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PHOTO-ELECTRO-OPTICAL REPRODUCTION TECHNOLOGY SURVEY

BY NORMAN D. WELCH

ENGINEERING DEPARTMENT

1 JULY 1978

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NAVAL SURFACE WEAPONS CENTER

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This report is an initial survey to determine the current status of Photo-Electro-Optical (PEO) reproduction technology. PEO includes topics such as image processing, electronic image acquisition, and reproduction. Included are several summaries describing PEO activity at various government and private installations, a summary of PEO technology and trends, a summary of PEO education sources, a bibliography of PEO-related literature, and a description of how PEO technology could be used to increase the effectiveness of NSWC's Photographic Branch.

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SUMMARY

At the onset of this study it was estimated that within ten years, the overall Photo-Electro-Optical (PEO) technology will advance to a point where the use of silver halide light-sensitive materials and associated developing processes can be effectively replaced by a system that couples computer technology with electronic image processing. This is an initial survey to better determine the accuracy of this estimate and to facilitate a general awareness of how PEO technology can increase effectiveness. The objectives of this report are to:

1) Determine the current status of PEO reproduction technology.

2) Synopsize some PEO technology trends.

3) Define a base of PEO techniques which could be applied directly by the Photographic Branch of NSWC in accomplishing its mission.

4) Provide a short directory of educational sources in PEO related areas.

W. L. Anderson

W. L. ANDERSON
By direction

PREFACE

This study consisted of a literature search and a series of visits made to several government and private worksites. During each visit, notes were taken that were later expanded into a worksite report describing some of the various aspects of the PEO work being done at that facility. Often, not all of the aspects of PEO work discussed in a visit were included in the final worksite report because they were either redundant of similar work described in another worksite report or the quantity or quality of the information gained about them was insufficient to report upon. Therefore, the worksite reports should not be taken as a complete description of all the PEO work done by those installations. The amount of emphasis placed upon each aspect of PEO technology, and upon each worksite itself, is directly proportional to the availability of key personnel, their cooperation, the availability of literature, the operational status of the equipment being discussed, and a few other things. Since a large portion of the information providing the basis for the worksite reports was gained orally, there was a high probability that either something would be misunderstood, misinterpreted, or misquoted. In an effort to maintain as much accuracy as possible, a copy of each of the individual worksite reports was sent to the contacts made at each installation along with a plea requesting them to correct any mistakes. At least one contact from each facility responded to this plea.

This report in its entirety reflects only upon areas and topics that the author actually read about, talked about, or personally observed throughout the duration of the study. Due to the brevity of this study, research in new methods of high-density data storage was not included. The United States Government also seems to be doing more PEO work in the area of intelligence than is mentioned in this report. These two areas should be looked into further in the event of a more detailed study.

I would like to acknowledge and thank all the people who contributed to the preparation of this report. I express special thanks to Paul Cords for seeing the need of this survey, initiating it, and giving me his support and cooperation; to Carl Franz, Charles Grover, Charles Spring, and Lawton King for providing me with starting ideas and advice throughout the study; to Karen Smith, Betty Neal, Peggy Brakefield, and the Word Processing group for their typing and secretarial support; and to all those people from various installations who freely and generously gave of their ideas and time to provide me with the materials and information I needed to produce this report.

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ILLUSTRATIONS

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Section 1

FACILITY REPORTS

1-1 AMPEX CORPORATION

Redwood City, California
Contact: William F. Justus

The Electronic Still Store (ESS) system (see Figure 1) was developed by Ampex for the video broadcasting industry. Most television broadcasting stations have one or several collections of 35mm slides and graphics that are used as backgrounds in newscasts and commercials. This system helps to eliminate prolonged searches for the appropriate image and makes the development of sequences quick and easy as well as having many slow/fast motion capabilities.

