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INTERACTIVE DIGITAL PROCESSING OF OPTICAL DATA

John Stephen Craig

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

INTERACTIVE DIGITAL PROCESSING OF OPTICAL DATA

by

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December 1972

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Interactive Digital Processing of Optical Data

by

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submitted in partial fulfillment of the
requirements for the degree of

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from the

NAVAL POSTGRADUATE SCHOOL
December 1972

ABSTRACT

Interactive digital processing of optical data is shown to be useful in investigations of pattern recognition techniques. A system including a flying spot scanner and graphics terminal for the optical to digital conversion and subsequent display of two-dimensional images is described. Application of such a system is demonstrated by interactive contour tracing and character recognition by template matching. Algorithms necessary for the applications are developed and tested.

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I. INTRODUCTION

The purpose of this investigation was to determine if interactive optical to digital conversion could be usefully employed in image processing. An interactive system involving simple hybrid and graphical display techniques to process two-dimensional images is described. Application of this system is demonstrated by interactive contour tracing and character recognition by template matching.

Optical character recognition (OCR) and image processing equipments have long been envisioned as the ultimate devices for data input. Despite many recent advances in the interpretation of pictorial data, there have not yet been developed machines which are capable of competing with the human eye. The amount of information contained in even a simple sketch or photograph requires a comparatively large amount of descriptive language, either written or spoken. It would therefore seem very worthwhile to direct research efforts towards picture processing by modern high-speed computers.

Perhaps the most immediate beneficiaries of OCR equipment are paper-work oriented businesses. Key punch operators are generally higher salaried than typists and also usually make more errors [1], [2]. Since nearly all data input to an office computer must first be written or typed, then translated to punched cards, how much simpler it would be to go directly from the written word to the computer memory. However, while many types of equipment have been developed to perform optical scanning

and subsequent digital processing there remains the problem of efficient input of pictorial data; not only is batch processing difficult due to the wide variety of document types and sizes, but also such problems as differences in simple character forms, e.g. script and printed, must be taken into consideration.

The types of applications which could benefit from digital processing of images are many and diverse. Monitoring of continuous graphical or photographic displays such as satellite photo-reconnaissance and satellite meteorological information could be performed by image processing computers [3]. Batch processing of medical laboratory data of the nature of blood samples, bacteria cultures, and X-rays could reduce the costs of such analysis and help relieve the shortage of personnel trained to perform these tasks [4].

II. DESCRIPTION OF AN OPTICAL SCANNING DEVICE

This investigation involved the interactive use of an optical scanner constructed for experimental use, a COMCOR Ci-5000 analog computer, an XDS-9300 digital computer, and an ADAGE AGT-10 graphics terminal. A description and discussion of the interactive system is contained in Section III. The objective was to control the scanner and subsequent digital processing from a graphics display console.

The term "optical scanner", in its correct technical sense, means a device whose function is the conversion of an image into electrical signals. However, current usage of the term often includes the associated hardware and software components which form a character or pattern recognition system [1]. The first definition will be used here as it is more precise and may prevent possible confusion with other system components.

There are many different types of optical scanners in use today. Most are based on the use of a cathode-ray tube, a revolving disk, or an oscillating mirror [1], [5]. The cathode-ray, or flying spot scanner, was the type used for this investigation and is widely used in the image processing field. Perhaps the most well known of these is the one used in the Postal Service's OCR equipment, which locates and classifies zip codes within the address portion of the envelope [1], [6]. A simplified block diagram of a flying spot scanner is shown in Figure 1.

The operating principles of the flying spot scanner are not complicated and are included here only as background material for the understanding of the interactive processing system. As shown in Figure 1 a spot on the face of the cathode-ray tube (CRT) provides a light beam

which is focused through a lens and then split into two beams. One of these light beams passes through a transparency of the image to be processed and then falls on the light-sensitive portion of a photo-multiplier tube. The photo-tube transmits a voltage, whose value depends on the intensity of light received from the beam, through amplifier circuitry to the output line; this voltage is called the transmitted light. If, for example, the transparency contains only vertical black lines evenly spaced with transparent areas, then whenever the light beam is positioned behind a black line little or no light passes through to the photo-tube, hence a minimum or zero transmitted voltage. When the light beam passes through a transparent area a maximum voltage is transmitted. This simple example illustrates the binary case, meaning only black (opaque) and white (transparent) lines are used to form the image on the transparency. If the transparency contained continuous shades of gray between the black and white extremes, such as in a black and white photograph, then a continuous range of voltage levels between the maximum and minimum levels could exist. This continuum of possible voltage levels could then be quantized into a desired number of gray levels.

The second light beam produced by the beam splitter in Figure 1 passes through a lens, falls on a photo-tube, is amplified, and is output on the line called reference light. This reference light value is simply a measure of the intensity of the light beam from the CRT spot and therefore can be used as a reference in determining the shades of gray levels in the transmitted light. The reference light could also be used as a correction factor for any anomalies in the scanner, such as component misalignment or CRT spot intensity variation at different points on the CRT face.

