning approach is much slower and more cumbersome than the direct selection approach, and is therefore usually used only in situations where direct selection is not possible.

Direct Selection Techniques

Direct selection techniques can take a wide variety of forms, but all essentially provide the individual with some mechanism for pointing. These techniques may take advantage of whatever body part over which the individual has best control, including finger, hand, arm, leg, knee, foot, head, or eye. In some cases, the individual can point directly to the particular item (see fig. 1). In other cases, some type of pointer such as a headstick, finger pointer, etc., may be used (see fig. 2). A very powerful new technique which has received much more application recently is the use of optical pointers. With this technique, an individual points using a beam of light. This approach has the advantage that the "length" of the beam automatically adjusts to the distance necessary to reach the item indicated. This allows the individual to exert much less physical control. It also permits the individual to stay in his best position, rather than having to lean in one direction or another to reach his choice, as he would with a mechanical pointer. This ability to maintain optimal position can greatly increase an individual's pointing capabilities. Individuals with good discrete pointing skills can generally use these various techniques directly. Other individuals can use these techniques to point, but their pointing motions may be mixed with erratic or involuntary jerking motions. The individual may not be able to hold his hand, finger, or pointer still over a single selection, or may not be able to press a single switch. In these cases, the "auto-monitoring technique" can be used. This approach has an "averaging" effect which allows an individual to point, even shakily, to an item, and have the system determine which item he or she is trying to indicate. Even if the individual makes occasional wrong selections, the system can ignore these false signals and pick out the desired target of the individual's pointing.

Most recently, research has begun into the use of eyes for direct pointing. Using the eyes to point is very difficult for a number of reasons. It isn't possible to attach something easily to the eye to use either as a pointer or as a reference for sensing eye position. Optical methods for determining eye position have been used, but generally these need to be individually calibrated, are sensitive to ambient light conditions or are sensitive to position and orientation. Many of the eye position-sensing systems also measure only eye position with respect to the head. In order to tell where the individual is looking, one must determine where the head is with respect to the target. These two pieces of information (eye position and head position) then need to be integrated in order to determine the position of the gaze. Although this approach is difficult to implement, its potential is great, especially for aids which are custom-fit to the individual. Practical implementation of this technique with custom aids is, however, at least several years away. Use of this system for public access terminals, where it would need to be self-calibrating and able to work with a wide variety of individuals, is farther away yet.

With these various techniques, it is usually possible to find some mechanism through which the individual can point or indicate directly. If

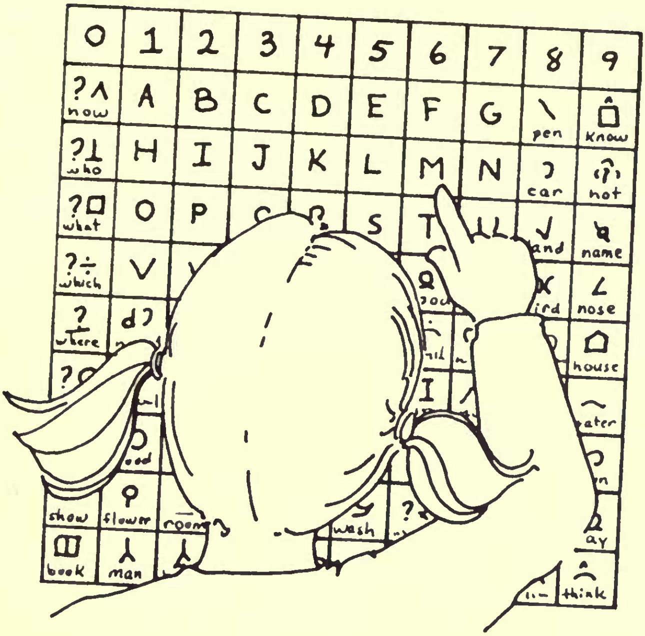

Figure 1. Direct selection by manual pointing

the individual can point directly, but only to a small number of items, then multisignal techniques such as encoding can be used (discussed later). For individuals who are unable to point at all, however, a scanning approach may be required.

