Bulletin of Prosthetics Research
BPR 10-37 (Vol. 19, No. 1) Spring 1982
Pages 7–17

Microprocessor-Based Communications System for the Non-Verbal Person with Serious Motor Handicaps: A Preliminary Report[a]

I. V.POLLAK, Ph. D.
Chairman
Division of Biomedical Engineering

Department of Electrical Engineering
University of Saskatchewan
Saskatoon, Canada S7N ONO

ABSTRACT

The system, which is discussed both theoretically and in terms of its clinical application, is designed around a relatively low-cost small personal microcomputer with CRT display, and is adaptable to any of the presently available micromachines with comparable capabilities. For users with relatively moderate upper-limb disability, the system provides an interface in the form of nine slightly recessed two-inch keys. An auxiliary board offers three additional keys which give more direct access to special functions. For more severely-handicapped users there is a "self-scanning" display mode which the user controls and responds-to by means of any suitable binary switch such as sip-and-puff, etc.

The user selects from a predetermined vocabulary stored in the microcomputer's memory. Each "word" of this vocabulary is accessed by selecting a single address. A "word" may be a regular work in the linguistic sense, or a phrase or sentence limited in length only by the availability of memory capacity. Individual alphanumeric characters and signs are also available, for letter-by-letter spelling-out of words not in memory, or for arithmetic notations and calculations.

The access system is organized in the form of a 3x3 matrix system stacked on three levels. In selecting a particular "word", the user at first views a sampling of the complete vocabulary, presented in nine segments. Selecting the segment of the vocabulary which seems as if it might contain the desired word, the user presses the key which occupies the analogous position on the nine-key board. The machine responds by showing a more detailed sampling from that selected part of the vocabulary, similarly divided into nine segments. Viewing this second-level presentation, the user again presses the corresponding key to select the segment which apparently (or clearly) contains (or is expected to contain) the desired word, and the machine responds by showing that section of the vocabulary. For this third-level presentation the screen shows the user nine words, each alone occupying a segment of the screen. This time, pressing the analogous key causes the selected word (or phrase) to be placed in memory and displayed at the top of the screen in a space set aside for display of the last-selected 10 or 12 words of the message that is in process of being assembled.

The "self-scanning" selection mode for the more severely handicapped user is organized according to the same basic pattern. However, selection at each level requires two contact closures to select row, then column, as a black-white reversal moves (scans) in the form of first horizontal and then vertical lines over the presentation on the screen. Thus, six contact closures at the appropriate moments are

[a]The work reported in this paper was supported in part by the National Science and Engi-

The signal "message completed" may be given using one of the keys on the three-key auxiliary board: at this, the entire screen is devoted to a display of the message stored in memory. The current system can present only 1,000 characters at a time, regardless of screen size: longer messages must be viewed in successive segments. A printer can be attached for hard-copy output, and consideration has been given to the addition of facilities for the computer generation of speech. Another, larger display screen can be operated in parallel to the small CRT, for classroom use, etc.

INTRODUCTION

Verbal communication is probably the most significant link between an individual and his or her human surroundings. A person deprived of this capability is severely handicapped in any relationship with society. Increased emphasis is then placed upon alternate means of communication to compensate, at least in part, for this deficiency.

Verbal communication involves two different physiological systems. One is the auditory sense, which serves as receiver for voice messages and also participates as feedback controller in the generation of speech. The other is a special part of the motor system, which powers and controls the vocal tract and its elements.

The generation of speech requires precise coordination and fast response of all involved segments of the neuromuscular system. Functional impairment is usually, but not always, of nervous origin. Very frequently it is accompanied by various degrees of dysfunction of other parts of the motor system including the upper extremities.

The principal substitute for verbal communication is one form or another of information transfer via the visual sense. In this group belong, e.g., the sign language of the deaf and communication in written form. In today's technological age an electric typewriter is frequently employed for the latter purpose, (1) but this inexpensive and relatively fast speech substitute is not available to persons with serious motor handicaps affecting the upper extremities. It is for this class of additionally handicapped non-verbal patients that the system described in this paper is primarily intended.

No known speech substitute comes even close to the versatility and speed of information transmission by the spoken word. When communication in written form is used, the rate of information transfer rapidly declines, especially when the motor coordination of the hands and arms is impaired. Reduced mental capabilities may have a similar effect.