The system consists of up to eight access stations (each of which may or may not have its own television monitor) and a microcomputer interfaced for I/O with one, two, or three disc drives providing real time, random access to as many as 814 images on a one-drive system, and up to 2442 images on a three-drive system. When only one drive is used, image manipulation capabilities are quite limited. The user can only store from an outside source and erase. With two or three drives, he is able to move an image in and out of whatever memory location/s he wishes. The number of images per disc is reduced when moving to multiple disc drives because the memory space required for internal functions (linking the drives to one another and to the computer) is increased. The microcomputer may include one, two, or three channels. Each additional channel allows another access station to view images independently of the others. For example, with only one channel, only one image can be viewed at a time; with two channels, two different images can be viewed on separate access terminals simultaneously; and with three channels, three different images can be viewed by three separate access terminals simultaneously. Access stations can be operated in a first-come, first-served manner or they may in effect be prioritized by assigning each of them to specific channels and disc drives. Any one of the 2442 images stored on line is accessible in less than 70 milliseconds from the time the operator types in its address. This address consists of the channel number, the disc pack number, and the track number. As the desired images are acquired, they may be stored in sequence. When played back in sequence, the access time between images is cut to one vertical time interval which is as close to instantaneous change as a television can get. The ESS system is capable of being interfaced with another computer that would be able to store the access addresses in any type of indexing system the user desired.

Even though only three disc packs can be on line at any one time, the system will accept up to ninety-eight different disc packs enabling the storage of 79,772 still images on and off line. The appropriate disc packs would have to be located and placed onto a drive in order to gain access to all of these. It takes approximately two minutes to change a disc pack by hand (not including the time required to locate it).

Digital images are created with a conventional television camera that plugs into the ESS system. Images can also be captured from video tape. The system converts the signal into digital form and stores each tape frame in approximately one thirtieth of a second.

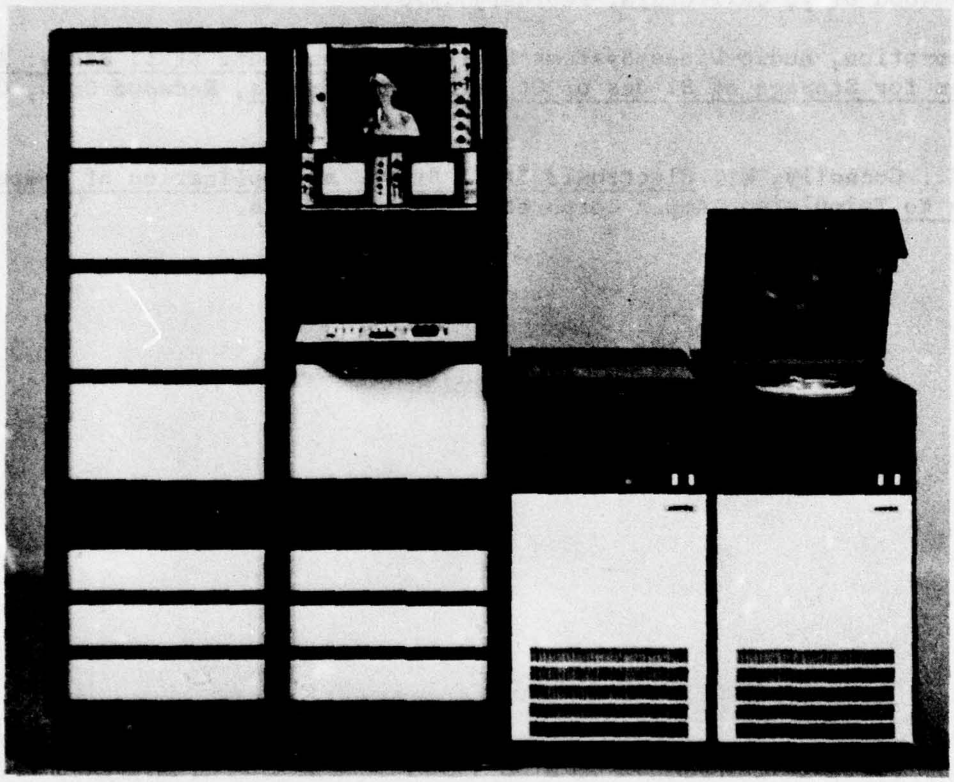

Figure 1. The ESS System With Two Disc Drives

Section 1-1

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Dierman, J., Connolly, W., Electronic Still Store: An Application of Computer Technology to Television, Ampex Corporation, January 1976.