Scanning Techniques

While direct selection techniques are methods where the individual himself points, scanning techniques are basically methods where something or someone else points for the individual. The individual then watches until the desired item is presented. At that time, he gives a signal of some type to indicate that the desired item has been reached. For an individual to be able to use this technique, he need only have some single motion which he can control. This can be a movement of any part of his body, or the cessation of movement. An eye blink, a look upward, a

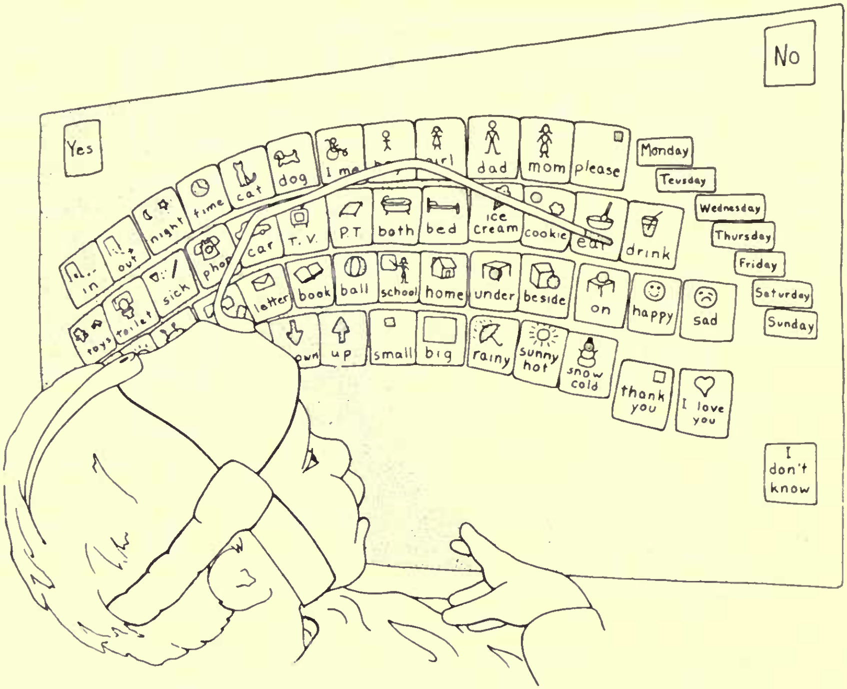

Figure 2. Direct selection by using a headstick

movement of the thumb, etc. are all acceptable movements which could be either observed or tapped using a switch. Because of this, scanning is an extremely powerful technique.

The disadvantages of the scanning approach is that it is much slower. This is especially true if the number of choices is large. If an individual must spell out information, for example, it can take a very long time to scan the alphabet, picking out each letter individually. The time required to transmit information in this manner ranges from long to excruciatingly long, depending upon the amount of information and the individual's response time.

One of the primary reasons for the extended time required to transfer information using the scanning approach is that the bulk of the time is spent displaying "wrong" choices. In order to accelerate the scanning process, therefore, several techniques have been developed to reduce the number of wrong choices presented. One method is the use of group/item scanning. With this technique, groups of items are first presented to the individual, until he gives a signal indicating that the desired item is in that group. The individual items within that group are then scanned individually until the desired item is reached. If a very large number of choices are possible, then a group/group/item approach can be used. The most popular forms of group/item scanning are row/column (or row/item) scanning and page/item scanning (see fig. 3).

