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IMAGE PROCESSING OF INDUSTRIAL RADIOGRAPHS

*NONDESTRUCTIVE EVALUATION BRANCH
METALS AND CERAMICS DIVISION*

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FINAL REPORT FOR THE PERIOD APRIL 1972 - JULY 1974

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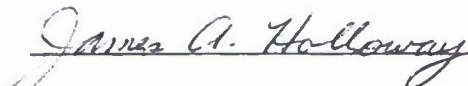
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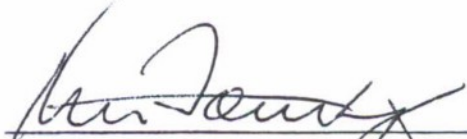
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Project Monitor

FOR THE COMMANDER


D. M. FORNEY, JR.
Nondestructive Evaluation Branch

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FOREWORD

This report was prepared by the Nondestructive Evaluation Branch (LLP)*, Metals and Ceramics Division of the Air Force Materials Laboratory (AFML), Wright-Patterson Air Force Base, Ohio. The effort was conducted under Project No. 7351 "Metallic Materials", and Task No. 735109 "Nondestructive Methods". Laboratory assistance was provided by the University of Dayton Research Institute under USAF Contract F33615-70-C-1337, and Universal Technology Corp. under F33615-74-C-5043.

This report covers work conducted during the period from April 1972 to July 1974. It encompasses a survey of facilities which represent a wide variety of approaches to image processing. The data was obtained in most instances at cooperative facilities with appropriate instrumentation using a set of control radiographs produced at the Air Force Materials Laboratory. Evaluation of this data as well as that provided by other sources was accomplished by the authors.

The authors acknowledge those facilities listed in Appendix I for their guidance and assistance. In particular, Mr. R. R. Rowand, Technical Manager for NDE, and Mr. T. Cooper, Chief of the Aeronautical Systems Branch (MXA), guided and directed this effort during its inception. Mr. Bernard Boisvert, Air Force NDI Program Manager, SAAMA/MMEW, Kelly AFB, Texas 78241, supported and encouraged work in this area and was responsible for procuring twenty image enhancement systems for Air Force use. Mr. T. R. Henderson,** University of Dayton Research Institute, assisted in the laboratory by providing the sets of control radiographs used for the evaluation.

Information pertaining to the evaluation of commercial products will not be used in whole or in part for advertising or promotional purposes. The products are commercially available items, and the data reported as a result of this effort were generated to determine potential applications rather than to obtain comparative results. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein nor on any manufacturer.

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I. BACKGROUND AND SUMMARY

The problems of reading radiographs at various Air Force facilities and extracting information to make comparative evaluations have created a need to investigate machine-aided information extraction approaches to lessen the burden and improve the efficiency and reliability of decision-making personnel. This interest by the Air Force has prompted an investigation of the state-of-the-art of image processing relative to typical images on industrial radiographs. In order to accomplish this, a series of control radiographs were produced in order to simplify this task. The control radiographs served as a method for evaluating the various parameters of the systems; dynamic range, sensitivity, and quantization capability, to name a few. Data was gathered also on scanning speed, scanning area, and cost. The results were tabulated. In general, the television systems, at present, have certain desirable features which make their application more feasible than the other systems for Air Force utilization. The other systems offer much higher resolution, scan stability, reproducibility, and versatility such as multiplication, subtraction, and convolution. Their slow speed, relatively high cost and complexity, however, limit application for the near future to a laboratory environment which has access to a large computer.

II. INTRODUCTION

The usefulness of radiographic inspection depends on the quality (and sometimes the amount) of information which can be extracted from the radiograph. The quality of the radiographic image is influenced by two factors; contrast and resolution. These two factors are influenced by exposure conditions which may degrade image quality: scattered radiation, geometric unsharpness, and radiation quality as well as film parameters such as density and graininess. If the image is of degraded quality, image processing approaches may be employed to restore, even enhance, the image.

Image processing has been used for some time on bio-medical radiographs as well as other photographic materials. Application to industrial radiographs has been limited. However, efforts are being made to utilize image processing techniques to reduce the burden of interpretation in cases where information is present but difficult to visualize. This would improve the efficiency and reliability of decision making personnel. This potential has prompted the initiation of this evaluation of the state-of-the-art of image processing systems. Both electronic scanning and photographic techniques were evaluated during the project when some eleven firms were visited and more than thirteen systems evaluated. During these visits sets of control or calibration radiographs, made at the Air Force Materials Laboratory, were used to evaluate the performance of the various systems. The output of these systems was varied. For example, some results were obtained by scanning of photographic film, while some were recorded by direct photography of a television screen. In other cases, the output image was produced on thermal sensitive paper or by typewriter print-out. Because of this variety, it was felt the data would have more meaning in table form with illustrations of the types of image processing available.

A description of the various scanning approaches will be presented initially, then the types of display systems, followed by a discussion of analog

and digital processing. The control radiographs will then be described, followed by a discussion of the survey results and conclusions.

III. IMAGE SCANNING SYSTEMS

An image may be extracted from a radiograph either by photographic methods or by employing various scanning systems of which there are a large variety. They are either electronic or electromechanical. These are divided into three categories: (1) microdensitometer, (2) television, and (3) flying spot and laser scanners. In general, the microdensitometer scanners extract information more slowly than television or flying spot scanners, taking advantage of their greater resolution capabilities and performance stability.

1. Microdensitometer Scanners

Scanners can be further subdivided into two types: flatbed and drum. Both use a light beam for scanning the radiograph. The major difference between the two types is fidelity of scan, repeatability, and the capability to locate detail accurately in the image. In general, flatbed scanners are superior in these respects, but their scanning speed is slower. Figure 1 is a diagram of a typical scanning microdensitometer. The intensity and size of the light source is controlled by the illuminating aperture and lens. The light intensity modulated by the film is focused by the imaging lens and aperture where it activates the photocathode of a photodetector. This signal is then amplified and converted to a digital signal, depending upon the particular type of instrument. The resolution capabilities of these systems in terms of scanning aperture size vary from as small as 12μ to as large as 800μ . The aperture size can be controlled very precisely and is adjusted according to the detail of the image, scan speed, or information desired in the output image.

Flatbed scanners, as the name implies, employ a flat plate of glass upon which the film to be scanned is placed. The glass platen is attached to a very precisely machined and aligned platform. Figure 2 is a photograph of the flatbed microdensitometer at the AFML which scans only in one direction. The flatbed scanners evaluated had the capability to move the film in both the x and y planes.