MESSAGE CODING

The common alphabet is an extremely efficient and flexible way of coding for an open-ended vocabulary. The rate of information transfer can, however, be substantially increased by imposing restrictions upon the size of the vocabulary which can be transmitted. To take full advantage of that approach, an access code has to be used which statistically matches this restricted vocabulary. For technical reasons an ideal match is generally not feasible, but fortunately the degree of matching is not very critical and a fairly coarse match may give results which are quite satisfactory for practical purposes.

In a communications device for speech-deprived persons, the speed of transmission becomes a consideration of prime importance. The obvious way to achieve this goal is selection of a suitable vocabulary of limited size coupled with an efficient type of coding. A fundamental theorem of information theory (2) tells us that the efficiency of an access code increases with increasing mean length of the message segment addressed by a single code symbol. That theorem is used in many practical applications and is the theoretical basis of the system described in the following. The price paid for faster access is a much reduced freedom in choice of expressions. For the purposes envisaged, a compromise solution which would partly reconcile the conflicting requirements of speed and versatility was deemed necessary.

Another feature regarded as important was the ability of the system to display the coded entry in open language. The output message ought to be understandable to a reader without any knowledge of the internal coding system of the machine. And it was desired that the amount of skill and knowledge required for data entry be a minimum.

For some potential users of a device of this kind a pictorial representation of the message is preferable to the normal alphanumerical form. Children with a degree of mental impairment (e.g. cerebral palsy) are a typical group of this kind. The symbolic Bliss alphabet (3) is probably the most common language visualization for these users. But even in these cases it seems to be desirable to have a second plain lettering output display available as an option. The described system is not primarily intended for this class of users, mainly because the graphic capabilities of the machine chosen are not adequate for that purpose. (Consideration was given to the limited use of Bliss symbolics as a guide for data entry. An overlay system in conjunction with a colour display was provided for that purpose. The results were not very satisfactory and the overlay concept was not incorporated into the prototype version.)

fairly complex logic operations. A few years ago a system of this kind would have been prohibitively expensive. The advent of low-cost microcomputers has changed the situation dramatically: a microprocessor-based system incorporating the concepts above can now be built at a reasonable cost.

THE COMPUTER HARDWARE

The system described in this report was designed around a small and low-cost commercial microcomputer (Fig. 1). The available memory capacity restricted the vocabulary in the prototype model to about 400 words. The vocabulary could be expanded easily by employing additional memory.

In the prototype model, instructions and vocabulary are read from magnetic tape into the operational memory of the machine. (Alternatively, a diskette could be used for the purpose, providing at the same time large amounts of additional memory.) This approach had the advantage that a standard model of the machine could be used, and that program and vocabulary could each be changed or modified easily. A significant factor in its favour was also the possibility to change easily to another language. In a commercial model, program and vocabulary would be stored in exchangeable ROM (read-only memory) modules.

The software developed permits the machine to be used also as a calculator for the basic arithmetic operations. The necessary instructions, represented by the symbols +, −, etc., and the numbers upon which to operate, are keyed-in in the same way as any other element of the vocabulary. A "shift" symbol is provided which switches the machine to this mode of operation and back to alphanumerical text.

FIGURE 1
Overall view of the communication system in use. The user is seen operating the system through the nine-key (3×3 matrix) keyboard interface.

A small CRT display is supplied with the machine, and a printing device can be attached if desired to provide hard-copy output, e.g., in the form of a letter. If necessary, a larger external display can be used in parallel to the original one. Such a display, which can make the message visible to a larger audience, is useful when the device is used in a classroom setting.

KEYBOARD ACCESS

The system provides for two modes of access. One, which is intended for persons with a modicum of control over their hands, is based upon a multi-element keyboard. This mode will be described first.

The second mode is intended for persons with complete loss of motor control of the upper extremities: all that is required is that they have the ability to close a binary contact within a limited interval of time.

The code adopted for the keyboard version uses sequences with uniform length m selected from a set of n different elements. The number of "words" N which can be expressed this way is:

$$N = n^m \qquad [1]$$

A "word" in this sense is a sequence of alphanumerical characters with arbitrary length (and in the future perhaps including graphic symbols) addressable by a single symbol of the address code. It may or may not coincide with a word in the ordinary linguistic meaning. As it happens, however, most of the "words" in the vocabulary are actually words in the linguistic sense; they were selected according to literature to cover the broadest range of everyday communication needs (4) (5).

It is generally assumed that for everyday use a vocabulary of about 800 suitably selected words gives adequate freedom of expression. Some modifications to this set may be needed to meet the special needs of a handicapped person.

