M. R. Bartz

The IBM 1975 Optical Page Reader

Part II: Video Thresholding System

Abstract: An adaptive video thresholding system is used in the Page Reader to minimize recognition failures due to contrast and line width variation. The main threshold operator is a linear function of the average contrast over a specified area. Adjustments to the threshold level are made by circuits that compute the average line width in a character, and by circuits that filter out spatial noise in the vicinity of the character. The different types of print quality distortions predominant in typewriter printing and business machine printing are handled by switching between different sets of threshold operators.

Introduction

The IBM 1975 Optical Page Reader is a multifont optical character recognition system designed to read the quarterly earnings reports submitted to the Social Security Administration. R. B. Hennis has described the organization and function of this system.[1] The present paper discusses the video thresholding portion of the 1975 system. The purpose of the video thresholder is to provide a means of determining whether or not an area on the document being read contains a portion of a character.

It accomplishes this purpose by measuring characteristics of the analog video signal obtained from a cathode ray tube flying-spot scanner and then setting a video threshold based on this measurement. A decision as to whether the video signal is to be classified as "black" or "white" (i.e., whether or not part of a character is in the area scanned) is made by comparing the amplitude of analog video to the threshold. The threshold system output containing the black-white information is then sent to a recognition unit for analysis and character identification.[2]

The engineering problem discussed in this paper is a version of the classical communications problem of separating a signal from noise. In this case there is no known model of the complex noise process, making it difficult to use statistical decision methods. The method adopted was to classify the types of noise that caused recognition errors with typical machine input documents, to design a set of thresholding operators to handle each of the error classes, and to adjust the parameters of the operators to minimize the number of errors.

The complexity of the video thresholding problem can be illustrated by contrasting the ideal case with the situation actually observed. In the ideal situation, where a character is printed with the best printer available on a very clean sheet of paper, the analog video signal would have only two, well-separated voltage levels corresponding to the white and black areas on the paper (if one ignores the sloping signal edges caused by a finite scanning aperture). The only noise signals would be caused by scanner electronics and paper surface variations, and they would be relatively small. Signal waveforms could be observed on an oscilloscope and a video threshold set half way between the white and black levels.

Under the above conditions a black vs. white decision would be very easy to make. Any number of different characters with equally good print quality could be scanned without readjusting the video threshold. Recognition errors would be extremely rare.

However, if print quality is variable, video waveforms have many signal levels and the threshold must be continually adjusted to prevent excessive recognition errors. Because of wide variations in print quality encountered on the documents that are read by the 1975 system, a means of automatically adjusting the threshold is necessary. Furthermore, the particular type of print quality distortion

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presented to the scanner determines the type of threshold adjustment that must be used.

Design of the video thresholder for the 1975 was preceded by a study of the distortions that could be expected to occur on the input documents. The basic structure of the thresholder was then developed to handle the predominant distortions, and techniques were selected for adjusting the threshold in such a way as to maximize the information content in the data flow from the scanner to recognition unit. This was done by evaluating the dependence of each threshold parameter on recognition performance since the recognition unit provides a useful means of measuring information content.

The bulk of this paper is a discussion of the engineering considerations that led to the selection of threshold operators. System schematics and an evaluation of the thresholder performance are also given. As a background to the discussion, the important print quality distortions are described.

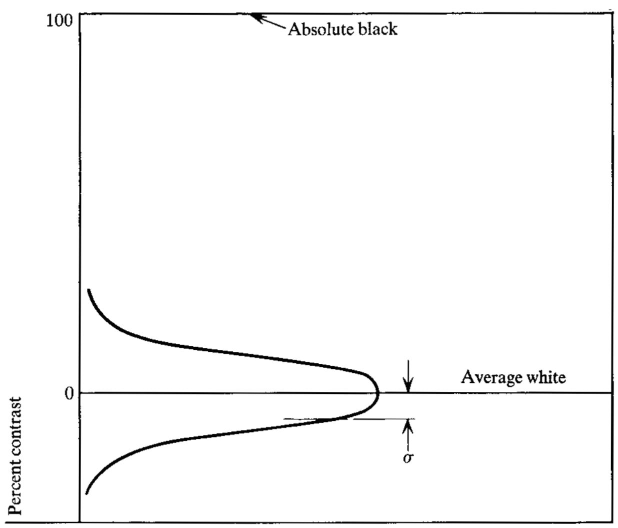


Figure 1 Definition of video signal levels. All values of contrast between 0 and 100 percent are considered "gray levels."

Print quality

Input to the IBM 1975 is printed on a standard document form (see Hennis[1]). The characters are printed with typewriters or machine printers and the type font is not specified. Upper and lower case characters are acceptable. Since no constraints are imposed on print quality, a very wide range of character distortions is present at the input to the system.

The predominant distortions observed on the input documents were classified as contrast variations, line width variations, and background noise. Each of these types of distortion has a particular influence on the design of the threshold system.

Contrast, C, is defined by the relation $C = [(R_P - R_I)/R_P] \times 100$, where R_P and R_I are percent paper reflectance and percent ink reflectance, respectively. Since contrast decreases with ribbon usage, large variations in contrast occur among documents printed with different machines. Contrast gradients (shading) may occur within a field of printed characters or within a single character. Field shading is a horizontal gradient across a line of characters that is produced when both ends of a printing mechanism, such as a chain-printer chain, are not equidistant from the surface of the paper. Character shading is usually a vertical gradient that occurs when a single type element does not strike flat on the surface of the paper. The contrast between two adjacent characters may differ if the type keys strike the paper with different impact forces. When contrast drops off radically within a small area of a character, the area is referred to as a void. Voids can be caused by defective ribbons or defective type keys.