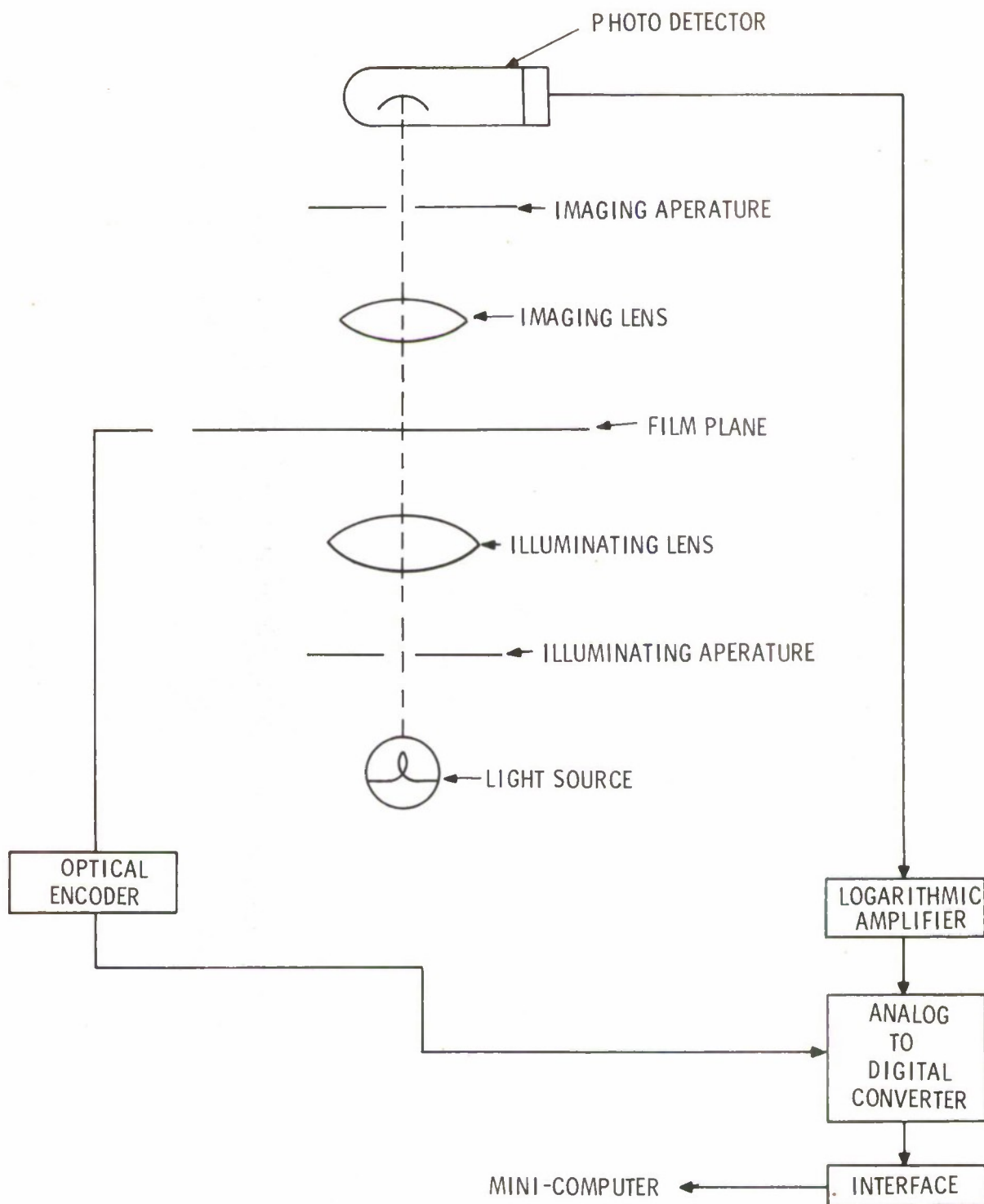


Figure 1. Block Diagram of a Typical Scanning Microdensitometer.

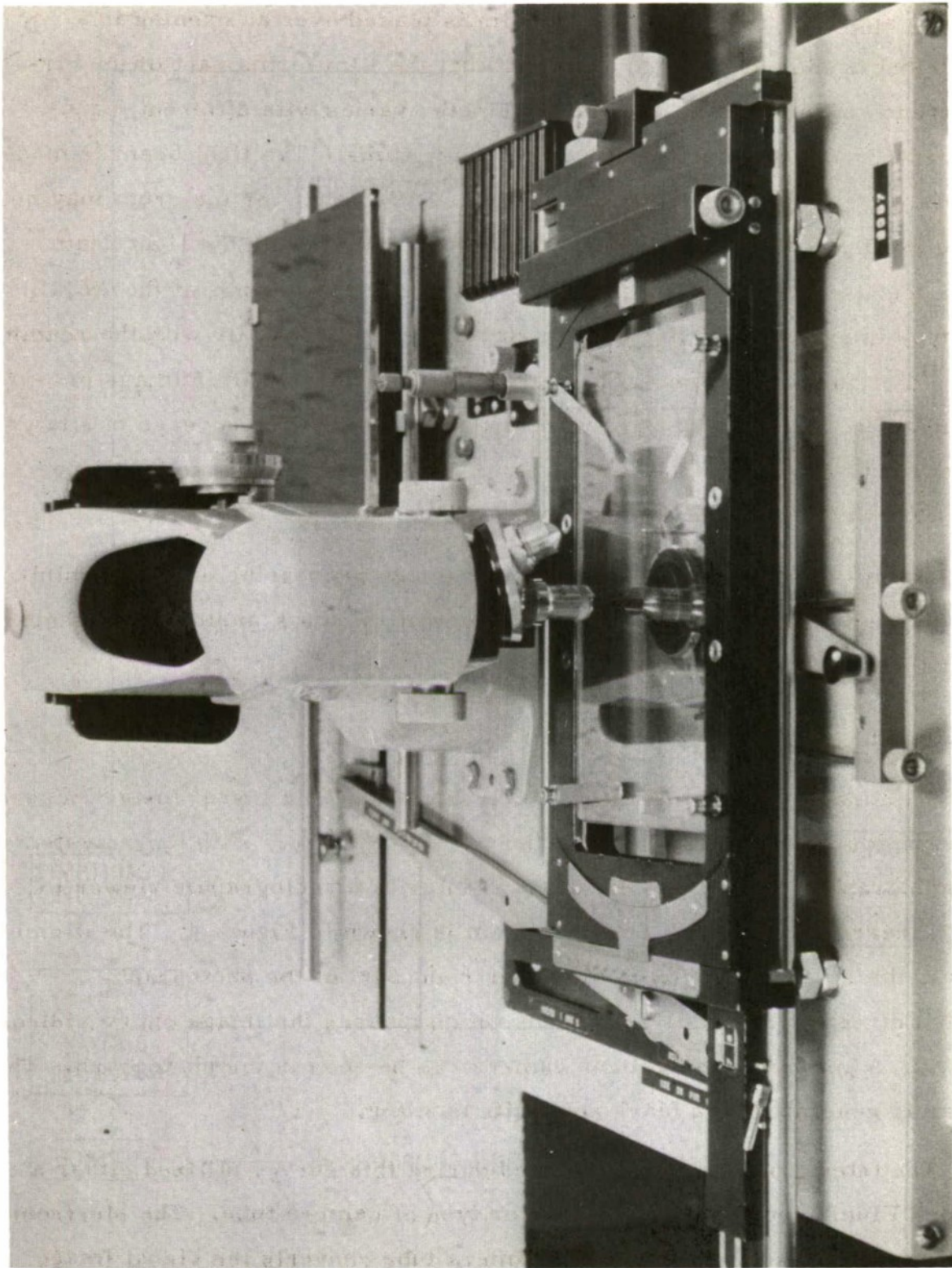


Figure 2. AFML's Flatbed Scanner.

The light source, aperture, lenses and photodetectors of the drum scanner are similar to those of the flatbed scanner. Film location and the scanning approach is different. The film is placed over an opening in a cylindrical drum and clamped to it such that the film forms part of the circumference of the drum. The drum diameter varies with different manufacturers, thus accommodating different size films. The light beam is made to move along the axial length of the drum as it rotates, or the drum may be moved axially at the same time as it is being rotated, with the light beam remaining fixed. Figure 3 is a photograph of a drum scanner at the AFML. This type of system also has another drum mounted coaxially with the reading drum which is used to photographically write information after image processing. The various approaches to image display will be covered in a later section, but many of the flatbed and drum scanning systems use the same approach in terms of image display as for scanning.

The microdensitometer systems for image processing employ a mini-computer for digital processing and for controlling the scanning parameters such as area and spacing.

2. Television Scanners

The image processors which electronically scan a visual image focused onto a photosensitive layer fall into the television class. With these systems, the radiograph is placed on a light box similar to a radiographic viewer to receive rear illumination. Such a system is shown in Figure 4. The illuminator is the rectangular box in the lower right part of the photograph. Located directly above this is the lens which focuses the image onto a vidicon camera. A portion of the vidicon camera can be seen in the photograph. The display is generated by a black and white monitor.

The television scanners observed during this survey utilized either a vidicon, Plumbicon, or image dissector type of camera tube. The electronic scanning process carried out in the camera tube converts the visual image to an analog signal, which in turn may be processed by analog or digital

