

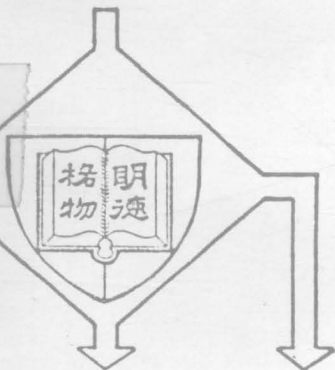
TECHNICAL REPORT

AN INPUT DESIGN FOR COMMUNICATION SYSTEMS
FOR NON-VOCAL PHYSICALLY DISABLED USERS

T H Tse

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ABSTRACT

One of the priorities in biomedical engineering is the design of communication systems for disabled users having both vocal and neuromuscular problems, such as the cerebral palsied. A major problem is the method of input. It is especially serious if the language used has a large character set, e.g. the Chinese language. This paper discusses an input design that is most suitable for Chinese language communication systems for cerebral palsied users. It employs a scanning methodology which compares favourably with other encoding methods currently in practice. The design is also useful in Chinese language videotex systems for normal users.

1. INTRODUCTION

Because of damages in their brains, a number of physically disabled people, such as the cerebral palsied, do not have proper vocal and muscular functions [1]. As a result, they are unable to speak and to write, even though they have normal intelligence. One can imagine the frustration of these people who are unable to initiate any conversation with other people, but can only respond to others by simple yes or no gestures. Their educational process is difficult because they can give little or no feedback to their teachers, and very soon they lose the incentives to learn [2].

In view of this, communication aids have been developed for the non-vocal physically disabled, and they fall into four categories:

(a) Manual Aids

They are usually in the form of communication boards, on which are drawn 100 to 400 graphic symbols [3]. The disabled person communicates by pointing to the symbols on the board, using a pointer held by his hand or secured from his head.

(b) Electronic Aids

A large display panel is the main characteristic of these aids. Letters of the alphabet are shown on the panel. The characters are lighted up in turn, so that the disabled person can select the appropriate character and have it typed on the typewriter [4]. Alternatively other aids allow the user to specify an alphabetical character by inputting a code through a special device such as a joystick.

(c) Microprocessor-based Aids

They are similar to electronic aids except that the visual display screen is used in place of the display panel. But they have the distinct advantages that they are much smaller in size, that they can be used for multiple functions and that text processing facilities can be built in so that users can easily correct their typing mistakes [5].

(d) Standard Microcomputer-based Aids

Another approach is to develop a software-based communication system on standard microcomputers, and add on special hardware devices such as joysticks only when necessary. It has been found [6, 7] that this approach is the most promising. Whilst the system can incorporate most of the features of other communication aids, it can also have sufficient flexibility to meet individual user needs, and to fit into individual application environments, such as the use as a teaching aid. It is more socially acceptable since the equipment can be used by the normal and disabled people alike. Furthermore, the costs of development and maintenance are much lower than other specially built aids.

Because of the findings in the last paragraph, a research project is set up to design and implement a standard microcomputer-based communication system for the cerebral palsied students of the Spastics Association of Hong Kong. One particular constraint of the system is that all the disabled users come from Chinese speaking families, so that Chinese is the medium of communication as well as the medium of instruction at schools. Unfortunately, Chinese character input is a major problem even for "normal" users. It is necessary, therefore, to design a special input methodology which is both easy to use by cerebral palsied users as well as giving efficient results. In this paper we shall:

- (a) discuss and evaluate an input design for communication systems using the Chinese language; and
- (b) outline its implementation in a communication system for the cerebral palsied students of the Spastics Association.

2. CURRENT INPUT METHODOLOGIES

Methodologies currently used for input into communication systems can be classified into 3 categories and are discussed below. Chinese language equivalents, wherever they exist, will also be included in the discussion.

2.1 Scanning

In this approach, a number of choices are presented to the user in the form of menus. The choices are highlighted in turn by a cursor. The user waits until his own choice has been highlighted, and then indicates an acceptance of that choice. To choose a letter of the alphabet, for example, it takes on the average 13 movements of the cursor before the desired character is reached. Hence this method has only been used in simple communication systems such as [8].