Background noise consists of all the contrast variations surrounding or adjacent to the printed character which would not be present if the printing were of high quality. For example, new ribbons often cause some degree of ink splatter around the character. Some type mechanisms move horizontally across the paper and after the primary type element strikes the paper, an adjacent element may have enough bounce to cause a secondary background image to be superimposed on the primary image. Another type of background noise results when small openings begin to fill in. This can occur with new ribbons or when type element openings become filled with debris from the ribbon. Considerable background noise (e.g., dirt) is caused by the document handling process.

Character line widths vary widely among documents which must be read by the 1975 system because of the many different type fonts which are used to print the documents. Line widths also decrease with ribbon usage.

Objectives of threshold design

The input signal to the thresholding system is called "corrected video";[1] it can be described by an average white level, a white level noise distribution curve with standard deviation σ, the intermediate gray levels, and an absolute black level (Fig. 1). The noise distribution curve results from noise frequencies (primarily from shot noise) contained in the information bandwidth (25.6 to 500 kHz), and must therefore be tolerated by the video thresholder. Average white is defined as the mean of the noise distribution curve and is assumed to be the zero level of the corrected video signal. Absolute black corresponds to 100% contrast, or ink reflectance, R_I, equal to zero. Video levels between average white and absolute black are called gray levels, and include all contrast values between 0 and 100%.

The standard deviation, σ, of the noise distribution curve (RMS noise) is about 0.025 (2.5%) for this scanner.

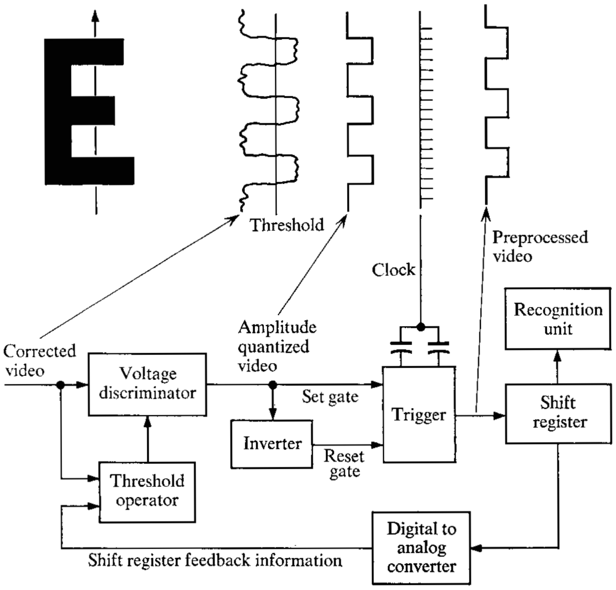
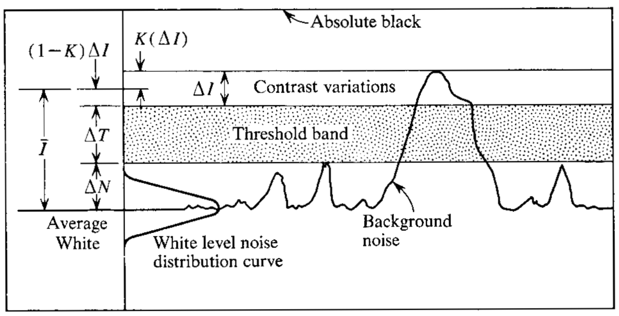


Figure 2 Video signal processing.

Figure 3 Notation for different signal-level ranges. Variation within ΔI is due to distortions of printed characters and within ΔN is due to background noise. Thresholds should be set within ΔT to achieve best patterns to present to the recognition logic. The constant K depends on the empirically determined difference between the peak value and the average value of the signal.



The lower limit of the information bandwidth (25.6 kHz) is determined by the fundamental raster frequency while the upper limit (500 kHz) is determined by the highest spatial frequency of the printing.

Fig. 2 illustrates the operation of the thresholding portion of the 1975 system. As the CRT spot scans vertically through a character, the corrected video signal varies according to the contrast along the line of scan. This signal is compared with a threshold by a voltage discriminator, and the discriminator's output is sampled by a 1-MHz system clock. The sampled video signal is then entered into a shift register in preparation for character recognition. Each shift register position represents a 5-mil square area on the document.

The problem of determining the level at which the threshold should be set can be described in terms of certain characteristics of the video signal resulting from a single scan through a character (Fig. 3). Let $\bar{I}$ represent the average value of the corrected video signal, ΔI the range of contrast variations due to distortions of the printed character, and ΔN the range of background noise above the average white level. Then, a threshold T can be set within a range ΔT, which falls between ΔN and ΔI, so that neither background noise or contrast variations will be reflected in the voltage discriminator output.

Furthermore, T can be adjusted within ΔT to give different pulse widths W at the voltage discriminator output. For T within ΔT, and assuming linear slopes on the pulse edge, the pulse width is defined by

$$W = W_{1/2} - \frac{200}{S}(T - T_{1/2}), \qquad (1)$$

where $T_{1/2} = \frac{1}{2}\bar{I}$, $W_{1/2}$ is the pulse width at $T_{1/2}$, and S is the slope of the pulse edge. The units of W are inches and of S, percent contrast change per inch.

Although the edges of the ΔI and ΔN bands as defined above could be detected during each scan through a character, their values can vary widely from scan to scan, and hence, it would not be practical or very meaningful to use such measurements as the basis for setting threshold levels. Instead, the ΔN and ΔI bands were regarded as loosely defined ranges having conceptual, rather than practical, value in designing the threshold operators.