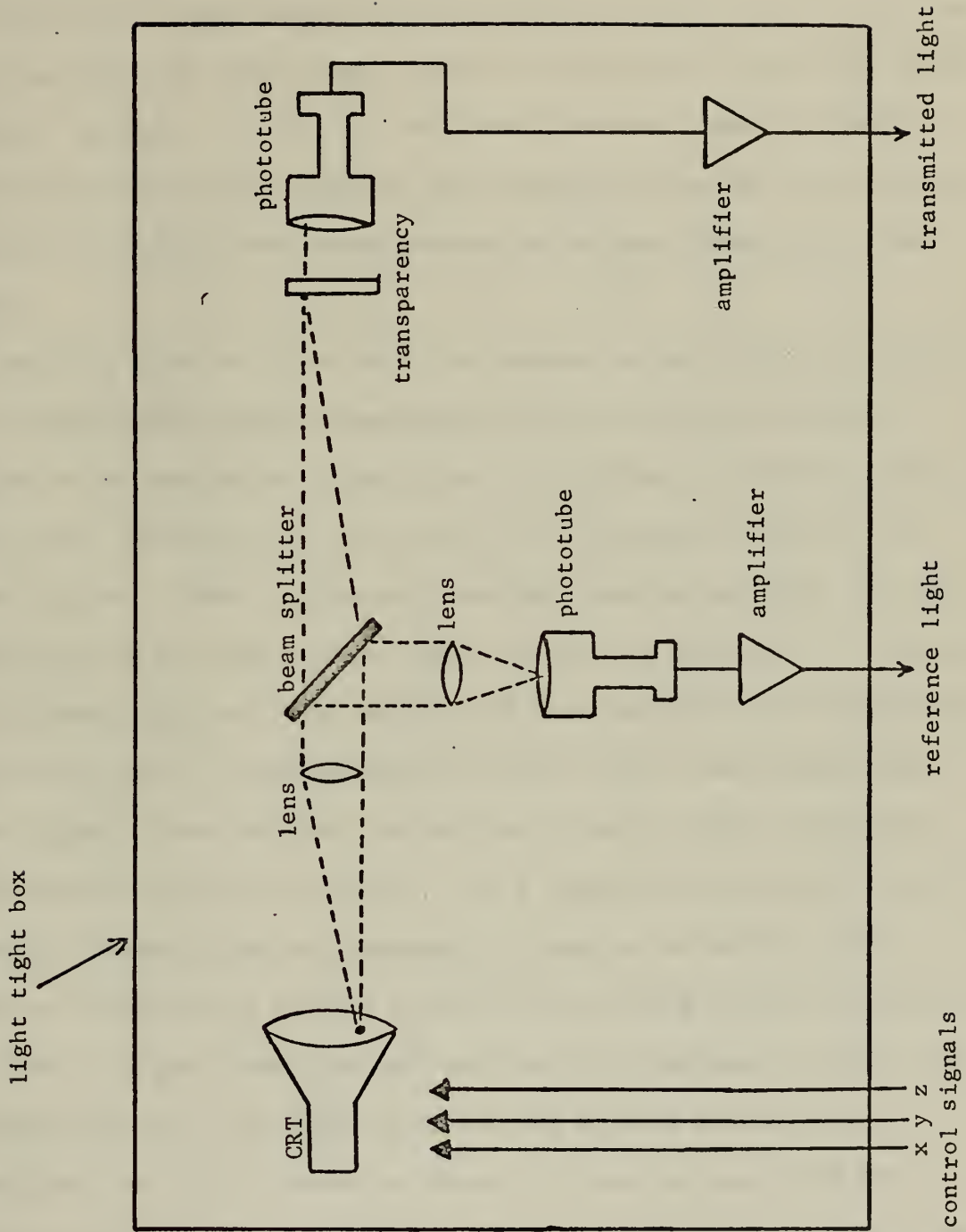
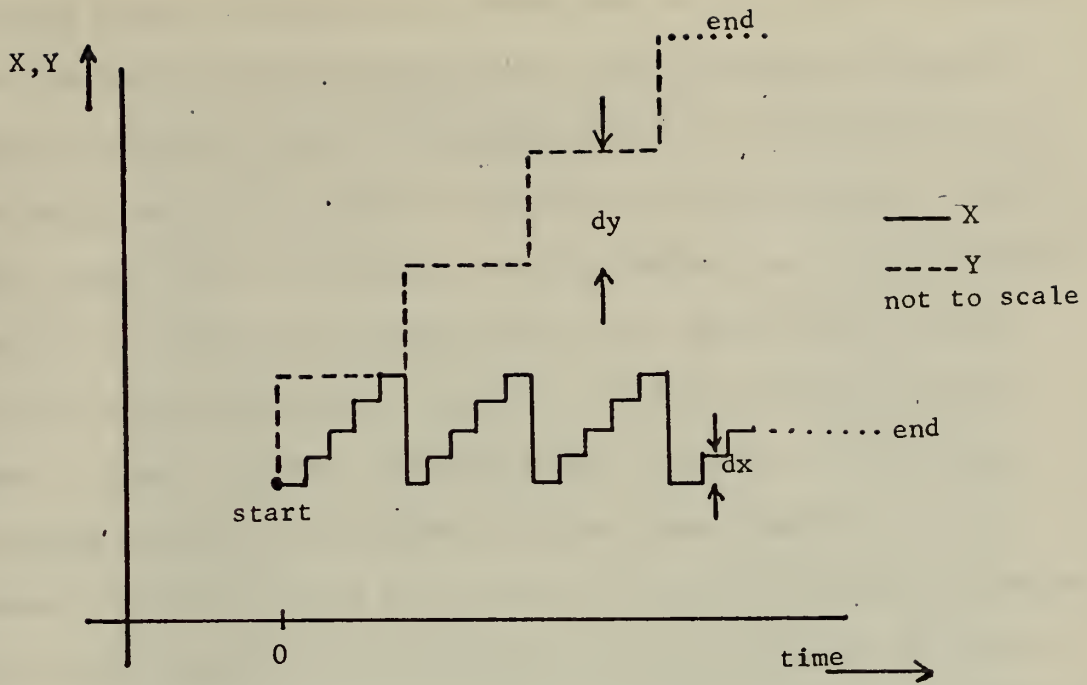


FIGURE 1. FLYING SPOT SCANNER DIAGRAM

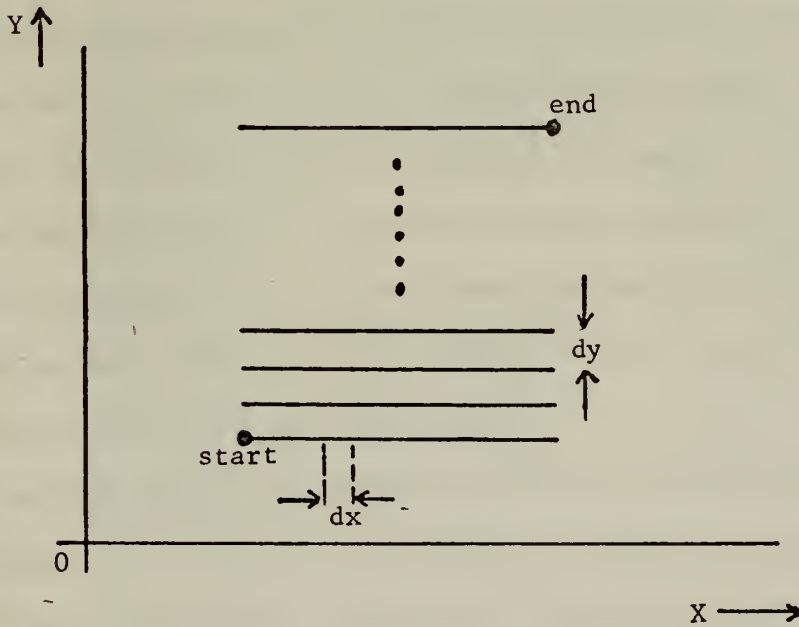
The conversion of the image on the transparency into quantized data suitable for input to a digital processing unit becomes simply a matter of driving the X and Y deflection yokes within the CRT so as to move the spot, and hence the light beam, through a scan pattern across the transparency. In Figure 1 these are the X and Y control signals. The Z control signal is used to control the intensity of the CRT spot so as to maximize the difference between minimum and maximum transmitted light signals.

Initially, tests were made with the scanner to determine the quality of the gray-level signal transmission and to provide an approximate measure of the resolution capabilities. Resolution is a relative term used in this application as the ability to distinguish between lines closely spaced. There are several possible scanning patterns; the most widely used is the raster scan, either vertical or horizontal. However, in this investigation a less complicated scanning pattern was chosen not only for the ease of implementation but also with a view toward subsequent digital-to-analog (DAC) and analog-to-digital (ADC) conversions which would be applied. Basically, the X signal voltage starts at the operator selected point and increases in steps of dx until the end point is reached; this results in the CRT spot being driven horizontally from left to right. When the spot reaches the right-hand end point the Y signal voltage is increased by dy and the X sweep is repeated. A simplified time plot is shown in Figure 2(a) and the resulting scan pattern in Figure 2(b). This pattern is also applicable to discussions in later sections concerning scanning patterns.

The results of the initial tests are shown in Figures 3 and 4. A Hewlett-Packard Model 1300A X-Y Display was found to be a convenient



(a) Time plot of scanning pattern X-Y components



(b) Scanning pattern of CRT spot

FIGURE 2. SCANNING PATTERN

monitoring display throughout the investigation. For visual estimation of the resolution and gray level range, it was necessary to generate a fast TV raster-like scan. The phosphor on the HP-1300A CRT does not retain brightness long enough for the eye to capture an image. Figures 3 and 4, then, are not completely accurate indications of the scanner's capability but also reflect degradation due to the HP-1300A display device and scope-photography techniques. It was determined that the scanner is capable of distinguishing lines less than 0.5 millimeters apart which was more than adequate for this investigation.

Examples of the types of applications for which flying spot scanners can be used were mentioned in Section I. At this point in the investigation it was determined that two particular applications would illustrate the potential uses of the scanner: (1) contour boundary tracing, and (2) character recognition by template matching. The technique of contour tracing involves the control of the light beam from the CRT spot so that it "follows" a given contour on the desired image. If then the X-Y coordinates of the CRT spot are sampled periodically and used as digital input to a computer then the original contour is "digitized" or "quantized" and can be further processed by conventional programming techniques. Contour tracing could be applied effectively to many common areas such as meteorological or topological survey maps.