Alternatively the user may actively move the cursor towards his choice [9]. This would slightly improve the speed because the cursor does not need to start from position zero and can move backwards and forwards. Still, the method is slow and has only been used for beginners or users with low mental intelligence [10].

2.2 Encoding

In this approach, the user enters a coded signal by means of a special device such as a special keypad or a joystick. The signal may be in ASCII, Morse code or any other system that the user is familiar. It can then be deciphered into an alphanumeric character by the microcomputer. Examples of its use are found in [11] (using ASCII) and [10] (using TWC code version DR2)

This same approach has also been adopted in Chinese language input methodologies. Chinese characters are encoded according to various criteria such as character shape, phonetics, strokes or radicals [12]. As a result we can use a standard sized keyboard to enter a code and have it deciphered to form a Chinese character. The length of the code per character varies according to the method used. For instance, it takes 6 bytes to enter into a Wang computer, 3.8 into a Multitech/Dragon terminal, and 3.7 into a Sinotronic terminal.

2.3 Direction Selection

In this method the user selects a character from a keyboard and enters it directly into the communication system. Using this method, the user does not need special training about codes but must be physically able to operate a keyboard. To improve the situation, keyboard guards have been used to allow the user to strike only one key at a time without disturbing the neighbouring keys. The user can also use a stick held by his hand or extended from his head to do the keying.

In Chinese language input, large keyboards are used for direct selection. In some keyboards such as the Ideographix or IBM terminals [12], a single key represents a small group of characters, which must be further selected by one or more "shift keys". In other keyboards such as the NCR terminals [21], each character is represented by a miniature key, which has to be selected by a special pen.

3. INPUT DESIGN AND EVALUATION

For the current study, our users are mainly cerebral palsied people who cannot make a sequence of precise movement. To ask them to encode a long message would be a very frustrating exercise. Errors are bound to be found. Further mistakes would probably result when attempts are made to correct these earlier errors. Also, they cannot use the direct selection method since large Chinese keyboards are impossible for them to access. Because of these physical limitations, the scanning approach is our only choice.

What we need, therefore, is a scanning methodology which is much more effective than simple methods that have previously been used. In this section we will discuss and evaluate the possibilities available basing on a set of 2400 Chinese characters. According to a statistical analysis performed in Princeton on one million Chinese characters, these 2400 characters make up more than 98 percent of the average modern usage [13]. The purpose of the design is to come up with an efficient scanning method for these characters.

3.1 Linear Scan

The simplest method of scanning is to list out all the characters and then highlight them one by one. When the correct character is reached, an "accept" key is pressed to enter the character. For the set of 2400 Chinese characters, they cannot of course be displayed on a single screen, but there is no problem at all for the system to switch from one screen to another automatically. On the average, we have to scan through half of the characters, or 1200 of them, before reaching the appropriate character.

Suppose the user can manage to indicate to the system whether the next scanning should go backwards or forwards. In this case we would not need to start scanning from the "origin" every time, but could start where we left off at the previous character. The mean number of scans required would then be the average distance from one random character to another, given by

$$\sum_{i,j} P_{ij} |i-j|,$$

where P_{ij} is the probability the next character will be in position j if the current position is i , and $|i-j|$ is the distance between the positions i and j . It has been shown (in [14] for example) that the expression is approximately one-third of the number of characters, or 800 in our case, which is still excessive.

One can theoretically reduce the number of scans further by binary search. The mean number of searches required for 2400 characters is roughly $\log_2 2400$, or 11.23. Unfortunately, there is no collating sequence in Chinese characters, so that the user would not be able to tell the position of the character expected. Hence the application of binary search would not produce the theoretical results.

3.2 Multi-Level Scanning

In order to avoid scanning through a large number of characters, it would be useful to divide the characters into a number of categories, so that we need only scan through one category to find the character. In this case two levels of scanning are performed: to scan an index to choose a category, and then to scan the actual characters within the category to find the appropriate one.