As an illustration of how the threshold level affects character recognition, Fig. 4 shows the bit-pattern representations of the same letter "O" generated when the threshold was set within the ΔI, ΔT, and ΔN bands, respectively. In Fig. 4a, with the threshold in the ΔI band, the pattern may be rejected by a recognition system because of difficulty in distinguishing it from a "C" pattern with a low-contrast right side. If such a noise situation had appeared on the left side of the pattern, however, the rejection probably would not occur. In Fig. 4c, where the threshold is in the ΔN band, the additional noise has made the "O" look like a "Q" to the recognition system. If a similar group of bits appeared disconnected and to the left of the pattern, correct recognition would be much easier. Another feature of the bit patterns produced by the different threshold levels is that they all have different average line widths. Since recognition logic may be sensitive to variations in line width, this feature must also be considered in choosing the threshold level.

The many causes of variation within the ΔI and ΔN bands make it impossible to set T at a level that is acceptable for every character. In the most difficult situation, where ΔN and ΔI are so large as to make $\Delta T = 0$, it is impossible to prevent rejections and substitutions from occurring at the output of the recognition unit. What is

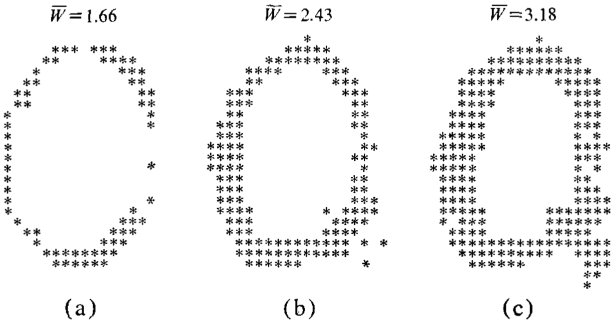


Figure 4 Effect of threshold setting on bit pattern; (a) threshold set within ΔI band; (b) within ΔT; and (c) within ΔN. The $\bar{W}$ values are the average line widths computed for each pattern.

possible, however, is to determine which types of noise occur most often and make recognition most difficult, and then set T at a level that will give recognition results that are statistically the best. The studies of noise sources and their influence on recognition were accomplished by visual examination of Social Security Administration documents and by analytical techniques involving computer processing of data.

The most significant conclusion of these studies was that threshold operator requirements were considerably different for documents printed with typewriters than for those printed with business machines. Background noise was a serious problem in both instances, but its nature differed in each. In business machine printing, most of the noise was due to ink splatter and background images. In typewriter printing fill-in noise was predominent because of the small openings in lower case letters. Line width variations were far more extreme in machine printing than in typewriter printing. These differences were used to advantage in designing the threshold operators because input documents to the system can be hand-sorted to separate machine-printed documents from the others. Hence, it is practical to call different threshold operators into use in the system by a manual switch.

Threshold operator for machine printing

The threshold operator for machine printing was designed to minimize shift register bit pattern distortions resulting from the two predominant noise sources; background noise due to ink splatter and background images, and line width variations.

Background noise is not confined to areas adjacent to the printed character, but can occur throughout the entire white area between characters. The threshold must remain above ΔN when scanning through these white areas, but above ΔN and below the ΔI band when scanning through characters.

Two types of threshold operators were considered, peak detection and video averaging. Peak detection involves measuring the highest signal amplitude, storing it on a capacitor, and then allowing it to decay at a rate slow enough to prevent appreciable errors in the stored value while scanning through areas between characters. This approach was rejected since the peak value depends on the highest contrast video amplitudes and ignores the fact that information is carried by video amplitudes covering a contrast range ΔI.

The averaging technique was adopted instead. A minimum threshold level $T_{\min}$ was defined as a threshold level between video amplitudes which have an extremely low probability of representing information and amplitudes which have a very high probability of being part of the ΔI band. $T_{\min}$ was set as close to the white level noise distribution curve as possible.

A term, $\bar{V}$, was defined as the average of all video samples greater than $T_{\min}$ within a predetermined area such that

$$\bar{V} = \frac{1}{N} \sum_{i=1}^{M_x} \sum_{j=1}^{M_y} V(i, j), \qquad V(i, j) > T_{\min} \tag{2}$$

where $\bar{V}(i, j)$ is the j^{th} sample of the i^{th} scan, N is the total number of video samples with $\bar{V}(i, j) > T_{\min}$ and M_x and M_y define the area over which $\bar{V}$ is evaluated.

The value for $\bar{V}$ is established during the left-to-right scan that precedes the right-to-left recognition scan of each line; it is evaluated over the space of several characters. During operation, the machine averages continuously, even during the recognition scan.

A threshold, $T(\bar{V})_M$, was defined to be a linear function of $\bar{V}$ such that,

$$T(\bar{V})_M = g\,\bar{V} + C_M. \tag{3}$$

The final output of the threshold operator, $(TO)_1$, is either $T_{\min}$ or $T(\bar{V})_M$ as shown in Fig. 5. A "black analog" OR circuit, which generates an output equal to whichever input is nearer black, prevents the output $(TO)_1$ from falling below $T_{\min}$. The transfer function of this operator is also shown in Fig. 5 along with measured maximum and minimum values of $\bar{V}$.

There was not a great deal of freedom in choosing the constants of Eq. (3). $\bar{V}$ was subject to a certain amount of error caused by the analog integrating circuit used to generate it. This, in turn, caused an error in $T(\bar{V})_M$ which was intolerable if g was greater than 2. Of course, g must be large enough to provide an adequate dynamic range for $T(V)_M$ as $\bar{V}$ varies from one extreme to another. On the basis of these considerations, $g = 2$ was chosen as the best compromise.