The second application serves to illustrate elementary character recognition. The technique of template matching was probably the first method used to recognize alpha-numeric characters by machine [7]. The "template" is simply a stored-in-memory representation of a letter, number or any other image. The optical scanner is used to scan and



FIGURE 3. HP-1300A DISPLAY OF SCANNED CONTOURS TRANSPARENCY

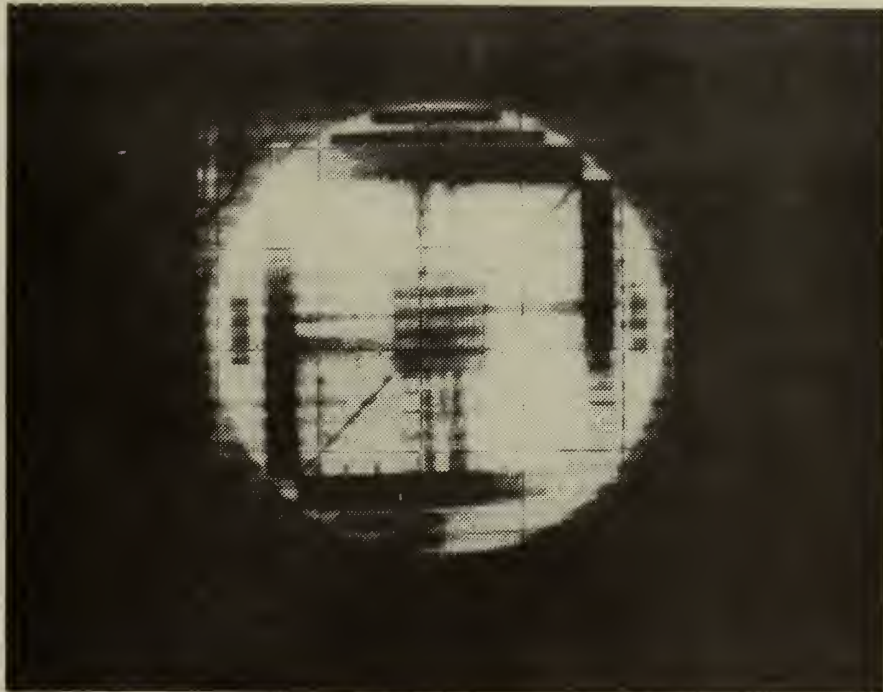


FIGURE 4. HP-1300A DISPLAY OF SCANNED RESOLUTION AND
GRAY-LEVEL TRANSPARENCY

quantize an unknown character and then the quantized unknown is matched against any given number of known templates. If a predetermined correlation exists between any template and the given unknown then a decision is made to "recognize" that unknown as a certain character [8].

It was decided to perform both applications in an interactive scanning control mode of operation to determine if this could be an effective method of utilization of a flying spot scanner.

III. DESCRIPTION OF AN INTERACTIVE SCANNING SYSTEM

The process of interaction can be thought of as two or more entities influencing each other's behavior. Specifically, interaction with a computer system means that a user can direct or control a problem or sequence of problems that a computer might be solving at a given time; the amount of interaction is a relative measurement which can range from very low to very high levels. Figure 5 shows a block diagram of the interactive hybrid computer system used to conduct this investigation. The human user in this system exercises control over the scanning, processing, and display functions thereby achieving a reasonably high degree of interaction.

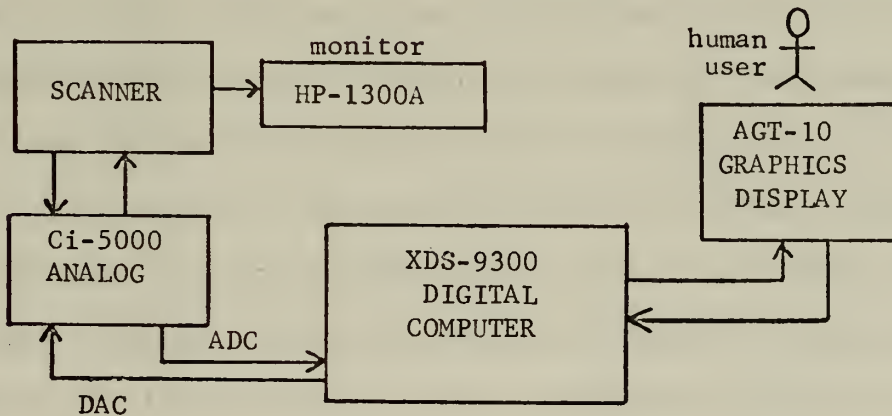


FIGURE 5. INTERACTIVE SCANNING SYSTEM BLOCK DIAGRAM

The flying spot scanner receives control signals directly from the analog computer. These control signals are the X and Y deflection voltages necessary to form a scanning pattern. Intensity, or Z signal, voltage was not changed by the computer system in this investigation.

The intensity control of the scanner was separately adjustable by the operator. The X-Y signals are generated by a digital computer program and transmitted to the analog computer via DACs. The transmitted light signal (TL) from the scanner is transmitted via the analog patch board and ADCs to the digital computer for further processing. Sequences of samples of the three voltages X, Y and TL comprise the primary variables within the digital processor necessary for subsequent image processing. The processed image is then sent to the graphics terminal CRT and displayed to the operator.

Since the purpose of this investigation was to implement and analyze some of the various aspects of interactive optical scanning, the constraints imposed by the available processing hardware were not considered detrimental to the objective. The XDS-9300 is a relatively slow-speed digital computer having a 24-bit word length and a memory cycle time of 1.75 microseconds. This particular installation has 32K (32,768) words of available storage, much of which is occupied by a real-time monitor. The DACs use 15 bits of precision at 100K (100,000) words per second while the ADCs provide 14 bit-precision words at the same transmission rate. Auxiliary storage is available on a drum or on magnetic tape, but neither of these devices was utilized for reasons which are discussed in Section IV. Data transmission from the graphics terminal to the XDS-9300 digital computer is at the rate of 250K words per second and 160K words per second in reverse.

The ADAGE AGT-10 Graphics Display is a digital computer with 8K, 30-bit words of core storage and twin disk-packs for auxiliary storage. The operator's console provides the operator with a 12 inch square CRT,

a teletypewriter keyboard, 16 push-button function switches, 6 variable control dials, a light pen and 2 foot pedals. Neither the keyboard nor the foot pedal was utilized during this investigation.

The decision to incorporate a graphical display of processed images was made early in the investigation. It was apparent that in order to be interactive, an image processing system must provide the investigator or operator with a visual display. As the only other available display would have been line printer plots, the advantages of a CRT display were obvious. It was therefore decided to utilize the graphics console with its associated CRT, function switches and variable control dials as the operator's station. From this position almost all desirable controls over the optical scanner, image processor and visual display can be performed.

The primary operator functions were considered to be (1) selection of the area to be scanned on the transparency, (2) selection of the number of samples to be taken, expressed as a resolution in both X and Y directions, and (3) selection of an intensity threshold which determines whether a sampled point is black or white. The CRT displays a box or frame which defines the area to be scanned. By adjusting the corresponding variable control dials an operator can change the height, width and position of the "scan box" to enclose the desired area within the transparency boundaries. Other dials enable the operator to select a desired intensity threshold and the number of sample points in the X and Y directions.