Assume that we divide the characters into categories of equal sizes. It can easily be shown that, given N characters the number of scans will be optimized when we divide the characters into \sqrt{N} categories. In the case of the 2400 characters then, we divide them into 49 categories, each with 49 characters. The mean number of scans will therefore be given by $49/2 + 49/2$, or 49 in total.

3.3 Categories of Different Sizes

We may want to improve the situation by relaxing the condition that all categories must be of the same size. It is found (see Appendix A) that for the optimum number of scans, the characters must be divided into 64 categories. The category sizes are 69, 68, 67, ..., 8, 7 and 6, respectively. Unfortunately, even if this is used, the mean number of scans is still 45.7, a saving of less than 7% from our previous method. Further, the user will have a harder time if all categories are of different sizes, so the idea has been dropped.

3.4 Matrix Row-Column Scan

To reduce the number of scans within each category, it would be useful to arrange the 49 characters in the form of a $7 * 7$ matrix [15]. The cursor which highlights the character to be input can then be moved horizontally across a row of the matrix, or vertically down a column, as shown in Figure 1. Any character can be reached by scanning across one row and then down one column. Now a row can be scanned through in 0 to 6 characters, or 3 on the average. A column can similarly be scanned. Hence any character in the matrix can be reached in 0 to 12 movements of the cursor, or 6 on the average.

To find any of the 2400 Chinese characters, we need first of all to scan through an index matrix (by 6 cursor movements), and then through a matrix containing the characters within the category (by another 6 cursor moves). The mean number of scans is therefore 12.

3.5 Initial Scanning Point

In the last section, we assumed that the starting point for any scanning was at one corner of the matrix. The mean number of scans can be further reduced if we take the middle of the matrix as the initial scanning point. The cursor in this case can move up or down the matrix, as well as to the left or to the right. The number of scans required to reach each respective point on the matrix is shown in Figure 2. The mean number of scans for a character in the matrix can be computed from the frequency distribution shown in the figure and is found to be 3.43.

To find any of the 2400 characters, we have to scan the index matrix and then the matrix containing the characters within one category. The mean number of scans required therefore doubles that for one matrix, and is 6.86.

3.6 Matrix Quadratic Search

An alternative way of selecting a character from a matrix is by means of quadratic search. It is analogous to binary search in linear cases. The matrix is divided into four quadrants, and the quadrant containing the desired character is selected by the user. A new matrix one-quarter the size of the original then results. This procedure is repeated until we have a $1 * 1$ matrix containing the desired character. Thus a 4-character matrix takes one search, a 16-character matrix takes two searches, and a 64-character matrix takes three. For a matrix containing 49 characters, it takes approximately $\log_4 49$, or 2.81, searches. To find a character from the 2400 character set, therefore, it takes two levels of matrix scans, or 5.62 searches in total.

3.7 Usage Frequency

In our discussion on matrix row-column scan so far, we have simplified our calculations by assuming that the usage frequency of Chinese characters is uniform. By referring to the Princeton million-character statistics [13], we find that this is far from being true. There are, for example, ten characters which are used for more than 16% of the time. The usage frequency of Chinese characters is summarized in Figure 3. (Other studies have been made in China for similar usage counts [12], but they are based on simplified Chinese characters, which will not be used in Hong Kong by the cerebral palsied students.) The following is an improvement on the row-column scanning methodology based on the Princeton statistics.

The most frequently used characters are placed in the positions of the matrices which require the least movements. For example, there is one character - at the centre of the matrix for category 0 - which requires no scanning movement at all. There are 8 characters which require only one scanning movement: four of them are situated next to the centre of matrix 0, and the other four are situated at the centres of four matrices which take exactly one scanning movement to call.

The frequency distribution of the usage against the number of scanning movements is shown in Figure 4. The mean number of scans is hence computed and is found to be 3.52. This compares favourably with encoding methods currently in use, such as in Sinotronic (3.7 codes per character), Multitech/Dragon (3.8 codes) or Wang (6 codes).

One can of course further reduce the number of scans by reducing the size of the character set used. Using an 1800 character set, for example, the average character requires 3.42 scans. Even when reduced to 1200, it still takes 3.25 scans. The saving is therefore insignificant in view of the drastic reduction of the number of characters that can be used.

