Automatic Registration in High-Speed Character Sensing Equipment

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Introduction

GREAT strides have been made in the field of data processing machinery. A wide variety of equipments has been developed which will quickly and accurately perform assorted operations on data fed into them. However, far less progress has been made on the task of efficiently providing these equipments with input data. The existence of a severe language barrier has generally necessitated the use of human operators to translate all data into machine language when it is first fed into a data processing system. In an attempt to efficiently overcome this language barrier, a number of different character sensing systems have been developed to serve as automatic man-machine links.

One of the problems faced by most character sensing systems is the relatively inexact fashion in which human beings tend to position information on a document, due both to economic considerations and to the flexibility of the human beings who normally operate on this information. Of great help under such circumstances is the ability of the character sensing equipment to register automatically and accurately on the specific information selected for processing. In fact, it is just such general flexibility which tends to distinguish an equipment suitable for field use from one capable of operating satisfactorily only under laboratory conditions.

Scanning of the Document

The automatic registration system to be described has been successfully employed in a number of different Analyzing Readers.[1] These high-speed character sensing equipments all utilize a high resolution scanner (usually mechanical) and photomultipliers to convert the optical image received from the document into electrical signals. As shown in Fig. 1, the document to be read is moved past a reading station, and an image of the information on the document is focused onto a scanning disk containing perhaps twenty to forty radial slits, each 0.010 inch wide. This disk is normally caused to rotate at a speed of ten to fifteen thousand rpm. Immediately in back of the scanning disk, and swept by light projected through the radial slits, is a fixed plate containing a slit 0.010 inch wide. As the document is moved horizontally past the reading station, an image of the information on it moves across the system of intersecting slits. A two-dimensional scan of the information is thus obtained by means of a beam of light passed by what is effectively a "flying aperture."

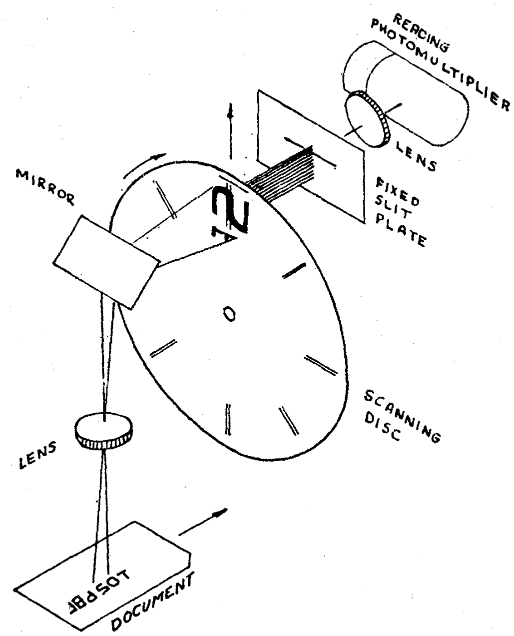

Fig. 1—Simplified view of scanner shows rapid scanning along one vertical axis of moving character image.

Considerations such as the horizontal speed of the document, the height of the field to be scanned on the document and the size of characters to be read will combine to determine the magnification ratio of the optical system employed, the length of the slit in the fixed plate, the number of slits in the scanning disk and the speed of rotation of the disk. Under normal circumstances, more than twenty vertical scans are made across each character, with adjacent scans overlapping slightly. In designing the scanning system, care is taken to insure that the effective cross section of the scanning beam will be substantially less than the narrowest line element normally occurring in the characters to be read.

The moving spot of light passed by the intersecting slits is focused onto a photomultiplier, where it is converted into an electrical signal whose amplitude is always proportional to the intensity of the spot of light. Since the length of the fixed slit is made slightly less than the chord between adjacent radial slits at that point, each scan across the fixed slit will produce a "black pulse" in the photomultiplier output at the point where light is completely blocked from the fixed slit. (See Fig. 2.) During the re-

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[1] Trademark, Intelligent Machines Res. Corp., registered U.S. Patent Office.