A special group of "words" of the vocabulary are the letters of the alphabet, the numerals, and the basic interpunctuation symbols. This makes it possible to spell and therefore to express, albeit at a slow rate, any word not contained in the rest of the vocabulary. The numerals, when used in conjunction with arithmetic symbols, permit use of the machine's capacity to carry out calculations and to display their results. (The use of a separate calculator-type keypad for numerical calculations is not considered at present.)

Another class of "words" comprises frequently used whole sentences. This technique is very useful in reducing the access time, but requires much memory. It is anticipated that in a future version, where more

Speed of selection—Once the organization of the vocabulary has been established, the rate of information transfer becomes determined by the mean access time necessary for the selection of an individual address. Each selection comprises m sequential steps; each step selects one out of the n available code elements (keys or display fields). Let Δ now designate the mean time needed to perform a single selection step. For a keyboard with given operating features, Δ can vary widely, depending upon the handicap of the user, his skill, and previous training. The access time will generally also be different for keys located at different positions on the keyboard.

With n different keys available and m steps (keystrokes) per selection, the time T required to identify to the machine a particular word is:

$$T = m \cdot \Delta$$

$$T = \frac{\log N}{\log n} \cdot \Delta \qquad [2]$$

The average word in the English language contains 6 letters plus space. Generally a minimum of about 50 characters (including numerals and signs) is necessary for expressing a messsage on a letter-by-letter basis. Using a code with the same number of elements n as above, the average length of the code symbol per letter becomes

$$m = \frac{\log 50}{\log n} \qquad [3]$$

Given the same mean access time Δ per selection step as before, the total time required for selecting a word on a letter-by-letter basis becomes in the mean

$$T_1 = 7 \cdot \frac{\log 50}{\log n} \cdot \Delta \qquad [4]$$

When this expression is compared with equation [2] it is found that

$$T/T_1 = \frac{\log N}{7 \log 50} \qquad [5]$$

For a vocabulary of N=1000 the block access method is, other things equal, about 4 times faster than the letter-by-letter approach. The improvement becomes much larger if the length of the average "word" in the block access mode is increased. That can be done by using, to a larger extent, stereotyped phrases and sentences as code "words".

Keyboard organization—When designing a communi-

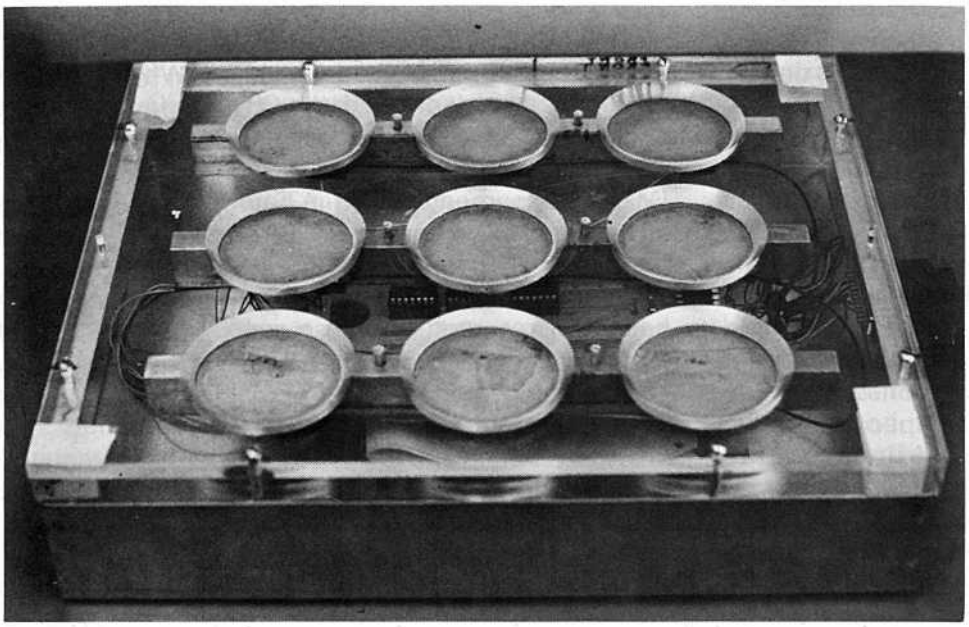


FIGURE 2
The 3×3 matrix keyboard. The two-inch diameter keys are slightly recessed below the surface. (This prototype version of the keyboard has a transparent top panel.)

