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Technical Note 245

FACTORS INFLUENCING THE DESIGN OF ORIGINAL-DOCUMENT SCANNERS FOR INPUT TO COMPUTERS

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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FOREWORD

This Technical Note has been prepared by Edward S. Stein and Associates for the Research Information Center and Advisory Service on Information Processing, Information Technology Division, Institute for Applied Technology, National Bureau of Standards. As a part of its function of encouraging cooperation and interchange of information in the field of research and development in information selection and retrieval systems, the Research Information Center issues from time to time state-of-the-art reviews and related reports on selected topics of interest. The present report involves consideration of specific aspects of design for input of material such as a full page of printed text to processing equipment.

Names and descriptions of specific proprietary devices and equipment are included for the convenience of the user, but completeness in this respect is recognized to be impossible. The omission of any method or device does not imply that it is considered unsuitable or unsatisfactory. Conversely, inclusion of descriptive material on any proprietary instrument, product, or process, does not constitute endorsement.

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FACTORS INFLUENCING THE DESIGN OF ORIGINAL-DOCUMENT SCANNERS FOR INPUT TO COMPUTERS

Edward S. Stein and Associates

This report considers some of the factors involved in the design and implementation of scanners capable of reading data from documents in their original form rather than from microfilm. The scanner is assumed to be part of a transcribing information processor such as the FOSDIC (Film Optical Scanning for Direct Input to Computers) type of machine. Advantages and disadvantages of microfilm as against original document scanning are discussed. Factors considered include the types of forms that are to be handled, paper handling problems, available electronic and mechanical scanning techniques, problems of resolution and image defects, precision limitations, and overall system limitations. A set of general specifications for scanners for direct data input to computers is developed in qualitative terms.

I. INTRODUCTION

Much progress has been made in the electronic computer field during the past decade, especially with respect to increases in internal computing speed, storage capacity, and versatility. Several devices have been perfected for high-speed print-out of computed results. To speed the entry of large amounts of both alphanumeric and graphic information into the computers, however, additional developmental effort is needed.

The FOSDIC (Film Optical Scanning for Direct Input to Computers) line of machines represents one of the earliest and most successful attempts to automate the conversion of information from original documents into a medium directly compatible with the input requirements of a large scale computing system. Each of the three versions of the FOSDIC machines that have been designed and constructed to date has utilized microfilm as an intermediate medium between the original document and the scanner-interpreter. The use of microfilm permits certain technical advantages, some of which are touched on in this report.

The success of FOSDIC III, as used by the U.S. Bureau of the Census during its 1960 Decennial Census, demonstrates that an automatic scanning device which can extract information from original forms prepared under field conditions can yield great savings in operating costs over the more usual intermediate card punching operations. Subsequent work with FOSDIC III has shown that this scanner, in conjunction with a suitable programming unit, can also perform such varied tasks as map reading, meter reading, and recognition of constrained, hand-printed characters, as well as "mark sensing" over a great variety of forms.

Further analyses of the Census operations using FOSDIC III have shown that substantial additional savings could result from the use of a scanner capable of reading the original document without resorting to microfilm as an intermediate step. Specifically, these additional savings would come about by reduction in those operating costs directly associated with filming the documents and processing the microfilm.

This report has been prepared for the purpose of examining the factors to be considered in the design and implementation of a scanner capable of reading documents in their original form. Such a scanner is conceived to be part of a transcribing information processor such as the FOSDIC machines.

Many different factors influence the selection of components for and the design of such a scanner. Some of these factors come about from systems philosophy; others result from consideration of reliability requirements, questions of economy and ease of design, problems of manufacture and maintenance, availability of components, and the like. In the absence of specifications for a particular application, this report will not describe an exhaustive design analysis using any particular technique or any particular components. We shall, however, discuss several possible techniques and components, relating their parameters where possible to the anticipated problems in the design and utilization of this particular class of scanning devices.

Section II of this report is an attempt to compare the operational use of microfilm with that of the original documents. Both advantages and disadvantages are discussed, using the Census operations as a model. The type of forms that may be involved are discussed in Section III. Again the Bureau of the Census is used as the source of illustrative examples.

Section IV discusses in general terms the problems of handling large sheets of paper, including some remarks on the special difficulties associated with turning pages in a bound book. Desirable characteristics of the scanner proper are dealt with at some length in Section V. A set of general specifications for scanners for direct computer input is developed in qualitative terms. An attempt is made to relate several available electronic and mechanical scanning techniques to these specifications.

As an alternative to these techniques, an electro-mechanical scheme is proposed using a light-weight fast-response indexing mirror in conjunction with a conventional cathode-ray flying-spot scanner. Multiplexing two mirrors is described as a means of speeding up the response of the scanner. The advantages of such a system are discussed along with anticipated design problems.

In Section VI some preliminary conclusions are drawn. Also included are a few suggestions of useful steps to be taken to continue the investigation into the area of less conventional approaches as suggested by some recent work in physics and the applied sciences. Development efforts leading to the preliminary design of an electro-mechanical scanner are recommended.

II. ORIGINAL-DOCUMENT SCANNING VERSUS MICROFILM SCANNING

In 1960, the Bureau of the Census made use of the FOSDIC III device in the processing of the massive collection of information resulting from the Decennial Population and Housing Census of that year. Because this processing included the preparation, handling, microfilming, and transcribing of information from millions of documents, the nature of this task makes it a particularly good choice for an operations model.

The processing can be roughly divided into four steps: (1) the special printing of some 57 million Census schedules, (2) microfilming these after completion by the Census enumerator, (3) developing the film with more than the usual care, and (4) transcribing the recorded information from film to magnetic tape using FOSDIC equipment. Each phase of the operation was carefully monitored by a quality-control inspection system [1]. The result was a well-run operation whose efficiency exceeded the planned estimates.

It was clear from analyzing this job, however, that operating costs might be substantially reduced and that certain other advantages might be gained if the intermediate steps of microfilming the documents and processing the film could be eliminated.

In addition to the cost considerations arising from the intermediate microfilm process, certain other considerations involved in the use of microfilm in the Census operation can be summarized briefly as follows [2]:

1. Time Factor -- A time lapse of approximately 24 hours occurs between the receipt of a document and the delivery of its microfilm image to the FOSDIC machine for scanning. This delay is caused in part by the adoption of an optimum exposure-to-development time which has been determined on the basis of FOSDIC scanning tolerances.

2. Additional Operations -- For microfilming each new type of schedule, the camera operator must be given special orientation. During the Decennial Census tabulations it was found necessary to run a statistical control on each new operational phase of the job in order to check that

the operator's hands would not be visible in the camera field and to insure that the sheets of paper were properly smoothed, positioned, and flat before microfilming. It was also necessary to check the camera periodically to make sure that it was clean and well-adjusted and that the field was properly illuminated.

Automatic cameras were considered, but current designs are such that, although the image does not appear particularly distorted to the eye, variations in internal film velocity result in severe variations in image intensity and scale along the direction of film travel such that the registration requirements for the FOSDIC interpreter are not always adequately met.

3. Control of Film Processing -- The tolerance in the FOSDIC scanner to differences in contrast requires that the film be subjected to a very close degree of control during development and fixing. Special care must be taken to prevent dust and dirt from entering the processor.

4. Availability of Equipment -- During the 1960 census, the operation had to be run under such controlled conditions that there was only one facility in the United States that was specially set up to handle the film. Even at that, troubles arose from incomplete dye-back removal. Not only was the processing equipment not available at all locations, but the flat-bed camera that was used is not easily portable.

5. Cost -- The use of microfilm cameras and film and the special processing requirements together, introduce a variable cost factor depending on the number of reels to be processed and the amount of time used on the cameras. This factor is higher when the size of the job is small. These costs could be reduced somewhat by the use of semi-automatic or fully automatic microfilming equipment. Houston Fearless Corporation of Los Angeles among others has manufactured automatic carefully controlled processing units to specification.

Technical Advantages in the Use of Microfilm

Although the operation of a system using a document scanner instead of a microfilm scanner should be advantageous, the designer of the document scanner faces more problems than if he were attempting to scan microfilm. Let us review some significant differences:

1. An original document scanner must necessarily collect only the diffuse light reflected from the document surface and avoid specular reflection which can cause glare.

If the scanner employs a flying spot or a flying aperture, the percentage of incident light that can be collected this way is small compared with the amount of transmitted light that can be collected through film. Further, a flying spot of light will show up the texture of the document as a kind of "paper noise". [51]

2. The smaller field size of a microfilm scanner permits simpler and more efficient optics. The light paths are shorter, and the lenses are of smaller aperture.

3. Although film drives must be designed to avoid scratching the film and cinching on the reel, the mechanical linkages required to move roll film are considerably simpler and less bulky than those necessary to transport large individual sheets of paper or bound books.

III. FORMS

Document forms such as those prevalent in government use appear in many different sizes and shapes. Although it is beyond the scope of this report to discuss the standardization of such forms, it may be helpful to list the types of forms that are likely to be input to document scanners:

1. Loose rectangular sheets varying from a few inches on a side to as large as 15 by 20 inches. They may be printed on one or both sides.

2. Books made up of loose rectangular sheets as described in 1, bound with a spiral binding.

3. Large standard size cards, such as IBM "Mark sense" cards.

4. Booklets or questionnaires that are often folded for mailing purposes.

The weight of the paper stock used for these forms may vary from heavy card stock 7 mils thick to tissue paper thin carbons only 2 mils thick.

Printing Tolerances

Although in the future computers may be expected to accept information from documents in the form of drawings or other nonliteral shapes, we shall confine our consideration here to applications involving only three kinds of input: (1) positionally constrained marks (either machine or man-made), (2) typewritten characters, and (3) hand-printed characters.

"Mark-sense" machines search for the presence or absence of marks in predesignated positions on the forms. These marks may be made either by a person filling out the form with a standard writing implement or by a printing machine, for example, a high-speed printer controlled by a computer.

In the more usual application, where the form is filled in manually, certain marking guides must be preprinted on the form to indicate the predesignated positions and to act as constraints. These marking guides must be carefully registered with respect to each other and to the edges of the document or to local "bench marks". It may be possible by extremely careful design of the scanner and by unusually close control of printing to construct the marking guides of such a shape as to be recognizable regardless of whether or not a mark is "entered". In this case, it would not be necessary to hold the required registration tolerances as close. However, it is much more likely that less difficulty will be involved in registration than in maintaining close uniformity in printing. [52]

Uniformity of printing refers both to line thickness and grayness of the impression. Response to the gray scale of printing would not seem to be important in a mark-sense machine where a deliberate attempt is usually made to quantize all values of reflectance below a given "threshold" to the same "black" level. In a more sophisticated mark-sense machine like FOSDIC III the gray level of the mark is detected so that erasures may be distinguished from correct entries. In this case it may be extremely difficult to construct the scanner so that it can distinguish between a heavy marking guide and a weak mark.