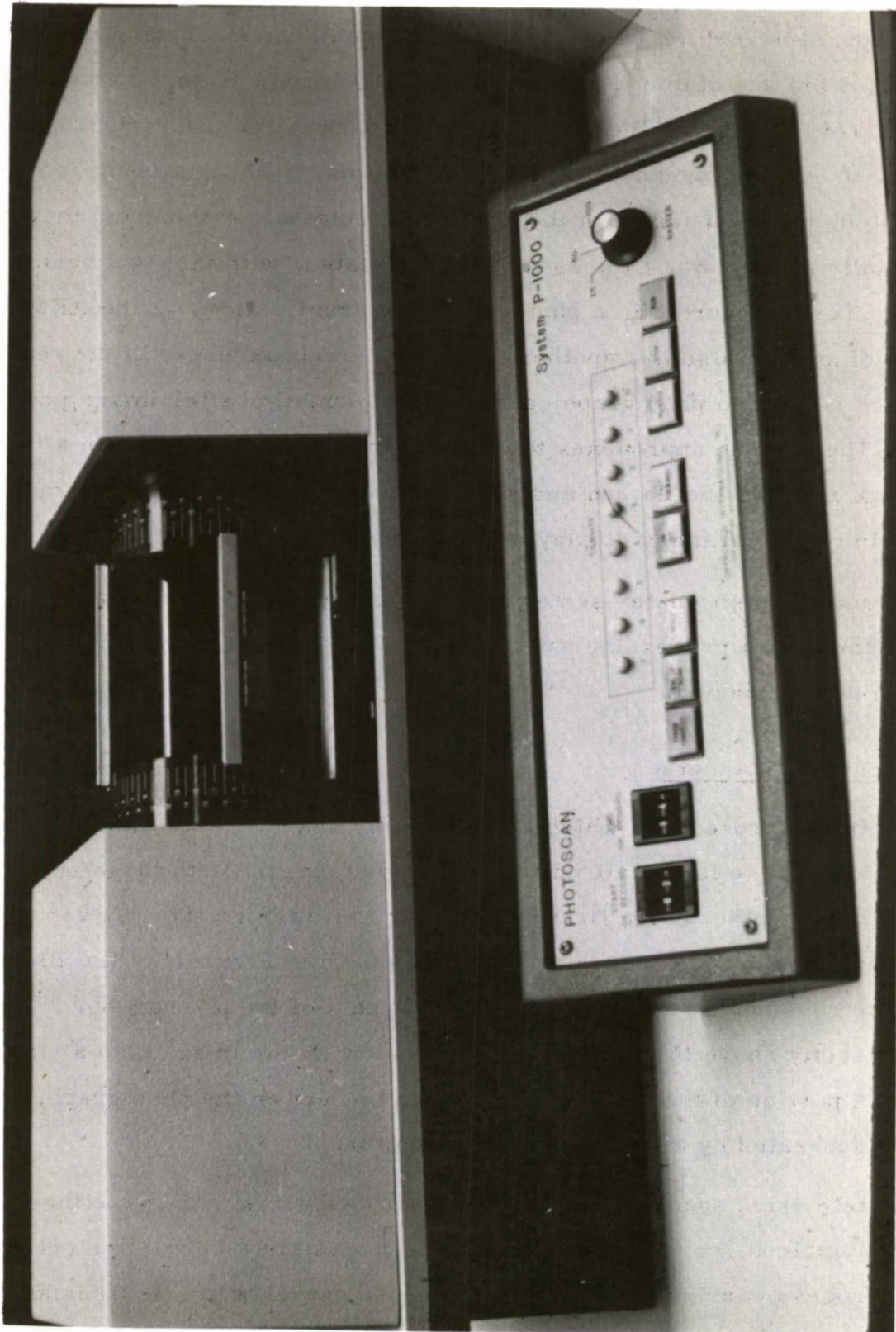


Figure 3. AFML's Drum Scanner.

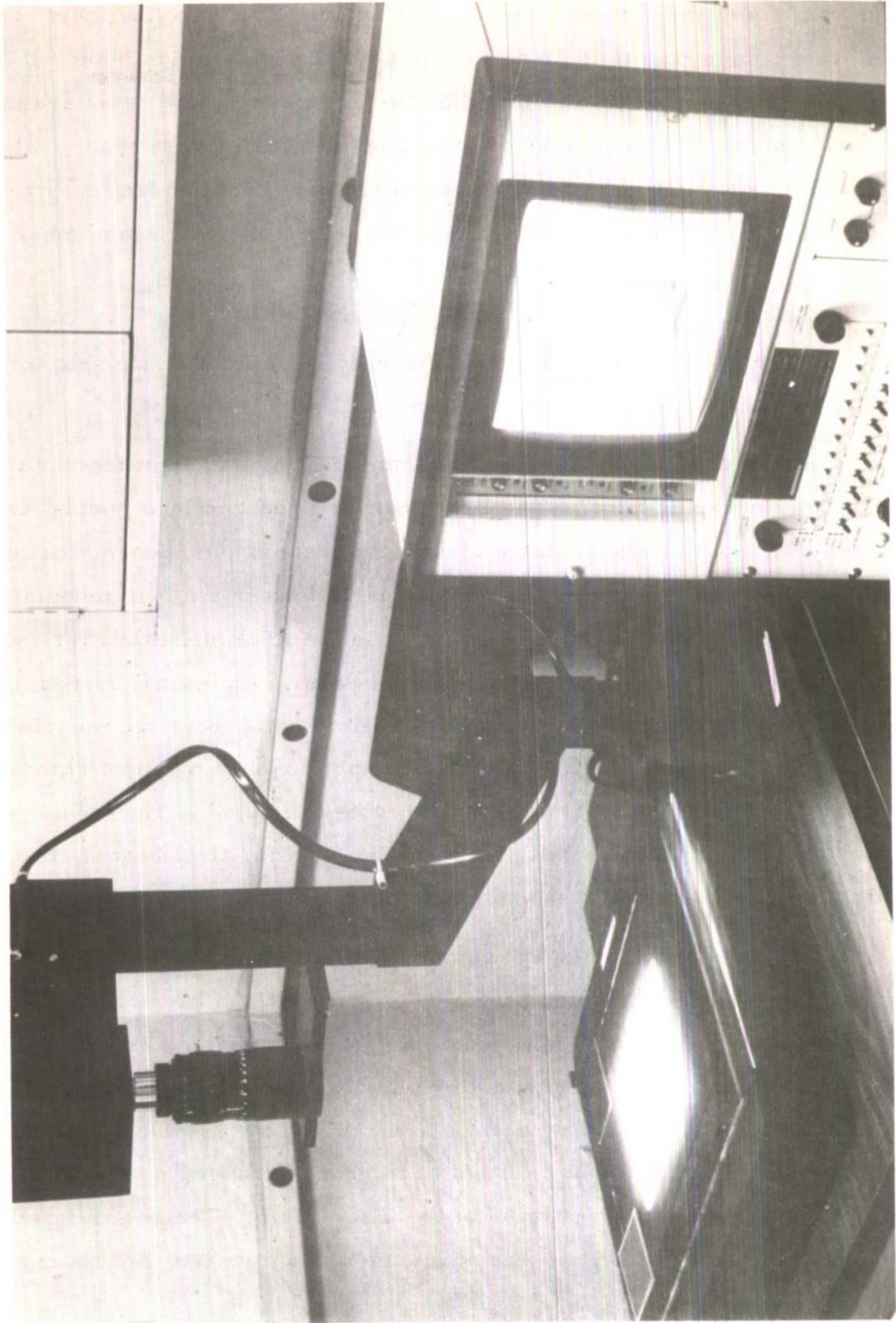


Figure 4. AFML's Television Scanner.

techniques. Generally, the scanning process is very rapid and in some cases real time image production is carried out. The imaging frame rate of the real time systems is 30 frames per second (this is the standard television frame rate used in the United States). Slower frame rates are used in some systems. The number of scan lines per frame vary from system to system. Some equipment use the standard 525 lines per frame (broadcast television scan line rate) and others use some higher scan line number.

3. Flying Spot and Laser Scanning Systems

Other types of image scanners observed included a flying spot (or jumping spot) scanner and a laser scanner.

The flying spot scanner utilizes a moving beam of light to scan the subject (radiographic film). The light beam is produced by a special cathode-ray tube which with its associated electronic scanning components causes the light beam to scan the film. The density variations in the film modulate the intensity of the beam of light, the same as in the microdensitometer systems, and a photocell detects the modulated light beam. An optical system is used to project the light beam on the subject or film and to focus the modulated light beam onto the photocell. The flying spot scanner may use standard television scanning rates or slower scan rates. Control of light beam size, shape, and stability is generally less precise than for light beams utilized in microdensitometer scanning systems.

The laser scanner uses a laser as the source of a coherent beam of light. Again, in this system the film density variations cause modulation of the light beam which in turn is detected by a line photodiode arrangement. The scanning process is carried out by physically moving the film through one coordinate, say the "y" direction, and causing the laser beam to scan the film on the "x" coordinate. A set of mirrors arranged on a rotating drum produces the scanning action of the laser beam. The relative stability of the laser beam intensity and the advantages of a coherent light source are desirable characteristics.

IV. DISPLAY METHODS

The image display used with the various processing systems include cathode-ray tubes (CRT), photographic writers, teletype printers, and write-out devices using sensitized paper.

1. Cathode-Ray Tubes

Cathode-ray tube displays are generally used by television-type image processors such as shown in Figure 4. Both conventional black-white and color CRT's are utilized. Other systems use a storage or long persistence CRT image display device.

Conventional black-white CRT's are used to display real-time image information such as that produced by edge enhancement systems.

Color CRT displays are used with false color or color contrast systems. Some systems use the conventional three-gun color tube, while others use the single gun Trinitron CRT color display. The latter CRT is generally used in the small screen, less expensive, color television monitors.

A third type of CRT display uses dark line scanning where the image is produced on a long persistence screen after the image scan is completed. The image decay is very slow; however, it can be refreshed at intervals. Also the image can be erased at will with very little background retention of the erased image. The background fluorescence is green and contrast is displayed in shades of green to black.

The resolution capability of the black-white CRT is generally better than color CRT's because of screen structure. The color dot structure and dot size limit resolution to 400 TV lines.

2. Photographic Write Systems

Several image processing systems use special photographic or Polaroid films for output image display including the drum and flatbed scanners

discussed previously. The film readout method is used because these systems are capable of high resolution performance. The image production process is a repeat of the input image scanning process. The density information which is in the computer in digital form in the case of drum and flat-bed scanners, is fed into a digital-to-analog converter. The analog output modulates the current of the light source and determines the exposure level of the film. The light beam, which is produced by a source such as a diode or light cell is passed through an aperture and focused on the unexposed film. The length of time required to read out the film image is generally the same as that required to scan the original input image. There are exceptions to this, however, if resolution or other output image characteristics are varied. The films normally used are either Kodak Shellburst types, which must be processed by the usual darkroom process, or the 4x5 in² Polaroid film.

3. Other Display Methods

Other methods of providing image information include heat sensitized paper writing devices, ink and typewriter printers.