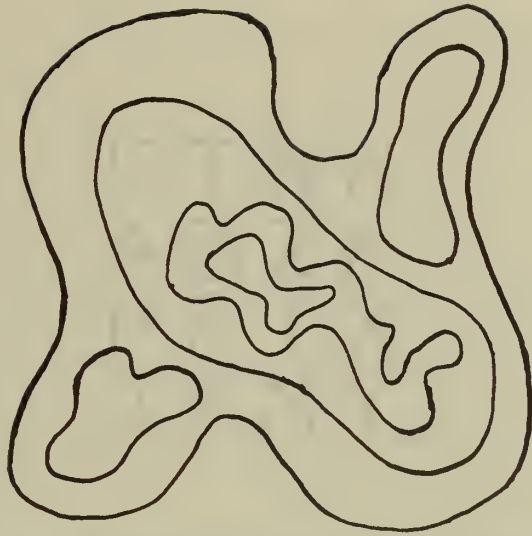
Secondary controls include the function switches and light pen. The 16 function switches enable the operator to control the program flow from the graphics display console. Such functions as starting the scan,

magnifying a displayed image, selecting either the contour tracing or character recognition routines and other "branching" types of operations were considered necessary for the desired degree of interaction. The light pen used with the AGT-10 CRT only detects the presence of light on the scope face; the associated software routine returns the array location pointer which identifies that particular image portion designated by the pen. Usage of the light pen for this investigation is discussed in more detail in Section V.

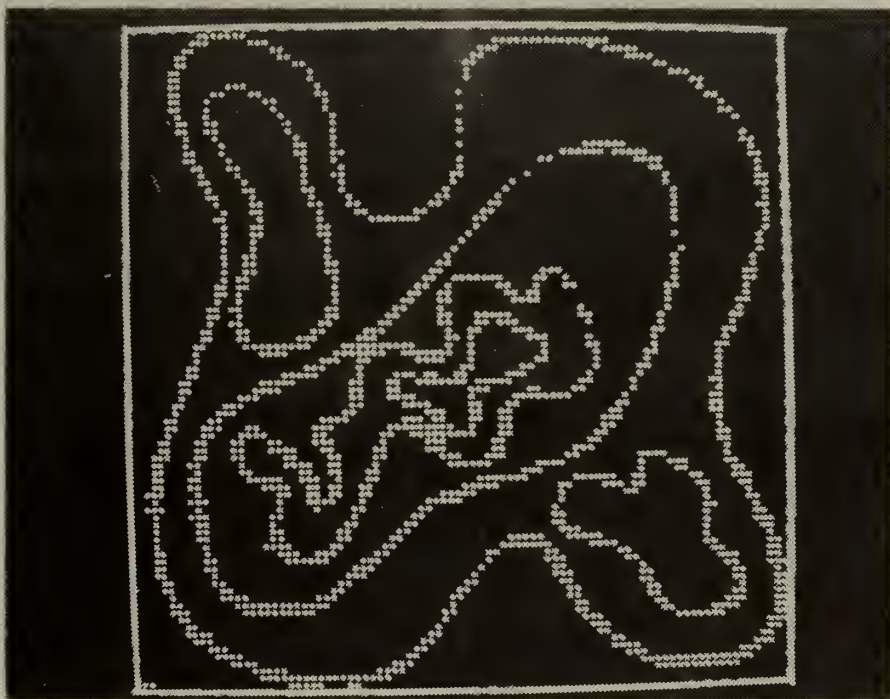
IV. PROBLEMS ENCOUNTERED

The core storage limitations of the XDS-9300 were mentioned in Section III. The overriding consideration affecting the decision to utilize the auxiliary storage available for the XDS-9300 was the small available core storage (8K) of the graphics display computer. Almost half of the AGT-10 core is occupied by a monitor and the routines necessary to interface with the digital processor. A working figure of 4900 was determined to be the maximum number of words which could be used to display processed image points or lines on the CRT; 1900 of these words are required to display information resulting from the application routines of contour tracing and character recognition. A single point displayed on the CRT, representing one black point on the transparency, requires two words in memory; therefore a 1500 point display restriction was imposed. Since even a coarse scan of 100 X 100 samples over a transparency which is 50 percent black requires a possible 5000 display points it is easy to see that the graphics computer core was a primary limiting factor affecting the development of an interactive system. Figures 6 and 7 illustrate the quantization of the two transparencies used for the applications and in both cases the number of points displayed is very close to the maximum allowed. Despite this limitation it was decided that sufficient points could be displayed on the CRT to achieve the general objectives of the investigation.

Of secondary importance was the memory available within the XDS-9300 where image processing operations were performed. One method of image



(a) Hand-drawn contours used for transparency

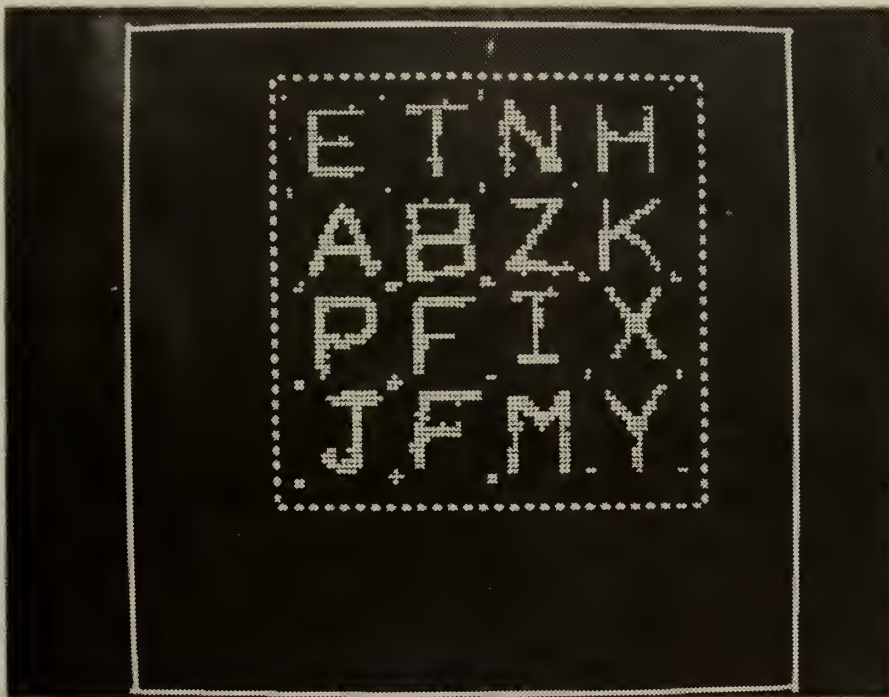


(b) CRT display of quantized contours

FIGURE 6. QUANTIZATION OF CONTOUR PATTERN

E T N H
A B Z K
P F I X
J F M Y

(a) Hand-drawn characters used for transparency



(b) CRT display of quantized characters

FIGURE 7. QUANTIZATION OF HAND-DRAWN CHARACTERS

processing requires bulk array storage of X-Y coordinates and transmitted light values prior to any processing of the scanned image. This method, when applied to the 100 X 100 sample, 50 percent black example would fill 30K words in main storage which is hardly feasible within the constraints of a 32K machine. This assumes real-type variables which use two words each in memory. Therefore each image point is processed during the scanning operation and scanning is terminated when 1500 image points have been identified. This procedure precludes the necessity for auxiliary storage yet provides sufficient data from a quantized image for interaction.

The length of time an operator must wait between the decision to scan an area and the presentation of the resultant quantized image on the CRT display can be considered a good measurement of the "interactiveness" of the system. Many parameters affect the time required to scan a given image only some of which could be software controllable. The primary hardware parameters are core storage and machine cycle time both of which have been previously discussed.