The value of C_M represents the quiescent point of $T(\bar{V})$; it was determined experimentally as -0.53 by evaluating its dependence on the recognition reject and substitution

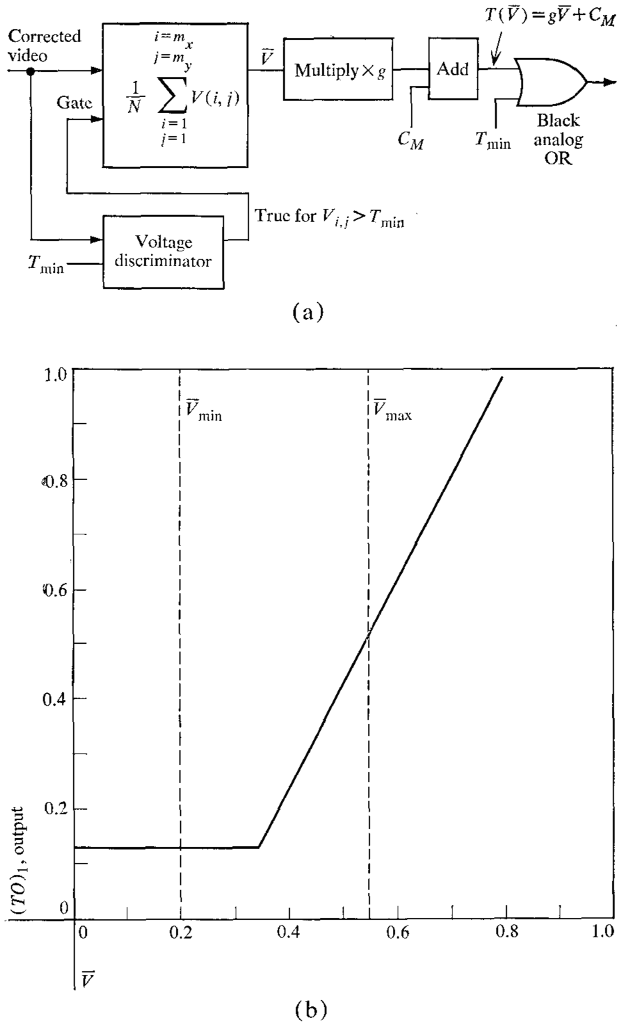


Figure 5 (a) Threshold operator for machine-printed documents; (b) graph of threshold as function of averaged video signal, $\bar{V}$.

rates. To determine T_{min}, the very lowest contrast printing available was scanned. Under these conditions $T(\bar{V})_M < T_{min}$, so the output of $(TO)_1$ was essentially equal to T_{min}. Several settings of T_{min} ranging from 5% to 20% contrast were then tried. It was found that $T_{min} = 0.13$ (13% contrast) was the best setting because the number of rejects and substitutions were minimal for this setting.

Character line width measurement

Examination of Eq. (1) shows that the output pulse width obtained from a single scan through a character can be adjusted about a value $W_{1/2}$. The value of $W_{1/2}$ is more or less a characteristic of the type font but it also depends on $\bar{V}$. Control of signal pulse width is limited by ΔN and ΔI, which vary significantly from document to document. Therefore, the main purpose of this control is to normalize the effect of variations in $W_{1/2}$ on the generation of character bit patterns.

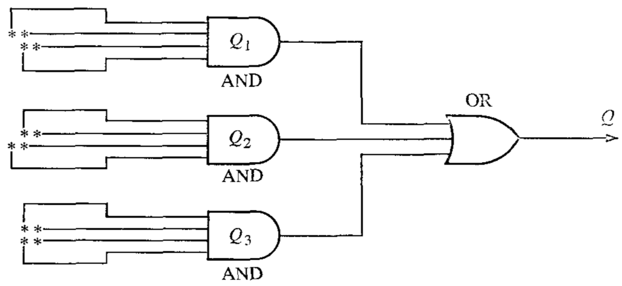


Figure 6 Logic for line-width measurement. Whenever certain shift register positions are detected as containing one of the three bit configurations shown, the output, Q, causes a counter to be incremented.

However, to enhance the recognition capability of the system, it is necessary to have a method of measuring and normalizing the line width of characters in terms of the number of "bits" that result from scanning. A method has been developed[3] for measuring character line width in which bits passing through the preprocessor output shift register are examined to see how often they occur in certain patterns. This method uses three logic ANDs (Q_1, Q_2, and Q_3) which can be satisfied only when the bit configurations shown in Fig. 6 are present in the pattern represented in the shift register. Each time one or more of the three operators is satisfied as the pattern passes through the shift register, a counter is incremented. The total number of these counts for a pattern is called Q. In addition, the total number of bits in a pattern is counted and labeled A. The ratio of Q to A is then used to compute an "average line width" for the pattern. The circuits Q_1 and Q_2 are used for measuring the width of diagonal pattern segments, and Q_3 measures vertical and horizontal segments.