The heat-sensitized paper display devices provide black and white and two intermediate shades of grey in their output images. The resolution is limited somewhat by the scanning stylus-dimensions and heat transfer characteristics in the system. The process is relatively fast and produces a hardcopy image as rapidly as the scanning process is carried out.

Images produced by line printers connected to computer outputs are generated by digitized video information. The computer is programmed to direct the printing of combinations of characters to produce grey tones by overprinting. The printing is made on standard printer paper. The grey tone ranges from white to black, with some four or five intermediate shades of grey. Each print location represents a data point taken from the original image and these data points are printed in horizontal and vertical rows to form the output image. Resolution is governed by data point size

and has little meaning unless the printed output is processed to make the printed elements small so that they blend into continuous tone.

The ink printer uses four ink jets, one each for black, yellow, magenta, and cyan, which lay down a dot pattern on paper mounted on a rotating drum. Each jet is controlled electrostatically in response to a continuous signal from magnetic tape, so that individual ink droplets either are deposited on the moving paper or deflected from their path and recirculated into the ink supply. Grey scale reproduction is made possible by the degree of filling and color of the dot pattern. Resolution is 288 points/inch.

V. ANALOG PROCESSING

Processing of the video (image) signal produced by any one of the scanning methods described in the prior sections of this report is generally necessary since it is in analog form. Thus, the signal processing part(s) of the system may be highly sophisticated consisting of several components. Each component has a capability to manipulate certain operational characteristics or provide functions to isolate and enhance specific details. Basically, the video signal is processed by either analog or digital techniques. After the signal processing has been accomplished, the resultant signal may require further processing before it can be utilized by the display device. For example, a video signal in digital form must be converted to analog form before it can be used by a conventional television monitor.

The video signal produced by the detector in the scanning device is an electrical analog, in time sequence, of the original radiographic or other film image. To carry out analog processing the video signal is not converted to another form but only its condition is altered. Filters may be used to remove or emphasize certain signal information, or video amplifier response characteristics are incorporated to produce a particular output video signal characteristic. Logarithmic amplifiers are sometimes used in these systems to linearize the log characteristic of film. Edge enhancement is a technique often used to bring out obscure detail in an image (Ref. 1).

1. Edge Enhancement

The technique of edge enhancement is used to make a discontinuity or sharp change in contrast in an image stand out sharply. Techniques observed during this survey include edge outlining and analog computer processing. The computer produces a signal proportional to the rate of change of density in the original image.

Several examples are given to show this effect. One of the images to be edge enhanced is that of a step wedge which is one of the images used as

a control radiograph to determine dynamic range. Figure 5 is a photograph of the step wedge displayed on a black and white monitor of a television system similar to that shown in Figure 4. This image is without edge enhancement. Figure 6 is a photograph of the same image with edge enhancement. Notice the sharp demarcation in film density at the edges of the steps. Another example, shown in Figure 7, is that of a series of penetrameters which will be described in more detail in a later section. This image was also used as a control radiograph. Each penetrameter has three drilled holes, but because of the radiographic exposure conditions the holes are difficult, some impossible, to detect and to reproduce. However, the three holes in the penetrameter marked 1.7 can be seen. Figure 8 shows an image on the same television system of these penetrameters with edge enhancement. The penetrameters and holes appear to stand out in "bas-relief", making the image more visible.

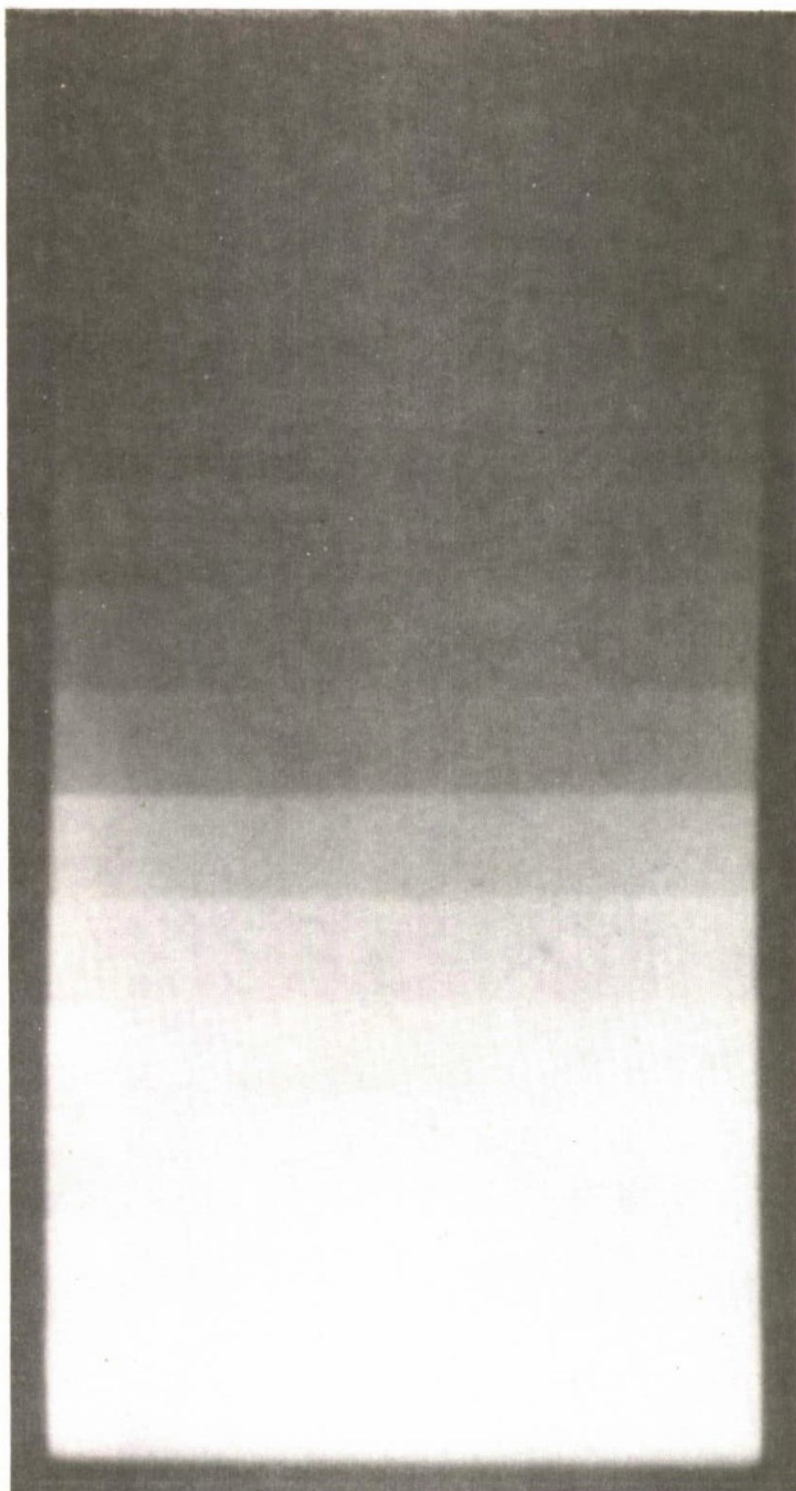


Figure 5. Monitor Display of Step Wedge.