Resolution and intensity threshold are the two software controllable parameters which have the greatest affect on scanning time. In general, increasing or decreasing one or both of these parameters will result in an increased or decreased scanning time respectively. Obviously taking 10,000 samples from an image is not going to take as long as taking 20,000 samples from the same image, but there is not a linear relation between resolution and time. The reason is that while a scan at one value of resolution might "find" 50 percent of the actual image point on the transparency, taking twice as many samples (increased resolution) might

not result in finding twice as many image points. Therefore the scan time required for the second case will not be twice as long as the time for the first. Intensity threshold also affects scanning time but to a lesser degree than resolution. Since all points which meet the operator selected intensity threshold are processed, a change in this threshold will usually result in a change in the number of image points which meet the criterion. Therefore since processing time is a component of scanning time any change in the former is directly reflected in the latter.

Various programming techniques available within Fortran IV and XDS-9300 assembly languages were used to determine the minimum processing time required to complete a scanning pattern exclusive of the resolution and intensity threshold parameters. Particular attention was paid to the arithmetic, memory access, and looping instructions within the scanning sub-program. The resultant program is felt to require a minimum of processing time to perform the scanning function.

Selection of the intensity threshold was initially performed by trial and error until an acceptable value was obtained. This procedure usually necessitated many repeated scans over the same area of a transparency. It was determined that this trial and error selection could be greatly simplified by instituting two operator controlled functions resulting in a "best guess" or "ball park" value for the threshold which can then be further adjusted by the previously mentioned variable control dial. One method scans a selected area of the transparency and computes the average transmitted light intensity; the other method computes the minimum intensity. Both methods then use the new intensity value as the "zero setting" on the control dial which can then be adjusted up or down. A very coarse scan is employed to minimize the time factor and in practice either method works quite satisfactorily.

The particular flying spot scanner used for this investigation, having been built for laboratory experimentation rather than for commercial applications, requires periodic minor adjustments by the operator. However, these adjustments are of the "front panel" type and are not considered to be significantly difficult in a laboratory environment.

V. SYSTEM APPLICATIONS

A. CONTOUR TRACING

Two commonly used methods of reducing a quantized image to "single line" form are (1) thinning, and (2) edge following or tracing. This discussion is restricted to images which present a closed line continuous contour and when quantized yield an N-wide pattern of independent points (N is the average width of a line). Figure 8 shows the model which is applicable to this discussion.

The process of thinning reduces an N-wide pattern of points into a 1-wide image. Briefly, the algorithm for this process examines each point and its relationship with its immediate neighbors; only those points necessary to completely describe the image boundaries are retained [9]. As this procedure is not easily adapted to an interactive system the tracing method was chosen.

The objective of a contour tracing routine using a flying spot scanner is simply to scan an image only along its outside perimeter resulting in a continuous line contour as shown in Figure 9. If this tracing can be displayed to the operator as the scanning progresses around the contour then operator-scanner interaction can be achieved. The scanning pattern now becomes that path within the N-wide image which defines the outer boundary. An algorithm was developed using the models shown in Figure 10.

The center of Figure 10(a) represents a known point on the boundary of a contour. The cardinal pointers from this point, numbered 1 through 8, represent direction of movement (DOM); the DOM serves as the basis

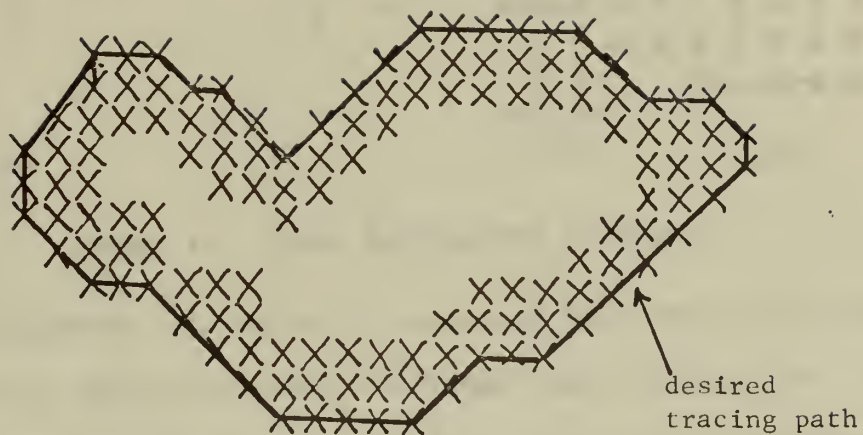


FIGURE 8. CONTOUR TRACING MODEL



FIGURE 9. COMPLETED TRACINGS OF CONTOURS FROM FIGURE 6

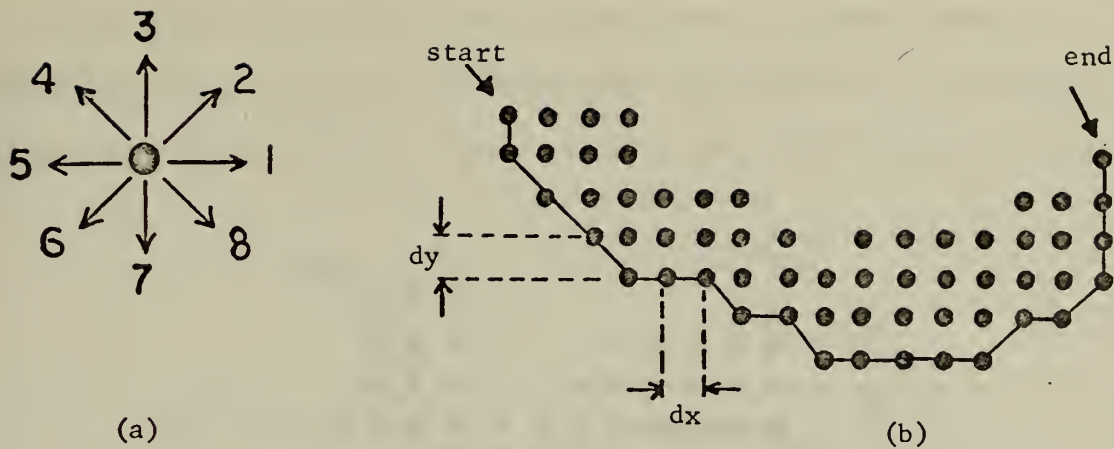


FIGURE 10. MODEL FOR TRACING ALGORITHM

for the algorithm. It is easily seen that the DOMs point to the eight neighbors of the center point, or "point under examination". A selected DOM, together with the pointers on either side of the DOM form a "DOM triple" which is used to locate the next point on the boundary.

Using Figure 10(b) as an example, the start point is the point at the upper left corner of the quantized image (this pattern is typical of part of a 4-wide contour line). To start the boundary tracing an assumption must be made as to the initial DOM. In the example of Figure 10(b) it is reasonable to assume an initial DOM of 7. To find the next point on the boundary the DOM triple is applied to sample three neighbors of the last known point. These three points are examined in counter-clockwise order. The first black point found is considered a new boundary point, the DOM from the previous point is computed, and the procedure iterates until the contour is defined.

The connected points in Figure 10(b) are the result of the application of this algorithm. The DOM progression would be: 7 (assumed), 8, 8, 8, 1, 1, 8, 1, 8, 1, 1, 1, 1, 2, 1, 2, 3, 3, 3. For the start point the DOM triple is 6, 7, and 8 which defines the three possible "next points" of $(x-dx, y-dy)$, $(x, y-dy)$, and $(x+dx, y-dy)$; the coordinates of the last known boundary point are (x, y) .