Consider, for example, the pattern of a vertical line W bits wide and L bits long. It is easy to convince oneself that the operator Q_3 will be satisfied $(L-1) \times (W-1)$ times as this pattern goes through the shift register. It can also be seen that although Q_1 and Q_2 will each be satisfied $(L-1) \times (W-2)$ times, none of these will be a time that Q_3 is not also satisfied; if $L \gg 1$,

$$\frac{Q_3}{A} = \frac{L(W-1)}{LW} = \frac{W-1}{W}. \quad (4)$$

Rearranging terms and replacing Q_3 by Q and W by $\bar{W}$ gives an expression that is used for computing the average line width of any pattern:

$$\bar{W} = \frac{1}{1-(Q/A)}. \quad (5)$$

Threshold adjustments based on a measured value of $\bar{W}$ can be made after a character is scanned. A line width

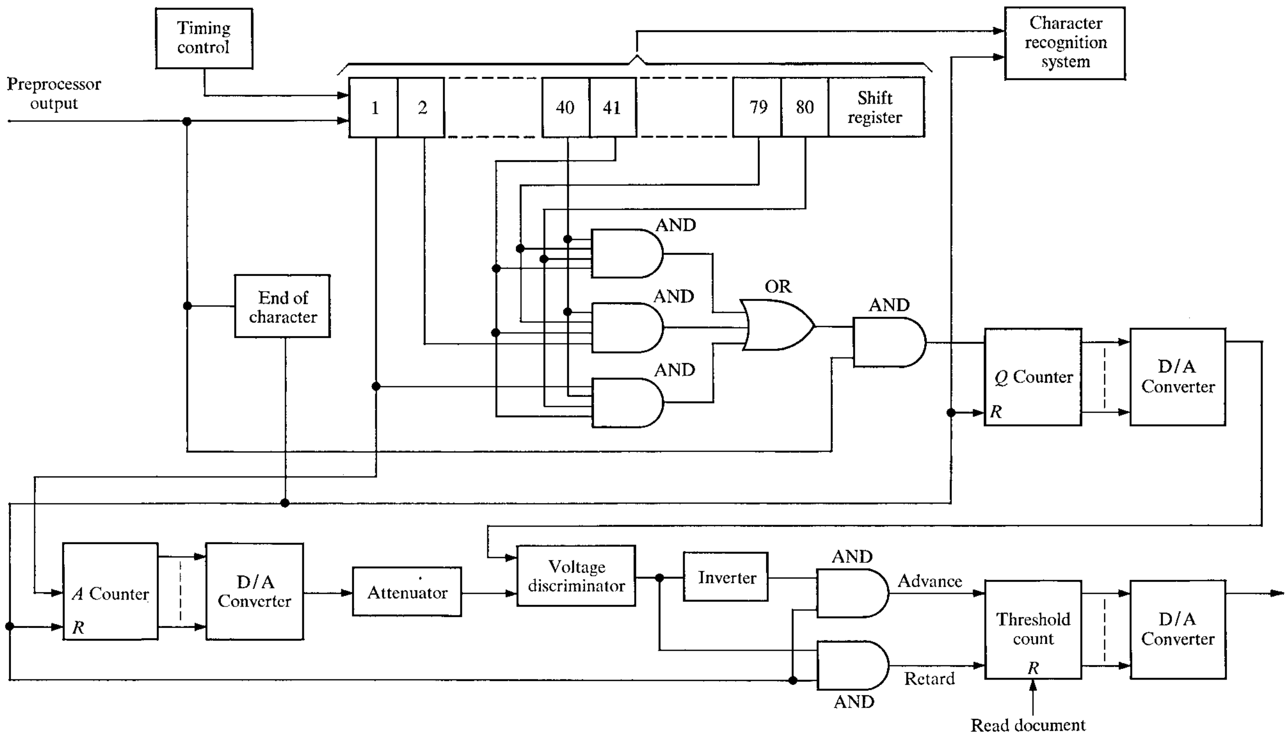


Figure 7 Circuit for generating threshold adjustment based on bit pattern line width. The output is the function $(TC)C_w$ included in Eq. (6).

servomechanism (Fig. 7) evaluates Q/A after each character is scanned, compares it to a predetermined constant q corresponding to some nominal average line width $\bar{W}_n$ and then adjusts the threshold in a direction which will make Q/A on the next character fall closer to q (or in other words, make $\bar{W}$ on the next character fall closer to $\bar{W}_n$).

The "end of character" signal (in Fig. 7) defines the beginning and end of a character and the area over which Q and A are determined. Q and A are converted to analog signals with digital-to-analog (D/A) convertors. A is then multiplied by q and compared to Q. If $Q > qA$, a four-bit threshold counter is advanced; if $Q < qA$, the threshold counter is retarded. The threshold count, (TC), is then converted to one of sixteen possible levels $(TC) \times C_w$, where C_w is a constant whose value is determined experimentally. $(TC)\,C_w$ can then be added to Eq. (3) to provide a threshold adjustment based on line width:

$$T(\bar{V}, \bar{W})_M = 2\bar{V} - 0.53 + \frac{15C_w}{2} - (TC)C_w. \quad (6)$$

The threshold $T(\bar{V}, \bar{W})_M$ now depends on both contrast and line width. The contrast information is used to determine the mid-point of the ΔT range and then another adjustment is made within ΔT based on line width information. $\bar{W}_n$ and C_w were calculated experimentally to be 4.0 and 0.013, respectively.

Threshold operator design for typewriter printing

Line width variations are not a major factor in typewriter printing. Background noise of the variety present in machine printed documents was not predominant, but enough was present to warrant use of a threshold operator based on contrast variations over the entire scanning area:

$$T(\bar{V})_T = 2\,(\bar{V}) + C_T. \quad (7)$$

C_T was determined experimentally to be -0.63.

Background noise due to "fill-in" was predominant in typewritten documents because of the small openings in lower case letters. This type of noise is adjacent to the character, so a threshold operator can be based on contrast information from a localized area surrounding the video sample on which a decision is to be made.

To decide on the size and shape of the area, some practical as well as theoretical considerations were made. The biggest limitation on the size of the area lies in the amount of analog storage required. If an analog delay line is to be large enough to store a complete scan, its length, τ, must be

$$\tau = (N - 1)\,RS + NS, \quad (8)$$

where S is the sample time (1 μsec); N, the width of the localized area, a, in number of samples; and R, the number of samples in one complete scan, including retrace time ($R = 39$).