large and T as short as possible. At first glance it appears that both conditions can be met by making the number of keys n very large; in the extreme n can be chosen equal to N and m becomes then unity—i.e. each key delivers a specific word! That approach has been used, e.g., in older typewriters and typesetting machines for the Japanese and Chinese languages. (It is gradually being superseded even there by recent developments in computer graphics). Inspection of expression [2] reveals, however, that T decreases only relatively slowly if n becomes large, always assuming that Δ is constant. However, Δ does not remain constant. Even for non-handicapped users, the mean time Δ needed for an individual selection step increases at a disproportionate rate when the number of keys on the keyboard exceeds a certain limit. That increase may more than offset any gain in T which could be predicted from equation [2].

For handicapped persons, n is much more restricted than for the non-handicapped. The optimum value of n depends upon the features of the keyboard design and upon the kind and degree of disability of the user. It would clearly be non-economical to try to provide each individual with a keyboard optimized for him personally. Instead a compromise solution was adopted. It provides for all users in this class a uniform keyboard consisting of nine oversize keys arranged in the form of a square matrix (Fig. 2).

"Self-scanning" keyboard—For persons with extremely severe motor dysfunctions, it is desirable to reduce to a minimum the amount of coordinated motor activity needed for each selection step. The re-

substitute for a manual keyboard (6). In this concept, the rows and columns of the keyboard matrix are sequentially addressed under the control of the processor. The line being addressed at any given moment is marked by field reversal on the screen. The user closes a contact when the scan reaches the **row** which contains or is expected to contain the desired word. The scan then switches to the columns and the user again closes a contact when the scan reaches the **column** containing the desired field. The contact closure stops and resets the scan. Contact can be initiated by a sip-and-puff switch, a neck or shoulder switch, an electromyographic signal, etc.

The self scanning access is generally slower than that by keyboard. Assuming again organization of the access code in the form of a square matrix with n elements, the time T_1 required for each selection step is on average $2\sqrt{n} \cdot \Delta_s$ where Δ_s is the time needed to react to the field reversal on the screen and to close the stop switch. The time T needed to select an individual word from a N element vocabulary is then:

$$m = \frac{\log N}{\log n}$$

$$T = T \cong m \cdot T_1 = 2 \frac{\log N}{\log n} \sqrt{n} \cdot \Delta_s \qquad [3]$$

The organization of the addressing scheme is also in this case based upon a 3x3 matrix. Provided Δ is approximately equal to Δ_s, the selection time for the self-scanning alternative is about six times longer than it is when the keyboard is used.

A mixture of block and letter-by-letter access — For

provide not only for block coding, but also for single-letter entry. Cases where this is necessary are names, numbers, special words, etc. Assume now that one out of 10 entries requires this approach, and assume the average length of the "words" requiring letter-by-letter entry to be seven characters. With these assumptions, the average time needed for "word" entry is increased by 60%.

The increase could be reduced by introducing a "shift" symbol; when activated, this symbol switches the machine to single-letter entry mode. In the single-letter mode the symbol length m could be reduced to two since $9^2 > 50$. That is, only two consecutive keyboard operations are necessary to specify a single-letter entry. The entry time per letter is reduced by 30%. The average entry time per word, in a string with nine words adressable in the block mode and one in the letter-by-letter mode, then becomes 1.4 times the block access time. This improvement is further reduced when the two shift symbols are taken into consideration. The "shift" mode for letters was, therefore not incorporated into the present software. If desired, this could easily be done in a future version. At present, the shift symbol is exclusively used to put the machine into the calculator mode.

Directly operated keyboard: implementation — A keyboard to be operated by handicapped persons, even those with only moderate impairment of motor coordination, has to be equipped with large-sized keys which can be activated with only very little pressure. In the present implementation, the active area of the keys is approximately two inches x two inches. The keys are recessed slightly below the surface of the cover board to reduce the chance of inadvertent closure of a key whilst the hand of the operator searches for the wanted key in a sliding motion. A delay circuit (with adjustable delay-time) provides further protection by eliminating the effect of spurious brief contact closures.