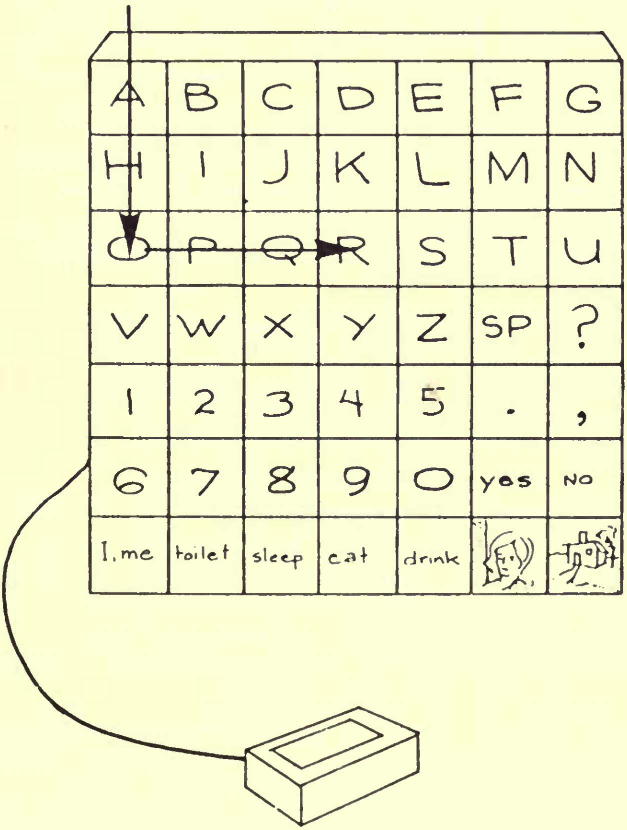

Figure 3a. Row-column scanning

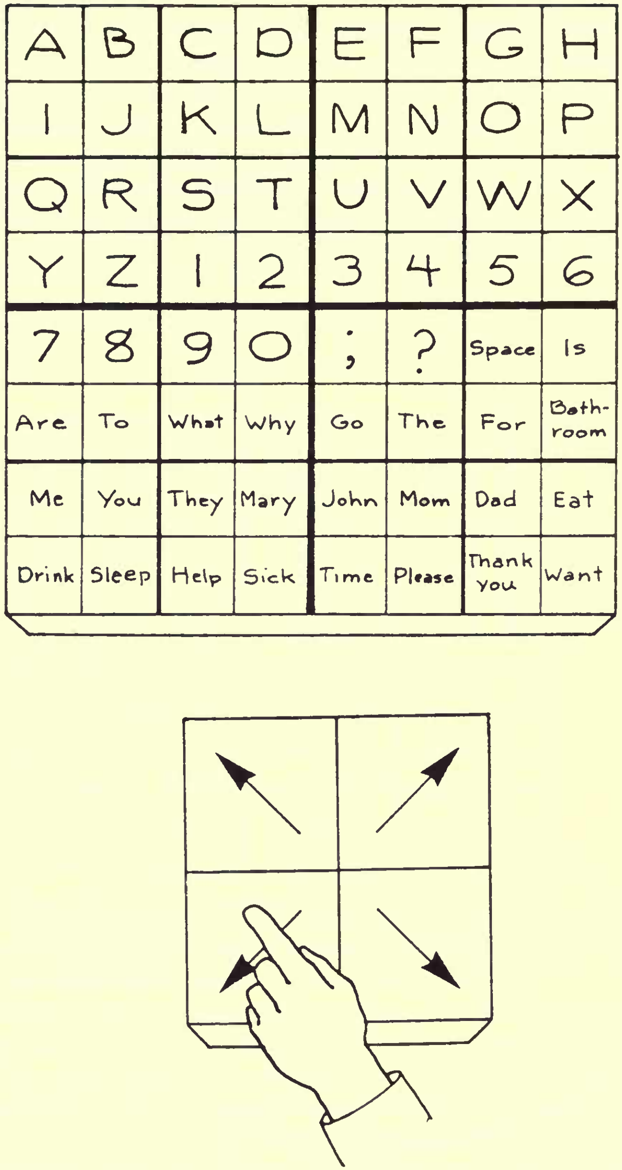

Figure 3b. Successive quartering

Another technique to reduce the number of wrong presentations is to arrange the items in order of frequency of use. Thus, the most used items are placed toward the front of the scanning routine, since they are more probably the next correct item. In cases where selections are used in a certain pattern, such as in English spelling, the most probable next letter will vary depending upon the preceding letter or letters selected. In such cases, the order of presentation can be changed after each selection to display the most probable next selection. This technique should be implemented with care, however, since it is sometimes more confusing to have the selection order change each time, causing the individual to take more time in his selection and thus losing some of the advantages of predictive scanning. Over long periods, however, the individual may be able to anticipate the changing displays so that this problem can be reduced or eliminated.