3.8 User Friendliness Considerations

We have seen that matrix row-column scan gives very promising results when characters are categorized by usage frequency. In practice, however, users would have difficulty in locating characters if categorization were done strictly according to frequency. In order to provide a more "user friendly" input methodology, the following two approaches are adopted:

- (a) To improve the coherence of each category, characters have to be re-allocated so that there can be common meanings, shapes or purposes in a category. This enables the user to identify a category more easily. Within a category, however, the characters are still arranged in usage frequency. The result has only a slight detrimental effect on the scanning efficiency, but the ease of use is much enhanced. An example will be shown in Section 4.3 when the communication system for disabled users is discussed.
- (b) The matrices do not only hold characters but also commonly used phrases, such as editing commands. The efficiency of the scanning process can be improved whilst easing the workload of the user.

3.9 Applications

A direct application of the input design is on Chinese language communication systems for the non-vocal physically handicapped, and will be discussed in the next section. In addition the method is useful for normal users in systems where the use of keyboards is not feasible. In a Chinese language videotex system, for example, the users in an average family cannot be expected to own a Chinese terminal because of financial reasons. Nor can they be expected to operate it efficiently. The scanning methodology provides a simple and inexpensive alternative. What is required is a joystick or a telephone with a push-button keypad.

4. IMPLEMENTATION

Based on the input design discussed, a communication system is designed for the cerebral palsied users in the schools of the Spastics Association. It can be conceived as an output prosthesis for a disabled student to communicate with his teacher, as illustrated in Figures 5 (a) and (b). The system is modularized so that the student can enter it through any module, depending on the level of his disability. The modules are shown in Figure 5(c), and are described below.

4.1 Computer Aided Instruction Module

This module consists of computer aided instructions for disabled students. It serves two purposes:

- (a) A means for students to read texts prescribed by the teacher. Because of the motor problems of the users, it is impossible for them to turn the pages of a textbook. The module thus stores up prescribed texts and hence serves the purpose of a page turner.
- (b) A means for the teacher to ask for response from the student through questioning.

The questions can be simply multiple-choiced, in which case the students will have no physical difficulty in giving an answer. But they can also be open-ended, such as "How would you like to spend the summer holidays?" To help students answer the latter type of questions, the next module would be necessary.

4.2 Text Processing Module

Because of the erratic movement of the cerebral palsied, it is very easy to make mistakes when trying to compose a long message, for example, in essay writing in schools. Instead of typing the message directly on to the printer, therefore, it is necessary to store up the message for possible corrections. The text processing module provides the means of doing this. Text processing facilities such as insertion, replacement, deletion, paragraphing, decoding, etc., can be applied to the messages. These functions can be called by the minimal operations provided by the input module described below.

4.3 Input Module

The input module allows the user to input Chinese characters or phrases into the system. The input method applied is based on the discussions in Sections 3.2, 3.4, 3.5, 3.7 and 3.8 above. The characters are categorized into 49 matrices, and selected by row-column scanning starting from the centre of the matrix. In order to provide user friendliness in the scanning processes, the categories are not divided strictly according to frequency, but considerations are also made for coherence of meaning within each category. The more commonly used characters are re-grouped according to application. For example, characters referring to food are grouped as one category, and those referring to clothing as another. The characters within one category are then arranged according to usage frequency in a matrix.

As to the less frequently accessed characters, they are re-grouped according to radical classification, and characters in the same classification are then displayed in a matrix according to usage frequency.

Further, the matrices do not only hold characters but also commonly used phrases, such as text processing commands.

In so doing it is hoped that a balance can be struck between efficiency and user friendliness.

4.4 Special Control Module

Since a considerable number of the cerebral palsied users cannot manipulate a standard keyboard, special control devices have to be built to facilitate the interface. Only two devices are designed for the moment:

(a) Enlarged Keypad

It consists only of 5 enlarged keys: up, down, left, right, and accept, as shown in Figure 6. It allows the user to specify the direction of motion of the cursor during the input scanning, and to accept a matrix or a character when the cursor reaches the appropriate position. A key template [16] is placed on top of the keypad to allow the user to rest his hand and to prevent him from striking two keys at the same time.