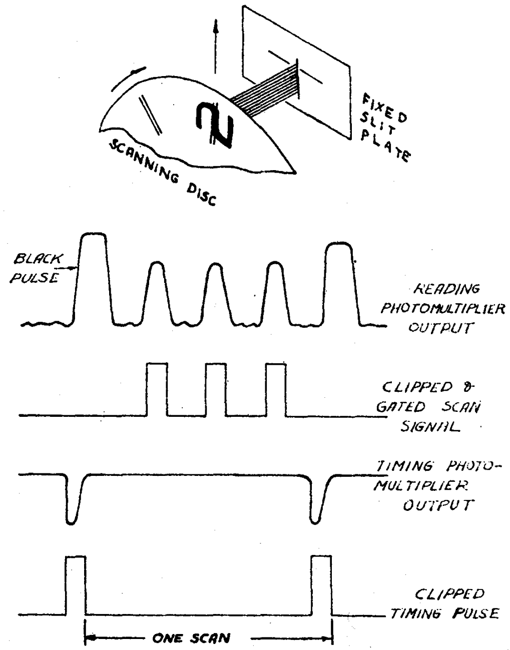

Fig. 2—Development of a clipped scan signal and timing pulse.

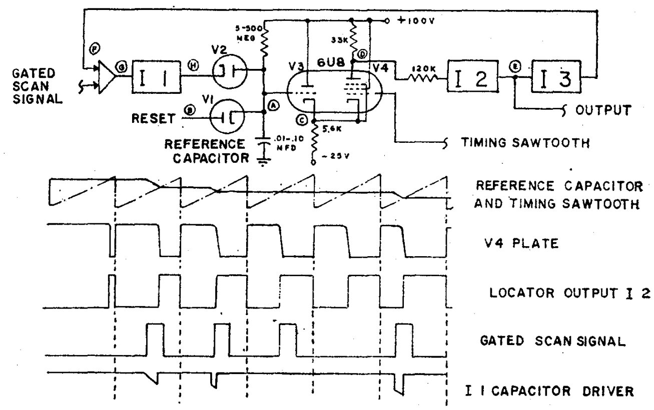

Fig. 3—Locator circuit marks time-in-scan of the earliest signal it receives.

mainder of each scan, pulses will occur only when the scanning of a line element of a character produces a marked diminution in the intensity of the light passed by the intersecting slits. This photomultiplier output is then fed to a video channel, where it is amplified and clipped at the voltage levels (+ 15 and − 25 volts) used in subsequent logical units. Also developed in the video channel is a feedback voltage which holds the amplitude of the "black pulse" constant, compensating for variation in document reflectivity and photomultiplier sensitivity.

A second photomultiplier and an exciter lamp, placed on opposite sides of the scanning disk, are used in a similar fashion to produce a timing pulse at the end of each vertical scan (see Fig. 2.)

Basic Operation of Locator Circuit

The operation of the aforementioned locator circuit, which has been used for automatic registration in machines with the above scanning system, can be analyzed with the aid of Fig. 3. In essence, the voltage established across the reference capacitor is compared with the timing sawtooth. This establishes the point within the scan cycle to be "marked for registration" by the switching of the locator circuit's output. Switching occurs at the earliest point in the scan cycle at which the information being tracked is detected on the document. A feedback loop causes the circuit to keep switching at this point until it is either moved to a point even earlier in the scan cycle by new information or reset to the end of the scan cycle at the end of reading.

Referring to Fig. 3, the signals at points B, E, F, and G are always at either + 15 or − 25 volts. The units I1, I2, and I3 are simple inverters whose outputs are clipped at + 15 and − 25 volts. They are designed to provide an output which is always the exact inverse of their input. The key potential in this circuit is the one established at point A by the reference capacitor. When the locator is not in operation, + 15 volts is applied to reset input point B, causing V1 to conduct until the capacitor is charged to the same potential. With point A at + 15 volts, V3 conducts sufficiently heavily to bring its cathode, point C, to + 15 volts. Under these circumstances, V4 will normally be cut off, conducting only during that brief period at the end of each scan when the timing sawtooth on its grid rises above the tube's cut off potential. Only during this period of conduction will the potential on the plate of V4, point D, be sufficiently low to bring the output of I2 up to + 15 volts. At all other times point E will be held at − 25 volts. Since the signal at point F is the exact inverse of that at point E, the AND gate input to I1 is enabled during almost the entire scan. Only the absence of a gated scan signal keeps point G at − 25 volts and point H at + 15 volts, preventing V2 from conducting.