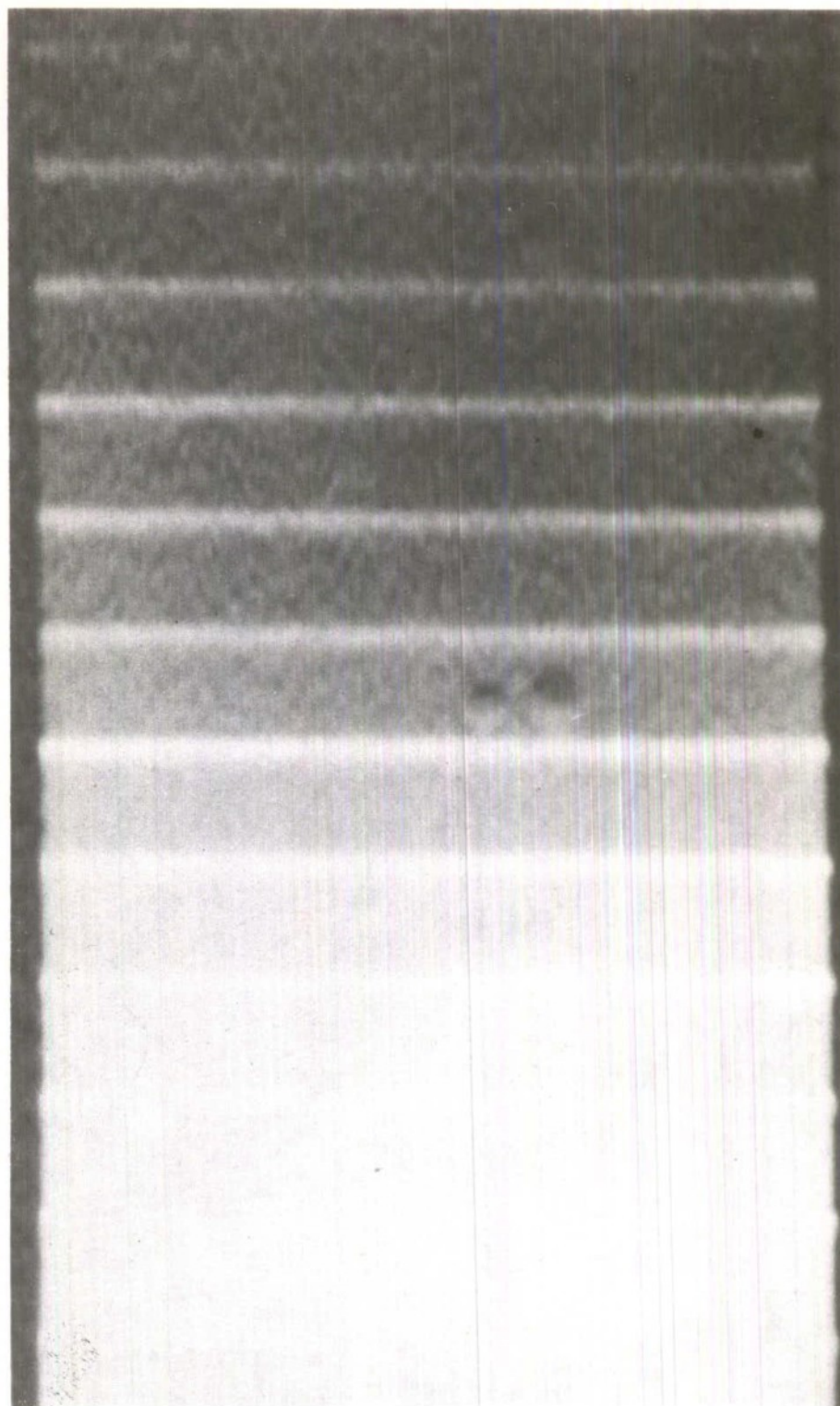


Figure 6. Monitor Display of Step Wedge with Edge Enhancement.

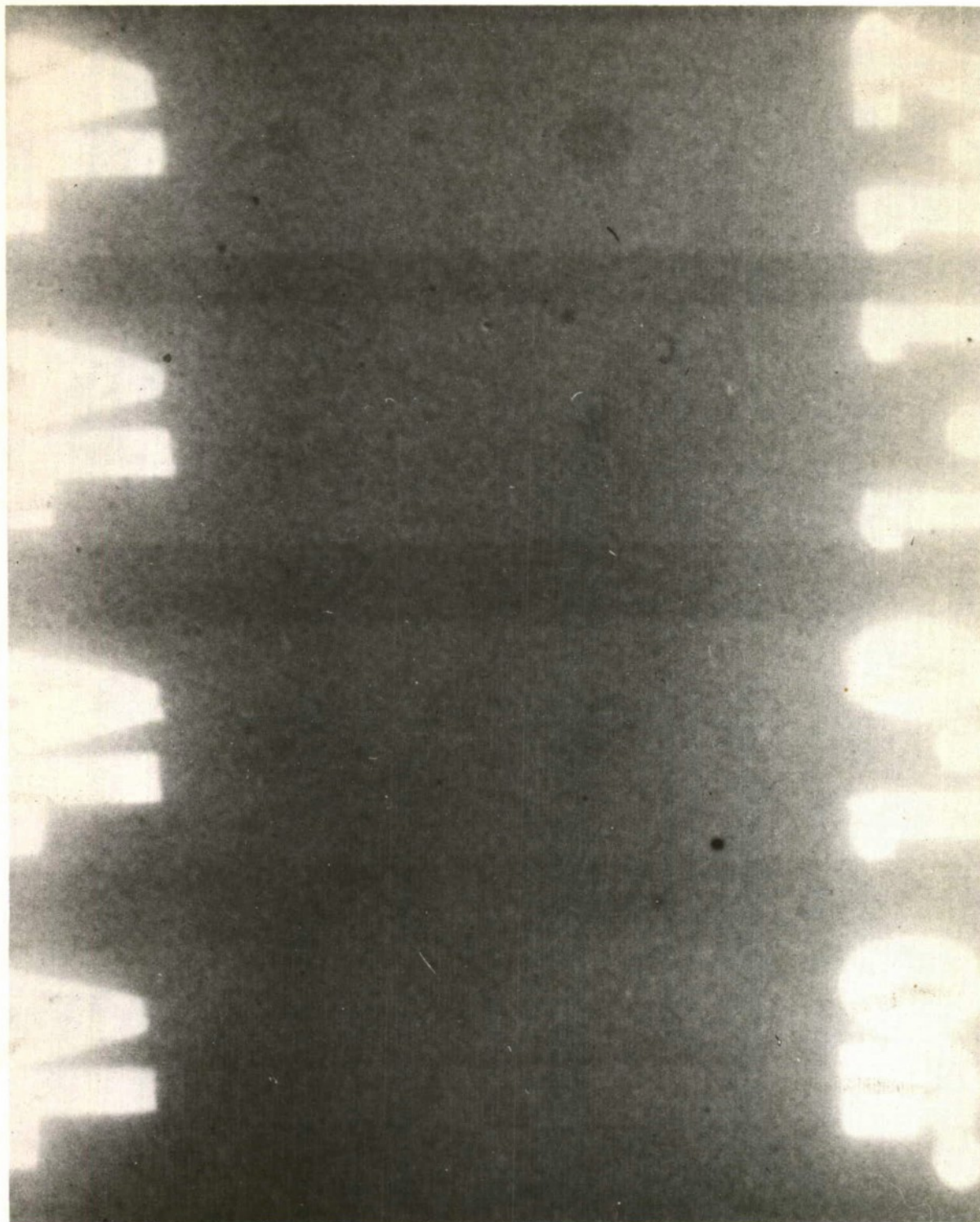


Figure 7. Monitor Display of a Series of Penetrameters.

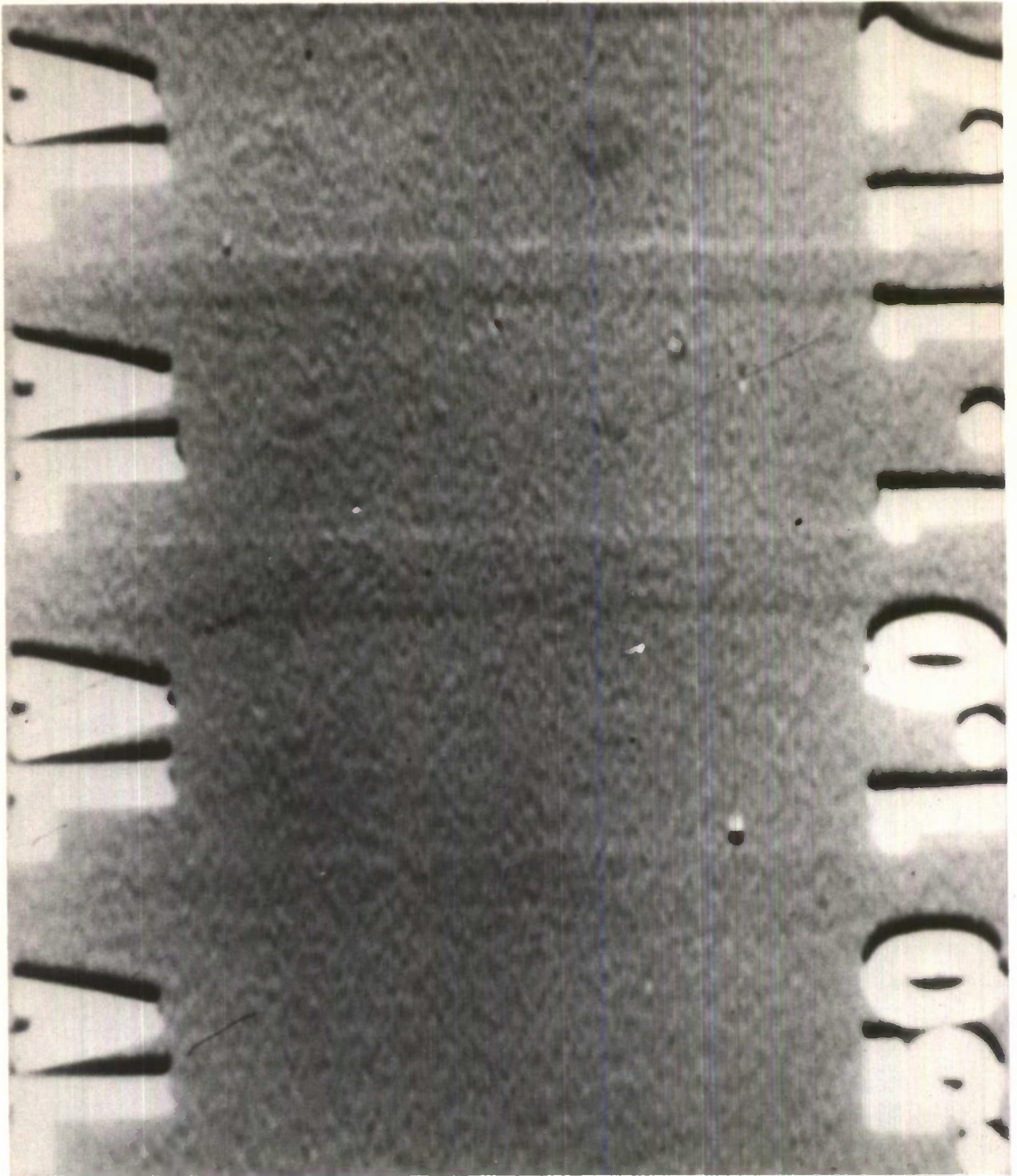


Figure 8. Monitor Display of a Series of Penetrameters with Edge Enhancement.