1-2 EROS DATA CENTER

U. S. Geological Survey
Sioux Falls, South Dakota
Contact: Fredericka A. Simon

The EROS (Earth Resources Observations Systems) Data Center is one of the primary archival storage centers for NASA's LANDSAT imagery, aerial photography maintained by the U. S. Department of the Interior, and imagery acquired by NASA from research aircraft, Skylab, Apollo, and Gemini Spacecraft. Approximately six million frames of film are stored and indexed by geographic location (latitude and longitude), scale, type of image (airplane aerial, LANDSAT, etc.), percentage of cloud coverage, film type (Black and White, Color, or specific spectral response), focal length, quality of image (scratches, newton rings, color imbalance, etc.), and the data taken. Descriptions and locations of each photograph in the library are contained in a computer along with this index. In order to obtain a photograph, the user gives the computer a list of identifiers to which the computer immediately responds with a list of all images filling this description. The user may continue adding identifiers until the list is small enough to suit him. The exact location of the images is also outputted by the computer, enabling them to be easily retrieved by hand from the shelves where they are stored. Presently the center contains only images stored on film, but they anticipate receiving LANDSAT images stored on high density digital tape by late 1978.

Section 1-2

References

U.S. Department of the Interior, Geological Survey, The EROS Data Center, Washington, D.C., 1977.

1-3 JET PROPULSION LABORATORY

Pasadena, California
Contact: William B. Green

Jet Propulsion Laboratory (JPL) is the father of digital image processing. Digital image processing was given birth at JPL while they worked on the Surveyor lunar lander, and continued to grow there throughout the Mariner missions to Mars, Venus, and Mercury and the Mars landing missions of Viking. Mariner 9 alone sent back approximately 7000 images, and the adaptive capabilities of this spacecraft required scientists to quickly decide what it was going to do next. This type of decision making demanded real time processing of many of the returned images. Image processing included removing distortions produced by the various camera systems and enhancement to aid the interpretation of these images. The following includes a description of some of the camera systems and processing techniques that have been used in Mariner 9 and Viking space projects at JPL.

CAMERA SYSTEMS

Mariner 9 Vidicon System. Two vidicon cameras made up the camera system on Mariner 9. Light striking the face of a vidicon tube causes a charge proportional to its intensity to build up on the back surface. This surface is scanned with an electron beam producing a signal which is converted into a nine bit binary number for each pixel (picture element) of the 832 x 700 array. Eight bits were used for recording the pixel intensity and the ninth for error detection. These eight bits provided 256 separate intensity levels (0-255). The camera required 42 seconds to scan the image, store the information obtained onto an on-board tape recorder, and erase the image to prepare the system to receive the next image.

The system introduced several kinds of distortion into the imagery. Geometric distortions were caused because the line scans were not perfectly horizontal and because changes in the surrounding magnetic environment affected the scanning beam. Photometric distortions were caused by remnants of past exposures and by shading. Old images could not be totally erased, therefore each new image had portions of past images still on it. Shading was caused by differences in sensitivity across the face of the vidicon tube. The reproduction of a perfect uniformly lit scene would appear to vary in intensity because of shading. Shading characteristics vary nonlinearly with the wavelength of light and temperature. All of these types of distortions are taken into account when the data processing is done.

Viking Orbiter Vidicon Camera System. This camera system was very similar to the one in Mariner 9 except it was able to image a larger array of 1182 x 1056 pixels and take spectral images. The latter capability came from a filter wheel that rotated various colored filters in front of the camera aperture. (Mariner 9 was also equipped with this filter wheel but was unable to use it because it became stuck in the early stages of the mission.)