As the tracing progresses the primary potential error condition occurs when a "new" black point is not found from examination of the "next points" defined by the DOM triple. Figure 11 illustrates this condition which can

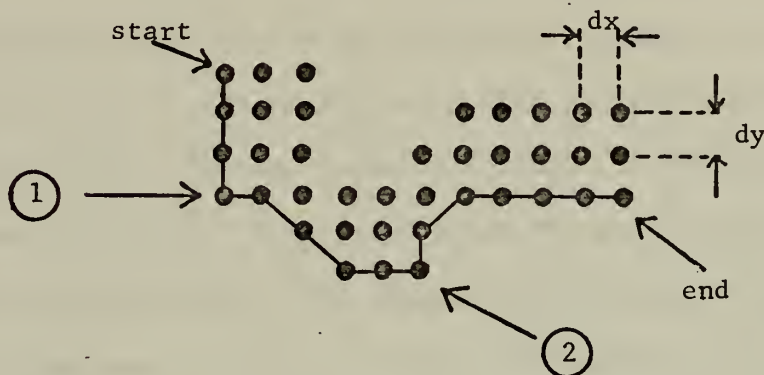


FIGURE 11. MODEL FOR LOST CONTACT SEARCH

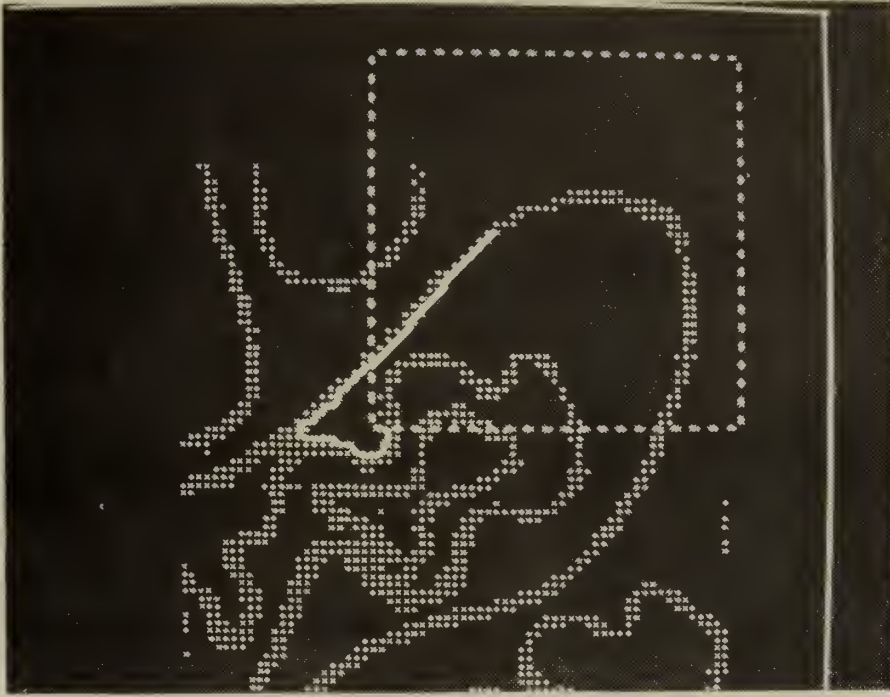
happen for a variety of reasons including a rapid change in the incremental slope of the contour, selection of a coarse dx and dy , or an insufficient intensity threshold setting. At point (1) the $DOM = 7$ produces an all-white triple which will not "find" the next point on the boundary; the same situation exists at point (2) with a $DOM = 1$. Therefore, provisions for a "lost contact search" must be included in the tracing algorithm.

A simplified "one time" search was deemed to be appropriate for this investigation and requires only a change in the last known DOM . When a DOM triple fails to produce the next point then a new DOM is assumed by rotating the old DOM 90 degrees CCW thereby defining a new DOM triple. Should this new DOM also fail to produce then an additional 180 degree rotation is made; further search is not attempted. These two DOM rotations along with the original DOM result in checking 7 of the 8 neighbors of the last known point. The 8th neighbor is already known to be on the contour. This error condition procedure is used at points (1) and (2) on the partial contour of Figure 11 to produce the connected

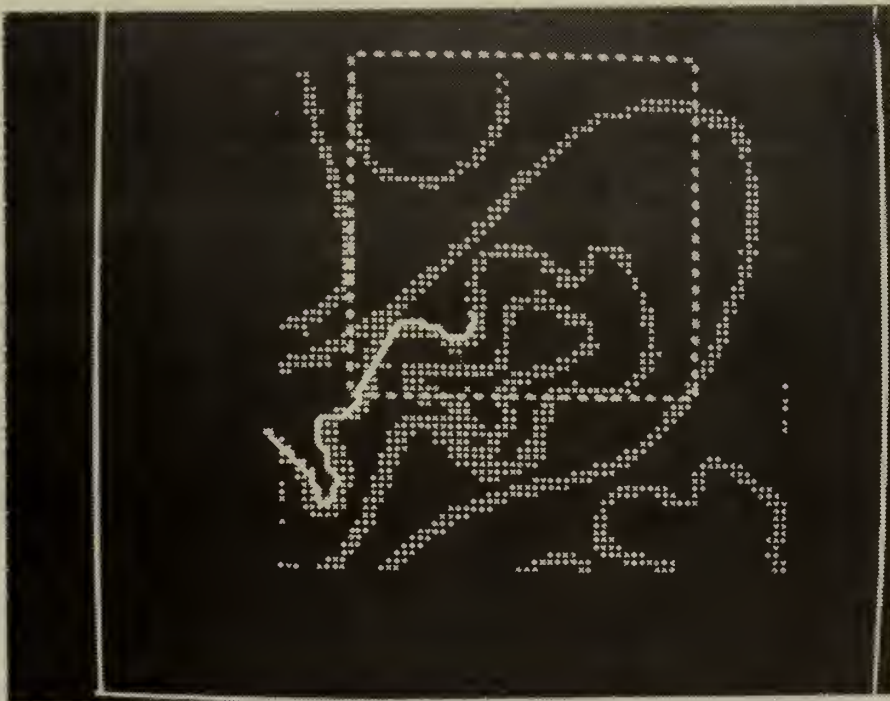
points. Additional search methods could be employed in the event the DOM rotation method failed, such as increasing the intensity threshold, increasing or decreasing dx and dy, or other similar techniques.

The contour tracing routine is initiated by a function switch; the scanner searches across the transparency from an operator-designated starting point until a contour boundary is found, at which point the tracing iterations begin. Each point found is immediately displayed to the operator on the CRT with line segments connecting the points. As the tracing progresses around the contour the operator can interact with the scanner by stopping the scan, designating the contour as a "completed contour" and storing it into memory, correcting what is felt to be a tracing error, or combinations of these functions.

Figure 12(a) shows an error which has occurred during an otherwise normal contour tracing. Because of the proximity of the contour being traced to another, the scanner has "jumped" to the outer contour and continued tracing along an undesired contour. Discovering that an erroneous tracing is occurring the operator can stop the scan and then by using the light pen designate the point at which the error was made. Now by restarting the tracing routine at a point further along the desired contour from the error point a straight-line connection is displayed between the two disjointed contour lines, the erroneous portion of the tracing is erased and tracing proceeds normally. This corrective technique is applied to the tracing shown in Figure 12(a) resulting in Figure 12(b). Figure 13 illustrates two other common error conditions which can be corrected by light pen. The ability of the operator to control the scanner while tracing a contour was considered to be significant for the demonstration of an interactive optical scanning system.