(b) Joystick

The joystick can be moved by the user in four directions corresponding to the motions of the cursor, as shown in Figure 7. When the appropriate character is reached, a separate button allows it to be accepted. The joystick can either be operated by the user's hand, or through securing it against any movable part of his body such as his head or his foot.

Other control devices have been researched upon in other studies and can be adapted for use in the system. Examples are optical actuation [17], eye tracking [18], humming tones [19] or myoelectric signals [20].

5. CONCLUSION

An input design for Chinese characters is made using the scanning approach. The 2400 most frequently used characters are divided up into 49 categories, each with 49 characters. In each category, the characters are displayed as a matrix, with the most frequently used characters at the centre. Row-column scanning is used, starting from the centre. It is found that in the optimal arrangement, only 3.52 scans are required to locate the average character. This compares favourably with encoding methods currently in use by normal users. But in practice slight deviation from the optimal is required to allow for user friendliness.

The approach is being implemented on a communication system for the cerebral palsied students in Hong Kong. Using special control devices, the input methodology can enable the students to access computer aided instruction and/or text processing facilities. The method can also be adopted by normal users in systems where direct keyboard entry is unavailable or uneconomical, e.g. in Chinese language videotex systems.

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APPENDIX A

Let n be the number of categories; and x_i be the size of the i -th category, i running from 0 to $n-1$. We are trying to minimize the average number of scans, given by

$$F(\underline{x}) = \frac{1}{N} \sum_{i=0}^{n-1} \sum_{j=0}^{x_i-1} (i+j),$$

subject to the constraints that

$$g(\underline{x}) = \sum_{i=0}^{n-1} x_i = N$$

and that the x_i 's take only integral values.

For a given n , we can first of all solve the problem using the Lagrange multiplier method, assuming the x_i 's to be continuous real variables.

Solving $\frac{\partial F(\underline{x})}{\partial x} + \frac{\partial g(\underline{x})}{\partial x} = 0$,

we get $x_0 = \frac{N}{n} + \frac{n-1}{2}$

and $x_i = x_0 - i$.

Then we can find the optimum integral solution by the branch and bound method.

This method is applied to the various values of n . For optimal $F(\underline{x})$, n is found to be 64, with $x_0 = 69$ and $x_i = 69-i$. $F(\underline{x})$ in this case is 45.7.

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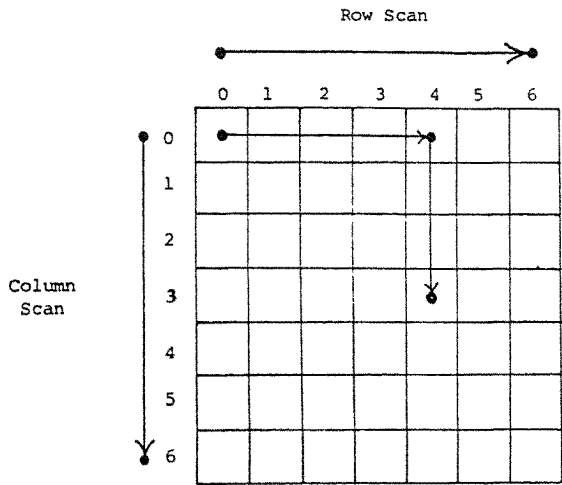
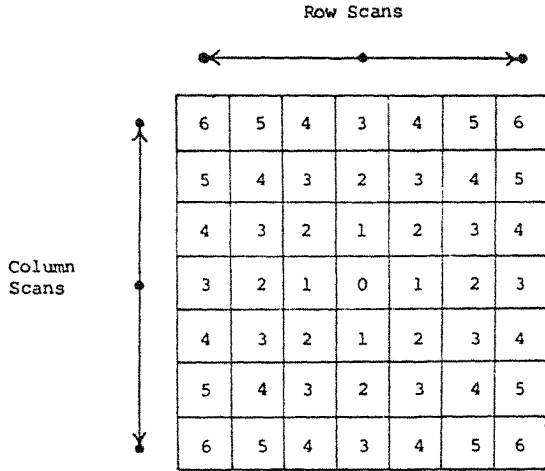