To put the locator into operation, the potential of point B is reduced to − 25 volts, effectively removing V1 from the circuit. The potential of point A still cannot rise above + 15 due to the clamping action of V2, whose cathode is normally at + 15. However, whenever a gated scan signal is detected during that portion of scan when point E is at − 25 volts, point G will go to + 15 volts and I1 will try to drive point H to − 25 volts. It can seldom do this, since the reference capacitor normally holds the plate of V2 above − 25 volts. Inverter I1, however, will conduct to the limit of its capacity, discharging the reference capacitor through V2 and driving the potential at point A down. Tube V3 will then conduct less heavily, the potential at C will drop to approximately that at A, V4 will conduct for a longer interval at the end of the frame, and input F will disable the AND gate in each frame earlier than before. This process will continue, with I1 driving the potential at A lower and lower, and the output of I2 getting up to + 15 earlier and earlier in the scan, until the output of I3 holds off the AND gate from the earliest point in the scan that a gated signal is detected until the end of the scan. The potential at point A will then remain relatively constant, causing the leading edge of the locator output, point E, to continue marking the earliest point in the scan that a gated scan signal was detected. This situation will continue until the potential at A is either driven still lower by the detection of a gated scan signal even earlier in the scan, or reset to + 15 volts by the signal applied at point B.

It was stated earlier that once set, the potential at point A will remain relatively constant until either driven still lower or reset to + 15 volts. The primary reason this potential does not remain constant is that current drawn by the grid of V3 tends to accumulate on the reference capacitor and slowly drive point A negative. To counteract this effect, a large resistance is connected between this point and a much more positive potential in order to draw electrons away from point A at approximately the same rate that grid current is supplying them. In general, it is safer to choose a resistance value which causes the potential at point A to drift very slowly positive, since it will simply be driven back down as soon as the output of I3 fails to hold off the AND gate while a gated scan signal is present. If, however, the potential at point A is permitted to drift in a negative direction, causing the locator output to mark erroneously a point earlier and earlier in the frame, nothing can drive the potential at A and the locator output back until the unit is completely reset.

It should be noted that the speed with which the potential at point A can be set or reset to the proper values is determined both by the capacitance of the reference capacitor, and by the rate at which electrons can be supplied by I1 and drawn off by the reset pulse.

Application of Locator Circuit

The basic method of operation of the locator circuit has been described above. In practice, the circuit is sometimes made to operate in slightly different fashions for different applications. For example, in one application the scan signals used to set the locator could simply be those used in the basic character analysis program. Other applications may require that the locator be completely positioned and performing its registration function before the information to be analyzed reaches the primary scanning station. In such case, the locator can be positioned by scan signals obtained from this same information as it passes one or more prescanning stations. Using the mechanical scanning system previously described, it is relatively simple to scan simultaneously a number of lines displaced horizontally or vertically from each other on the document. In all applications, however, the basic goal is to register in a known manner on the characters to be read, and to do so with sufficient precision to permit an analysis of the various strokes comprising the characters. An example of the general manner in which characters are normally distinguished from one another is provided by the table in Fig. 4. Here, eleven different stroke criteria are employed