(a) Tracing jump out



(b) Corrected tracing

FIGURE 12. ERROR CORRECTION OF ERRONEOUS TRACING

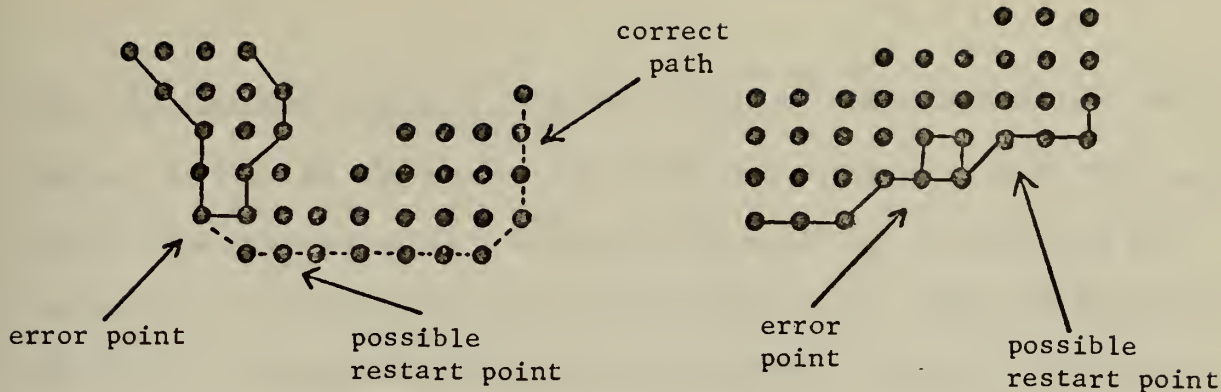


FIGURE 13. OTHER POSSIBLE TRACING ERRORS

Consideration was given to modifications to the tracing algorithm which would compute the point at which the contour was completed, "smooth" the finished contour by using sophisticated approximation techniques, and to include more rigorous searching procedures in the event of "lost contact". However, it was determined that these modifications would in general greatly increase computation time and thereby significantly reduce the desired degree of interaction. The objective of demonstrating interactive optical scanning within the constraints of the laboratory equipment had been fulfilled and it was decided that any further development of the interactive tracing technique was beyond the scope of the investigation and not within the capability of available equipment.

B. TEMPLATE MATCHING

The basic idea of template matching was discussed in Section II. This technique was one of the first used in early character recognition systems. Template matching was chosen as the second application showing that an interactive system can be useful in image processing.

Character recognition by template matching can best be described by a direct comparison with a type of children's toy where the child

must fit circular, square, triangular, and other shaped blocks into their respective slots in the board. The slots then are templates for the various shapes of blocks and while a circular block might fit roughly into the square slot it will fit best into the circular slot. While the procedure for the toy is simplistic the analogous character recognition technique is considerably more complicated.

In order to employ the interactive scanning system in a character recognition routine it was necessary to narrowly define the objective of this application. Little consideration was given to scanning and processing times, multifont characters, or techniques of registering the quantized character with the template. After scanning and displaying a quantized character on the graphics CRT, the operator can direct the system to "recognize" the selected character and then to display the answer to the operator. The objective then became the demonstration of a simple, interactive character recognition routine.

A template matching algorithm was developed by using a 24 X 24 sample raster scan. The sample size was chosen to conform to the 24-bit word size of the XDS-9300 computer so that upon completion of the scan an "image array" of 24 words containing the 576 samples from the character is stored in memory. The operator selects a character for recognition by positioning the "scan box" so as to enclose the character and then directs the system to "recognize". At each sample point a 0 or 1 is added to the word in the accumulator of the XDS-9300 depending on whether the point is white or black respectively; the word in the accumulator is then shifted left one bit and a new sample is analyzed. A new word is constructed in the accumulator for each 24 samples until

the scan is completed. This 24 X 24 image array of 0's and 1's now defines the quantized image and is then compared to the templates in memory. A template is another 24 X 24 bit array for each recognizable character with 1's only where 1's are expected in a sample of this character. The templates were constructed to conform to the general type of font shown in Figure 7.

The 576-bit image array is compared bit for bit with each of the 576-bit template arrays by using the logical AND operation. Each resulting 24 X 24 array then contains 1's at those bit positions where a match occurs between an image bit and a template bit (both are 1's), and 0's where there is no match. Counting the number of 1's in this array yields the number of match points between the image array and a particular template. Figure 14 shows two typical quantized characters with their corresponding templates.

The recognition decision is computed by two different methods. The "brute force" method simply uses that template which produces the greatest number of match points (most matched) and displays on the CRT to the operator the corresponding character. The second method (best percentage) involves computing a percentage P for each image-template comparison by using

$$P = \frac{(\text{no. of match points})}{(\text{no. of 1's in template})} \times \frac{(\text{no. of match points})}{(\text{no. of 1's in image array})}$$

Decision and display is now made as before using that template which yields the largest value of P. In practice both methods are computed during a single scanning operation.

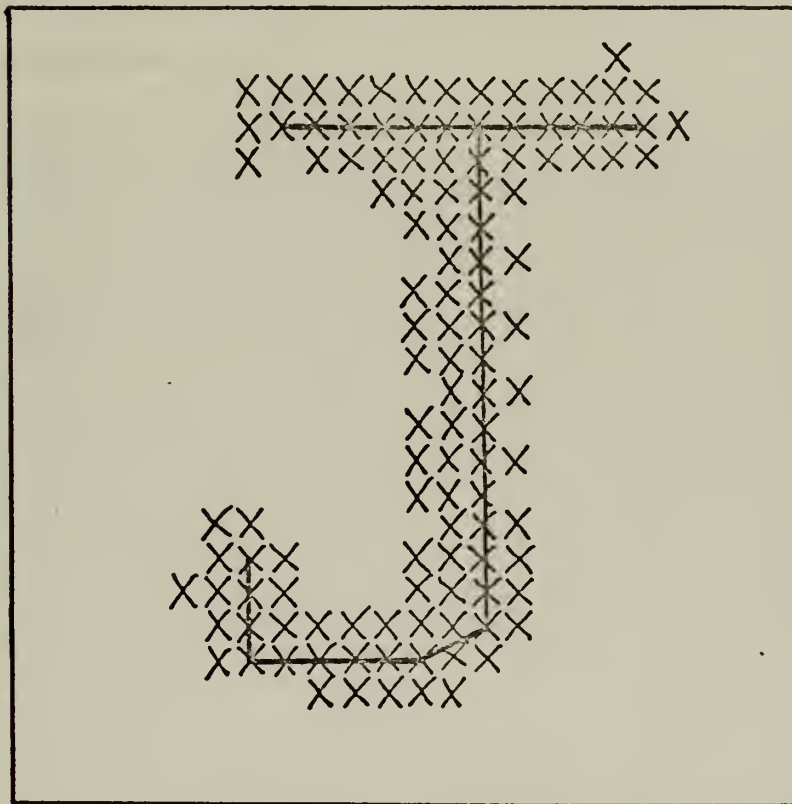
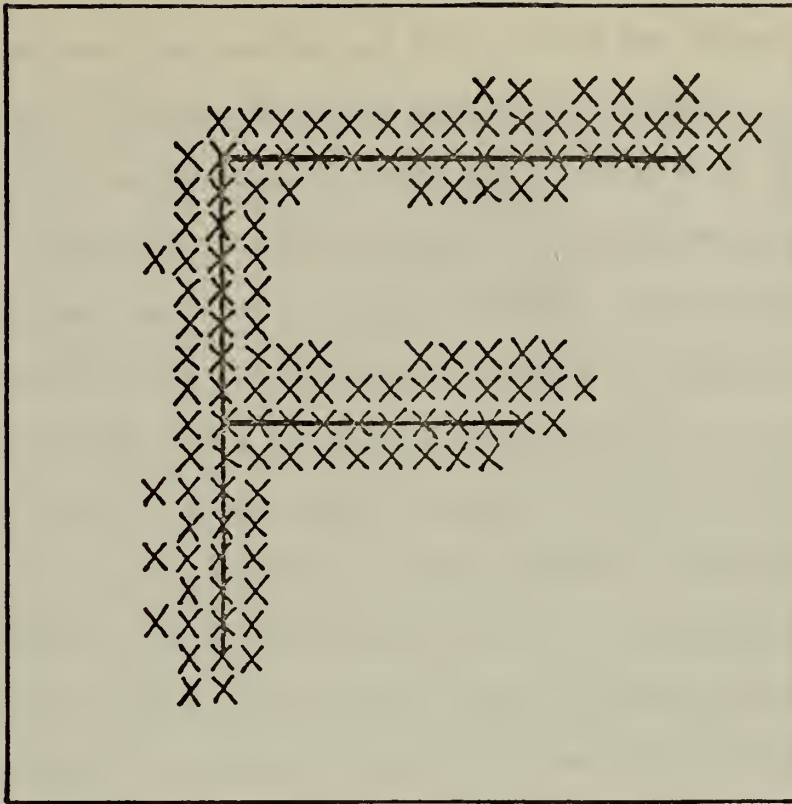