It is to be noted also that if the scanning aperture is larger than the thickness of the scanned line, it may be impossible to discriminate between thin black lines and wider gray ones. If the scanner is required to adjust its relative position on the basis of local reference marks, gray printing can cause mispositioning. If all reference points and marking guides on a document can be printed close to the same weight and line thickness, it is possible to make the scanner self-calibrating for sensitivity, performing the calibration at the beginning of each document scan and holding the "threshold" setting until all information on that side has been processed.

FOSDIC III contains such a self-calibration circuit. Even so, a careful quality-control inspection was needed during printing of the Decennial Census forms to detect poor inking and defective or worn plates.

If information is to be extracted not in the form of positional marks but as actual typewritten characters, then marking guides will not in general be required. A generous area must be allotted for a field of characters, and care should be exercised in the layout so that lines, printed symbols, reference marks, and the like will not be mistaken for the substantive information. If preprinted characters and/or symbols are to be read along with the typewritten material, then control may have to be set up to insure that the quality of the printed matter is not too dissimilar from the quality of typewritten material.

Since the information in this case is contained in the connotation of the character and its sequential relationship in a group of other characters rather than in its precise geometric position, reference bench-marks are less likely to be needed. If they are required however, the same control over printing uniformity may be necessary as for the mark-sense machine.

Information recorded as hand-printed characters is more likely to require constrained areas on the document. Thus the control exercised over printing may have to be as careful as for the mark-sense application.

Documents with printing on both sides can be troublesome if heavy inking causes the impression to be visible through to the reverse side. The effect of this "show-through" can be minimized during scanning by resting the document on a black bed, but at the cost of lowered contrast.

Guillotining

Large presses accept oversize sheets of paper on which several impressions of the form are printed at once. The individual sheets must be separated by cutting. Normally this is done with care, but since a paper handler will undoubtedly be dependent on the edges of the document for registering it in the scanning position, extra precaution must be used to prevent the impressions from being badly skewed.

IV. PAPER HANDLING

Manual Handling of Large Documents

If the document form is large and contains a great deal of information such that the scanning time will consume approximately a quarter of a second or more, it may be wise to consider a manual means for placing the document in position under the scanner and stacking it after processing. Manual feeding may be especially attractive if the documents are subjected to a great deal of rough treatment before the operation.

An operator can spot defects in the printing or the preparation of the form, can smooth out wrinkles, folds, or dog-ears, can correct for skew in the impression, and can patch up torn portions, and the like. In short, an operator can handle manually those cases which a mechanical handler would be hard-pressed to detect, much less correct.

The frequency of occurrence of these problem cases will of course influence the choice of man or machine. The question of the number of defective sheets that must be manipulated will have to be economically balanced against the disadvantages of a somewhat slower operating rate and the tendency for the operator to introduce his own errors.

A good approach for a new system design in an application involving the handling of large sheets is to arrange the scanner so that either mechanical or manual handling can be used, begin trial operations with a manual method, and then incorporate a mechanical feeder if it proves desirable. Experience with manual feeding will undoubtedly be of value in the subsequent design of the mechanical handler. In general, manual handling will probably prove superior if a variety of sizes of forms must be accommodated.

Mechanical Handlers

In the past, many machines have been constructed which have as part of their function removing sheets of paper one at a time from a stack or pile, processing them, and then restacking them in output bins. Examples of this kind of machine can be found in the printing and reproducing and the business machine industries, where manufacturers such as Addressograph-Multigraph, Standard Register, Pitney-Bowes, Burroughs, and others have made machines that handle paper in various sizes, shapes, and weights, doing so reliably and accurately. The development of punched card accounting systems has resulted in numerous machines for handling cards one at a time at rates up to 3,000 a minute. The need for automated post office equipment has recently produced new machines for handling mail which are able to deal with a wide variety of sizes, shapes, thicknesses and weights of mailing pieces. It is reasonable to assume that among these various existing machines can be found paper handling techniques applicable to an original document scanner.

Generally a paper handler can be divided into three main components. These are (1) the hopper which holds the unprocessed documents, (2) one or more processing stations, and (3) one or more stackers which are the final receptacles for the processed documents.

1. Hoppers

A hopper accommodating many different sizes of forms would usually have adjustable sides. The operator should be able to load the hopper easily, without stopping the machine.
(NOTE: If necessary, stopping the machine to reload need not cause too great a time loss under certain conditions. For example, allowing only one second to scan each document on each of two sides and a full two minutes to refill the hopper and unload the processed documents, only 10% of the operation time will be lost if the hopper can hold 1,200 documents. This would require less than 10 in. of depth.)

2. Pick-Off Techniques

Several techniques have been exploited for removing sheets or cards from hoppers and bringing them into the processing position. The paper or cards have been removed from the pile by (1) pushing, (2) pulling, and (3) lifting. Pushing is best illustrated by the many card-feeds in common use which employ a wiping action (friction roller) or a picker knife engaging the edge of the card. Pulling is usually accomplished by having fingers engage the edge of the desired sheet, clamp down on it, and snatch it away from the pile.

Lifting is usually done by suction or vacuum feeding. A good example of the vacuum approach is an Addressograph-Multigraph reproducing machine which employs vacuum arms that descend and lift the edge of the sheet from the pile and pull it toward the processing station. Another unusual but excellent pick-off is found on a character reading machine made by Rabinow Engineering Co. This vacuum feed, the "conical", uses a rolling cone which engages a corner of the topmost document and then rolls the corner away from the pile and up into rollers which advance the sheet toward the processing station. By this method, doubles (two sheets fed simultaneously) are virtually eliminated.

Rabinow Engineering Co. also makes a special vacuum pick-off for letter-mail feeding. In this arrangement, two paddle-wheel-like assemblies, each with several vacuum cups at the periphery, rotate counter to each other. They are so arranged that an envelope picked off by the lower wheel will transfer to a cup on the upper wheel. Since both sides of the envelope are alternately held, only one letter at a time can be fed and doubles cannot occur.

Vacuum pick-offs suggest effective approaches to the problem of handling different sizes. For example, one can make a hollow rod with an adjustable slot and connect it to a vacuum source. Such a rod can be used to grasp a document along the width axis, lift it from the pile, and move it into position before the scanner. It might also turn pages in a book. The arm could be made adjustable, not only across the width of the document but in the length dimension as well, by changing the radius of the linkage moving it. Compliant overtravel would allow the rod to descend into the hopper so that regardless of how high the pile or the book may be, the rod will be in firm contact with the uppermost sheet before starting its swinging motion.

Double-sided documents can be inverted by rolling them around a drum instead of stacking the first time and then sliding them under the drum to the stacker the second time. This would probably operate faster than a swinging vacuum arm, but would cost more and could not be adapted to turning pages in a book.

3. Processing Station Considerations

The current FOSDIC III microfilm scanner accomplishes edge registration with the help of calibration marks printed in the top and left-hand margins of each document. These calibration marks are carefully registered with the balance of the printing on the document (Figure 3) and permit the scanner to locate the top and left margin lines accurately. Unless done carefully, guillotining (cutting the paper) will result in skewing the margin lines with respect to the edges of the sheets. FOSDIC III incorporates a de-skewing (tilt) adjustment which is automatically performed at the beginning of each frame of microfilm. It is based on the deviation of a line drawn through the two calibration marks on the left edge from an absolutely vertical line. In an original document scanner, the sheets of paper would have to be registered by their edges. The accuracy of this registration will determine the skew of the printed image relative to the scanning head. A very simple arrangement for aligning sheets is to bring them up against two right-angled stops. In order to guarantee that the sheets actually reach the stops, moving belts or rollers can be used.

In addition to edge registration there may be a problem of smoothing and flattening a sheet before attempting to scan it. An aerodynamic phenomenon is encountered in working with large sheets of paper, i.e., the tendency for a sheet to fly in its own airstream. Attempts to smooth the paper at high speeds may be troublesome. One possible approach is to enclose the scanning area tightly so that by using vacuum on the bottom of the scanning position the air pressure may be reduced directly beneath the sheet, thus minimizing the aerodynamic effect and encouraging the sheet to cling to the bed of the scanning position.

4. Stacking

In dealing with loose sheets, the sequence of sheets within the pile after stacking is important. If sheets are pulled from the top of the stack and if the original sequence is to be preserved, the sheets must be either inverted after being examined or they must be placed on the bottom of the final stack. Double-sided documents must be inverted regardless, and the inverted sheet could then be slid onto the top of the final stack.

One scheme which is well adapted to placing sheets on the bottom of the stack utilizes large counter-rotating helical springs with a wide pitch. As documents are sent into the springs, they move upward along the helix. The final stack rests atop the springs. This stacker has the interesting property that, regardless of how the sheet enters the stacker, no damage is done to it. In addition, it is quite tolerant of differences in document thickness. The differences in height and width of the document would have to be accommodated for by means of adjustable sides. Because the stack rests on the moving springs, there is a practical limit to the number of forms that can be accumulated in the stack at any one time. In the "Uptime" punched-card reader, the final stack is almost vertical. With large loose sheets there would be trouble in sustaining such a stack, which is likely to collapse without some pressure on the sides. Another means of stacking documents utilizes vacuum cups to lift the paper from the scanning position, and then either invert it onto the top or push it into the bottom of a stack.

The above mentioned techniques take considerable time. Since the scanning operation for FOSDIC-type systems will typically consume one-quarter second or more, it will not be as costly to stack paper this way as in some operations where the document is scanned much more quickly. In any case, an optimum stacking arrangement would be one in which the document is snatched out of the scanning area just as the next document is placed in it. The stacking operation proper could then be performed at a slower rate during the scanning time of the next document.

5. Bound Books

Several alternatives exist for an operation which would be required to process the information contained in bound books: (1) The binding could be removed from the book so that only loose sheets are handled, (the book could be rebound after scanning), (2) An operator could both insert the book into the scanning area and turn the pages. (3) The operator could insert the book and have the pages turned by the paper handler. (4) The handling of the book could be completely automatic.