Viking Lander Facsimile Camera System (Fig. 2). The Viking Lander system also included two solid-state facsimile cameras, each consisting of twelve diode sensors. Four were high resolution black and white diodes designed to be in focus at different distances from the spacecraft, one was a low resolution black and white diode to obtain a panoramic view of the Martian surface around the spacecraft, three were low resolution color diodes (red, green, and blue), three were low resolution infrared diodes, and one diode was used to observe the sun through the Martian atmosphere. A mirror scanned the image across the sensors, recording one 512 pixel vertical line at a time. The entire camera unit and housing rotated to obtain the adjacent scans needed to make a two-dimensional image. The number of increments in one revolution of the camera was variable up to a maximum of 9000 lines.

This camera system also had some unique distortions of its own. The red, green, and blue diode sensors were all also sensitive to infrared light, causing their intensity readings to be high. The camera rotation produced an image that would look fine if the paper was curled into a cylinder but was greatly distorted when displayed on a flat sheet of paper.

IMAGE PROCESSING. Two general types of image processing are done. Subjective enhancement benefits human viewing and interpretation of photographs while quantitative processing takes out inaccuracies introduced by the system. The following are examples of the processing JPL has done.

Contrast Stretching. Since Mars is a very low contrast planet, this technique was invaluable in the Mariner and Viking missions. All of the intensity values contained in a scene tended to group around a very small intensity range. This technique sets the lower end of this range to "0," the upper end at "255," and stretches the remaining intensity values over the entire viewing range (see Fig. 3).

High Pass Filtering. High pass filtering causes only deviations from the local average intensity to be recognizable. These deviations are then recorded as deviations from a midscale gray (see Fig. 4). If part of the scene is very dark and another part is very light, this program sacrifices information about the overall intensity of the image in order to emphasize fine detail. This program eliminates the shading characteristics of a vidicon camera.

Contrast stretching can be combined with high pass filtering to stretch the intensity values of the deviations across the entire viewing range, making it possible to detect even the smallest of changes.

Mosaicking. In some cases it is easier to interpret the image of an entire scene than it is to interpret just small portions of it, but it is also often impossible to capture an entire scene in just one frame. This necessitates joining several smaller images together. In order to do this, all geometrical and intensity differences must first be corrected. Geometrical corrections include things such as enlarging, reducing, stretching, compressing, and changing the point of view.

Replacement of Missing Lines. When a line of data is missing, the lines on either side are averaged together and these values are put in for the missing line.

Data Point Errors. Normally the intensity values of the pixels tend to change very gradually. Most of the time, a pixel error will not follow this pattern but

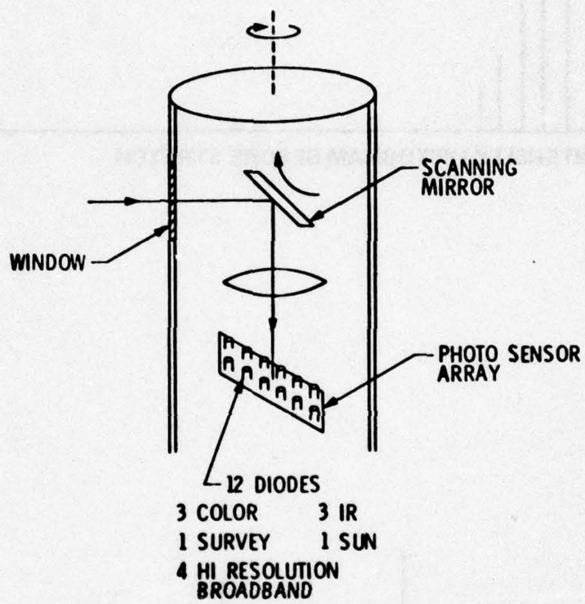

***Figure 2. Schematic of the Viking Lander Facsimile Camera**

*Green, W. B., "Computer Image Processing -- The Viking Experience," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, June 6, 1977.