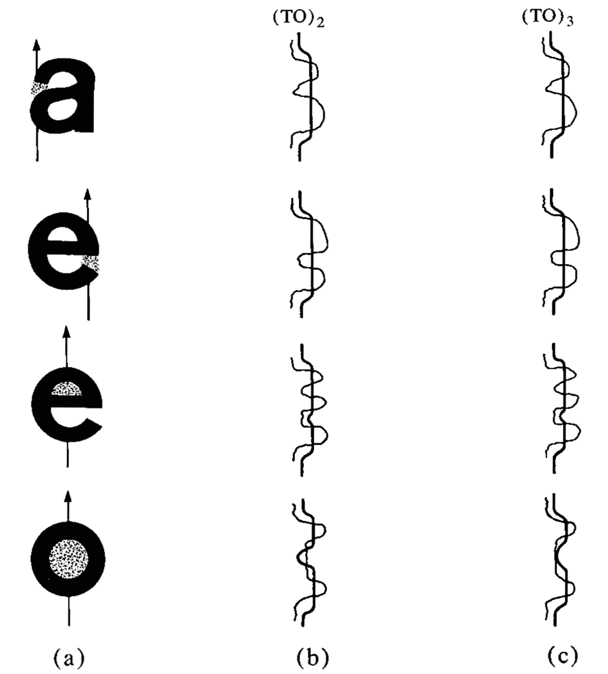


Figure 8 Fill-in noise in printed characters; (a) line of scan; (b) video signal (light line) and threshold generated by $(TO)_2$ operator (heavy line); (c) video signal and threshold generated by operator that includes spatial noise rejection feature.

For an N of three, $\tau = 81$ sec. The delay line bandwidth would have to be 500 kHz, making this approach rather impractical with presently available lines.

The IBM 1428 Optical Reader[4] uses a delay line which stores information from a 0.015 in. × 0.030 in. document area. A two dimensional raster is used to eliminate the need for an excessively long delay line. However, a two dimensional raster could not be considered in the IBM 1975 without drastically altering the system design. The approach taken was to use a delay line long enough to store only five samples within a single scan and then re-evaluate the situation after experimental results were available to see if a larger line could be justified. The delay line had five taps (including input and output) spaced 1 μsec (one sample time) apart. The center tap video was compared to a threshold to determine whether the sample was black or white. This is a very important feature because it enables a decision to be based on two samples ahead and two samples behind the sample in question.

Design of the threshold operator was accomplished by considering several special situations of fill-in noise (Fig. 8a). In many of the special cases illustrated, a situation often arises where only one or two of the five samples are information samples and the others are lower amplitude noise samples which should be called white bits.

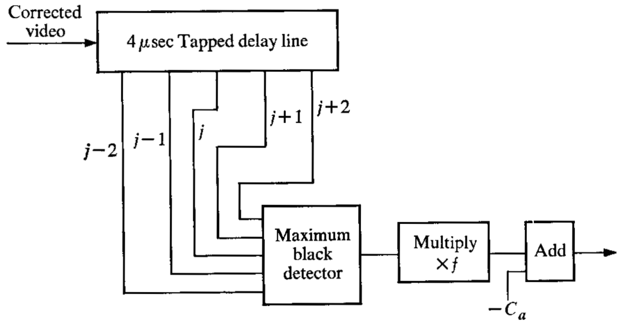


Figure 9 $(TO)_2$ operator.

The quantity $V_{\max}$ can be measured by determining the highest video level in the delay line. A threshold, $(TO)_2$, can then be made a linear function of $V_{\max}$:

$$(TO)_2 = f[V_{\max}] + C_a. \tag{9}$$

Proper choice of f and C_a depends almost entirely on the printing noise levels. The best performance was achieved with $f = 1.23$ and $C_a = -0.38$.

Waveforms showing $(TO)_2$ relative to the analog video are shown in Fig. 8b. Examination of these waveforms shows that satisfactory results were obtained in the first three cases but not the fourth. The situation represented by the filled-in o occurred often enough to warrant combining the $(TO)_2$ operator (Fig. 9) with a spatial noise rejection feature.

The new operator, $(TO)_3$, is shown in Fig. 10. Here, the capacitor circuit stores a voltage, T_c, with negligible leakage over a period of several scans. T_c can be increased (moved towards black) by $(TO)_2$ until $T_c = (TO)_2$. T_c can be decreased to T_{avg} or zero depending on which level is nearest white when $(TO)_2 < T_{\text{avg}}$.

$$T_{\text{avg}} = \frac{1}{5} \sum_{n=j-2}^{n=j+2} V_n + C_{\text{avg}}, \tag{10}$$

where V_n is one of the delay line samples and j is the index of the sample for which a decision is to be made.

The analog OR circuits generate an output that is equal to whichever input is nearest white or black as indicated in Fig. 10. The trigger is set equal to one on every black-to-white transition. It is reset to zero during retrace or after the video has been black for 3 μsec.

Fig. 8c shows $(TO)_3$ relative to analog video. Notice that the noise rejection feature has not changed the threshold setting in the top three cases, but the case with the relatively large filled-in area has been improved considerably.

