A TV SWEEP function allows the user to examine a localized area for diagnostic or corrective purposes. This function will be initiated automatically whenever the tracking procedure encounters difficulty. The console operator may also use this function to investigate any data point along a line by selecting the point of interest with the position-indicating pencil. The scan responses are analyzed and a display is generated which nominally fills the entire graphic console screen. This enables the user to observe a magnified view of a localized area on the image (as it appears to the scanner). Figure 9 shows a TV sweep display of a typical junction. The size of the sweep area is approximately .5 x .5 inches on a 20x20 inch document.

The "X" indicates the center of the scan raster. The user may adjust the threshold level or change the location of the scan raster via appropriate alphanumeric keys. The raster may also be moved by indicating a desired location with the pencil. A new raster scan and display will then be generated. The system understands that the position-indicating pencil position superimposed over the TV sweep display refers to the corresponding position in the actual scan raster. Other appropriate system operations may be initiated from this mode at any time.

If a diagnostic study reveals that automatic line tracking is impractical for some reason, coordinate points may be stored in conjunction with the TV sweep facility. This function allows the user to add the current center of the scan raster as a data point and thereby move manually over an area of difficulty before resuming automatic tracking. Under extraordinary circumstances (e.g., very poor film, poor document quality, or an extremely congested image), an entire line can be digitized in this manner.

The CHANGE PARAMETERS function allows the user, through a combination of multiple choice and alphanumeric keyboard responses, to change many of the scan parameters. The value of each parameter is displayed on the graphic console CRT along with suitable descriptions (Figure 10). Through the use of a multiple choice sequence employing the position-indicating pencil, the user may select a parameter and type in a new value for that parameter. This function allows the user to materially change the performance of a subroutine from the console. These parameters are used within the programs both as numeric constants and as switches for branching operations.

DISPLAY AND REVIEW OPERATIONS

The graphic console 10x10 inch CRT is the principal medium by which the computer communicates with the user. Throughout the sys-

![Figure 9. Junction of Two Lines.](image)

![Figure 10. Parameter List.](image)
tem, messages are continually being displayed on the CRT to which the user must respond. Although this display is low in accuracy with respect to the scanner or recorder, it is also utilized for the purpose of displaying scanned results. A display of the scan results may be used to check for completeness and to monitor the progress of the scanner. To some degree, the accuracy of the scanned results may also be checked at the graphic console.

As a film image is scanned, the digitized coordinate points are stored in an in-memory table. The structure of this table is quite simple. Each element of scanned data is stored as a linear array, with suitable identifiers and pointers to the next element of data. The scan operations may at any point in their logical sequence call upon the display operation to generate a pictorial representation of the in-memory scan data. A typical display is shown in Figure 11.

If an error condition has occurred during some previous function, the display operation may be so signalled. This will result in a small box being superimposed over the location of the error, plus addition of a suitable error comment (Figure 12).

After the scan results appear on the graphic console CRT, the following review operations become available.

a) Increase Scale
b) Change Mode
c) Identify Dimensions
d) Identify Coordinates

By selecting the INCREASE SCALE function, the size of the display will be doubled.

Any scan data which falls outside of the field of the CRT is deleted by appropriate programming. Reselection of a display returns the scan results to their original scale. The CHANGE MODE function may be used to display all lines either as a continuous curve or as a series of crosses. The latter mode allows the user to ascertain the number and location of each single digitized point. The ability to view individual scanned points is essential when the scanner is being used to capture a minute feature of a line.

If some portion of the display outside the field of view is desired, the pencil may be used to point to the edge of the field. Removing the pencil from the screen will cause the scanned data to be redisplayed with the selected point relocated at the center of the field of view. Figure 13 illustrates a display in which the user has reviewed his scanned results by centering the field on the end of a line and magnified the scale four times to examine an end condition in detail.

Within the operation of the scaling and field centering mechanism can be found a lesson in man-machine interaction. A variety of functions can be selected subsequent to a display. Typical of these is the LINE SCAN function. After this function is selected, the user is requested (by comment on the graphic console screen) to use the pencil to point to a location on the screen. Thus, the sequence of operations was to select a function (by depressing a
program control button) and then point. Our initial operational experience taught us that the more natural instinct was to point and then select an operation. Similar instances of man-machine interaction being uncomfortable were noticed throughout the development of the system. In most cases, the problem was rectified after user and programmer discussed alternative sequences of operation. Thus, many operations communicate with the man in more than one way, thereby anticipating the variety of ways in which a man may respond to a given situation.