Encoding Techniques

Even with the above scanning acceleration techniques, the scanning approach is generally still considered to be a second choice to any type of direct selection technique. For situations where the individual can only select a small number of items, however, the total selection space (total number of possible selections) can be expanded by using what have been termed *encoding techniques.*

Encoding techniques constitute only one part of a larger category of techniques which use multiple signals from the user to increase the "selection space" that an individual would have with direct selection, or decrease the "selection time" of an individual using the scanning approach. Some multisignal techniques for scanning were discussed above, such as group/-item scanning.

A parallel to the group/item concept in scanning is two-number encoding or group/item indication using direct selection. With this technique, an individual who is able to point to only ten numbers could quickly select from 100 items by simply pointing to a pair of numbers. One can think of this either as indicating a number from zero to ninety-nine, or as selecting one of ten groups, and then one of ten items within the group. In both cases, the time and movements involved are identical. The major difference is in how the information is displayed. There are advantages to either approach, although the pairing of individual numbers with individual choices is almost always the superior approach due to the reduced amount of visual scanning and processing necessary. These individually coded selections can then be grouped if desired or appropriate (see fig. 4).

Thus, the advantage of the encoding technique is that it can be used to provide an individual capable of relatively little movement or accuracy

12	A	24	H	36	O	52	V
13	B	25	I	41	P	53	W
14	C	26	J	42	Q	54	X
15	D	31	K	43	R	56	Y
16	E	32	L	45	S	61	Z
21	F	34	M	46	T	62	SP
23	G	35	N	51	U	63	;

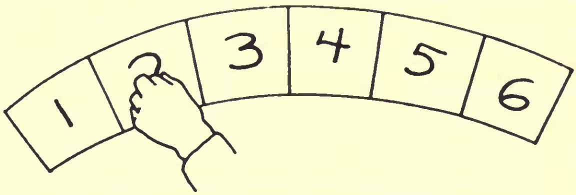

Figure 4a.
Two-movement encoding

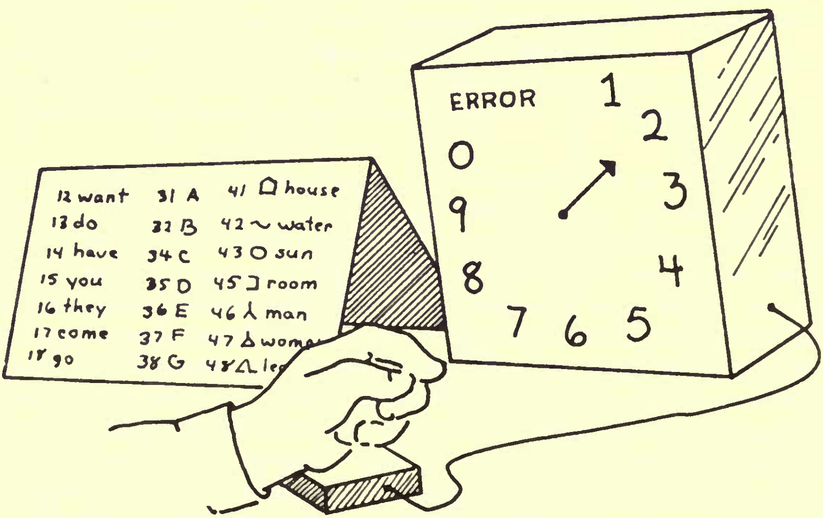

Figure 4b. Scan encoding

with the ability to point to a large number of items. Ten widely spaced keys, for instance, could be used in a two-movement encoding technique to select any key on a keyboard or selection panel. Three-movement encoding would allow one to specify any of 1000 keys or selections.