The first alternative is attractive because it requires no special mechanical means for handling the book beyond those for dealing with loose sheets. The second approach has the advantage that the book is kept intact during the scanning. Since an operator can turn large pages almost as fast as a mechanical paper handler, not much time would be lost by having the operator do so. However, experience has shown that a properly constructed and well-adjusted machine can usually do a routine task such as turning pages more reliably and accurately than a human operator. Therefore, if an operation requires that the book remain as a single unit, the paper handler should preferably be designed so that it can turn pages as suggested in alternative 3. Double-sided documents must be inverted before reading the opposite side. It is possible to design a paper handler so that the arm that inverts loose sheets can also be used for flipping pages in a book.

The scanner might also be constructed so that the scan portion can be physically divorced from the paper handler. This means that a separate paper handler for bound books would be constructed and the scanning head moved into position over it as desired. Alternative 4 would require an additional conveyor to move the books. Since an operator must be in attendance regardless, alternative 4 represents a dubious advantage over the others.

Figure 1 is a sketch of a possible arrangement for handling double-sided documents in bound books.

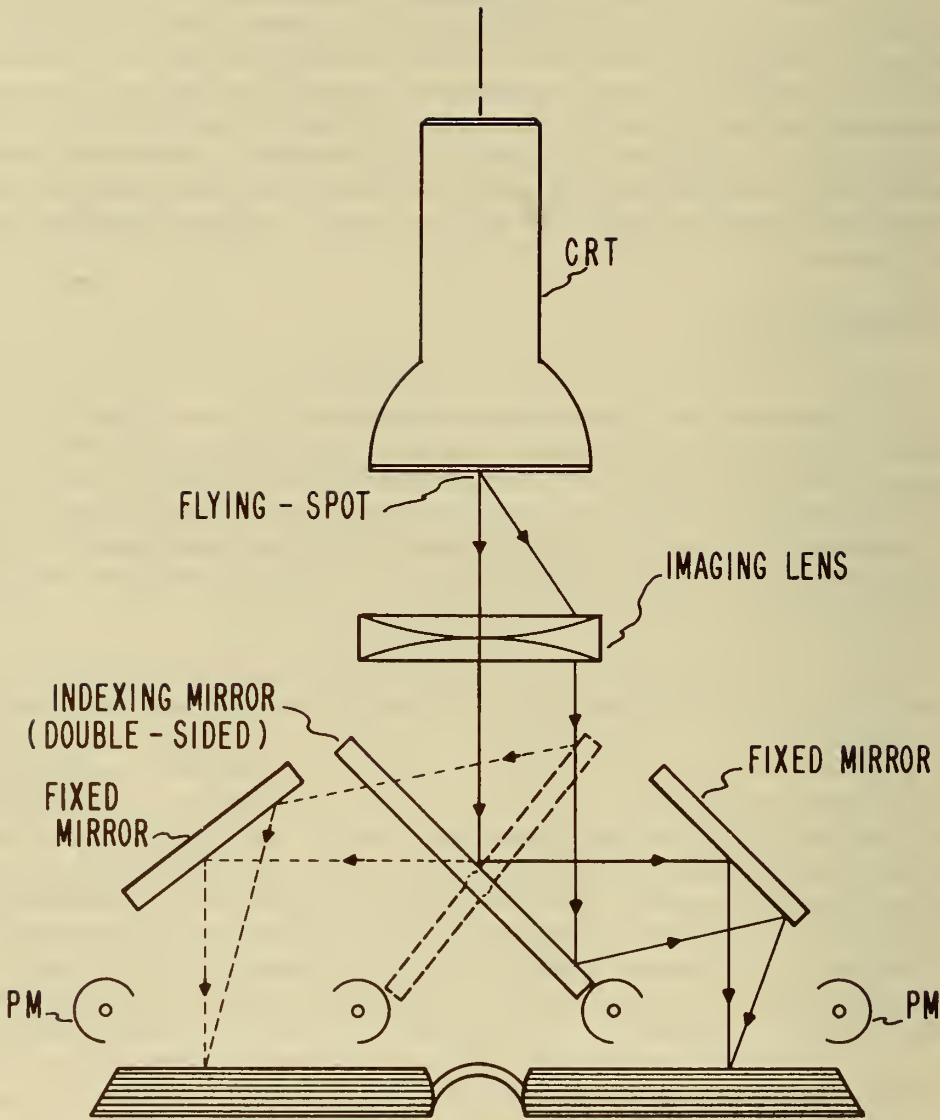

Figure 1. Arrangement for Scanning Pages in a Book

6. Other Problems with Forms

In addition to the problem of poorly aligned edges which can come about during the guillotining operation, there are other defects, with respect to original documents which in a manual microfilming operation would be apparent to the camera operator so he could either eliminate the defect or cause the sheet to be rejected at the time. Ragged edges and crumpled sheets are not uncommon, especially if the forms are shipped or mailed to the processing location. It is unlikely that a paper handler that could cope with this kind of damage would be economically feasible. It is, however, reasonable to assume that the criteria that were employed in FOSDIC III for determining if a frame could be calibrated will not be sufficient in such cases and that more elaborate calibration schemes would have to be devised. For example, it might be feasible to measure the overall size of the document and compare it with evenly spaced intervals in two dimensions, as well as to examine for rips and tears through the use of a time-integrating circuit.

Another problem is posed by the dimensional instability of paper with time. Paper will absorb moisture and can shrink or expand as a result. This overall linear change in dimension (not to be confused with changes in the projected dimensions as occur in badly folded documents) can be allowed for as in FOSDIC III by providing a separate size calibration for each dimension based on special printed marks in the top and left margins of the form.

7. Static Electricity

A common problem when handling paper at higher speeds, especially in atmospheres of low humidity, is that of static electricity. This phenomenon manifests itself in stickiness of the paper. The paper tends to cling to rollers, fingers, or the bed of the machine. Although in a particular paper handler not very many sheets per second would need to be processed, the instantaneous velocity of the paper over the various members of the paper handler would be high enough to generate a static charge.

Various techniques are known for discharging the charges on the paper and on parts of the paper mover. These include using conducting rollers, providing a discharge path by means of thin metal fingers, and keeping radioactive materials such as polonium in close proximity to the paper on the feed to discharge it. Static electricity need not necessarily be a serious problem, but it should be kept in mind during the design of the paper handler.

8. Rejects

In case a document has been rejected by the scanner as unreadable, it is usually desirable from an operational standpoint to isolate the document. This can be done by providing an alternative bin for reject documents. An arrangement that is mechanically simpler, marks the document with an actuated stamp and later depends upon manual methods for extracting and reprocessing such rejects. The choice between these two approaches depends on the percentage of rejects expected and whether or not retrieving the original document will be the only way of correcting errors available.

Introduction

Assuming the task of moving the document into scanning position can be dealt with by a well-designed paper handler using well-known techniques, we can now turn our attention to the more basic and critical component, the scanner proper.

The task of translating visual images into electrical signals has been approached successfully many times since the mid-19th Century [3]. Photographs were sent by wire as early as 1881 [4]. Just after the turn of the Century, several ingenious attempts at improving the art resulted in experimental transmissions of photographs will quite respectable fidelity.

The earliest methods for transmission of half tones used a selenium cell sensor to which light was transmitted through a photographic negative. Mechanical pick-ups were later substituted for the tungsten light and the selenium cell, and the photographic negative was discarded in favor of alternative forms. Belins used a pointed stylus to track light and dark areas as hills and valleys on a raised surface representation of the photograph. In Charbonelle's device, differences in resistance were detected from a half-tone carbon black representation. In all these early schemes as well as in our contemporary facsimile devices, the photograph was clamped onto a cylindrical surface and scanned along a close helical path. Many minutes were required to transmit a picture in this way [5].

The growing interest in television stimulated several other inventions designed to transmit an image of a scene in its entirety within a time interval equal to the period of the persistence of human vision, which was taken to be roughly one-tenth of a second. It was soon realized that to approximate the great detail resolvable by the human retina and to transmit the resulting information in the required time interval necessitated sophisticated systems of wide bandwidth, high resolution, good stability, and inherently low signal-to-noise ratio [3].

In an effort to realize the equipment economy of serial scanning and still transmit the wealth of information in a scene, all-electronic pick-up systems were conceived which exploited the low inertia and small dimensions of a beam of electrons [6]. The past few decades have seen the successful development of several electronic pick-up tubes and systems applied to the practice of television [7].

The rapid rise of automatic data processing in the past 20 years, the vital interest in document storage and retrieval, and the need for automatic surveillance techniques have brought new emphasis to the art of processing graphic imagery.

General Requirements of the Document Scanner

The art of photography and its television offshoot create imagery destined ultimately to be viewed by an eye and interpreted by a brain. The advantages of communicating directly with a human, with all his reasoning ability and integrated past experience, permit the designer in these arts to take certain liberties with quality. The human can always relate what he sees to his prior experience, filling in omissions and otherwise correcting for imperfections in the image, as well as selecting only that information which is of interest to him at the moment. He may vary resolution at will, scanning a complete scene at a glance while recognizing the grosser features, yet easily able to bring all his reasoning power to bear on the minutest element of the picture if necessary.

Today's computing machines, on the other hand, although considerably faster and more precise than humans, have relatively primitive "reasoning powers", in spite of recent attempts to endow them with more powerful associative logic. Since information accepted into a computer is viewed literally, any deviation from a perfect image is likely to result in wrong decisions or confusion in the machine. This, then, is the basis for several important differences in quality requirements between television facsimile and computer input. To summarize a few general points of departure:

1. The rate of data transmission to a computing system (excluding real time operations, of course) has no critical minimum, whereas in television the persistence of human vision is the rate-determining factor. Although higher rates of input to the present generation of faster computers seem ever more and more desirable, this factor can generally be made secondary to the more important restrictions of resolution, stability, distortion and signal-to-noise ratio.

2. The constancy of resolution and the amount of geometrical distortion throughout the entire field of view are parameters which affect the quality of the image but are only of subjective importance in the psychology of the television viewer. The transmission of precise information into a data handling system, on the other hand, requires extremely close attention to both.

3. In order to minimize the storage requirements of the computing system, it may be desirable to endow the scanner with the facility for selecting only certain kinds and amounts of data and ignoring or omitting to scan the rest.

On some cases, the ability to change resolution on command from the computer can helpfully restrict the amount of detail at the input. It may be preferable to alter the sequence of bits scanned to avoid awkward editing requirements in the computer. An example might be a device for scanning a printed page in which the lines, characters, symbols, etc., may vary widely in size, shape and position. An optimum scanner for this purpose would be one in which the resolution and scanning pattern could be altered from place to place over the field depending on the particular line, character, or symbol being scanned. These requirements are in contrast to the common television or facsimile pattern case wherein adjacent bits of information are scanned in an unvarying sequence.