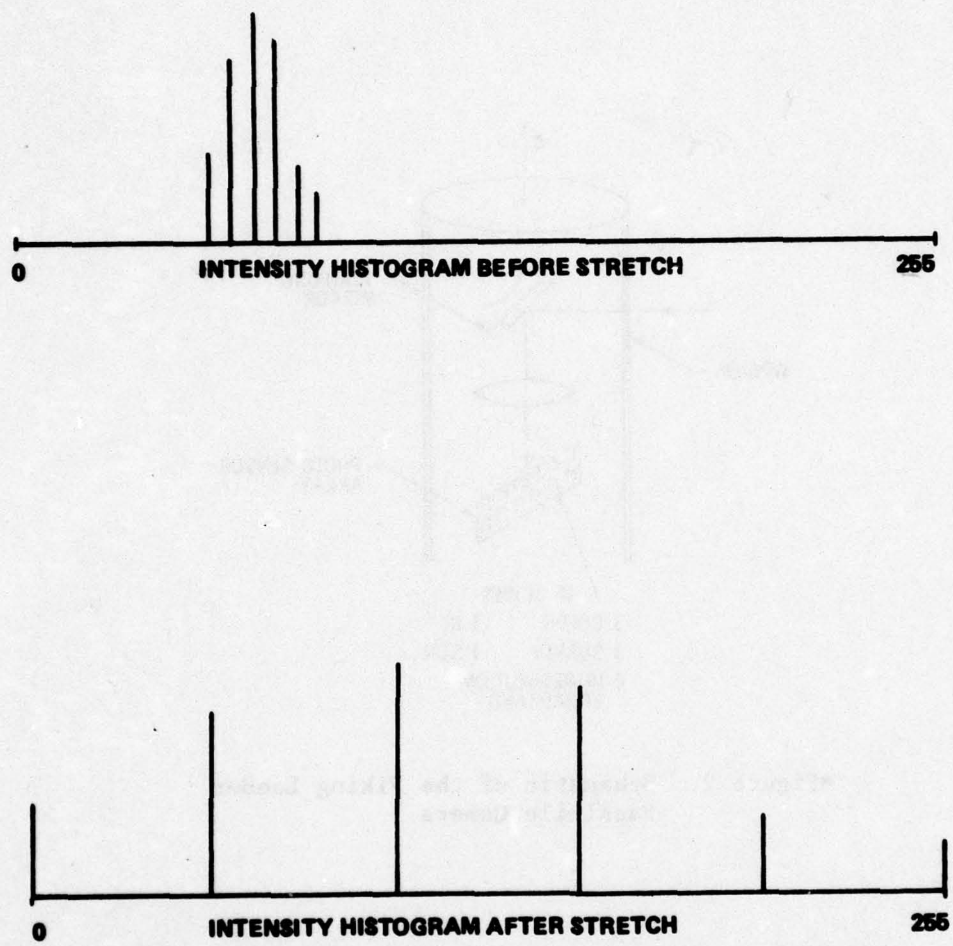

FIGURE 3. CONTRAST STRETCHING

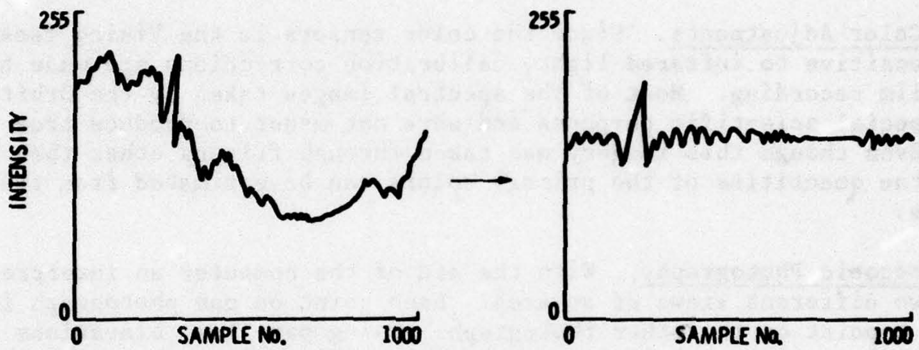

FIGURE 4. PICTORIAL REPRESENTATION OF DIGITAL HIGH-PASS FILTERING ** (LEFT, A PLOT OF INTENSITY ALONG A SINGLE LINE WITHIN A PARTICULAR IMAGE. RIGHT, THE RESULT OF APPLYING A HIGH-PASS FILTER TO THE IMAGE LINE. LOCAL DETAIL HAS BEEN RETAINED, BUT THE GENERAL LOW-FREQUENCY TREND FROM BRIGHT TO DARK HAS BEEN REMOVED BY THE FILTERING PROCESS.)