FIGURE 14. QUANTIZED CHARACTERS WITH IDEAL TEMPLATE MATCH

The template matching routine was tested using the 16 characters shown in Figure 7. Figures 15 and 16 show typical results as displayed to the operator on the graphics terminal CRT. Tables I and II both illustrate the "confusion" factor associated with each recognition method and also demonstrate the greater accuracy of the best percentage method. A "confusion table" shows the results of a number of recognition tests of a certain character and a measure of the system's recognition capability can be derived from the total number of answers "off the diagonal". For example, in Table I, of 10 trials on the letter "Y", 9 trials resulted in the correct answer "Y" and 1 trial returned a "T". By dividing the total number of correct answers by the total number of trials for each method it can be seen that the results of the tests contained in Tables I and II yield 83.1 percent correct for the most matched method and 92.5 percent for the best percentage method.

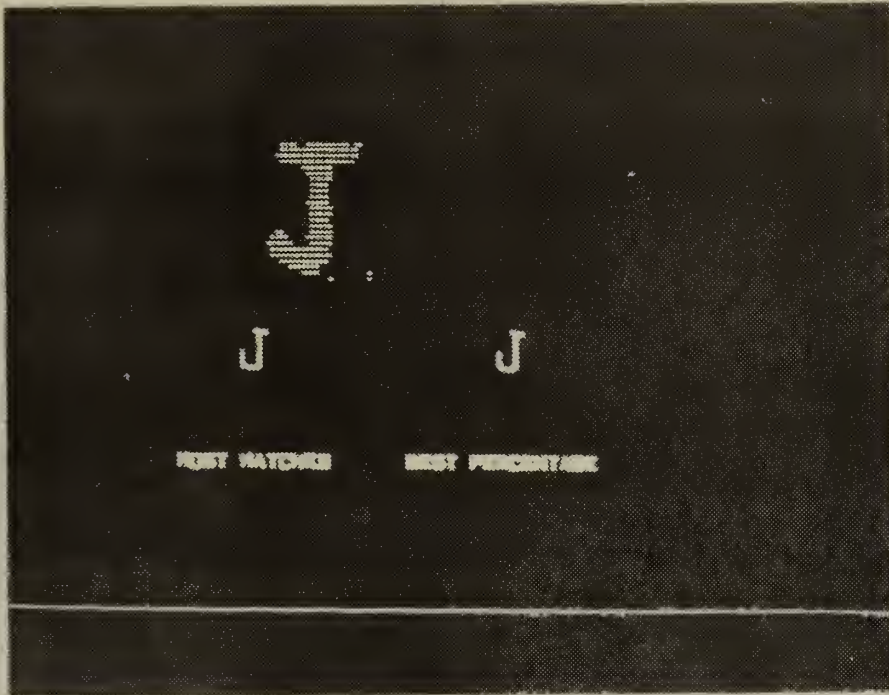


FIGURE 15. DISPLAY OF TEMPLATE MATCHING RESULTS--BOTH ANSWERS CORRECT



FIGURE 16. DISPLAY OF TEMPLATE MATCHING RESULTS--ANSWERS DIFFERENT

SCANNED LETTER

	E	T	N	H	A	B	Z	K	P	F*	I	X	J	F	M	Y
E	10															
T		3														1
N			10													
H				7												
A					9											
B				3	1	10			2		1					
Z							10									
K								8								
P									8	4				3		
F*										6				3		
I		7									9					
X												10				
J													10			
F														4		
M								2							10	
Y																9

*Third row "F" in Figure 7

TABLE I. CONFUSION TABLE FOR MOST MATCHED METHOD

Scanned Letter

Template

	E	T	N	H	A	B	Z	K	P	F*	I	X	J	F	M	Y
E	8															
T		8									1					
N			10													
H				10												
A					10											
B						6										
Z							10									
K								10								
P						3			10							
F*	2									10				3		
I		2									9					
X												10				
J													10			
F														7		
M						1									10	
Y																10

*Third row "F" in Figure 7

TABLE II. CONFUSION TABLE FOR BEST PERCENTAGE METHOD

VI. SUMMARY AND CONCLUSIONS

The desirability of optical to digital data conversion was briefly discussed in Section I. A device to accomplish this conversion, the flying spot scanner, was introduced as the primary building block around which an interactive scanning system was developed. The system constraints and problems encountered were described together with the solutions used to surmount these difficulties. The interactive system was demonstrated in applications to the problems of contour tracing and template matching and the results of these applications were briefly discussed.

It is concluded that interactive optical scanning is an effective means of investigating pattern recognition techniques. In particular, the technique of interactive contour tracing could be effectively applied to many areas utilizing graphical data some of which were discussed in Section I.

It is recommended that further experiments be performed with the flying spot scanner used in this investigation as an optical input device for such applications as gray-level quantization, machine reading of text, and biomedical pattern recognition.

Techniques of gray-level quantization could be applied to the output of the scanner so that more practical applications can be investigated. By using the XDS-9300 auxiliary drum storage enough samples can be processed to make gray-level quantization feasible within the system constraints and by judicious data handling the concept of the interactive system could be retained and even expanded. A more thorough investigation of the uses of the reference light signal voltage and digital control of

the Z-signal voltage (CRT spot intensity) would be helpful in this application. To facilitate image processing investigations an additional output device to produce "hard-copies" is necessary; the presently available devices are not well suited for this purpose.

Practical application of the contour tracing routine can be expanded to include bulk storage and complete processing of many contours, again retaining system interaction. Such a system could be very useful in the analysis of oceanographical and meteorological contour charts which are readily available. Drum storage and more sophisticated data processing techniques would aid in this type of investigation.

Character recognition routines, of which there are many, could be tested and evaluated using the scanner as the primary input device. A necessary prerequisite to this type of application would be a routine for automatic registration of characters during or after the scanning operation. When acceptable alpha-numeric recognition algorithms have been tested, techniques for complete optical input of textual data could be investigated.

The potential of image processing as applied to the biomedical field was briefly discussed in Section I. Both contour tracing and gray-level quantization could be effectively employed in the problem of cellular analysis by pattern recognition. A good example is the distinctive shape of the sickle cell. The scanner used in this thesis cannot easily handle batched inputs for large-volume production runs, but it can certainly be used for recognition of biomedical data. This is another application area where research can be significantly aided by the use of interactive techniques.

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13. ABSTRACT

Interactive digital processing of optical data is shown to be useful in investigations of pattern recognition techniques. A system including a flying spot scanner and graphics terminal for the optical to digital conversion and subsequent display of two-dimensional images is described. Application of such a system is demonstrated by interactive contour tracing and character recognition by template matching. Algorithms necessary for the applications are developed and tested.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
interactive digital processing						
flying spot scanner						
template matching						
contour tracing						
optical to digital conversion						
image processing						
pattern recognition						

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