Some Representative Specifications

The applicability of television type pick-ups or any other imagery technique to original document scanning ought to be measurable against a set of specifications. These specifications must naturally reflect the peculiar requirements of computer input and should be employable as a means for comparing alternative possible approaches.

In the following paragraphs we will attempt to define some useful specifications. We will, then, examine briefly several alternative pick-up techniques, relating them where practical to these parameters.

To further systematize the relative appraisal of alternative approaches, we have subdivided the specifications into categories, grouping together those parameters which represent limitations in (1) accuracy, (2) precision, (3) overall system, and (4) operation.

1. Accuracy Limitations

The ultimate detail and fidelity obtainable from a scanner can be termed the accuracy of the device. The ability of the scanner to transmit an exact electrical equivalent of the image is limited by three main factors:

a. Resolution. The size of the basic scanning element limits the detail detectable. In the case of a moving aperture scanner, the basic element is approximately equal to the effective aperture size. Inasmuch as the video signal output from a serial scanner can be modified by time functions, for example, the aperture distortion compensation used in television camera circuits, the final resolution obtainable is not altogether dependent on the element size. For purposes of comparison, however, we can use the gridded line standard for television to evaluate the scanning device independent of following amplifiers, it being evident that the higher resolution pick-up will always yield the higher ultimate resolution with suitable compensation.

Resolution Response, as defined in the IRE Standard, is "the ratio of (1) the peak-to-peak signal amplitude, given by a test pattern consisting of alternate black and white bars of equal widths corresponding to a specified line number, to (2) the peak-to-peak signal amplitude, given by large area blacks and large area whites having the same luminance as the black and white bars in the test pattern".

Television Line Number is defined as "the ratio of the frame height to the width of each bar of a test pattern composed of alternate equal width black and white bars . . . ." [8].

Limiting Resolution, which is usually the maximum figure stated on data sheets, is generally taken at about 10% response.

If the scanner is so designed that the rate of motion of the aperture (or flying spot) is constant, then resolution can be increased by boosting the highs in the video amplifier. If, however, the sophistication of the scanner is such that the rate of motion is variable, it may be necessary to consider the resolution response only at the 100% point.

Since the effective aperture size, and consequently the resolving power, of a pick-up may not be constant throughout the extent of the document area, and in some devices may vary as a function of the lights and darks present in the image, it does not follow that the highest score on the maximum obtainable resolution test will reveal the best device for extracting fine detail in a practical system. These inconstancies in resolution as a function of position in the document image and of image content are considered under Image Defects. The change in resolving power with time is treated under Instability.

b. Image Defects. An image defect here connotes any variation or non-linearity of the various parameters as functions of the geometrical location of the scanning aperture or its equivalent with respect to the field of view. Thus, the term might be applied to the nonlinearity of the deflection characteristic of an electron beam scanning device; it can be applied to changes in effective aperture size with position in the field; it applies also to the sensitivity or light transfer characteristics if they are not constant over the field; it may describe defects in the geometrical optics associated with the scanner.

Image Defects may be further subclassified:

(1) There is a regular form of distortion describable by continuous low order equations, extending over the entire field and symmetrical about its midpoint. Certain aberration defects are of this class and can be minimized by compensating lenses, or by operating on a scanning beam with magnetic or electrical fields which are functions of the position of the beam in the scanning area.

(2) "Irregular distortion" describes defects assymmetrically positioned relative to the midpoint of the field or occurring in isolated places. Such kinds of distortion are generally more difficult to correct and can be thought of as a kind of position-dependent noise.

(3) There is a distortion present in low velocity beam-scanning pick-ups, the amount of which is dependent on the distribution of light in the image being scanned. Since this is somewhat time-dependent as successive images are processed, it is covered later under the paragraph on Instability, but is mentioned here since it is fairly constant during the time of processing any particular document. This type of distortion can be called "highlight distortion".

c. Light Transfer Characteristic. The shape of the light transfer characteristic will determine at once both the extent of the dynamic range and the least difference in light level which is detectable by the pick-up.

2. Precision Limitations

Two main factors reduce the probability that at any given instant, a pick-up will be performing to its greatest accuracy. These are noise and instability.

a. Signal-to-Noise. The electrical energy output from a pick-up device as a function of the incident radiation is invariably accompanied by noise. This noise arises from (1) statistical randomness of the incident radiation due to the granularity of light, (2) thermal emission from photo-cathodes, (3) shot effects, (4) resistor noises, and (5) amplifier noise [9].

The first source of noise is present in all pick-up devices since it is characteristic of the fundamental nature of light. Its importance, however, decreases with higher levels of illumination, and it is of interest only when considering the limiting sensitivity of a pick-up.

The other sources of noise are byproducts of the particular imaging system used and depend on the operating temperature, emission current, bandwidth, and the like.

The signal-to-noise characteristic of a pick-up is generally a more important parameter than sensitivity. What is needed for comparison purposes therefore, is a figure of merit which can express the overall excellence of the pick-up device when used in a practical system. Jones has suggested that a quantity he calls "detectivity" is a more useful figure of merit for detecting devices than sensitivity or responsivity, because it includes the bandwidth. He defines detectivity as $d = \frac{s}{np}$ where s is the signal out and p is the radiation power input in watts and n is the noise RMS fluctuation of the output in terms of output RMS volts or amps. Since n is expressed at a particular bandwidth, d will be also [11].

Regardless of the choice of parameters, once having deduced from the manufacturer's specifications the inherent signal-to-noise capability of a pick-up, it will be necessary to include other sources of noise in order to predict an overall signal-to-noise ratio for the scanner. That is, operating temperature, wave length of incident radiation, speed of response, modulating frequency and bandwidth of the noise must all be presupposed and any specifications available must be normalized to the assumed values before comparison is made.

b. Non-uniformity. A sixth kind of noise is dependent solely upon engineering design and manufacturing skill and cannot be predicted from theoretical considerations. It manifests itself as a variation in signal from point to point over the scanning field even when scanning a uniformly illuminated subject. This kind of noise arises from non-uniformity in consistency or thickness of photocathodes or targets in electronic scanning tubes, differences in hole sizes and/or spacings in NIPKOW scanning discs and the like.

Although oriented spatially over the field, the effect of this non-uniformity cannot be predicted because of the misregistration possible for each document with respect to the scanning field.

Unfortunately, quantitative data for this factor is never supplied by a manufacturer of components and must be surmised from photographs of the results of scanning a test pattern, in which case it may be indistinguishable from other forms of noise. It remains for the designer to subject sample pickups to tests in order to measure the non-uniformity of response and then attempt to compensate by optical filters, signal voltage compensation, etc. Of course, any degree of compensation achieved this way will apply only to a single component. The compensation pattern would have to be altered for each replacement used.

This factor becomes more critical with higher resolution and/or sensitivity.

c. Instability. Instability reflects the comparative constancy of parameters with time. It can apply to resolution, aperture registration, sensitivity, and so on. A further subdivision can separate types of instability into (1) long-term drift, (2) long-term deterioration (unidirectional long-term drift), (3) short-term drift, and (4) warmup (initial drift at turn-on).

The last type might be classed as an operating limitation since it is presumed to be unimportant after the first m minutes, but if m is a significant percentage of the total operating cycle, it will have to be regarded as a continuous performance limitation.

There seems to be a marked tendency to overlook the importance of instability at the outset of an engineering design phase. Since instability often connotes unreliability and since representative operating conditions under which to measure and report it are not obvious, many manufacturers do not mention instability, let alone supply curves with their data sheets. The equipment designer must then secure sample components and subject them to his own stability tests. He must naturally simulate or extrapolate through all possible operating conditions, including prolonged life testing. After this extensive and expensive process, he must then assume the risk that the components which he has tested may not be representative of the manufacturer's output and that his curves will not apply to other samples.

Sadashige has recently published useful stability data pertinent to television pick-up tubes. He includes curves showing the effective drift on aperture response for the image orthicon [10].

3. Overall Systems Limitations

a. Methods of Scanning. Let us here consider two classes of systems employing scanners. In the first class, which we can call Class 1 systems, the scanning aperture (or apertures) is positioned over every element of the information area, adjacent areas being examined in sequence according to a preset unvarying pattern (from document to document or scene to scene). Radar, television, facsimile, mark sense machines, and most of the present-day character readers are all members of Class 1.

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Class 2 systems, conversely, are those in which decisions as to whether or not to scan a particular elemental area of the document and/or decisions as to the manner in which an area is to be scanned can be made and re-made during the scan interval for the document. A programmed control unit or a computer communicates with the scanner proper in real time, causing the scanner to skip over unwanted information, omit detail, etc. Class 1 systems can, in effect, be considered as special cases of Class 2 systems.

It is beyond the scope of this report to discuss the relative merits of either system. Suffice to say that each has utility in certain applications. Since this report assumes that many different applications for an original document scanner will be feasible, we must keep in mind the distinctions between these two systems and we will refer to them often, especially in this subsection.

b. Adaptability. The term adaptability refers to the inherent capacity for programmability possessed in greater or lesser degree by a pick-up device. This is obviously a critical characteristic in a Class 2 system and of less importance in Class 1. Even in a Class 1 system, however, problems of mechanical misregistration of the document, paper shrinkage, and the like may make it important that the scanner possess a high degree of adjustability in order to be self-calibrating or self-normalizing. Hence, one should include the adaptability factor when rating various pick-up devices comparatively.

c. Maximum Attainable Bit Rate Bandwidth. A commendable design for any document scanner is one in which the data handling rate is limited only by the speed of paper handling. Unfortunately, to achieve this goal on large documents with the present state of the art would require complicated and expensive equipment. For this report, let it be assumed that the scan time will limit the information handling rate and that this condition can be tolerated by the system.

The maximum scan rate will be limited by several factors: (1) response of the pick-up to changes in light level, (2) characteristics of the aperture positioning control, (3) amplifier delays, and (4) maximum permissible bandwidth as set by allowable signal-to-noise ratio.

Any pick-up can be thought of as a transducer, converting radiant energy to electrical energy. As such, it can be described by a transfer-function, derived from an equivalent circuit consisting of an impedance containing both real and complex parts. In general, these terms will not be linear and may not be stable with time.

If the pick-up operates with a flying aperture (or the equivalent in the case of a flying spot system), then a separate transfer-function and equivalent circuit can be used to describe the response of the aperture position to changes at the deflection amplifier input. The two equivalent circuits may possibly share a mutual impedance term.

In practice, both transfer-functions can be determined by transient analysis of the response to step functions. Armed with transfer-functions, amplifier compensation and damping can be added and the response time calculated. Thus, pick-ups with their amplifiers can be considered as open loop servo mechanisms with almost linear characteristics.