****Green, W. B., "Computer Image Processing -- The Viking Experience," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, June 6, 1977.**

will be drastically different from all those in its immediate neighborhood. JPL has a program that checks the images for pixels that deviate from their local average by more than 50 intensity levels. It regards these pixels as errors and replaces them with the local average.

Reduction of Residual Image. The effects of the residual image are lessened by subtracting a portion of the previous image from the one being exposed. The portion subtracted depends upon the pixel position on the frame, the brightness of the previous pixel, and the brightness of the present pixel.

Reduction of Shading Characteristics. A linear approximation is made of how the sensitivity of the vidicon tube changes as the wavelength of light and temperature change. Correction adjustments are then made according to this approximation.

True Color Adjustments. Since the color sensors in the Viking facsimile system are also sensitive to infrared light, calibration corrections are made to the data prior to film recording. Most of the spectral images taken by the Orbiter vidicons were for special scientific purposes and were not meant to produce true color imagery. Even though this imagery was taken through filters other then red, green, and blue, the quantities of the primary colors can be estimated from these photographs.

Stereoscopic Photography. With the aid of the computer an interpreter can match up two different views of an area. Each point on one photograph is correlated with a point on the other photograph. Using parallax, elevations can be calculated. As well as correlating photographs with one another, JPL is capable of also correlating such things as census data with a LANDSAT image.

DATA BASE. A massive image data base has been collected throughout the various projects JPL has been involved in. Over 30,000 images including the originals and enhanced versions were produced from the Mariner 9 project alone. This data base is stored on microfiche in a computer linked, data-management system. In order to retrieve an image, the user types a few key describing words into a teletype. The computer responds with the number of images it has fitting this description. The user again types in key words and the process continues until the number of photographs is small enough to view each one. The system automatically loads the microfiche cards into a reader displaying them in sequence to the user, enabling him to choose exactly which photographs he wants.

Section 1-3

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1-4 NASA: EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS) PROGRAM

Goddard Space Flight Center
Greenbelt, Maryland.
Contacts: Kevin Gilson, Fred McCaleb, Ronald Tognetti

ERTS contains two imaging systems, the return beam vidicon (RBV) system, and the multispectral scanner (MSS) system. These systems gather pictorial information about the earth's surface and transmit this to various ground receiving stations located in Greenbelt, Maryland; Gilmore Creek, Fairbanks, Alaska; Goldstone, California; and several foreign countries. This information is stored on magnetic tape, processed by a computer, and restored on magnetic tape. Depending upon the user and his applications, this tape will then either be further analyzed by computer or be used to produce a hard copy photograph that can be analyzed by photo interpreters.

The satellite circles the earth in a nearly North-South, sun-synchronous orbit allowing it to photograph the entire surface of the earth in 18 days. There are presently two of these satellites in operation, so essentially a picture of any part of the earth can be taken about once every nine days.

IMAGE DATA COLLECTION

Return Beam Vidicon System (RBV). The RBV system is essentially 3 televison cameras, each with a different spectral response. (See Fig. 5). The signals produced by these cameras are transmitted to earth in analog form. At first they were intended to be the major data gatherers, but that burden soon shifted to the MSS system when the cameras broke down on the first satellite.