	0	1	2	3	4	5	6	7	8	9
LONG VERTICAL LEFT	+		−	−	−	−	+	−		−
LONG VERTICAL RIGHT	+	+	−	+	+	−	−	+		+
HORIZONTAL TOP	+	−	+	+	−	+	−	+	+	+
HORIZONTAL MIDDLE	−	−	+	+	+	+	+	−	+	+
HORIZONTAL BOTTOM	+	+	+	+	−	+	+	−	+	−
SHORT VERTICAL UPPER LEFT & LOWER RIGHT	+	−	−	−		+	+	−	+	+
SHORT VERTICAL UPPER RIGHT & LOWER LEFT	+	−	+	−	−	−	−	−	+	−
SHORT VERTICAL LEFT & RIGHT SIMULTANEOUSLY	+	−	−	−		−	+	−	+	+
SHORT VERTICAL UPPER LEFT				−	+					
LONG VERTICAL LEFT & RIGHT SIMULTANEOUSLY	+								−	
MIDDLE PROJECTING RIGHT					+					−

+ CONDITION MUST BE DETECTED

− CONDITION MUST NOT BE DETECTED

Fig. 4—Character is identified by correct combination of detected and not detected conditions.

to provide a minimum of two differences between any pair of numbers in a particular type face. This program would not be possible if the lower, middle and upper portions of the characters could not be identified fairly precisely.

The character identification program shown in Fig. 4 is the one actually employed in the Scandex[2] character sensing system, which automatically processes imprinted gasoline credit card invoices. This equipment reads the customer's account number, as imprinted on the reverse side of an invoice card, and punches it into the same card. Since carbon paper is used to make this impression, we are sometimes confronted with smudges adjacent to the characters to be read. In addition, the vertical registration of the account number on the invoice card varies appreciably, being affected by the registration of the credit card during the embossing operation, the position of the credit card relative to the invoice in the imprinter, and the precision of the Scandex card feeding mechanism. To achieve accurate registration on the account number despite the presence of smudges, the locator is programmed to track a point two-thirds below the tops of the characters. This is accomplished, as shown in Fig. 5, by employing two simultaneous scans spaced a character width apart, summing their scan signals, and operating on this sum. Thus, small spurious information will not affect the location system. With the point-in-scan marked by the locator circuit serving as a reference, the characters are then divided into top, middle, and bottom thirds by appropriate time measuring circuits.

Another Analyzing Reader, in which three locator circuits are incorporated, is presently being employed to process automatically utility company billing stubs prepared on tabulating machines. An example of such a stub is shown in Fig. 6. In this application it is necessary that the machine record the first two and last four digits on the top line, the four digits on the second line, and the total on the bottom line of the stub. Here the problem is one of

[2] Trademark, Farrington Manufacturing Co., registered U.S. Patent Office.

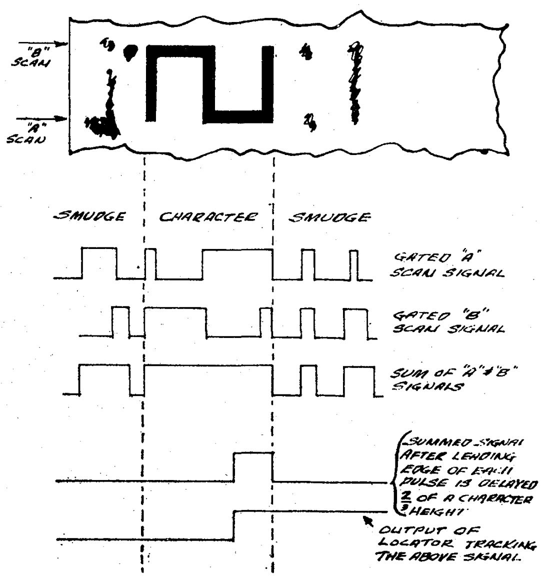

Fig. 5—Scandex locator tacks point two thirds below top of combined scan signals.