Thus, it is possible to provide individuals having a wide variety of physical handicaps with access to systems of any level of complexity. Techniques exist, in fact, which can allow any individual, no matter how severe the physical handicap, to control information-processing systems. Choice of the appropriate technique will depend upon the application, the amount of information required, the variety of individuals who will be using the system, and the amount of modification which can be reasonably expected. For custom, personal aids, these constraints would be much different than for public access computer or information-access terminals.

Cognitive Considerations

In addition to the physical and sensory considerations, systems need to be designed which can be used by individuals having varying cognitive and language capabilities. Some design considerations are necessary to ensure that the systems can be used by younger children or by elderly individuals. In other cases, modifications might be implemented to allow the systems to be more easily used by individuals with specific language or cognitive processing difficulties resulting form stroke, injury or other conditions.

Typical considerations in this area would be: (1) use of simple visual displays; (2) use of large, plainly-marked input panels; (3) use of a minimal number of keys and options—use of a hidden-option approach; and (4) use of simple categorical presentations. Most of these are self-explanatory. The hidden-option approach allows the system to support faster and more efficient data entry approaches for individuals who are familiar with the system, while providing a perhaps slower but much more straightforward data entry or retrieval procedure for other individuals. Two techniques for achieving this are: (1) to make a number of the options invisible so that they can be called up, but are not necessarily displayed to the novice; (2) to have prompted and nonprompted input sequences.

Practical Considerations and Constraints

From the previous section, it can be seen that the problem of access lies not in finding a method to provide access to these systems for individuals with severe physical or sensory handicaps. There are a large number of techniques which can provide very effective interface approaches for individuals with almost any type of physical or sensory handicap. The problem instead is one of finding a practical, cost-efficient and effective method for providing this access.

User Constraints

Design constraints fall into two categories: user constraints and manufacturer/distribution constraints. The user constraints will vary somewhat depending upon the application for which the special terminals will be used. In general, however, there are four basic user constraints, especially for public access terminals. The system and modifications must be: (1) obvious, (2) easy to learn, (3) easy to set up or connect with, and (4) reliable and easy to maintain. The first two are, of course, general rules; they apply not only to handicapped individuals, but to the population as a whole. The third is appropriate mainly in terms of use by handicapped individuals. Adaptation of the systems for these individuals should not take even a few minutes nor require an engineer. Librarians are not going to have the time to hook up each individual as he comes in, or to remove or put away equipment carefully after each use. If the method for interfacing to the system is simple, it will be used. If the system is at all complex, however, it will generally not be connected or maintained. If, in addition, the system requires any significant amount of extra training on the part of the library staff or the handicapped individuals who will use it, the changes of it being utilized are further decreased.

Maintenance is another important area of concern. Will adding these capabilities make the system prone to breakage? A system which is in one piece, keyboard and display together, will be much more reliable and need less maintenance than a system which is built around many separate, interconnected units. No matter how simple and firm the connectors, they are always susceptible to being pulled and pushed, knocked, hit, and jammed. Systems with multiple components from different sources also make it much more difficult to maintain the system. Extra mechanical adaptations, which would be in the way for nonhandicapped users and therefore removed and replaced with each use, are also much more susceptible to damage and loss. Replacement and maintenance of modified systems is a very serious problem, and becomes more serious as modifications increase in number and complexity.

Manufacturer and Support Constraints

In addition to the constraints mentioned above, there are a number of considerations with regard to the manufacture and maintenance of the systems. One of the first concerns of the manufacturer is cost. If the basic terminal costs x, how much more would the terminal cost with the modifications included? How much would it cost to research and develop these extra capabilities as a part of the basic design? If a library would pay *x* for the system, how much more might they pay if these features were added?