VI. DIGITAL PROCESSING

In digital processing of a signal, if it is initially in analog form it must be converted to digital form and then processed by appropriate devices. The digitizing procedure is used because a signal in digitized form can be conveniently applied to computers for processing, or magnetic discs or magnetic tape recorders for storage for future processing.

An analog signal is digitized by separating its various levels and encoding each with a numerical value or quantized level. In this form, the signal may be measured by appropriate instrumentation. Measurements of film density, distances, areas, etc., were some of the capabilities demonstrated by equipment surveyed during this project.

The numerical levels used for quantizing a signal may be any of the following: 8, 16, 32, 64, 128, 256, etc. with the latter being the highest quantization encountered during this survey. Thus, a video signal of a radiograph can be quantized to 32, 64, 256, etc. grey levels. The signal digitization method is used with microdensitometer, television, flying spot, and laser scanning systems. In some television systems the signal levels are color coded by electronic digital techniques as described in the next section. In other television or specialized scanning systems, the digitized signal levels are encoded to represent data points in the image. The image is broken up into a sequence of data points, cells, picture elements, or pixels (all of these words or terms have similar meanings as they are used in the context of this report) by the scanning process. The output image is then reassembled cell by cell in some ordered matrix arrangement. Images are arranged in a 2048 by 2048 cell format, 4096 by 4096 cell format, or some even digit subdivision of these numbers.

Digital processing by a computer provides versatile techniques for manipulating the information extracted from an image (Ref. 2, 3, 4, 5, 6). Such processing may be used to restore information lost from the original or to enhance detail in the original image.

Information may be obscured by density gradients, coherent noise, low contrast, or loss of certain frequency components. These conditions may occur during transmission by electronic equipment or in photographic processing. These detrimental effects may be reduced or eliminated from an image by using one or all of the following techniques such as intensity manipulation, multipicture operation, geometric manipulation, spatial frequency filtering, and analysis by mathematical operations. Using these techniques can result in grey scale alterations or density gradient alterations, correction of geometry distortions, overlay or matching of two images, and correction for details lost by shading and glare effects. Also, image sharpening may be attained by 2-dimensional filtering, shapes of objects may be analyzed, information may be added or subtracted from the image, and subjects in the image may be counted.

One of the potentially powerful multipicture manipulations is subtraction. This is not a new technique (Ref. 7, 8). It involves an initial radiograph of an object and a second radiograph taken later, i.e., two radiographs. During the intervening time period, the environmental factors acting on the object, for example, may produce changes. If this should occur, the subtraction technique reveals only the changes; the features which do not change are not imaged. The usefulness of this technique when accomplished by optical methods, however, is limited because of the difficulty in obtaining two pictures which are identical in terms of orientation and exposure. It is possible to correct for distortions and conditions of exposure and development using digital techniques (Ref. 9).

1. Color Coded Contrast

Analog signals can be digitized and the resultant signal levels assigned various colors which are displayed on a color television monitor. This technique is sometimes referred to as false color contrast imaging. Its usefulness lies in the eyes' ability to respond to color changes better than to changes in grey. The colors used vary among different systems, but some of the basic

colors include red, blue, yellow, green, brown, violet, orange, cyan, plus, of course, black and white. In addition, different hues, perhaps three or four, of each of the colors listed are sometimes used. Thus, it is possible to process a signal into as many as 32 colors, each color representing an image grey level or a film density value level. Figure 9 is a black and white reproduction of the step wedge shown in Figure 5 presented in false color on a television system. The impressive feature is that the density variations across each step of the wedge are more obvious and when viewed on the color monitor appear as changes in hue.

2. Computer Control of Image Processing

The image processing systems which use computers to control their operational functions include the drum and flatbed scanners and some of the television type scanners. Also, the flying spot (jumping spot) and laser scanners operation is programmed through computer control. The operator communicates with the computer by a teletype keyboard to instruct the computer and receive data from the computer. Where special instructions to the computer for image processing are required, such a variation of system response characteristic, the program information is punched onto a paper tape at a time prior to processing. At the appropriate time during the image processing procedure, the paper tape is run and the computer performs the instructions provided from the tape.

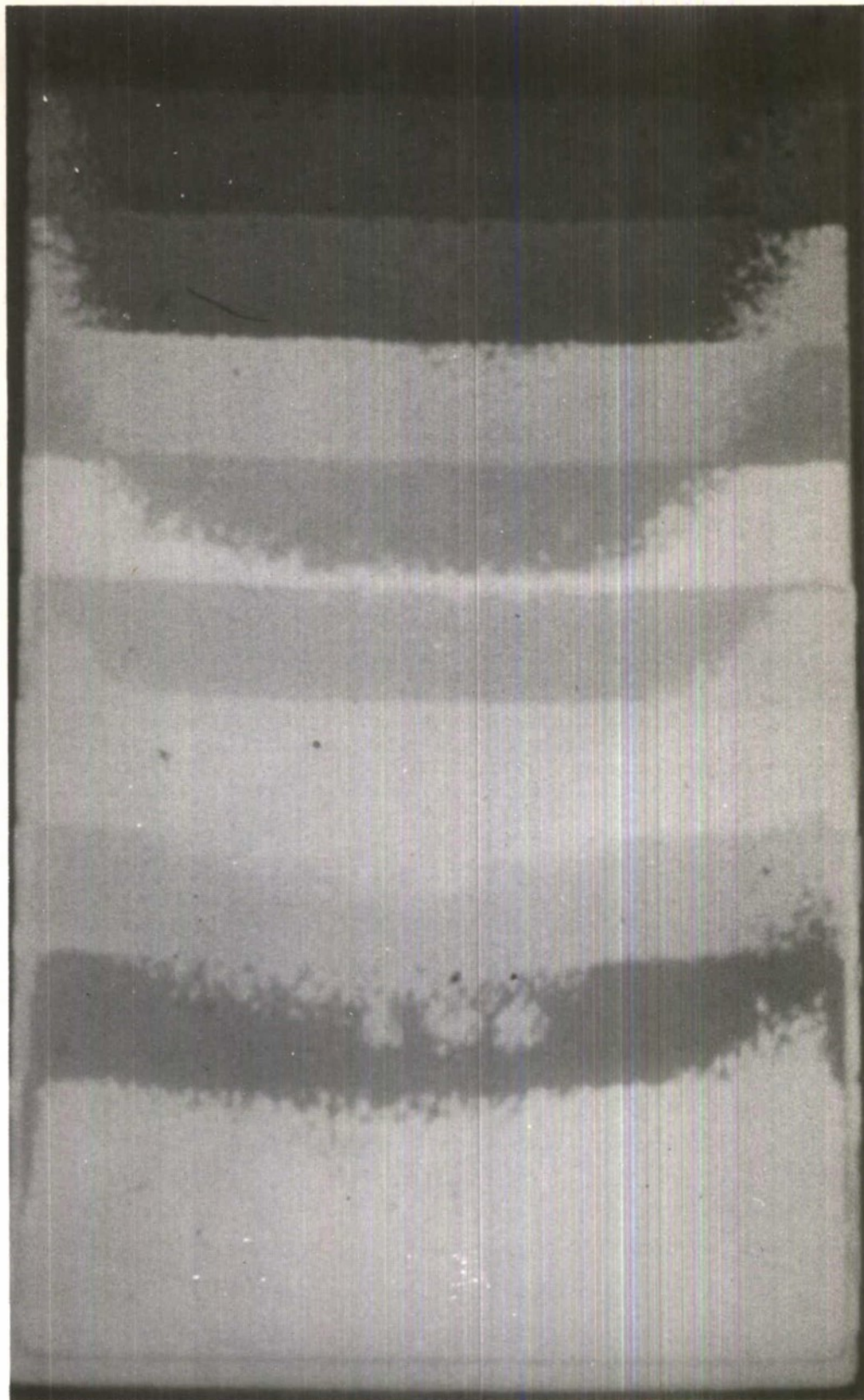


Figure 9. Monitor Display of Step Wedge in False Color.