If the scanner includes a feedback loop and is self-adjusting or self-calibrating, or is used to track a line or register on a point, then it may be treated as a closed loop servo and further analyzed with Nyquist plots, etc.

Factor (4) above refers to the dependence of noise in the system on bandwidth. The bandwidth should be set wide enough to pass the highest and lowest frequencies encountered in extracting information, but no wider, in order to limit noise. The highest frequency encountered will depend on the speed of response to changes in light level, the abruptness of changes in light level in the formation as a function of position (detail), the scanning rate, and the resolution of the pick-up. The lowest frequency will depend on the scanning rate and the widest dark or light area that must be detected without appreciable droop in the output.

For fast response high resolution pick-ups, the bandwidth may have to be reduced to obtain a satisfactory signal-to-noise ratio; then in order to preserve detail, the scanning rate will have to be reduced. Consequently, the information handling rate will be reduced. Fortunately, as mentioned earlier, this is usually a noncritical systems parameter.

d. Capacity. The capacity of the scanner is taken to be the maximum number of information bits that can be extracted from a document side. It is dependent on the size of the field and on the resolution. Distortion must be considered over the entire field, the highest information density possible usually occurring in the center of the field where resolution is greatest. In the practical case, capacity will be considerably reduced by geometric distortion and instability.

e. Special Systems Considerations. In some applications, special characteristics may be particularly important. For example, the storage capability of some pickups may be invaluable in situations where the illumination time must be limited. For example, it may not be practical to stop the document at a discrete reading position. In this instance, a high-intensity strobe lamp can be flashed while the document is in transit. The brief but bright instantaneous image can be impressed on a pick-up exhibiting long time storage properties and the information scanned from the target by an electron beam. The erasability and recovery characteristics of the pick-up then become of critical interest since it is essential that all stored information be removed before the arrival of the next document at the strobe station. This may be a particular problem in a Class 2 system where only a portion of the stored image may be scanned by the electron beam.

Provisions for erasing the unscanned portions must then be incorporated.

4. Operational Limitations

Just as an author must always keep his readers in mind, so a designer must keep his users in mind. If a scanner is to be used anywhere but in a laboratory, it should be designed to minimize operational problems. Some general operational problems are (1) ease of maintenance, (2) ease of operation, (3) frequency and ease of adjustment, (4) frequency, ease and cost of replacement of parts, and (5) first costs. These are obvious and well-known, and need not in general be belabored here. Item (2) however, merits further remarks.

Consider the case of a Class 2 system in which the scanner is controlled by an external program. Since the format of the scan of such a system is a function of the program used, debugging the program may take considerable operating time unless a means, preferably visual, is provided which can be used to quickly verify the action of the program on the scanner. Such a means can be called a "viewer". Certainly a Class 2 scanning system ought to contain a viewer. The ease with which one can be provided can be used as another basis for comparison amongst choices for the scanner components.

Mechanical Scanning

By a mechanical scanner, we mean any scheme for optically sensing information that does not employ a deflected electron beam as an integral part. Mechanical scanners are somewhat simpler than their electronic counterparts, are significantly more stable, can achieve the same or better resolving power, and usually exhibit fewer image defects. In Class I systems, mechanical scanners are capable of slewing rates only an order of magnitude slower than the fastest electronic means.

In Class 2 systems, however, the need for adaptability places all mechanical means at a disadvantage. The relatively large inertia members cannot be deflected or diverted rapidly, and the overall processing efficiency drops to a fraction of that possible using electronics. Resolution cannot be altered as simply or as rapidly as in electronic systems.

We shall now consider briefly several mechanical schemes which have been used in Class I systems in the past and others which have recently been suggested using fiber optics:

1. Full Set of Photocells or Parallel Scan

The most rapid scheme for scanning a complete field of information is to sense the entire field simultaneously and then to carry out the logic necessary to extract the information in parallel. The time required to scan a complete field using such a technique is equal to the time required to scan any element. Such parallel schemes have recently been employed in several character recognition systems. In these schemes, all elements of the character-image field are sensed simultaneously with a multiplicity of photocells and the results are simultaneously compared with appropriate masks (to determine the best matched character). In scanning a large field such as would be presented to a full-page document scanner, a proportionately greater number of elements will be scanned and many more photocells would be required. In fact, we can expect several thousand bit positions to be available in the case of "mark sensing" of the whole area on one side of the document. If in addition certain fields were marked by handwritten or printed characters, the number of elements would have to be increased accordingly.

To offset the benefit of virtually instantaneous sensing, at least two disadvantages must be noted: A large number of parallel paths and redundant components must necessarily be utilized, and registration of information on the document with respect to the sensors is critical.

Since time will be consumed in moving paper and in recording the information onto the output medium, the advantage of instantaneous sensing becomes somewhat dubious. Consequently, this technique is not recommended for the original document scanner.

2. Full Set of Fiber Optics -- Serial Scan

By employing fiber optics, it is possible to construct a scanning system which uses light efficiently yet has the simplicity of a serial scan. Since the minimum element diameter for the "mark sensing" application is about a tenth of an inch and for character recognition perhaps one-twentieth of this, a set of 0.005" diameter fibers dispersed over the fields in those areas in which information is to be found, excluding the non-significant areas such as printing and margins, could be brought together into a tight bundle which can be scanned using a Nipkow disk. Such an arrangement is described in a patent recently assigned to Gulton Industries, Inc. [12].

The advantage of this configuration is simplicity. The cost of such a set of fiber optics would exceed the cost of a pick-up tube at the present time, but since the fibers are not expendable elements there should not be the need for future replacement. The chief disadvantage of such an arrangement is the lack of versatility which is inherent in all serial periodic scanning schemes.

3. Line of Photocells -- Serial/Parallel Scan

A single set of photocells arranged in a line transverse to the direction of paper travel has been used in a "mark sensing" machine constructed by IBM. In this arrangement the number of cells in the line equals the number of elements to be scanned in one line. The paper moves at constant speed past the row of cells which are periodically sampled for their output.

For the "mark sense" application, the simple line of photocells implies the desired simplicity. However, the requirement of handling the paper during scanning complicates the mechanism. Accurate registration becomes difficult when the paper is in motion. As an alternative, it is possible to arrange the photocells on a movable arm which sweeps across the document, but this cannot substantially reduce the complexity of the device.

Because the output of the line of photocells is a simple bit representation of information across the line, it is necessary to rearrange the information into the desired logical arrangement in a buffer store following the scanner. The large size of the documents would presumably require an unwieldy and expensive buffer.

4. Single Line of Fibers -- Serial Scan

If the aforementioned scheme of a line of photocells is replaced by a line of light fibers and then the termini of these fibers are scanned with a Nipkow disk, the result is a serial scan of each line from left to right and a line-by-line scan of the document. This arrangement eliminates several photocells and amplifiers, requiring only one fiber for each element in a line to be scanned. It suffers from the same disadvantages of having to move paper past the row of fibers. It has an advantage of an absolute minimum of hardware.

5. Disk Scanning

Since the invention of the Nipkow disk in 1884, many scanning arrangements have been developed utilizing a rotating disk perforated with one or more holes. These holes are arranged around the circumference of the disk in such a manner as to permit successive sweeps of the optical path over the image to be scanned.

The Nipkow disk and its many variations are capable of extremely high-speed scanning when used in conjunction with high-speed photo-multipliers. In order to realize such high speed, however, it is necessary to construct a disk and scanning assembly capable of high-speed rotation. This requires a well-balanced assembly spinning on heavy-duty ball-bearings.

Electronic Scanners

Electronic scanners all employ a beam of electrons moving through a vacuum onto a target or a flourescent screen. As was stated earlier, all present day electronic scanners are outgrowths of devices originally designed for television pick-ups. Insofar as the quality requirements for television are somewhat more liberal than those for computer input, none of the present pick-ups is an optimum component for a data-processing scanner element. An excellent general reference on these and other components is "Television" by Zyworkin and Morton [13].

1. Image Dissector

The image dissector pick-up tube consists of a photo-emissive surface, an electron deflecting means, and an aperture. A light image focussed onto the photo-emissive surface forms an electron image of the scene which is then moved and re-focussed at a scanning aperture located at the rear of the tube. Deflection means moves the image past the aperture. Electrons are permitted to pass through the aperture, usually onto an electron multiplier which amplifies the current.

Let us briefly examine the dissector in the light of the specifications proposed in the preceding paragraphs.

a. Resolution. The resolution of the dissector depends upon the useful area of the photo-cathode and also on the size of the scanning aperture. Typical dimensions are 2 3/4" maximum diameter for the photo-cathode and 0.005" diameter for the scanning aperture (type FW 146). Note that in order to view a 15-inch document, a magnification ratio of approximately 7 to 1 would have to be employed and in order to resolve a 5 mil line on the document, the effective scanning aperture would have to be reduced to about 0.0007" in diameter. The actual dimensions of the aperture are dependent on the electronic magnification ratio within the tube.

b. Distortion. Distortion here is primarily in resolution and lens aberration. Both irregular and regular distortion is present. Contributing factors are spread of the electron image in transit to the aperture, and defects in the focussing field produced by the electron optics. Little representative data are available on distortion.

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c. Light Transfer Characteristic. The output current increases linearly with light intensity. At high values of multiplier output current, there is voltage saturation of the secondary emission current in the final stages of the electron multiplier.

d. Signal-to-Noise Ratio. Since the active photosensitive surface in the dissector is an electron emitter, noise varies as the square root of the current produced by the incident light. For the dissector with a multiplier, the signal-to-noise ratio can be calculated as follows:

$$\frac{\text{Peak current}}{\text{RMS noise current}} = \left[SLA \frac{(D - 1)}{2Dm^2 e \, \Delta f} \right]^{1/2} \qquad [23]$$

where

S = photosensitivity of photo surfaces in amperes per lumen;

L = light intensity in foot candles measured at the photocathode;

a = aperture area in square feet;

m = linear magnification of the image within the tube;

D = the secondary emission ratio of the first multiplier dynode;

e = the electron charge and

Δf = the bandwidth in cycles per second.

The scene illumination necessary to produce L is

$$I_S = \frac{4f^2 L}{TR}$$

where

I_S = scene illumination in foot candles;

f = the effective aperture of the lens;

T = the transmission factor of the lens;

R = highlight reflectance and

L = illumination on the photocathode.

Note that the signal-to-noise ratio depends on aperture size, so attempts to increase resolution by lowering aperture size require increased illumination to achieve equal signal-to-noise ratio.

e. Non-uniformity. Some non-uniformity in the characteristics of the photo-emissive surface in an image dissector is to be expected. Whether this is significant would depend primarily on the resolution required.