Multispectral Scanner System (MSS). The MSS system consists of 24 sensors, four columns of six sensors each. Each column has a different spectral response as shown in Table 1. (None of the imagery produced by NASA is true color simply because none of the cameras or sensors are sensitive to blue light.) A plane mirror scans the image of the earth across this block of sensors. Each individual sensor emits electric signals that vary in intensity with the amount of light that strikes them. This analog information is digitized and then transmitted to the ground in a single stream of information. Since there are six rows of sensors, it is gathering six rows of pixel (picture elements) data per scan. Each entire image taken of the earth (100 nautical miles square) can be stored in approximately five-and-one-half inches of magnetic tape.

RECORDING DATA ON FILM

Electron Beam Recorder (EBR). The EBR is used to reproduce a black and white transparency for each of the spectral ranges, three from the RBV cameras and four

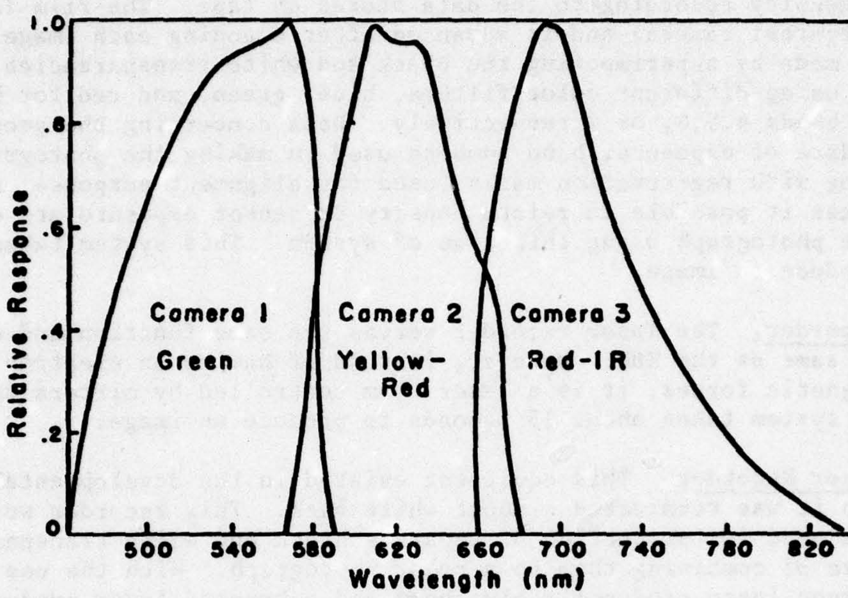

FIGURE 5. RESPONSE OF RBV SYSTEM *

TABLE 1. MSS SPECTRAL RESPONSE PASS BANDS **

Band	Wavelength Range
4	500 to 600 *nm*
5	600 to 700 *nm*
6	700 to 800 *nm*
7	800 to 1100 *nm*

*Polger, J. E., "Generation of Color Imagery from Earth Resources Technology Satellite (ERTS) Data Return," Eynard, R. A. ed., Color: Theory and Imaging Systems, Society of Photographic Scientists and Engineers, 1973, p. 339.

**Ibid, p. 341

from MSS sensors. The EBR is very much like a cathode ray tube with the phosphor screen replaced by a piece of film. The beam scans the film in a faster manner varying in intensity according to the data stored on tape. The film is in a roll (just like a typical camera) and is advanced after scanning each image. A color photograph is made by superimposing the black and white transparencies onto a piece of color film using different color filters, blue, green, and red for RBV bands 1,2,3 and MSS bands 4,5,6, or 7 respectively. Data concerning the geographical coordinates, date of exposure, band numbers used in making the photograph, and sun angle along with registration marks (used for alignment purposes) and a gray scale that makes it possible to relate density to sensor exposure are easily written on the photograph using this type of system. This system takes about 20 seconds to produce an image.

Laser Recorder. The laser recorder serves the same function and operates basically the same as the EBR. However, instead of having an electron beam controlled by magnetic forces, it is a laser beam controlled by mirrors and other optics. This system takes about 15 seconds to produce an image.