It has already repeatedly been remarked that the keyboard is organized in the form of a 3x3 matrix (Fig. 2). In a later version not shown in the photograph, three additional keys of identical shape are arranged to the left of the main matrix. Activation of the first of these keys cancels the latest selection even if only partially completed. It is intended for the correction of unintentional errors. When it is operated twice, all words back to the last period are deleted. The second key produces the signal "message completed" and causes the full message to be displayed on the screen. (It will be seen later that, before the operation of this key, only the two last lines of the message appear on the screen. A second operation of this key serves to cancel the "message display" command, and third operation of this key erases the whole message from

The third key has a different kind of function. The communication device described is designed to double as an environmental control unit. When the third auxiliary key is depressed, the CRT display is blanked and the machine is switched to environmental control. A second operation of this key reverses that process. (Message segments keyed-in before the switch to the environmental control mode remain preserved in memory.)

Originally, three symbols of the normal vocabulary had been reserved for these special functions. That feature is still preserved, and is utilised mainly in the self-scanning mode where provision of an auxiliary keyboard is not feasible. The auxiliary keyboard was provided to speed up the generation of these frequently used instructions; it can be deleted without affecting the function of the device.

General operational comments — In the prototype version the machine has to be switched on by hand. After switching on, program and vocabulary are loaded into memory. Both operations usually require the assistance of a non-handicapped person. In a commercial model this obvious drawback would be avoided by storing program and vocabulary in a non-volatile ROM. A suitable main switch would then be provided to allow activation or deactivation of the device by all but the most severely handicapped.

The 3x3 matrix organization is thought to represent a reasonable compromise between the various sometimes conflicting demands. There is, however, no evidence that 3x3 represents the best or even-near best system. It may well be that a 5x5 or 6x5 organization, with only two selection steps, would provide superior performance. We lacked the time and facilities to carry out a sufficiently long series of experiments to answer that question.

Organization of the vocabulary

Clearly it cannot be expected of the operator to remember the keystroke combinations for all words of a large vocabulary. In the present design the message display screen of the device is used to provide the necessary guidance. A complete display of the vocabulary, together with the corresponding code combinations, would be impractical even if the capacity of the screen would permit it. With a full display, the screen would become cluttered and difficult to read. A poster-size print-out of the vocabulary proved to be useful during the learning stage, but was generally disregarded later.

The processor employed comes with a small CRT display as integral component. If desired a second

vide better readability over larger distances, a feature which is useful, e.g., in a class room setting. It does however, not increase the capacity of the display, because it is controlled by the same software routines in the main processor as the built-in device.[b]

The display of the machine used provides 25 horizontal lines with 40 vertical single-character columns, for a total of 1,000 characters. (A newer version of the same machine has a larger 80-column built-in display.) The organization of the vocabulary has to match the keyboard design (based upon a 3x3 matrix) to the capabilities of the screen. To this purpose the vocabulary is built up from submatrices of 3x3 elements organized in the form of a multilayer pyramid. (Fig. 3) Selection proceeds from the top of the pyramid down to the base: a particular selected element in the highest-level group designates one among the nine subgroups of the same size in the next-lower level. The selection proceeds until the base level is reached.

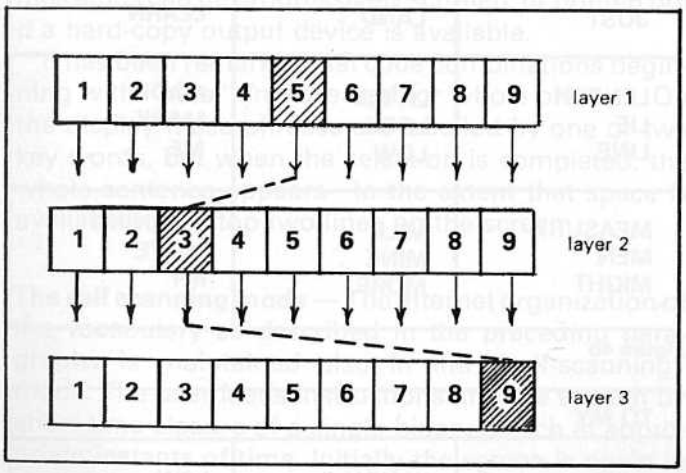
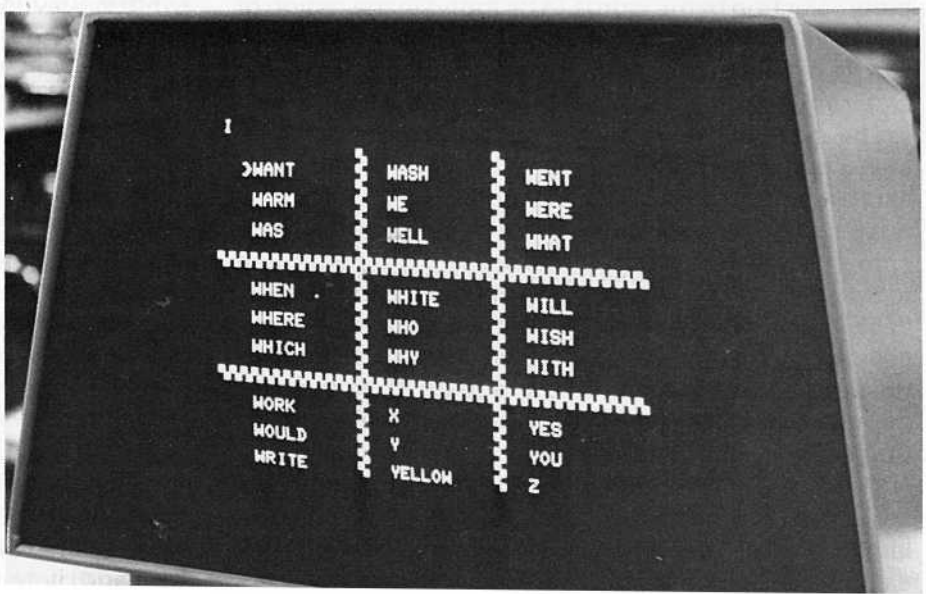