During a very early attempt to utilize the image dissector as a document scanner (53), consideration was given to creating an optical mask (using the dissector itself as a means of generating it) whose point-to-point light transmission characteristics were complementary to the sensitivity of the photo-cathode in the dissector. The mask would be placed directly in front of the dissector thus hopefully normalizing the sensitivity over the cathode area.

Several problems were anticipated with this technique. First, the slightest misregistration of the mask relative to the tube could enhance the non-uniform response instead of minimize it. Also, the mask would reduce the light reaching the tube requiring additional illumination of the document. Finally, the generation of the mask would have to be very carefully carried out so that no other noise or power supply variations could be recorded on it. To the author's knowledge, no use of such a mask has ever been successful. Because the image dissector is a nonstorage type of pick-up, it is the least sensitive of all existing TV pick-up tubes.

f. Instability. Little data are available on the stability of these tubes, but as in photomultipliers there are fatigue effects on the photo-cathode. Ambient temperature can affect focus by altering the size and shape of deflection and focussing coils. Care must be exercised in order to stabilize the high voltages used in focussing. One manufacturer suggests that the tube envelope temperature be maintained below 35°C. to avoid cesium migration which contributes to the long-term deterioration of the photo-cathode.

g. Data Handling Rate-Bandwidth. The speed of operation of the dissector is limited primarily by noise considerations.

h. Capacity. The capacity is limited as in most other cases by the resolution. The bit capacity will be approximately equal to the useful photo-cathode area divided by the aperture area.

i. Adaptability. Since the aperture size is mechanically fixed, changes in resolution can only take place by a change in magnification ratio between document size and photo-cathode image size. In this respect, the dissector is inferior to beam scanning tubes in which the effective aperture size can be changed electrically or magnetically. Abrupt deflection changes should pose no problem. Relatively little power is required to control the small currents involved, and controlling deflection from a digital programmer should present few obstacles.

j. Operational Limitations. Being one of the simpler pick-up tubes, the dissector requires relatively little control and adjustment. It is extremely long-lived, having no filament, although cesium migration in the cathode tends to reduce overall image quality in time. The first cost is between $1,500 and $2,000, depending on the configuration.

k. Viewing. Class 1 systems using an image dissector can be viewed by a kinescope monitor. Class 2 systems can also employ a kinescope. A small scanning raster superimposed on the rest position of the deflection currents will permit a look at the neighborhood around the point in interest. The image can be blown up on the kinescope screen, and the extent of the area viewed can be changed by changing the dimensions of the viewing raster.

l. Summary. The image dissector is a possibility for a document scanning input. For a large document containing a large number of information bits, the resolution, signal-to-noise, insensitivity, distortion, and instability would present a number of difficulties that would make the design of the scanner a formidable task. Used in a hybrid electronic-mechanical optical scanner as suggested below, however, the resolution requirements of the pick-up might be considerably eased and the illumination raised to a high value. In such a case, the image dissector may well be favorably considered for some of its advantages of simplicity and long life.

2. Iconoscope and Image Iconoscope

The iconoscope consists of a photo-emissive mosaic and a high-velocity scanning beam. Incident light frees electrons from the sensitized surface of the mosaic and the scanning beam neutralizes the resulting charge pattern. The changes in charge during the scanning are sensed in the capacity of the mosaic, the unsensitized side of which is a plate, known as the signal plate, which is connected to a video amplifier. Since charge integrates on the target as light impinges on it, this tube is many times more sensitive than the image dissector.

The image iconoscope is a more sensitive version in which the freed electrons are drawn to a target, there to liberate additional secondary electrons. The scanning beam deposits the neutralizing charge onto the second target.

Zyworkin and Morton have analyzed the iconoscope in great detail and have revealed considerable information that could be used to infer its applicability to document scanning [13].

The use of a high-velocity scanning beam, however, yields a characteristic so objectionable as to be practically insurmountable in a data processing system. This is its gross instability (as we have defined it here). Briefly, the high-velocity beam striking the mosaic or target liberates a shower of secondary electrons some of which fall back onto the target giving rise to a spurious redistribution of charge known as "shading".

The effect of this in a television system is to produce patterns of shadows in the picture, the distribution of which is dependent on the distribution of highlights in the original scene. Shading can be corrected by an operator in a TV studio, using manual controls. Here the effect on document scanning would be to reduce contrast in areas on the document in a way that would be most objectionable and which would result in effectively low signal-to-noise ratio.

Other factors represent additional difficulties, but spurious shading would appear to rule out the use of this tube on the basis of this factor alone.

3. Orthicon and Image Orthicon

The orthicon is a low-velocity scanning tube of the light storage type utilizing a two-sided target. The image orthicon is a sensitive version employing an image section before the target. Because of the widespread usage afforded the image orthicon, the literature contains many exhaustive analyses of this tube as applied over the years to television and more recently to infrared surveillance systems and astronomy. Until recently (1960) image orthicons were invariably made with glass targets.

Several objectionable characteristics of the tube could be traced to the use of glass. "Stickiness", for example, is the term applied to a tendency of the target to "remember" a scene which had been impressed on it for an extended period. Ion conduction in the glass which results in depletion of carriers is thought to be the cause. Another problem was that of "burn-in" which referred to the deterioration of the target due to prolonged bombardment by electrons on an illuminated area.

A semiconductor target made of magnesium oxide has appeared in some new tubes [26]. Since its operation depends on electron conduction, both of the effects described above are eliminated. The new target has higher resistivity in the lateral dimension, thus reducing leakage. This allows the charge to remain on the target for a longer time before leaking off, which in turn has the effect of increasing sensitivity and resolution, but which aggravates the problem of utilizing the tube in Class 2 systems.

a. Resolution. DeVore rigorously analyzed the limiting resolution in image orthicons in 1948 [15]. He found that resolution depended on (1) the wave length of the incident light, (2) the light level, (3) the particular construction of the target (resistivity, thickness, etc.), (4) defocussing due to angle of incidence of the scanning beam, (5) the stored charge pattern, (6) the mesh of the target screen, and (7) the modulating frequency. A curve of amplitude response versus line number for the GL5820 (at 35°C.) shows 100% modulation out to 140 lines, the 50% point at 400 lines and the 10% point at 700. A limiting resolution of 700 lines would be just about enough to resolve a printed numeral on a 10-inch high document field. Aperture compensation in the form of augmented highs would be required to approach this resolution.

b. Image Defects. The electron optics used in the image orthicon are complicated. Both electrostatic and magnetic focussing are used. Magnetic cross-talk from the deflection circuits into the image section can reduce resolution unless the deflection circuits and the scanning beam are kept inactive during illumination of the document. The image section can be shielded to limit this cross-talk.

The problems of electron focussing yield distortion in both resolution and registration of the effective scanning aperture, the electron beam, in this case [14]. Another problem arises because of changes in the beam diameter due to changes in the charge pattern on the target. The low-velocity beam is also subject to effects of stray external fields. The addition of a field mesh in front of the target has reduced distortion considerably in newer tubes.

c. Dynode Noise. In the image orthicon a kind of "noise" is present in the video signal which is attributable to non-uniformity in the surface of the first dynode. The beam returning from the target is directed onto the first dynode in a small (approximately 1/4 of an inch) version of the scanning raster. Any nonuniformity in spots on the dynode changes the amount of secondary emission liberated and, consequently, the total video output current. Because of the periodic regularity of the scan, this nonuniformity shows up as apparent variations in sensitivity with time and hence is thought of as a signal noise component. This problem is minimized by careful attention to surfacing of the first dynode. No mention of it is made in the data sheets supplied by the manufacturers.

d. Light Transfer Characteristics. The light transfer characteristic is linear or nearly so up to the point of saturation which comes about when the target potential reaches the target screen potential. The range is large, better than 100 to 1 in most tubes.

e. Signal to Noise. The image orthicon is the most sensitive of the current TV tubes. It is available with either wide spaced or narrow spaced targets. Wide spaced targets yield better signal-to-noise ratios at low light levels. The narrow spaced targets on the other hand yield better signal-to-noise ratios at high light levels. For a document scanner, the light level can be controlled to yield a satisfactory signal-to-noise ratio at a comfortable operating light level.

f. Instability. As with other deflected electron beam tubes, there are changes in deflection sensitivity with temperature. In addition, the image orthicon shows other more insidious effects of time and temperature. For example, the manufacturers recommend a warm-up time of at least an hour before use in a camera. They also mention the likelihood of after-image effects during the break-in period of new tubes. The GL 5820 shows a decrease of 5% in response to a pattern of 300 lines over a temperature range from 30 to 45°C.

The lateral leakage of charge that takes place on a target means that the signal derivable from each point will depend not only on the integrated effect of the radiant energy impinging on the point but also on the elapsed time since the last visitation by the scanning beam.

Consider a document moving into scanning position and illuminated for a time T. If the target is assumed uncharged at the outset of the scanning period, then electrons striking it from the image section will cause a charge pattern to build up roughly proportional to T times the highlight illumination striking the photo-cathode. If scanning commences after T, then because of lateral leakage the latest visited elements would retain the least charge. If illumination is present during scanning, the charge continues to build up and the net charge at any element by the time the beam strikes it will be the difference between the accumulation and the leakage.

Note that although a compensating signal could be applied to the video output to make up for the apparent decrease in sensitivity due to lateral leakage, the apparent change in resolution would still show up. The new semiconductor targets are to be preferred for the reason that they minimize lateral leakage.

g. Flare. Under certain operating conditions, secondary electrons emitted from a bombarded element will fall back onto the target close by. This results when elements which are highly charged due to high incident radiation emit secondaries which are not attracted to the mesh provided for their collection. This corresponds to the spurious shading in the iconoscope and can be minimized only by very careful setting of the operating points.