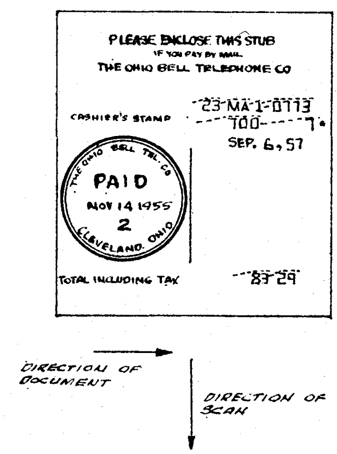

Fig. 6—Locator circuits track characters in first, second, and last lines.

variation in position of the lines to be read, both with respect to each other and to the top and bottom of the stub. This variation in positioning results from the paper form being fed, both in the tabulator and in the cutter, by pins substantially smaller in diameter than the holes in the paper. To correct this variation, the top of each of the lines to be read is tracked by a different locator circuit, as shown in Fig. 6 and, in greater detail, Fig. 7. To prevent that locator which tracks the second line from moving up into the top one, its input is gated so that it can only track scan signals more than a character height away from the first vertical locator.

A third Analyzing Reader employing locator circuits is an automatic page reader developed for an agency of the Department of Defense. This equipment is required to read double-spaced, typewritten information line by line, automatically advancing the page vertically at the end of

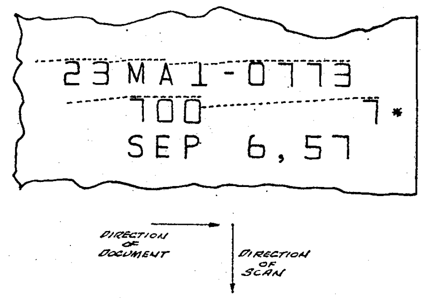

Fig. 7—Locator circuits track adjacent lines on billing stubs.

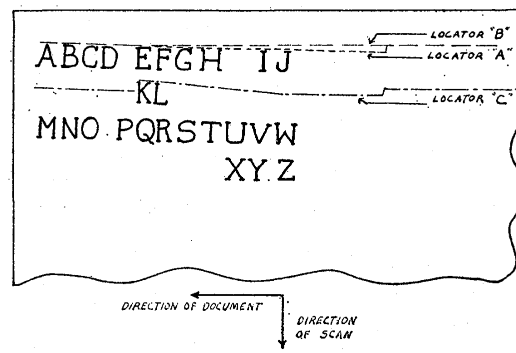

Fig. 8—Locator circuits track normal and substitute characters in spite of tilt.

each line. It is also required to read any "substitute characters" typed between lines in place of the characters immediately above them. (See Fig. 8.) One serious registration problem encountered in this application was the lack of control over distance from the top of the page to the first line on the page. A second problem was the fact that the typed lines are not always parallel to the top of the page. To overcome these problems, a scan capable of covering four single-spaced lines is used, and three locator circuits are employed for tracking purposes. Locator A normally tracks the tops of characters. However, when no characters are detected for a specified length of time, it tracks locator B instead. Locator B, in turn, tracks locator A for a number of characters at the beginning of each line, after which its input AND gate is disabled for the remainder of that line. Locator C will normally track to within a specified distance of locator A, this distance being such as to put it in the middle of the "substitute character" zone. However, whenever it detects a signal earlier in the scan than this point, yet more than a character height later in the scan than locator A, it will track that signal.

In this application, locator B is used to remember the vertical position of the beginning of each line. With this as a reference, the machine can tell where to look for the beginning of the next line even if the lines are tilted. Since it is essential that the point-in-scan marked by locator B not drift significantly during the relatively long time that its input AND gate is disabled, its reference capacitor is made ten times as large as normal.

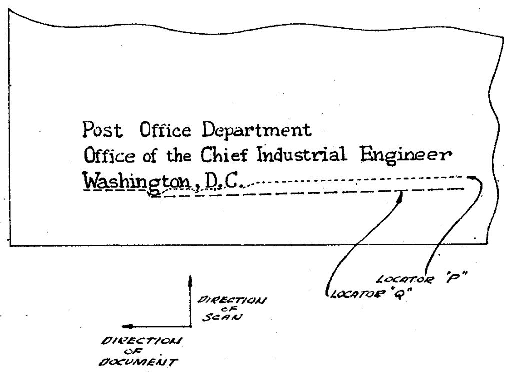

Fig. 9—Locator circuits with slow and fast positive drift of the reference capacitor voltage.