While in review mode, the user is also frequently concerned with the accuracy of his results. The system provides two means for reviewing the accuracy of the scan data before storing the data on disk. If a square border has been registered from the film image (1.09x1.09 inches on film), all interior points are related to the coordinates of the corners of the border through the use of a four point perspective transformation. At the paper input station, the border would normally appear 20x20 inches square. The user through the use of the CHANGE PARAMETERS function may define the coordinates of the corners of the border. Thus, the user may select any point interior to the border and receive the inch coordinates of that point. The point may be selected by pointing with the position-indicating pencil or by using linear arrows on the alphanumeric keyboard to vernier a pointer.

If no border registration is available, the only accuracy test which can be made is to check the chordal distance between two points. For example, if the scanner were used to digitize a sine wave consisting of two cycles, the user could measure the chordal distance in inches between the ends of the cycles on the original document. An IDENTIFY DIMENSION function allows the user to use the pencil to point to two locations on a line and receive a display of the chordal distance between the two points. In this case, the program searches for the two points on the scanned line nearest to the two locations selected by the user. The program displays the distance assuming an 18.33 reduction ratio between document and film image.

**MODIFY AND STORE OPERATIONS**

The development of an elementary set of modify operations was a direct result of monitoring the use to which various users put the system. The most frequent request was for operations to delete erroneous data. Here again let us emphasize that the scanner and computer are utilized to perform the elementary operations while the user (through graphic console displays) retains judgment as to the correctness of the results.

A typical situation might be that the scanner began to digitize a scratch on the film rather than a line on the film image. The requirement for data deletion operations led to three methods for deleting data. The console operator may select a DELETE LAST SEGMENT function and cause the last element of scanned data to be deleted from in-memory storage. An entire line or a single point may be deleted by pointing to a location on the graphic console screen with the pencil and selecting the desired operation. In these two cases, the item of scanned data, be it a line or point, nearest to the selected location is deleted from in-memory storage.
Another frequently requested operation was the ability to add intermediate points to a display of scan results. Because of its finite sampling capability, the scanner may miss a particularly critical point on a line. In these cases, the user may point at the display with the pencil and cause a coordinate point to be inserted in the scanned results at that point. A high degree of accuracy may be obtained by adding coordinates in this manner, particularly if the scale of the image is enlarged before any operation is attempted.

After all scanning, review, and modify operations have been completed, the user can choose to save these results by storing them on a random access disk file. For our purposes, each digitized line is assigned a unique data name (e.g., LN5-1-537-R) which determines its storage location on disk. Any other application-oriented program may have access to this data by referring to the same data name. Library I/O subroutines are available to the programmer for storing and retrieving data from the disk.

The function which stores data on disk provides the facility for transforming the digitized points to any desired coordinate system. The manner in which this is accomplished is for the user to provide the desired coordinates of two of the scanned points (usually the left and right end point). This data enables the STORE function to compute a linear transformation between the raster unit coordinate system of the scanner and the desired output coordinate system.

Since the STORE function requires alphanumeric input, we were interested in the variety of ways in which a man could communicate this data. The devices which could be made available for the transmission of alphanumeric data are as follows:

- a) Alphanumeric keyboard used as a typewriter
- b) On-line card reader
- c) Scan and recognition of characters in the field of the image
- d) Writing with the position-indicating pencil on the face of the graphic console CRT
- e) Multiple choice operations by pointing with the position-indicating pencil on the face of the graphic console CRT

The options which are currently available are (a), (b), and (e). Our experience leads us to believe that (d) is not practical, simply because of the ease of using a typewriter and monitoring the message on the face of a CRT. Scanning and recognition of character sets on the film image is obviously very desirable. This work is under current development but will not be reported on in this paper.

When a line or series of lines have been scanned, reviewed, and modified, the console operator may elect to save the results by choosing the STORE function. At this point, all scanned data is corrected according to a table of calibration data stored on disk each morning by maintenance personnel. The calibration data gives a measure of the distortions in the scan raster. This data is obtained by scanning a high accuracy metal target. The calibration data may then be used to correct subsequent scan results.

After correction, all extraneous coordinate points (those lying within an epsilon of a straight line) are removed from the line. Resultant lines are then displayed singly on the graphic console CRT. A typical display is shown in Figure 14.

The density of points will be a function of line curvature. The user then has a multiple choice option in which he may choose to utilize card data, typed data, or border data for supplying coordinate information relative to the line. The pencil must be used to point to one of the fields in order to select the appropriate mode of input. We have found that when processing a volume of information, the users will prepare data cards ahead of time and utilize this mode of alphanumeric input. If only one or two lines are to be processed, the typed input will more likely be selected. In this case, the STORE function leads the user through a series of questions and responses, in which he is either required to make a choice or type in a reply at the alphanumeric keyboard. In all cases, a message on the graphic console CRT instructs the user as to the next operation or required response. As an added
feature, the user may select the BORDER DATA option, in which case the coordinates of all digitized points are related to the coordinates of the corners of a 20x20 inch border. The coordinate values of the corners of the border are assumed to have been preset by the CHANGE PARAMETERS function.