VII. PHOTOGRAPHIC PROCESSING

There are two approaches to image processing which for this report are classified as photographic. The first is a "purist" approach involving a minimum of complex electronics. The approach is better known as photographic extraction (Ref. 10). In this process a density slice is taken of the original and stretched by exposing it on a very high contrast emulsion such as lithographic film. The lithographic films used are designed to transform a continuous grey tone image into an image consisting of almost black and white (because of the high contrast or gamma). The point at which the original lower density level (light) of the radiograph will appear as black, and the higher densities (dark) will appear as white on the lithographic film is determined by the printing exposure and subsequent precision processing. The density that is to be extracted from the radiograph is termed the "critical density". To extract a selected density increment, it is necessary to prepare two extraction negatives: one above and another below the critical density. Next, the extraction representing the higher density is reversed. The reversed or positive and the negative extraction (representing the lower density) are then sandwiched together and printed. The printed image will only contain amplified information within the extracted range, densities above and below being masked off. Depending upon the results, the technique can be repeated, or the printout can be by dye transfer or Type C color printing. Each color corresponds to a particular grey level in the original radiograph. The result is similar to that obtained with digital processing using the color coded contrast technique. Edge enhancement is also possible by printing the positive and negative extraction sandwich slightly out of register, giving the same appearance to the images shown in Figures 6 and 8.

Another photographic process uses a technique known as "dodging". This can be accomplished manually or electronically with a special contrast printer (Ref. 11). The instrument utilizes a CRT and a photomultiplier. The CRT produces a raster scan and the photomultiplier circuitry controls the

raster velocity depending on the light transmitted by the radiograph. Using this approach, contrast may be simultaneously increased or decreased depending on the density of the film. Thus, low density areas are increased in density, improving contrast, while the density is reduced in high density regions, lowering contrast. This reproduces the densities on a more linear portion of the characteristic curve, improving visualization.

The photographic approach to subtraction has been mentioned previously. A special emulsion may be employed for reproduction of the information on the original radiograph. This emulsion which has a reversed image is then placed in contact with another radiograph taken of the same subject after an interval of time has passed. Any changes which have occurred become more visible. As stated, the usefulness of this technique when accomplished by optical methods is limited because of the difficulty in obtaining two pictures which are identical in terms of orientation and exposure.

VIII. CONTROL RADIOGRAPHS

A set of control radiographs made at the AFML was designed to be used to evaluate certain parameters of the various systems described in the preceding paragraphs. The objective was to determine factors such as contrast range or density range, sensitivity, and the degree of enhancement capability via these radiographs. All radiographs are on 8-inch by 10-inch double emulsion films and duplicate sets of these radiographs were made on Industrex type M and type AA films. These radiographs included images of an aluminum step wedge, a magnesium wedge, aluminum plate with penetrameters, a titanium weld, and a TV test pattern chart. Other features or factors were determined through brochures, or by discussing the system's features with individuals at the facilities.

One radiographic image, shown in Figure 5, was used to evaluate the density or dynamic range of the systems. The image is a step wedge made of aluminum with twenty steps. The film density range is from about 0.4 density units on the first step to greater than 4.0 density units on the thirteenth step. Industrial radiographic emulsions are capable of densities greater than this, but a working range is from 1.0 to 3.5 density units.

Radiographs of a 1.75 inch thick aluminum plate were produced with a series of penetrameters as shown in Figure 7. For those not familiar with penetrameters, these are plaques of the material being radiographed whose thickness is nominally 2.0% of the total thickness. They contain three holes. The diameter of the holes is one (1T), two (2T), and four (4T) times the thickness of the penetrometer. From Figure 7, the penetrameters are labeled 0.5, 1.0, 1.1, and 1.7. These numbers indicate that the penetrameters have thicknesses of two percent of 1.7 inches, 1.1 inches, etc. Thus, these penetrameters represent about 2.0, 1.25, 1.14, and 0.57 percent contrast sensitivity, respectively. Depending on the holes which are visible, the detail sensitivity would be more, equal to, or less than the contrast

sensitivity. If, for example, only the 4T hole is visible in the penetrameter, the detail sensitivity would be 1.4 times the contrast sensitivity. If the 2T hole is visible, the detail and contrast sensitivity would be equal. If the 1T hole is visible, the detail sensitivity is 0.7 times the contrast sensitivity. This type of penetrameter is widely used as a radiographic image quality indicator (IQI) in the United States. These images were made at three densities, 1.5, 2.5, and 3.5, because the penetrameter sensitivity changes with film density. This is an emulsion characteristic; film contrast increases with density.

Another image used to evaluate system parameters (if appropriate) was a continuous wedge made of magnesium. This wedge has a series of five grooves of various depths. This radiograph was useful for determining the degree of enhancement that a system is capable of achieving.

The image of another step wedge is shown in Figure 10. This is a graphite-lucite combination arranged so that the total thickness of the two materials is constant. The steps are equal on the left and right hand portions of the wedge. On one side there are four drilled holes in the graphite steps. Pieces of a broken drill bit (which appear white on the radiograph) can be seen and are located in the thinnest graphite step. The purpose of this image was also to determine sensitivity over a wide density range, but the IQI was a side drilled hole instead of a hole drilled in a penetrameter.

A radiograph of a welded titanium plate was provided which contains lack of fusion and microporosity. The base metal thickness is 0.125 inches and the film density is about 2.0 density units. This radiograph was used to determine if the subtle conditions of the weld could be reproduced and enhanced.

The final image of the set was a standard TV test pattern. The test pattern was a halftone reproduction on double emulsion film. It was made in two sizes, 6-5/8 inches by 8-7/8 inches and 3 inches by 4 inches, to accommodate the different areas of scans by various image processing

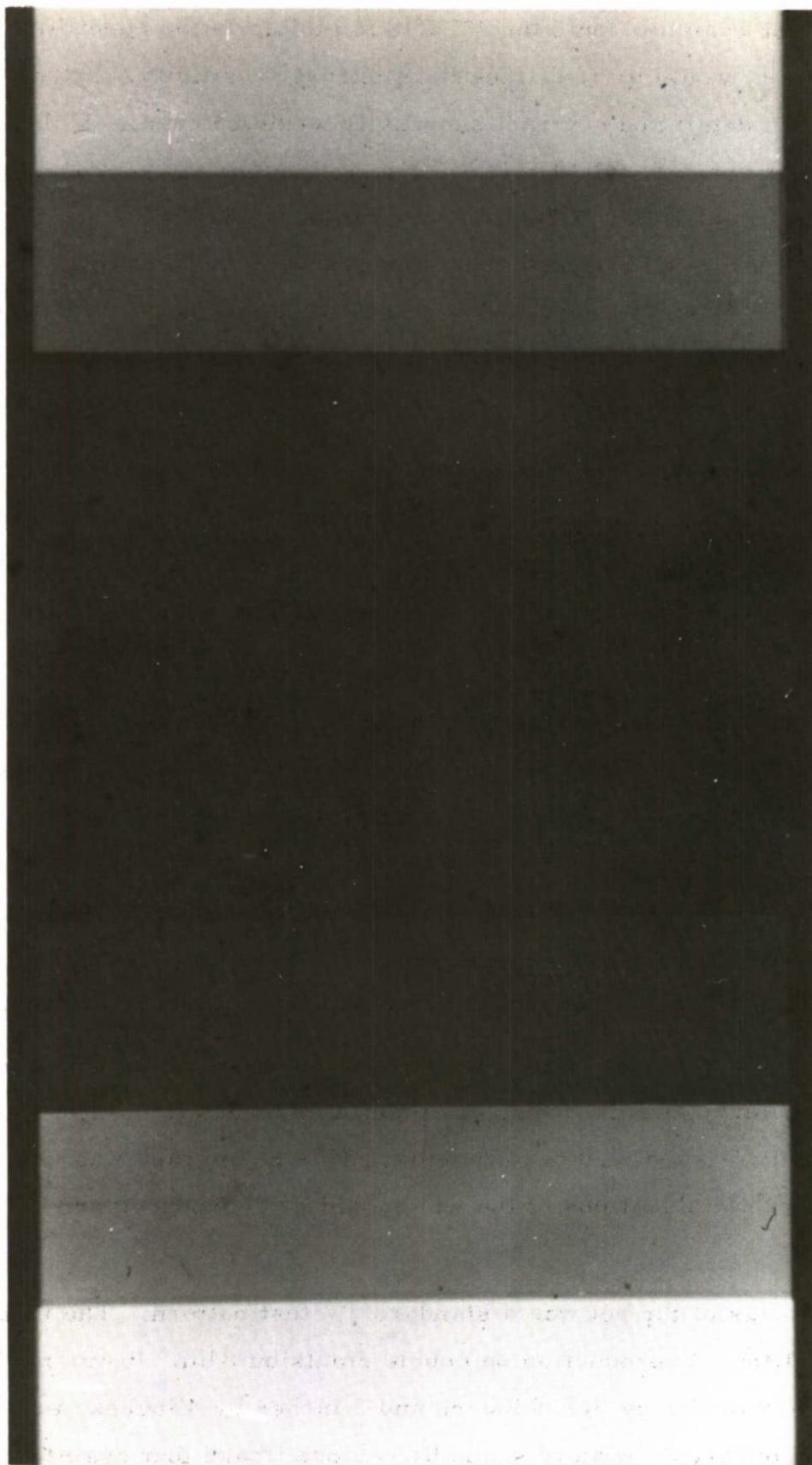


Figure 10. Radiographic Image of Graphite/Lucite Wedge.

systems. This test chart provides an indication of the resolution, grey scale or contrast range, and scan linearity of a system.