FIGURE 3
The selection hierarchy is represented above as a schematic diagram. At right is a typical view of the display after the user has taken the first active step in the selection sequence. In this case the user had asked to see a more complete sampling of the region of the vocabulary suggested by the items appearing in square 8 as shown in Figure 4a on the following page. Two more signals will be required of the user to complete selection of the desired word.



In the present implementation, the number of levels is three. The largest number of choices available in this organization is, therefore, $9^3 = 729$, but insufficient memory capacity in the prototype machine reduced the size of the practically useable vocabulary to about half of that value. With additional memory, the vocabulary could easily be expanded to very near the theoretical limit, and for further expansion a fourth layer could be added to at least part of the base of the selection pyramid. For the time being this eventuality has not been considered necessary.

The first group of words (code numbers 111 to 199 (mod 9)) contains individual alphabetical characters, numerals and most of the punctation symbols found on a standard typewriter keyboard. In addition, this group contains the control symbols, which are normally accessed from the separate keyboard as described earlier. The arithmetic symbols +, −, etc., when used in conjunction with the "shift" symbol, serve also as instructions to the processor to carry out the corresponding arithmetic operations and to display the result.

The next 7 groups characterized by the nonary first digits 2−8 were used for individual (linguistic) words in alphabetical order. The words adopted were judiciously chosen from lists of the most frequently used words in the American-English language (4) (5). (Some deviations were made from these lists to comply with

[b]It has been suggested that, for direct personal communication purposes, a second small CRT connected in parallel and facing the person addressed might be valuable. It would facilitate a more conventional conversational style with direct eye contact, etc., instead of the side-by-side, over-the-shoulder style using a single CRT.

the specific requirements of the patient-users and their anticipated average cultural background.) Though application to other languages especially French and Ukrainian, was contemplated, no efforts were made to select a basic vocabulary for these languages.

The last (ninth) group was reserved for stereotyped sentences which by themselves may each represent a complete message. (Example: "I am hungry".) With larger memories becoming available at moderate cost it is anticipated that, in the future, messages of this type will make up a larger proportion of the total vocabulary.

Correlating keyboard and screen — The display screen has two separate functions: one is to display the selected message, the other is to assist the user in the keying process. Consider first the latter.

Figures 4a–4c represent the appearance of the display during the consecutive phases of the selection of the word accessed by the (nonary) code number 539, as schematically indicated in Figure 3.

Figure 4a shows the display which allows the user to begin the selection process. At the upper-left corner of the screen (on one of the two lines reserved for display of the last part of the message that has already been selected) appear the words "TO MY". The user in this example now wishes to add the word "LEFT" which in alphabetical order should be found among the words displayed in the second square of the second row (location 5).

The display is basically organized in squares each of which corresponds to a key on the keyboard in the respective position. The display in Figure 4a is a sampling of the complete vocabulary available to the user; by depressing key 5 the user asks to see a more complete selection of the words to be found in the region of the vocabulary delimited by the word "I" over the words, "LENGTH", and "MEASURE" displayed in square 5 and the word NAME in square 6.