After all alphanumeric information has been entered, a summarizing message is displayed on the graphic console screen. An example is shown in Figure 15. The console operator is requested to pass judgment on the quality of the results before they are stored on disk.

RESULTS

The actual performance of the equipment and system can best be measured by the accuracy and detection capability of the scanning operations. For these reasons, a series of experiments was conducted, aimed at determining the accuracy and detection capability of the device under various operating conditions.

Figure 16 is a plot of the distribution of errors in scanning a vertical straight line located at the center of the image field.

It should be noted that this figure was generated via the CRT recorder which is a feature of the image processor. Also note that the unit squares along the chordal length of the line are measured in units of 5 inches, while the deviations are measured in units of .05 inches. As can be noted, the maximum deviation of the data from a straight line is ±.02 inches and there is a high frequency noise level of ±.005 inches. The original system objective was ±.01 inches average deviation on a 20x20 inch document. If this test is repeated with no utilization of calibration correction, the results are as shown in Figure 17.

Notice that while the high frequency noise level does not change, the maximum deviation or distortion is now .04 inches.
The second measure of system performance is the detection capability of the scanner. The range of threshold over which a line can be located is a measure of detection capability. Below a certain threshold level, the scanner cannot detect any changes in the percentage of light transmission between background and lines. Above a certain threshold, the scanner will detect light over the entire image. This type of data may be plotted for a single film document for lines of various thickness. Figure 18 is a typical plot of minimum and maximum threshold level versus line width.

The maximum threshold level is the noise level, or the point at which the photomultiplier will always see light. This is a fairly constant value over the entire film image. The minimum threshold level is, of course, a function of line width, until such time as the line widths become appreciably greater than the effective CRT spot diameter. Various qualities of documents and various film exposures will move the wedge left or right and widen or close the wedge. For each particular digitizing application, wedge samples may be taken to determine the limits of detection. Optimum operating performance may be obtained from the combination of parameters which provide the widest wedge located furthest to the left with respect to line width. Extensive tests are now being conducted on a range of documents to determine these limits of detection. These test results will serve as a guide line for judging the quality of all documents.

CONCLUSIONS

This system can best be described as a line digitizer which is being used as an experiment in processing graphical data. It combines the speed and accuracy of automatic line tracking with the decision capability of a human operator. The system as conceived and implemented has proven the feasibility of close man-machine interaction. While it is not practical to operate the equipment and system with no training, users have become proficient in its use after only one or two hours of instruction. Through the use of graphic displays, it has been possible to program the computer to communicate with a console operator in a medium which is easily understandable. Thus, the utilization of a human operator as the key system component has been very successful. This has been particularly true when automatic line tracking is impractical and the user has had to intercede to assist the scanning.

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REFERENCES


A GENERAL PURPOSE PROGRAMMING SYSTEM FOR RANDOM ACCESS MEMORIES

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I. INTRODUCTION

During the past ten years, information processing technology has made significant advances in many directions. Faster, less expensive, more flexible hardware has been continually announced by the various computer manufacturers. In the software area, the FORTRAN, ALGOL, and COBOL languages have been developed and improved and more efficient compilers are now available. Applications now include the complete spectrum ranging from free-standing analytical programs to large complex information processing systems.

Computers have been applied to business information processing problems with varying degrees of success. Many accounting operations and facets of historical record-keeping have been mechanized with proven time, cost, and accuracy benefits. Those types of business operations dealing with planning and control (or command and control if you are part of a military establishment) are receiving considerable attention from the mechanization standpoint. While many mechanization attempts have been made in this area, the proven successes are few. To some extent this can be attributed to the greater complexity of these classes of problems and the fact that information must be stored, retrieved, communicated, and processed concurrent with the flow of orders and materials.

The information processing field seems to be moving exponentially in the direction of "real time" and total or highly integrated information systems. This movement has been accelerated by the introduction of larger, faster, and more economical mass random access memory devices coupled with faster computers and better communication equipment. These new facilities offer the information system designer a new opportunity 1) to organize his information files with minimum duplication and redundancy, 2) to provide a better man-machine interface by giving people quick access to information, 3) to store, retrieve, and process information when the need arises rather than when the computer schedules dictate, 4) to provide a single data base for many applications as opposed to the arbitrary sequencing of single files for each particular application.

Any attempt to exploit the opportunities presented by the new mass memory devices places a high burden on the information system designers and programmers. This is true because it is difficult to structure and organize complex information relationships within the parameters of the mass memory devices. It is also