IX. RESULTS OF SURVEY

As stated in the introduction, the results were obtained through actual visits to firms that manufacture these systems, from discussions with the firm representatives, and through evaluation tests of the firm's equipment, where possible, using the control radiographs. The test results of the image processing systems were obtained in the form of photographs taken from television screens, by hardcopy output from processors, and reproductions from photographic enhancement of radiographs. Because of the various forms in which these results were obtained, it was felt that the data could be understood more easily if compiled in tabular form. This is presented in Table I. The results were arranged according to the basic scanning process utilized by the systems.

The following factors were considered the important criteria regarding the performance of the individual systems: (a) cost, (b) rapid area scan up to 14×17 in², (c) rapid data analysis and display, (d) wide dynamic range including the capability for resolving detail at densities as great as 3.5, (e) better than 2.0% penetrameter sensitivity, and (f) reproducibility. A statistical approach for evaluating drum scanners can be found in the literature (Ref. 12).

TABLE I

RESULTS OF EVALUATION USING CONTROL RADIOGRAPHS

Type of Scan	Flatbed	Drum	Television	Image Dissector	Other (Laser & J.S., CRT)	Photographic
Cost	\$70K	\$27-\$75K	\$12-\$20K	\$55-\$65K	\$100-\$150K	\$17-\$150K
Quantization Levels	256 grey levels	20-256 levels	10-32 color hues	64-256 grey levels	64-256 grey levels	130 grey levels
Density Range	0-4.0D	0-3.0D	0-3.4D	0-2.4D	0.3-2.0D	0-4.0D
Quantization Resolution	0.02D	0.02-0.16D	0.03-0.15D	0.03-0.1D	0.03D	0.03D
Area of Scan (typical) in ²	10x10	5x7 to 10x10	8x10 to 12x16	2.25x2.25	1.75x1.8 to 10x12	16x20
Aperture Size	20 μ	25-100 μ and 800 μ	electron beam	12 μ	20-40 μ	--
App. Scan Speed	0.026 in ² per min	15-70 in ² per min	real time	1.0 sec. 91 min/frame	30-45 sec per frame	200, 8x10 in ² /hour
Dynamic Range (using Al step wedge)	not evaluated	5 to 13 steps	1 to 14 steps	11 steps	8 steps	13 steps
Penetrameter Sensitivity %						
1.5 Density	*	not	1.25	1.25*	1.14	
2.5 "	1.6 *	evaluated	1.14	1.25*		
3.5 "	1.6		1.25			1.14

* Without Computer Processing

X. CONCLUSIONS

All of the systems evaluated can be applied to industrial radiographic images to certain degrees of success depending on the processing required. The results obtained from the systems, however, depend on the quality of the original radiograph. Some systems can improve the quality to a greater extent than others, but much more effective processing can be accomplished if the radiographs are taken with an optimum technique. Another influencing factor is the lack of criteria for selecting a radiograph or an area within a radiograph for processing. In addition, with computer processing digital filters can be designed if the frequency content of the image is known. Unfortunately, this information is generally not available and must be determined by time-consuming trial and error methods. Difficulty is encountered also because of the characteristics of x-ray film. For example, unlike conventional film the emulsion is coated on both sides of the base. This presents a problem if scanning at high magnification is required. With the short depth of focus, one of the sides of the emulsion is not resolved. Also, with double emulsions, very high densities are registered under certain exposure conditions. In order to extract information from high density regions, an intense light source is necessary or the time for data collection must be increased. For example, some systems using the flying spot scanner increase dwell time by slowing the electron beam down when regions of high film density are encountered. Even so, at very high densities all of the systems cannot process the image without excessive noise being produced. The large film area, up to 14×17 in², or the wide range of densities cannot be accommodated by some of the systems.

The television system, at present, has certain features which make its application more desirable than other systems. Some of the TV systems have a resolution (with magnification) of better than 2% penetrameter sensitivity, wide dynamic range, and the capability of quantizing the image providing a false color presentation of individual density increments within the

original image. Some of the other advantages are edge enhancement and densitometric measurement capability, digital readout of the relative areas of the same density level, real time scan and display of results, and low cost.

The television systems suffer from saturation between adjacent low and high density regions of the radiograph with a resulting loss of detail in these areas. These systems are susceptible to glare so that masking of the image is necessary and operation should be conducted in a darkened room. Variations in shading occur due to the characteristics of the vidicon and changes in light intensity across the area of the illuminator. This latter condition is not objectionable in black and white display systems, but could lead to error with false color display systems.

The other systems offer much higher resolution, scan stability, reproducibility, and versatility of techniques such as multiplication, subtraction, and convolution. However, because of their slow speed, relatively high cost and complexity, these systems will be limited for the near future to a laboratory environment which has a fairly large computer capacity available.

REFERENCES

1. Vary, Alex, "Investigation of an Electronic Image Enhancer for Radiographs", Materials Evaluation, December 1972, Vol. XXX, No. 12.
2. Andrews, H. C., Computer Techniques in Image Processing, Academic Press, N. Y. 1970.
3. Rozenfeld, Azriel, Picture Processing by Computer, Academic Press, N. Y. 1969.
4. Billingsley, F. C., "Applications of Digital Image Processing", Journal of Applied Optics, Feb. 1970, Vol. 9, No. 2.
5. Selzer, R. H., "Improving Biomedical Image Quality with Computers", JPL TR 32-1336, Jet Propulsion Laboratory, October 1968.
6. Janney, D. H., Hunt, B. R., and Zeigler, R. K., "Concepts of Radiographic Image Enhancement", Materials Evaluation, Sept. 1972, Vol. XXX, No. 9.
7. Hanafee, W., and Stout, P., "Subtraction Technique", Radiology, October 1962, Vol. 79, No. 4.
8. Ludovico, N., "Subtraction Interference Technique in Radiography", Radiographia, March 1964, No. 8.
9. Selzer, R. H., "Digital Computer Processing of X-ray Photographs", JPL TR 32-1028, Jet Propulsion Laboratory, Nov. 1966.
10. Lohse, K. H., "Application of Photographic Extraction Techniques to Nondestructive Testing of Graphite and Other Materials", AFML-TR-70-162, Air Force Materials Laboratory, November 1970.
11. Shelton, W. L., Adkins, G. R., "The Correlation of Nondestructive Test Techniques with the Fracture Behavior of ATJ-S Graphite", AFML-TR-72-38, Air Force Materials Laboratory, August 1972.
12. Dekaney, A., Guthrie, L. E., "Determination of Feasibility of Applying Computer Analysis of Titanium Alloy Microstructures to Quality Control", AFML-TR-73-123, Air Force Materials Laboratory, August 1973.

APPENDIX I
FACILITIES PARTICIPATING IN SURVEY
OR CONTACTED DURING SURVEY

Antech, Inc.
550 Newtown Road
Littleton, Mass. 01460

Control Data Corp.
Image Research Laboratory
Research Division
2800 East Old Shakopee Road
Minneapolis, Minn. 55440

Dicomed Corp.
7600 Parklawn Avenue
Minneapolis, Minn. 55435

Earth-Satellite Corp.
1747 Pennsylvania Avenue
Washington, D. C. 20006

Eastman Kodak Co.
Research Laboratories
Rochester, N. Y. 14650

E. I. DuPont de Nemours & Co.
Photo Products Department
Chestnut Run Laboratory
Wilmington, Delaware 19898

International Imaging Systems
510 Logue Avenue
Mountain View, Calif. 94040

Jet Propulsion Laboratory
Image Processing Laboratory
California Institute of Technology
Pasadena, Calif. 91109

Lockheed Missiles & Space Co. Inc.
Palo Alto Research Laboratories
Communications Information Sciences
Sunnyvale, Calif. 94088

Log Electronics, Inc.
7001 Loisdale Road
Springfield, Va. 22150

Mead Technology Laboratory
3481 Dayton-Xenia Road
Dayton, Ohio 45432

NDE Unlimited
188 E. 17th Street
Costa Mesa, Calif. 92627

Optronics International, Inc.
7 Stuart Road
Chelmsford, Mass. 01824

Photometric Data Systems Corp.
841 Holt Road
Webster, N. Y. 14580

Spatial Data Systems Inc.
132 Aero Camino
Goleta, Calif. 93017

Tech/Ops Instruments
Northwest Industrial Park
Burlington, Mass. 01803

University of California
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