The system's response to key 5 depression at this stage is represented by Figure 4b. Each of the three sample words "I", "LENGTH", and "MEASURE" now appears at the head of one of three nine-word strings spread across the width of the screen, grouped three to a square and each occupying one row of the display. "LEFT" still does not appear but logically (alphabetically) should be found among the words displayed in the third square in the first row (square 3), so the user depresses key 3 and the system supplies the presentation seen in Figure 4c.

This time, each square contains only one word and the screen is showing an actual region of the vocabulary instead of a sampling as in Figures 4a and 4b. Thus each of these nine words represents a possible selec-

TO MY		
NUMERALS SIGNS SYMBOLS	A BACK BOOK	CALL DARK EACH
FACE GARDEN HAD	I LENGTH MEASURE	NAME PAPER RAIN
SAID TABLE TYPE	WANT WHEN WORK	PHRASES

Figure 4a

TO MY		
I IS JUST	KEEP KNOW LAND	LATE LAY LEARN
LENGTH LIE LINE	LITTLE LOOK LOW	MADE MARK ME
MEASURE MEN MIGHT	MILE MINE MORE	MORNING MOVE MY

Figure 4b

TO MY		
LATE	LAUGH	LAW
LAY	LEAD	LEAN
LEARN	LEAVE	LEFT

Figure 4c

9, and depressing key 9 will complete the 5-3-9 selection code. The system will respond by placing the word "LEFT" in memory as part of the message and will add it to the line at the top of the screen

can, of course, simply depress the correct sequence of keys without going through the mental process of alphabetical extrapolation elaborated here. For less adept users it might seem useful to show a more generous sampling from the vocabulary during the first two "sampling" phases of the process. That would be possible, especially on the 80-column screen, but it has appeared that it would not make operations easier for the general user.

The message "TO MY LEFT" used in the example is not meant to suggest that only very short messages are possible. The two lines at the top of the display are intended to show only the most recently selected words. When the two lines are filled the first one is simply scrolled up out of sight. The full message is kept in memory and displayed upon the command "Message completed"; at that time the screen is blanked from all other entries. Capacity of the present display limits the length of message that can be displayed at one time to 1,000 characters, but longer messages can be progressively scrolled, or printed out if a hard-copy output device is available.

It has been remarked that code combinations beginning with "nine" are reserved for whole phrases. On the display these phrases are labelled by one or two key words, but when the selection is completed, the whole sentence appears—to the extent that space is available in the top two lines on the screen.

The self scanning mode — The internal organization of the vocabulary as described in the preceding paragraphs is maintained also in the "self-scanning" mode. The user feeds instructions into the system by short-time closure of a single binary switch at appropriate instants of time. Initially the screen is again in the state shown in Figure 4a. A first activation of the control switch then starts the scanning process.

The scanning intervals are controlled by the computer and can be adjusted to meet the reaction speed of the user. The beginning of a selection sequence is marked by field reversal of the first **row** of squares on the display. (During field reversal the displayed characters which usually appear bright against the dark background of the screen turn dark, whilst the background becomes light.)

If the code digit to be selected lies between one and three, the user should operate his control switch during this period, whereupon the field reversal switches to the first **column**. If, during an interval somewhat longer than the reaction time Δ_s of that particular user, the control switch is not activated, the field-reversal line advances to the second row. In this stage the control switch would be activated by the user if a code digit between 4 and 6 is desired. To key in a digit row. (If no action is taken even during this interval, the scan is reset and has to be retriggered by an impulse from the control switch.)

Once a particular row has been identified by closure of the control switch, the vertical columns are sequentially scanned in the same way as the rows were. With identification of a particular column, the desired code digit has been identified — it corresponds to the position (number) of the square where the selected row and selected column intersect.

After identification of a particular digit the scan reverts to the rows and the display switches from the configuration of Figure 4a to that of 4b. For a complete three-digit selection the procedure has to be repeated three times. After the third selection step the display returns to configuration 4a and the scanning process begins again, after a slightly longer delay.

Note that while the above paragraphs express the procedure as the selection of code digits, the user can be simply identifying squares in which the displayed words describe, with increasing precision, the region of the vocabulary which seems most likely to contain the word the user wishes to communicate . In the self-scanning mode, note that two switch operations, each timed to fall within a particular portion of the scan progression, are required to select a particular square (digit) of the three-digit code number — whereas the keyboard user selects squares (digits) by simply depressing each time the key which is in the analogous position on the keyboard.