Since the image orthicon operates with very small voltage differences between elements, it is highly subject to external interference and must be well shielded. Voltages must be distributed from carefully regulated power supplies.

h. Information Handling Rate-Bandwidth. The image orthicon is capable of high bit rates if used as a document scanner. The time required to discharge an elemental area can be measured in microseconds. The overall information handling rate, especially in Class 2 systems, would be modified by the requirement for completely discharging the target between exposure to documents. (See discussion of Adaptability.)

i. Capacity. Assuming that sufficient compensation is used and that at least 500 TV line resolution is attainable over the entire field, if each information bit is estimated to be 15 mils square, then an active area 10 inches by 7 1/2 inches could be processed.

j. Adaptability. The storage capability of the image orthicons especially of the newer tubes, adapts them to applications in which the document must be strobed with light while moving. The target can be scanned during the time between documents, but care must be exercised to discharge the entire target before the next strobe time. This can only be done by flooding the target or by successive sweeps of the whole field by the scanning beam. Portions of the document can be selected by deflecting and gating the beam on and off at will.

k. Operational Limitations. The relatively short life resulting from "sticking" and "burn-in" has been considerably lengthened with the newer tubes. Serious problems would still be encountered in a data processing application because of the complex adjustment procedures required to select operating points. Warm-up would probably be an hour-long ritual requiring the constant attention of a trained technician. Replacement costs are approximately $2,000 per tube. Viewing would have to take the form suggested earlier for the image dissector.

1. Summary. The image orthicon could conceivably find utility in systems in which the document must be strobed while moving. Its extreme sensitivity and excellent signal-to-noise characteristic would simplify the illumination requirements. However, distortion would make it difficult to approach the limiting resolution, and operational problems would make for an unwieldy device. A system using a static reading station would better be served by an image dissector although the illumination level would have to be thousands of times higher.

4. Vidicon

The vidicon made its appearance in television practice about 1950. It is distinguished from other light-storage camera tubes by its simplicity, relative stability, ease of adjustment, and much lower cost.

a. Resolution. The vidicon uses a photoconductive target. This surface has been recently improved to the point where the output is reasonably uniform over the entire surface [10]. In addition to the surface uniformity of output, the particle size and the minimum beam diameter set the maximum resolution of which the tube is capable. Some attempts have been made to improve resolution, notably by increasing the target voltage and the deflection currents in an attempt to make a beam of sharper focus. This has been successful at least in one published instance in which the maximum resolution claimed was 1,000 TV lines [17].

Changing beam current changes the effective aperture of the beam and consequently the resolution. Also, the effective beam aperture changes with the magnitude of potential relief on the surface, which means that the resolution will change as the beam moves over the pattern depending on the charge pattern stored [18].

b. Image Defects. The vidicon depends on a cathode ray beam to discharge its target during scanning. If the cathode ray beam is not perpendicular to the surface at the time of its striking, the discharge may be incomplete. This inability to discharge the surface of the target evenly is known as beam landing error [19]. In television practice this is accommodated by coupling into the cathode a beam modulating signal which is a function of the scanning period.

The television scan is a periodic pattern, but if we consider the use of the vidicon as an asynchronous digitally programmed scan (in a Class 2 system), it might be necessary to generate such a beam modulation signal from a digital source. This does not appear difficult since the digital source would be available for deflection regardless, but the modulation voltage must be made a trigonometric function of the deflection angle rather than a linear function of the deflection voltages.

As with any electron optical system, the vidicon is subject to the usual lens distortions and can be corrected in a similar manner either by compensated deflection voltages or by external magnets [21].

c. Instability. The original vidicons were notorious for their response to slight mechanical vibrations. Newer developments have eliminated this, notably in the RCA vidicons developed for the Tiros weather satellites.

One of the prime disadvantages of a vidicon is its inherent time lag which has been analyzed by several investigators in the field. In a recent paper the authors attempt to divide the lag in the vidicon into two separate components [20]: (1) The commutational, i.e., incomplete recharging, and (2) the relaxation effect in the target material, including establishing equilibrium between excitation and recombination. Another way of summarizing lag is that when the image is impressed on a formerly dark photoconductive surface there is a finite time required to bring the photoconductive layer back to its unexcited state. This comes about because of combination and recombination of carriers in the surface [22]. The time lag increases with decreasing light and at low levels has been measured in hundreds of seconds.

With the vidicon, as with other television pick-ups, there are adjustment problems which arise because the parameters of electrode voltages are interrelated [23]. With the vidicon the target voltage affects the dark current, and the dark current varies approximately as the third power of the signal electrode voltage. The focus voltage also affects the dark current and unless the focus voltage is modulated as a function of deflection voltage, there will be a slight variation in focus from one portion of the scan to another. The dark current is also a function of ambient temperature and time.

d. Noise. Because of the non-uniformity of the photoconductive surface, a residual noise is generated as the scanning beam traverses the surface. The signal-to-noise ratio is generally set at 100 to 1.

e. Systems Considerations. National Data Processing Company of Dallas, Texas, has constructed an optical character reader using a vidicon. In this application, light is flashed onto a document for only 10 microseconds. This is sufficient time to charge the photoconductive surface to a point where it can be scanned during the next 90 milliseconds. In a paper on "An Optical Character Recognition System Using a Vidicon Scanner" presented at the Symposium on Optical

Character Recognition in 1962 [49], it was stated that the vidicon face used can store the image for a few hundred milliseconds. There is no mention of the particular vidicon tube used in this system.

A contrast circuit is used to normalize the signal with respect to a background. This presumably will make the gradual decay of the target image less perceptible to the character reading system. Three sweeps are used after each exposure, each sweep traversing the entire face of the tube. Since the field in the original document scanner is many times larger and the scanning times involved are much longer, the NDP system is not indicative of all the problems which can be present in utilizing a vidicon scanner.

Use of the vidicon in a digital mode would be made more difficult by the lag characteristics because the aperiodic characteristic of digital scanning would result in an indeterminate time between the start of scan and its end, resulting in what would be serious changes in signal. This might be normalized, as many instances of nonuniformity can, by a comparison of the signal point with the background area or by superimposing a long-time beam current variation which complements the lag. Viewing in a vidicon system would be approached as in an orthicon system.

f. Summary. The vidicon could find application in a scanner similar to the one built by NDP. Here the storage characteristic is used to allow the paper handler to move the document while scanning. The long time inertial lag, however, could severely limit the operating rate beyond the savings apparently introduced by not stopping the document. Multiplexing two or more vidicons in a hybrid system as suggested in the next section could speed things up, but is obviously more complicated and expensive.

5. Miscellaneous Scanning Tubes

a. Isocon. To rectify the undesirable characteristics of the image orthicon (in television, at least) whereby the relative noise increases with decreasing light level, a tube was constructed in which the scattered electrons in the return beam were collected rather than the main beam [24]. Because an illuminated element in the target would be charged positively, the beam incident on a light element is somewhat defocussed, and the return beam, although smaller than from a dark element, will contain more scattered electrons. Thus, in the isocon the current entering the multiplier increases with increasing light and the noise also increases.

In all other respects, however, the tube, which has never been built for the general television camera market, seems to be inferior to an image orthicon and shows no promise of correcting the objectionable adjustments and instability characteristics that make the image orthicon unattractive for document scanner use.

b. Ebicon. This is a tube consisting of an electron imaging front end and a target which is made selectively conductive by bombarding electrons from the imaging section instead of by direct light [25]. The target is then scanned by a low-velocity electron beam and the video signal derived by a process exactly similar to that in the vidicon. The result is a somewhat more sensitive pick-up, but one in which most other characteristics are inferior to the vidicon for document scanner applications. For example, resolution is somewhat lower because of electron scattering in the image section, and inertial lag using current target materials is somewhat longer.

6. Cathode-Ray Tube Flying-Spot

One of the earliest television scanners was the cathode-ray tube flying-spot. In this well-known arrangement, a point of light from an electron beam formed on the face of a cathode-ray tube is deflected over a scene. The reflected light is gathered by a sensitive photomultiplier whose output current constitutes the video signal. See Figure 2.

Although present-day CRT flying-spot systems are invariably used as film pick-ups, in which transmitted light is received by the phototube (as in the FOSDIC machines), several configurations have been demonstrated that prove the practicality of a reflective scheme. One of the latest of these was perfected as an inexpensive camera for color television [27]. This is the "Vitascan" system by the A. B. Dumont Co., which is similar to a somewhat smaller arrangement publicized several years earlier [28]. Here several photomultipliers are arranged around the scene and connected in parallel. All stray light is eliminated from the scene except for brilliant bursts from a bank of xenon lamps during the vertical retrace time which constitute the general room illumination. Although the resolution obtained in the "Vitascan" is considerably lower than what would be necessary in a document scanner, it is worth citing as a working system using limited light and multiple pick-ups.

Let us now consider the flying-spot scanner as a possible document scanner:

a. Resolution. Resolution has been improved recently by the use of transparent phosphors. Tubes have been constructed producing spot sizes of 0.0005 inch. In order to achieve such resolution, the beam current must be extremely low, resulting in very low power levels which severely limit the light available at the screen.

b. Image Defects. The usual aberration defects associated with electron optics are present in the cathode-ray tube. Since there is no charge stored on the face of the tube, "highlight distortion", such as is present in the image orthicon and to a lesser extent in the vidicon, is not present in the CRT. The beam can be deflected or