Fig. 1 Matrix Row-Column Scan



| <u>No. of Scans (x_i)</u> | <u>Frequency (f_i)</u> |
|--|---|
| 0 | 1 |
| 1 | 4 |
| 2 | 8 |
| 3 | 12 |
| 4 | 12 |
| 5 | 8 |
| 6 | 4 |
| | <hr style="width: 50%; margin: 0 auto;"/> |
| | 49 (N) |
| | ===== |

$$\begin{aligned} \text{Expected no. (per matrix)} &= \frac{\sum f_i x_i}{N} \\ &= \underline{\underline{3.43}} \end{aligned}$$

Fig. 2 Frequency Distribution of Scanning Movements from the Centre

| <u>No. of Occurances</u> | <u>No. of Characters</u> | <u>% Frequency</u> |
|--------------------------|--------------------------|--------------------|
| > 10000 | 10 | 16.58 |
| 5001 - 10000 | 13 | 9.45 |
| 3001 - 5000 | 32 | 12.41 |
| 2001 - 3000 | 37 | 8.97 |
| 1001 - 2000 | 106 | 15.41 |
| 501 - 1000 | 176 | 12.80 |
| 301 - 500 | 208 | 8.07 |
| 201 - 300 | 191 | 4.63 |
| 101 - 200 | 397 | 5.77 |
| 81 - 100 | 150 | 1.31 |
| 61 - 80 | 230 | 1.56 |
| 41 - 60 | 294 | 1.43 |
| 21 - 40 | 556 | 1.62 |
| | <u>2400</u> | <u>100.00</u> |
| | ===== | ===== |

Fig.3 Usage Frequency of 2400 Common Chinese Characters

| <u>No. of Scans</u> | <u>No. of Char.</u> | <u>% Frequency</u> |
|---------------------|---------------------|--------------------|
| 0 | 1 | 4.51 |
| 1 | 8 | 11.07 |
| 2 | 32 | 17.43 |
| 3 | 88 | 19.78 |
| 4 | 184 | 18.40 |
| 5 | 304 | 13.35 |
| 6 | 408 | 7.45 |
| 7 | 448 | 4.46 |
| 8 | 400 | 2.03 |
| 9 | 288 | 0.84 |
| 10 | 160 | 0.47 |
| 11 | 64 | 0.19 |
| 12 | 15 | 0.04 |
| | <u>2400</u> | <u>100.00</u> |
| | ===== | ===== |