Time is also a very important factor for the manufacturer. The goal is to deliver a finished product to the public as quickly as possible. Will these adaptations mean another six to twelve months on the drawing board? If the system is already in production, can these adaptations simply be added to the system, or will completed terminals have to be reworked? If they must be redesigned, what happens to the terminals and the systems already out in the field?

Documentation and training force up costs and add to the time involved. It costs an incredible amount of money to create user manuals. Will these special-purpose features mean additional training materials and training time for library staff? How much extra training will be necessary for the manufacturer's representatives? How will this affect the cost of the overall systems?

Practical Solution Strategies

All of these factors are very real, and must be taken into account when considering modifications of systems to optimize their use by individuals with handicaps. For this reason, it is not sufficient simply to develop or describe techniques for providing access for handicapped individuals. Instead, it is necessary to tackle the much more difficult task of determining techniques which can not only provide effective methods for access, but which also can minimize the cost, maintenance and other aspects necessary for the techniques to be practical and implementable. With these constraints in mind, one can examine the various strategies discussed earlier. Of particular interest will be the identification of those strategies which can best accommodate the various constraints.

Strategies for the Visually Impaired

The first technique discussed was visual enlargement. Displays can be made larger through a number of electronic techniques, but these are all technically complicated and would involve extensive modification of the circuitry in the terminal. Moreover, magnifying the display in this fashion only permits the user to view a portion of the overall display. If all of the letters were made twice as high (and twice as wide), for instance, the user would only be able to see one-fourth of the original screen at a time. To see the entire screen, he would have to look at four different displays or be provided with some type of electronic "moving window" which would allow him, in effect, to move around on the original screen. This, again, is expensive and somewhat disorienting visually.

Use of an optical magnifier for this function, however, would provide the same basic capability at much reduced cost. Essentially, the terminal could be outfitted either with a large magnifier which would sit in front of the screen and allow the individual to see the entire screen magnified by some factor, or with a large hand-held magnifying lens which could be attached to the terminal or desk with a chain. Maintenance, construction and replacement of these magnifiers would be very simple. Many libraries already have magnifying lenses of this sort, and visually impaired individuals are generally familiar with the use of such lenses.

The second general technique mentioned was the use of tactile displays. These displays are almost always very expensive, since they are designed using nonstandard technologies. In addition, these systems generally require extensive training to be used effectively, and therefore do not lend themselves easily for use with a public terminal. Finally, since the systems rarely use full-page displays, some modification of the display format may be necessary to provide an easily comprehensible tactile display. For these reasons, it would be difficult for terminal manufacturers to build any type of tactile display into their terminals. A better approach would be to provide an output port from the terminal. This alternative would both be inexpensive and provide a ready mechanism for individuals to connect their personal tactile displays. In addition, libraries that so desired could connect to these ports special tactile computer terminals designed specifically for a given population.

The questions surrounding the practicality of voice-output or talking terminals closely parallel the previous discussions. In general, it would be very difficult for computer terminal manufacturers or information retrieval system developers to design voice-output systems as accessories to an overall system. Auditory display of information usually needs to be done in a method quite different from visual displays of information. One major difference is that a visual display is essentially a parallel display of all of the information on the screen. An auditory display is a serial display of the information. Layout of the screen, the format of presentation, and the methods used to scan displays to select the desired information differ in large degree. For this reason, the best approach here, too, would be to provide a port to which individuals could connect their individual aids.

Another very simple and cost-effective strategy is to provide a composite video signal on an output jack. This would allow the system to have a second CRT display. That second display could be anything from a slightly larger television monitor with a moderate expansion of the display to a projected television screen. In this manner, one could theoretically have a terminal with a keyboard and a four-by-six-foot screen. With this technique, the entire screen can be expanded in size, not just a portion of it.

Computer video output is already provided on some terminals, and for other terminals would add as little as $3-$5 to the cost.