A fourth Analyzing Reader employing locator circuits is an automatic mail sorter being developed for the Post Office Department. In this machine, programming considerations make it desirable that we be able to register on the bottoms of the various characters in the bottom line, as with locator P in Fig. 9. This is achieved by connecting a relatively low resistance between the reference capacitor and + 100 volts. In this case, 18 megohms is used, causing the reference voltage to drift in a positive direction relatively quickly when not being set down by input scan signals. The danger in this approach is that the locator might occasionally drift up to the previous line, and confuse it with the bottom one. To prevent this happening, a second locator, with a much larger "pull-up" resistance (in this case, 500 megohms) is made to track the same characters. This locator will behave more like locator Q in Fig. 9, drifting upward at a much slower rate. Now, by using locator Q as a reference, an alternate input for locator P can be developed to prevent its drifting to a point more than three fourths of a character height later in the scan than locator Q. As can be seen, this permits locator P to follow the bottoms of those characters in the bottom line very closely without any danger of its drifting into the previous line.

An interesting problem encountered in this same mail sorter application was the need for determining immediately the fact that we have begun reading a new line in a staggered address. A normal locator circuit tracking the bottom of the bottom line on a document will, in such a case, simply drop down to this new line. How, then, do we determine that this has occurred? The technique presently employed is to have an additional locator track a point roughly three fourths of a character height below the line being read. The presence of a scan signal earlier in the scan than this point indicates that we have begun scanning a new line in a staggered address.

A locator circuit can be made to track a specified distance ahead of the input scan signal by simply delaying the leading edge of its output pulse by a fixed amount before inverting it and feeding it back to the AND gate. Unit M1 in Fig. 10 is used to accomplish this delay. As can be seen from Fig. 10, the leading edge of the M1 output pulse, and hence the trailing edge of the I3 output pulse, follow the leading edge of the locator output pulse by a fixed interval. The presence of M1 does not, however, alter the basic operation of the locator circuit itself. Whenever the AND gate's output is positive, V2 will conduct and cause the locator to mark a point earlier and earlier in the scan. It is only I3's disabling of the AND gate that prevents scan signals from improperly advancing the locator output all the way to the beginning of the scan. Scan signals can advance the locator only if they occur while the output of I3 is positive. We see, then, that scan pulses will continue to advance the locator until the trailing edge of I3's output is brought to the same point in the scan as the leading edge of the earliest scan pulse. Of necessity, the leading edge of the locator output will then be marking a point-in-scan which is the specified distance ahead of the earliest scan signal detected.

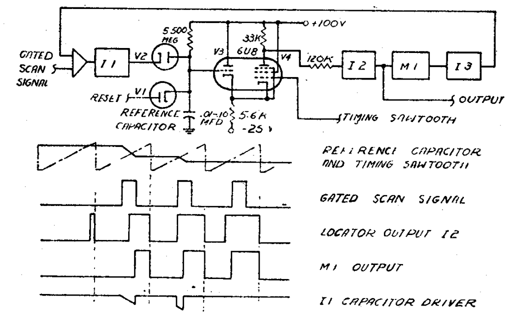

Fig. 10—Locator circuit marks a specified interval before the time-in-scan of the earliest signal it receives.

Conclusions

In most high-speed character sensing systems, automatic registration is extremely helpful in: 1) overcoming poor registration and extraneous marks on the document, 2) compensating for tilt of the information to be read, and 3) accurately dividing the characters to be read into vertical zones for purposes of stroke analysis. A special locator circuit is employed in a number of IMR Analyzing Readers to provide such automatic registration. Minor modifications of the circuit permit the control of such characteristics as the speed with which it can be set, the speed with which it can be reset, the timing stability of its switching point, once set, and the degree to which it can register on misaligned characters. Registration on a variety of types of information, either in restricted zones or anywhere on the document, is possible. The usefulness of this locator circuit has been thoroughly established through its application to various Analyzing Readers presently under development or in use in the field.

Acknowledgment

The basic locator circuit was developed by David H. Shepard of Intelligent Machines Research Corporation. Techniques for applying it to different models of Analyzing Readers reflect the contributions of numerous members of the IMR staff.