Cancellation, screen blanking and similar commands are treated as special "words" of the vocabulary and are selected in the same way. To reduce the time needed for these frequently needed selections, they are placed at the beginning of the first group and subgroup.

Bliss symbols—The graphic capabilities of the machine used at present are not adequate for the generation of Bliss characters. Several attempts were made to provide a Bliss equivalent of the different stages of keyboard display by other means, especially by various kinds of overlays, but as already remarked the results were not considered satisfactory. An important

[c]Alternatively, the procedure can be thought of as a successive narrowing down of the region. In a sense, it can be likened to the looking up of a word in a dictionary. First to be selected is a group of

reason for this conclusion was that the techniques used could serve as input assist, but did not provide a Bliss output. It was concluded that the Bliss alphabet could be used in a system of this kind only if the processor employed had much-enhanced graphic capabilities and substantially more memory than the one which was available (7)(8). Not investigated was the attractive alternative to modify the Bliss symbols so as to make their computer generation easier and less demanding with regard to hardware and software.

FUTURE PLANS

Three further developments are considered for the near future. One which is already in the process of implementation is adaptation of the system to serve as an environmental control unit. The modified device could then for many users replace a separate environmental control unit, a version of which had been developed previously.

Consideration is being given to the addition of facilities for the computer generation of speech; the desired message could then be displayed on the screen and/or produced in spoken form.

Finally, it appears that a downscaled miniature version, which could be mounted on a wheel chair and used as a mobile unit, would be desirable.

CONCLUDING REMARKS

Two prototypes of the device reported in this paper were built, and were tested to a limited extent. The first prototype used an older version of the microcomputer; the newer model of the same microcomputer employed in the second prototype has a number of useful additional features, especially a 80-column screen and a larger memory. The two versions are software-compatible. No effort was made to utilise the larger memory capacity in the second model for an increase of the vocabulary.

After some initial problems the system seemed to work satisfactorily. This is not intended to say that no further improvements could be made. Dr. B. Moore from the Cancer Institute in Melbourne (8) suggested, e.g., the incorporation of video games and instructional programs, especially for children but also for adults. The limited size of our group (and insufficient funding) prevented the development of software for those undoubtedly desirable additions. The same factors precluded broadly based clinical trials. We would be happy if other institutions, with better facilities and more manpower, could continue where we had to leave off. We are prepared to assist in efforts of that kind to the extent of our ability.

ECONOMICS

Finally, a word about economics. Handicapped persons usually do not suffer from an overabundance of money, and public assistance seems to be quite limited all over the world. One of our key aims, therefore, was to keep the cost of the device at the lowest possible level, sometimes doing so at the expense of additional desirable features. The microcomputer used retails at present for slightly above $1,000, and even with substantially more memory the price should not exceed the $2,000 mark. A substantial reduction in cost could be achieved by using a commercially available downstripped version of the processor which does not incorporate a display. A standard home TV receiver (assumed to be available anyway) would serve the purpose.

The software developed for this system ought to be adaptable to a downstripped machine used with TV or, for that matter, to any of the current micromachines with comparable capabilities. Only minor alterations to software should be required. As for hardware, the matrix keyboard and the additional user/machine interface devices needed for use in the "self-scanning" mode should, even from small-scale production, cost no more than several hundred dollars. We are, therefore, looking at a total cost ranging from about $1,500 upwards. That figure assumes that the device is made available tax-free and on a nonprofit basis. Less expensive versions of microcomputers could be used to reduce costs further. On the other end of the scale the need for maintenance, instruction, etc., may push the price higher.

ACKNOWLEDGEMENTS

The work reported in this paper was supported (as noted earlier) in part by the National Science and Engineering Research Council of Canada and in part by a grant-in-aid awarded by the Federal Summer Youth Employment Program. A fairly large group of persons was at one time or another involved in the development and testing of the system. Space does not permit acknowledgement of more than a few of these by name. The cooperation of Mr. Krell of the Saskatchewan Council of Crippled Children and Adults was extremely helpful. Professors M. J. Murphy and H. Klein of the College of Education of this University provided guidance in selecting the vocabulary employed. Most of the software was developed, debugged, and tested by Professor A. E. Krause of the Department of Electrical Engineering, also of this University. Hardware development and overall assembly of the system was the work of Mr. M. Poettcker, then student in the same Department ■

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