As with all of the techniques discussed here, the best overall approach to the problem of optimizing terminals for use by specific populations of handicapped individuals is to contact major centers for the visually impaired and to talk with professionals who are experts in the area of adaptation for this population. They can be provided with the specific constraints of the situation, and can offer guidance as to the most practical, cost-effective and useful approaches for that particular situation.

Strategies for Use by Physically Handicapped Individuals

As pointed out earlier, the most efficient and straightforward techniques are those of direct selection. For this reason, attention should first be turned to techniques which can be used to implement this type of approach. The first modification to be provided should be a keyboard guard or mask (see fig. 5). A keyguard or mask is simply a plate of plastic, wood or metal which fits over the keyboard and has holes drilled or punched in it directly above each of the keys. The purpose of the guard is to give the individual a surface on which he can rest and slide his hand without accidentally activating the keys. To operate individual keys, he simply moves his finger, thumb or dowel down through the holes (which are the same size as or slightly larger than the keys). Such keyboard guards can be made quite easily and inexpensively. IBM, for example, manufactures them for all of their typewriters and sells them for about ten dollars. Keyguards for public access terminals should be designed so that they can be easily attached or removed, to allow use of the terminals by nonhandicapped individuals as well. When in place, they should be firm. The space bar should be treated as any other key on the keyboard, except that three holes may be provided instead of one. A cutout the size of the entire space bar should *not* be made in the keyguard, since this usually results in a large number of inadvertent spaces by the individual.

Another approach is to provide alternate keyboards. These keyboards could be expanded and recessed (under a keyguard) to facilitate use by different handicapped individuals. This approach, however, is very expensive and would require the fabrication and fitting of various sizes and configurations of keyboards to accommodate different types of physical disabilities. Here again, a good approach is to provide an input connecter which would parallel the functions of the keyboard. Many handicapped individuals who require special keyboards have custom communication aids. With such aids, they could simply connect to the port, if it used a standard code (such as ASCII), and be able to duplicate *all* the functions of the keyboard.