T_{avg} must be capable of discharging the capacitor storage circuit to a level such that $T_{\text{avg}} < T_{\min}$ when the delay line is filled with white video. The value chosen for C_{avg} should be less than $T_{\min}$, which equals 0.13, and it should be large

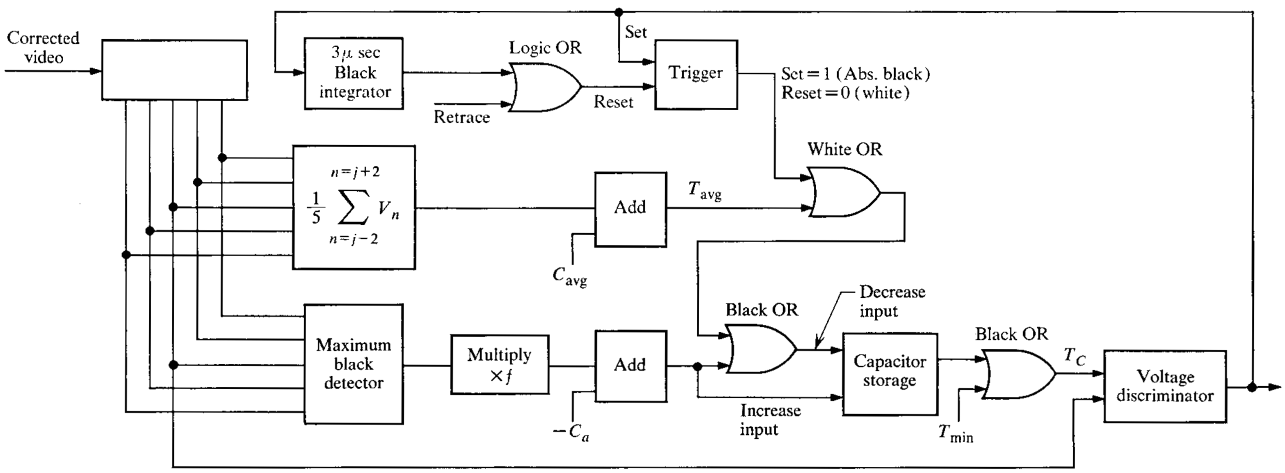


Figure 10 $(TO)_3$ operator.

enough to hold T_c above the level of fill-in noise, as illustrated in the bottom row of Fig. 8. A value of $C_{avg} = 0.1$ was chosen as a reasonable compromise.

Using $(TO)_2$ in the form defined by Eq. (9) presents an objectionable pattern characteristic for the recognition logic. When the input consists of high contrast printing with narrow line widths ($W_{1/2} < 2.5$ bits), the $(TO)_2$ operator sometimes produces patterns with $W = 1$ bit. To prevent patterns of this type from occurring, the threshold operator was modified to include a measurement derived from the dynamic line-width circuit. The modified operator is given by

$$(TO)_2' = (TO)_2 - 0.20 + 0.013\,(TC). \qquad (11)$$

Here, the line width circuit senses the presence of narrow line width patterns and, in effect, moves the threshold closer to white.

Evaluation methods

As an initial step in the evaluation of the thresholder design, documents with a variety of print quality distortions were scanned and computer print-outs of the character bit patterns were produced. Adjustments of the threshold operator constants were then made on the basis of a visual inspection of the bit patterns. This procedure was continued until the preprocessor could produce enough patterns that were judged by subjective criteria as satisfactory input for the recognition unit. This sort of adjustment is necessary, but limited in effect, primarily because the number of documents that can be analyzed in a reasonable time is small and because the decision on whether a pattern is acceptable or not is completely subjective. Hence, more elaborate techniques involving computer processing were devised to refine the design.

The effect on recognition reject rates of varying the operator constants was used as a means of selecting the best values. Reject rates were determined for several values of each constant and the value that minimized the reject rate was selected for use in the threshold operator. In order to obtain reliable reject rates about 35,000 characters from 350 documents were sampled for each calculation. The bit patterns of the characters rejected by the recognition system simulator were then visually examined to determine what kind of distortion was responsible for rejection. If one particular type of distortion were the cause of a large number of rejects, it would be seen as an indication that major redesign of one or more threshold operator was necessary.

Another, less successful, computer simulation technique for selecting threshold operator values involved converting the analog video signal into digital form and storing the gray-level information on magnetic tape. This tape served as input for use with a computer program that simulated threshold operators and generated character bit patterns. Since the simulation did not include an entire recognition logic, it was necessary to decide whether patterns were acceptable or not by a manual process. Although this technique had serious limitations on its effectiveness, it was valuable in studying video characteristics in the early development of the threshold operators.

Evaluation of the component parts of the thresholder enabled us to conclude that the circuits for averaging the video signal over the area occupied by several characters and for dynamically adjusting character line-widths have the most significant effect in improving character recognition rates. It was obvious from visual inspection of character bit patterns that the local contrast operator, which uses only five samples of video information, is inadequate