Fig. 4 Frequency Distribution of Scanning Movements for 2400

Common Chinese Characters

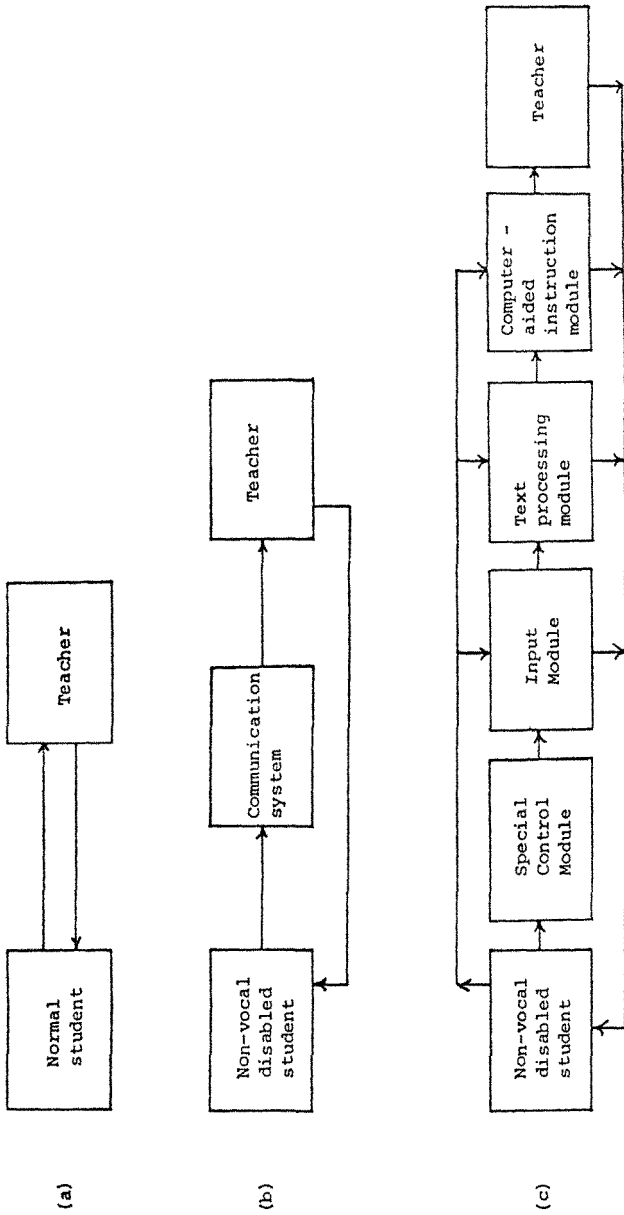


Fig. 5 Overview of Communication System

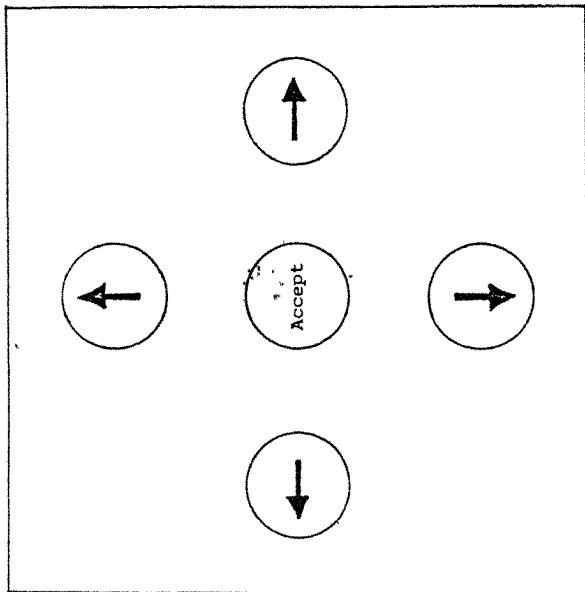


Fig. 6 Enlarged Keypad

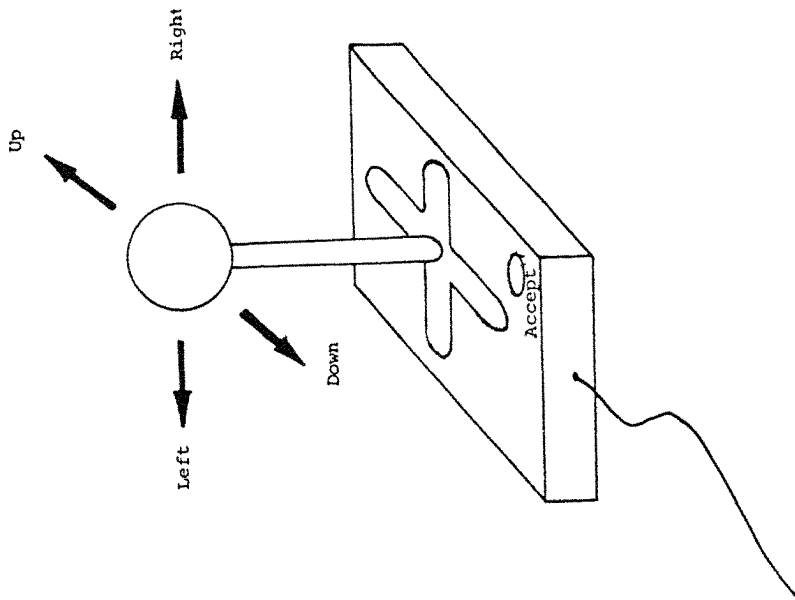


Fig. 7 Joystick