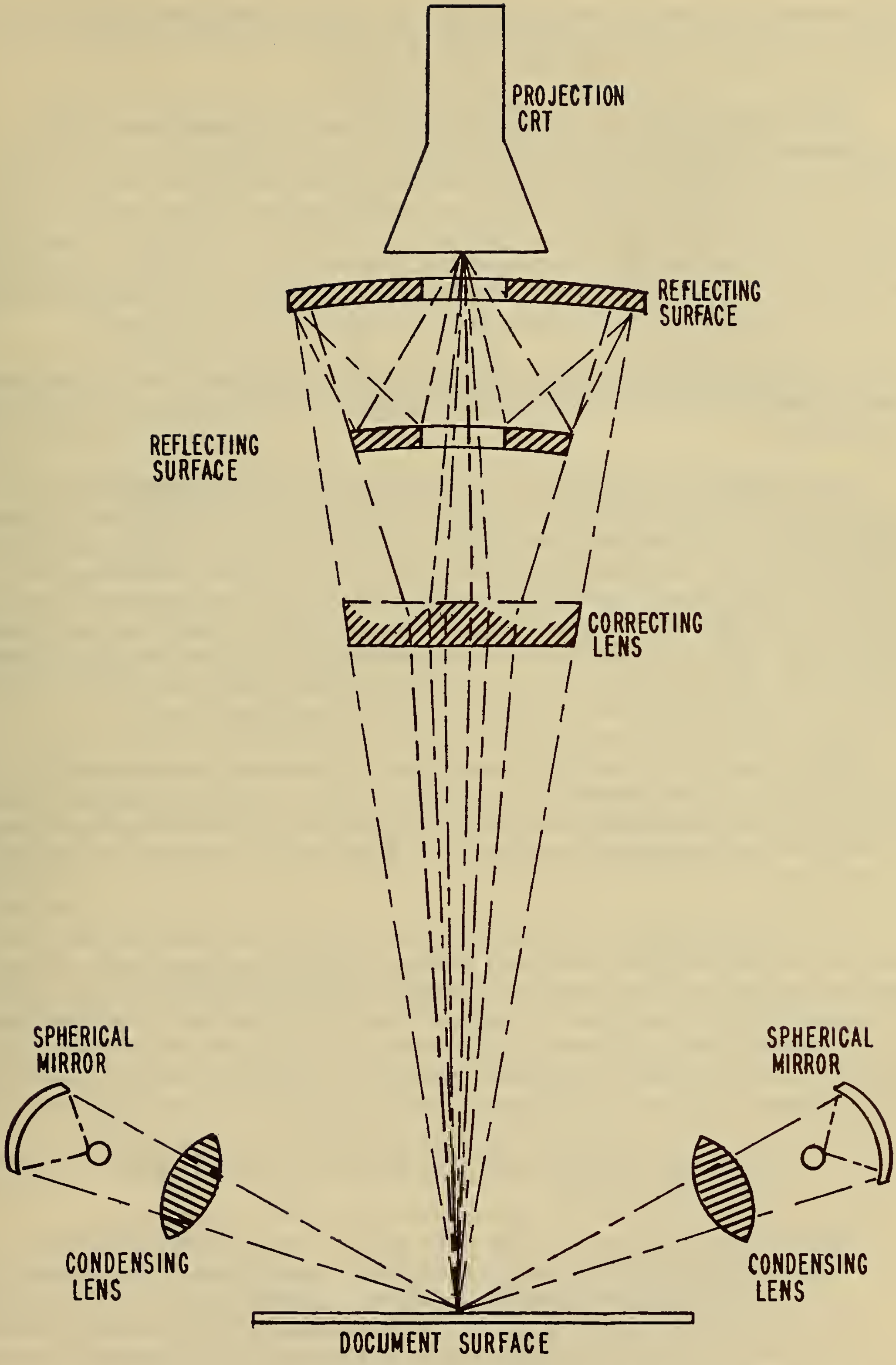

Figure 2. CRT Flying-Spot Scanner with Reflective Optics

defocussed by stray external fields unless carefully shielded. Resolution decreases and non-linearity of the deflection increases as the spot is moved farther from the axis of the tube.

The photocathode in a photomultiplier is nonuniform [29]. If the incident light is permitted to traverse the surface, considerable variation in output current will result. Condensing lenses must be used to restrict the light to a very small portion of the cathode regardless of from which part of the field it is received. Due to nonuniformities in the phosphor and the effects of nonuniform browing, intensity of the spot varies over the face of the CRT. This can be compensated for by a closed-loop servo using a monitor phototube (or tubes).

c. Light-Transfer Characteristic. The response of the phototube is linear, although fatigue of the photocathode is noticeable at high light levels.

d. Signal-to-Noise. Noise is present in the photomultiplier. Shot noise predominates and is proportional to the half-power of the emissive current and the bandwidth. The signal-to-noise ratio increases as the half-power of the light level. Hence the major problem in the use of a CRT flying spot is that of achieving sufficient light for satisfactory signal-to-noise ratio while retaining satisfactory resolution. Thermal noise is also present. This can be significantly reduced by operating the tube in a refrigerated container. At least two successful containers have been recently reported [30, 31].

Since noise in the photomultiplier is random in character, multiple phototubes operated in parallel should yield a higher signal-to-noise ratio than a single, more sensitive one. This is because signal currents would be directly additive, while noise currents would add as the rms sum.

e. Instability. As with all other electronic pick-up devices, the characteristics of both CRT and photomultiplier change with temperature, so warm-up is essential. Drift in the phototube is noticeable, especially at high currents. Intensity gradually falls off in the CRT. Any instability in the power supplies can cause great variation in performance. In general, however, stability is higher in this system than in the image orthicon or vidicon.

f. Maximum Information Handling Rate-Bandwidth. The speed of the system is limited by:

(1) The decay time of the phosphor. Phosphors which have been made for special purposes can be used with photomultipliers to produce a pulse, rise and fall, in less than 10 nanoseconds [29]. It is estimated that with this phosphor a numeric character could be scanned in less than 2 microseconds, based on 50 recognition points and an oversize field to allow for misregistration.

(2) The signal-to-noise ratio. Note that photomultiplier noise increases as the square root of the bandwidth.

(3) The slewing rate of deflection. Depending on the power available into the deflecting means, damping required, and the like, and the distances that the beam must travel between "reads", it is likely that the slewing rate will be the major speed-limiting factor.

g. Capacity. As expected, the capacity will depend on spot size and overall field covered by the CRT scan.

h. Adaptability. In this regard, the flying-spot scan is outstanding. The beam can be indexed anywhere in the field with excellent repeatability, and the resolution can be changed at will by simply defocussing the beam.

i. Operational Considerations. Depending on the phosphor used, a CRT can be inexpensive to purchase and replace. The simplicity of the electromagnetic deflection/focussing means requires significantly less adjustment than either the image orthicon or the vidicon. Viewing can be accomplished directly by using an image intensifier arranged so that it can be moved over the field. If only a small portion of the document is viewed at a time, the poor resolution of this tube will not be a problem.

The most serious operational difficulty likely to be encountered will arise because of the extremely low light level. Stray light must be carefully eliminated. If the system is made to work with UV (image intensifiers for viewing UV are available) and if incandescent room illumination only is used, this would be less of a problem. The operator must be protected from soft X-Rays and from excessive UV radiation.

j. Design Considerations. A few years ago, several papers in the Bell System Technical Journal described in some detail the design considerations and procedures which preceded the construction of a flying-spot storage system for automatic telephone switching [32, 33]. Although this system used transmitted light through a series of masks, the reasoning used and many of the calculations would be invaluable to anyone contemplating the design of a flying-spot scanner for a document reader.

k. Summary. Because of its inherent simplicity, low cost, and general all-around excellence, the flying-spot scanner appears the best suited of all pick-ups considered here for use as a document scanner. Its shortcomings could be overcome by careful design:

(1) In order to gain maximum light utilization, a modified Schmidt optical system such as is used in projection television could be used. Other problems, such as poor depth of field and spherical aberration would be introduced

thereby, but the increase in light could be worth the additional difficulties [34].

(2) In order to increase the light level without reducing resolution, a fiber optic faceplate can be used. A correctly constructed faceplate can reduce the aberration in a projection system [35].

(3) In order to increase the light level without burning the phosphor, the faceplate can be cooled by blowing cold air on it. This will also serve to keep dust from accumulating which may be attracted by the high electrostatic field.

(4) In order to increase resolution in spite of the larger spot size that would result from increased brilliance, an electro-mechanical system using a moving mirror in conjunction with the CRT could be used.

Electro-Mechanical Scanner

The ideal scanner for documents would combine the stability, high resolution, and low distortion of mechanics with the adaptability and generally higher speed of electronics, coupled with a high signal-to-noise ratio. It can be seen from the preceding discussion that such a scanner has not yet been built. The electro-mechanical scheme suggested here combines one or more moving mirrors with one or more electronic pick-ups.

1. Indexing Mirror

It is possible to control a movable mirror in two axes by a magnetic field in such a way as to direct the spot from a cathode-ray tube onto several sub-fields in the plane of the document [36, 37, 38]. This could yield the following advantages:

> The diameter of the spot on the cathode ray tube face could be increased by an amount dependent on the number of sub-fields used, thereby increasing the available light and easing the resolution requirements; or keeping this spot size constant, the total area of the CRT face devoted to the scan could be reduced by the same factor. This allows the design to restrict the scanning pattern to the most linear region of the tube. The disadvantage of this arrangement is, of course, that time must be spent in indexing the mirror.

a. Light-Weight Mirrors. The construction of astronomically accurate light-weight mirrors has been undertaken by at least two firms in the United States under the sponsorship of the U.S. Government. Progress indicates that significant weight reduction is possible [39, 40].

b. Optics. If a reduction in image size from the face of the CRT to the mirror is made, the mirror can be of very small dimension, reducing its inertia and permitting faster response. Care would have to be exercised to hold the length of the optical path constant over the entire field. The mirror surface might have to be concave and the document held by vacuum against the bed of the scanner. The bed might have to be formed as part of the surface of a sphere whose center coincides with that of the mirror. Spherical reflecting mirrors could be used at the CRT, the mirror and at the pickups, resulting in low f/numbers throughout.

2. Multiplexing

To increase the operating rate, two mirrors can be used, one held stationary with the moving CRT beam incident to it and reflecting onto the document surface, while the other, in darkness, is being indexed to the next succeeding sub-field position. The beam would then be transferred to scan on the other mirror while the first is being moved.

If transferring the spot from one mirror to the next proves difficult optically, two CRT's can be used, each with its own deflecting circuits. Certain optical problems would undoubtedly be introduced by multiplexing. For example, it may be necessary to use prisms back-to-back in order to superimpose the rays from each mirror. The adjustment of the positions of the optical components would necessarily be quite critical.

VI. CONCLUSIONS AND RECOMMENDATIONS

Conclusion

In the absence of a particular application and specific requirements as to size of document, extent of information, to be scanned and interpreted, desired resolution, system control, and the like, one can not take a dogmatic stand on the relative merits of the scanners discussed here. However, some generalizations can be stated:

1. None of the existing components can be used as is to scan a document 15 inches by 15 inches if the objective is to extract enough information to recognize a typewritten numeric character 0.1 inch high anywhere in the field and at the same time serve as a part of a Class 2 system.

2. Most improvements in electronic pick-ups have been largely directed towards improving their applicability to television. More recent work has been in the direction of improving sensitivity while attempting to maintain resolution and distortion figures. As we have seen, document scanning has somewhat different and in many ways much more critical requirements. It is conceivable that special pick-ups could be manufactured to meet these special needs but at considerable expense per unit.

3. The electro-mechanical arrangement proposed in the last section shows promise of fulfilling many requirements of a document scanner. Used in conjunction with multiple photomultipliers, a fast-decay high-brightness CRT such as the 5ZP16, and a carefully constructed movable mirror could result in a moderately fast, precise, highly versatile instrument. It is believed that sufficient justification exists for the initiation of the preliminary design of the electro-mechanical scanner.

Recommendations

To this end, a set of functional specifications should be established based on the maximum resolution, minimum signal-to-noise ratio field size, type of control, operational speed, first cost, etc., as guidelines for the designer.

Although not covered in this report, several approaches to scanning, arising out of schemes for deflecting light that have been reported in various letters patents, could be investigated and critically examined in the light of the specifications developed in the last section of this report [41, 42, 43, 44, 45, 46, 47, 48].

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