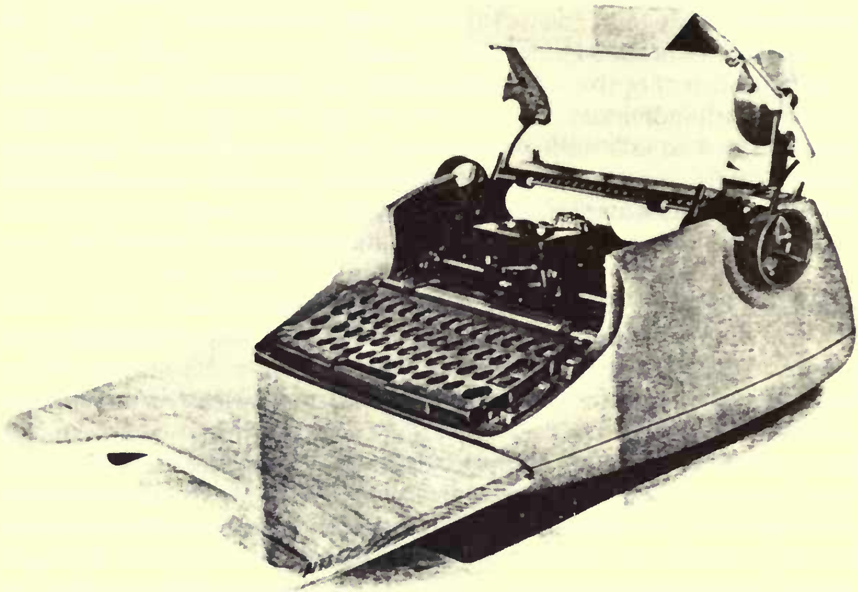

Figure 5. Guarded keyboard

Another very powerful direct selection technique is the use of a light-beam pointer. This can be attached to the head, held in the hand, attached to a limb, etc., in order to provide an effective means of pointing. One technique for implementing the light-beam pointer is to use a long-range light pen coupled with a cursor on the terminal screen: the cursor moves to wherever the light beam points. Any system already configured to use a light pen could be easily modified to use this particular technique through software modifications and redesign of the light pen itself. This would allow for direct menu selection of items by individuals with fairly severe physical handicaps. It would also facilitate ease of use by elderly individuals or individuals prone to fatigue, for whom normal light pens may be difficult to use for extended periods of time; they could simply hold the light pen in their lap and point it at the various items on the screen. If a "keyboard" were provided at the bottom of the screen, individuals could use the light pen for typing in entries, as well as for selecting items from the menu. If the menu used up the entire screen, a white square in one corner of the screen could be used to allow the individual to switch from the menu display to a keyboard display to type in his messages. With this technique, the "auto-monitoring technique" described earlier could be used to allow individuals with less accurate pointing skills to use the system.

This latter technique could also be of value to nonhandicapped librarians and data-entry personnel. By simply clipping the light pen to the bow of their glasses, for example, they could use the light beam capability to cause the cursor to jump to different portions of the screen instantly, rather than having to use a slowly moving cursor to inch their way around the screen when filling out new entries. They would use the keyboard for normal data entry. The cursor can be moved simply by holding down a special key which activates the headpointer, allowing instant repositioning of the cursor anywhere on the screen.

For simple menu-type selection, a scanning routine can be implemented within the terminal. The only hardware modification necessary would be the addition of a miniature phone jack. The rest of the modification can be implemented as a rather simple addition to the selection algorithm. The actual scanning routine would be invisible to anybody using the terminal. The nonhandicapped user would make his selection using the keyboard or light pen in the normal fashion. The special scanning software routine needed by handicapped users would be triggered by a switch closure coming into the system through the miniature phone jack. At the first switch closure, a cursor scans the choices on the screen one at a time. This scanning process slowly decreases in speed until a second signal is received from the input jack. This second switch closure selects a particular item from the menu and also establishes a comfortable scanning rate. Subsequent switch closures would initiate and halt additional menu scans, always at the comfortable scan rate. Such a system should always include a method for confirming each selection to be sure that the individual selected the item actually wanted. This can best be accomplished by having the system scan two choices, such as CANCEL and CORRECT, after each selection until the individual selects one or the other. This scanning can be done at a fairly slow speed, since there are only two choices.

For larger numbers of choices, the linear technique described above can be extremely slow. In these cases, a group/item scanning approach or a scan/encode approach can be used, depending upon the method normally used for the display and selection of the various options.

Joysticks for directed scanning techniques or number pads for encoding techniques can also be used. In general, these types of interfaces involve not only significant hardware additions to the terminals, but also changes in the format and overall selection procedures. Although these techniques can be more efficient than some of the scanning techniques, they generally are not practical in terms of implementation in public access terminals. Individuals who regularly need and use these types of input techniques often have custom aids which they can use, and which could be interfaced to the terminals through an auxiliary keyboard port, as described above.

SUMMARY

A wide variety of techniques and procedures have been developed for providing rapid and effective means for input and control to individuals with different types of handicaps. For these approaches to be used in public access data entry terminals, however, a large number of considerations need to be made beyond those which pertain to the design of special aids for use strictly by handicapped individuals. Among these are cost, complexity, maintenance, additional training and setup time. Even with these constraints, however, there are simple, low-cost modifications which can be made to computer terminals to enhance their use by individuals having a wide variety of disabilities. Incorporation of these modifications can be done most easily at the initial design stages of the hardware and software for the system. Many of the techniques, however, can also be retrofitted at relatively low cost. When considering such modifications, either in the initial design or in retrofitting, it is important to contact professionals who have expertise in making similar modifications.

With careful thought and planning, low-cost and effective modifications can be made to the terminal to allow access by a large number of individuals who would otherwise be unable to use these systems. This can result not only in better access to these "public" terminals, but can also open up new job opportunities for handicapped individuals in developing and maintaining such databases or information systems.