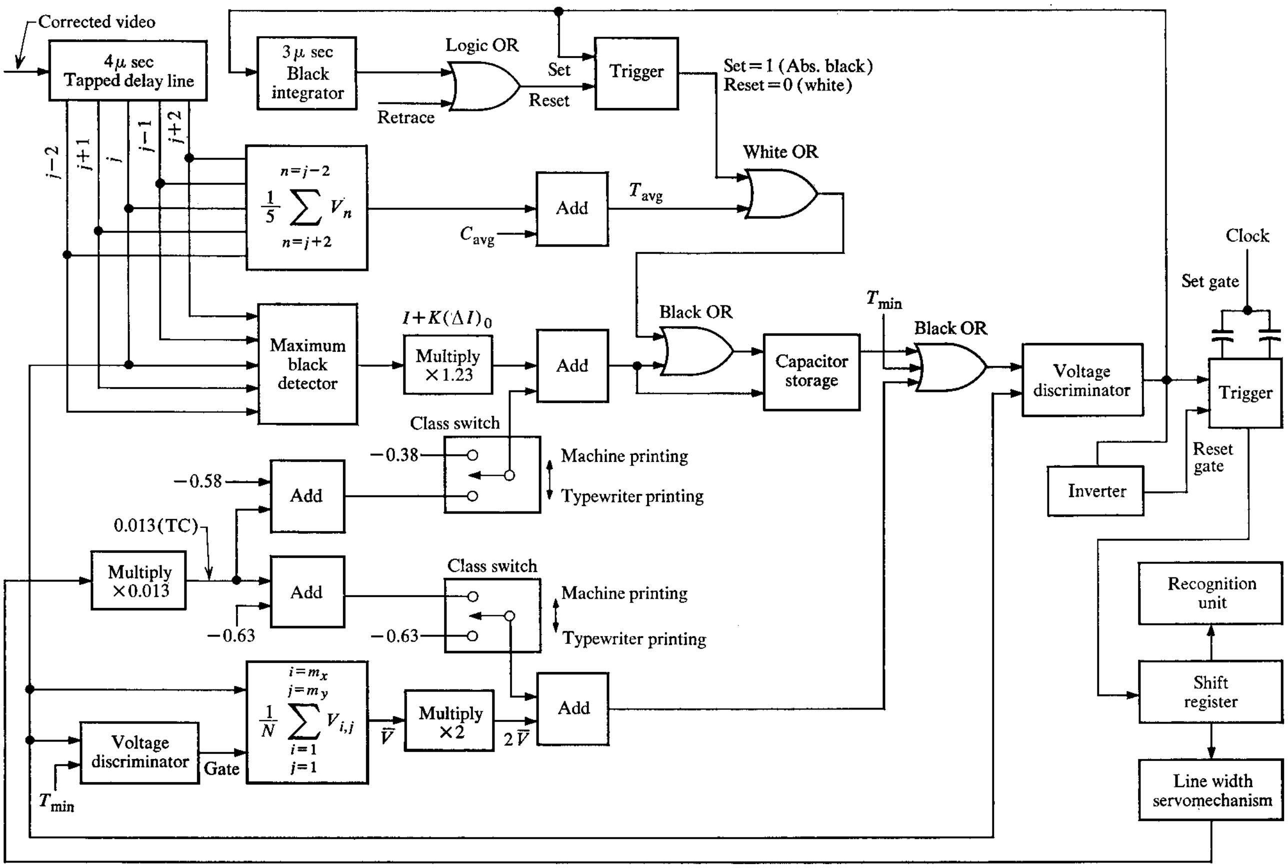
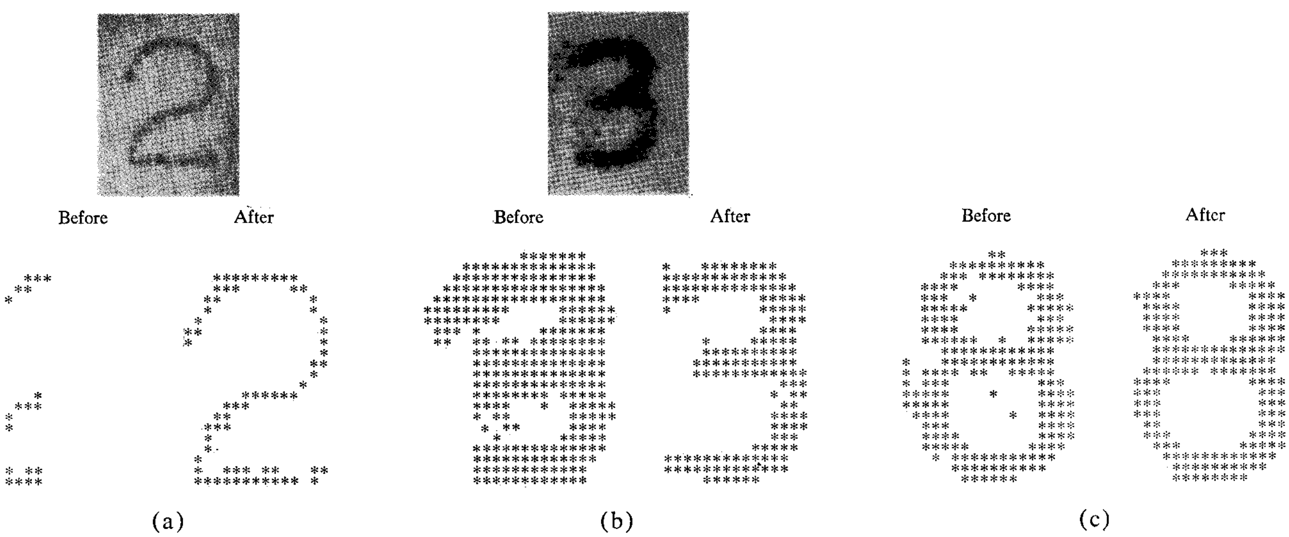


Figure 11 Final configuration of thresholding system.

Figure 12 Some examples showing effect of adaptive thresholding. The left bit pattern of each pair was obtained with a threshold fixed at 20% contrast.



when used by itself, but it did make a significant improvement in recognition rates of typewritten characters when it was used in conjunction with the large-area operator. Use of the dynamic line-width circuit reduced the reject rate of machine-printed characters to about half of that observed when the circuit was not used.

Fig. 11 shows the final configuration and operator values selected for the thresholder. It combines the large-area contrast operator, the dynamic line-width circuit, the local contrast operator, the spatial noise filter, and the switches used to select the operator constants appropriate for machine-printed and typewritten documents. It can be seen how the switches allow the large-area contrast operator to be dominant for machine-printed documents and the local contrast operator to be dominant for typewritten documents.

Figure 12 shows some character samples and the bit patterns generated with a threshold fixed at 20% contrast, and with thresholds determined adaptively by the preprocessor system described in this paper.

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