Color Laser Recorder. This equipment existed in the developmental stage before work on it was terminated a short while back. This recorder would have eliminated the need for production of separate black and white transparencies and the process of combining them to a color photograph. With the use of dichroic filters, an argon laser produced a blue beam and a krypton laser produced both a red and green beam. Each of these beams was individually modulated according to the data stored on magnetic tape. The three beams were then combined into one beam which is used to scan a piece of color film (see Fig. 6). Since this recorder was still in the developmental stages, it had a few major problems. Each piece of film had to be hand loaded into the machine and much hand tweaking (fine adjustments) had to be done before the production of each photograph. It was not uncommon to require six hours of work to produce a respectable photograph. Mr. Fred McCaleb felt that with a substantial amount of time and money this could have become a feasible system.

CRT Recorder. In the CRT recorder system, the image is displayed on a screen very similar to that of an ordinary television. Then basically a camera takes a picture of the screen. None of the prints made using this process were actually seen by the author but their quality (characterized as being very flat) was reported to be inferior to the quality of the prints produced by the EBR or laser systems simply because the hues produced by the phosphors in the screen were not the same as those passed by the filters used in color film.

Computer Processing of Data. The computer makes corrections in the data gathered by the RBV and MSS systems by taking into account the following things:

(a) Other data received from the satellite concerning such things as the orientation of the satellite to the earth and the angle of the sun.
(b) The differences in sensitivity of each RBV camera and MSS sensors.
(c) The direction and speed of the scan of the earth's image across the MSS sensors. (The light hits the blue sensor first and the red sensor last).
(d) The specifications of the film recording device that will be used to produce the photograph.

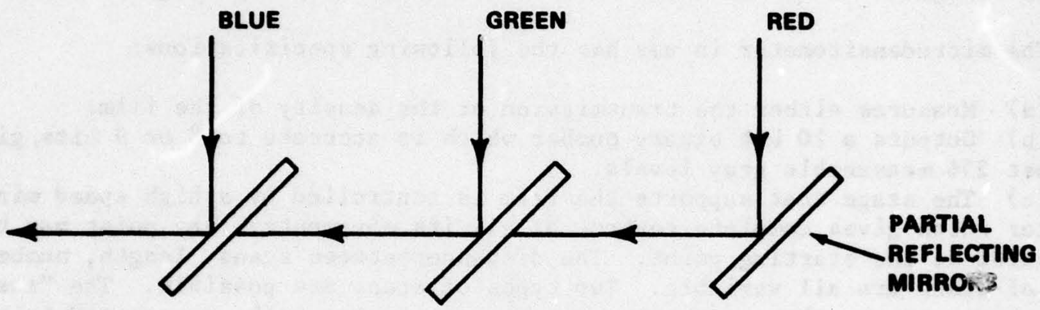

FIGURE 6. COMBINING THE LASER BEAMS

The computer also reorganizes the data, putting it back onto magnetic tape in the most suitable form for hard copy production or further computer analysis (quite common among users but not common at Goddard) depending upon the user's needs. These magnetic tapes are shelved in one of two buildings. When any specific image is to be reproduced, the tape containing the image must be located and loaded onto a tape drive by hand.

MICRODENSITOMETRY. The microdensitometer NASA has is used mainly to determine the modulation transfer function (MTF) of the system they are working with. Knowing the MTF they are able to predict how sharp edges will be and determine the smallest distinguishable object. They can also use it to analyze very small portions of a photograph, but it is too slow to be used for redigitizing photographs. Using its smallest sampling size (2 micron sample), it would literally take days to redigitize a 200 mm x 200 mm (their standard size) photograph.

The microdensitometer in use has the following specifications:

(a) Measures either the transmission or the density of the film.

(b) Outputs a 10 bit binary number which is accurate to 8 or 9 bits, giving at least 256 measurable gray levels.

(c) The stage that supports the film is controlled by a high speed minicomputer which gives complete control of all its movements. Any point may be designated as the starting point. The distances between scans, length, number and speed of scans are all variable. Two types of scans are possible. The "raster" first scans across, then scans the next row on its way back, as opposed to the "edge" which scans across, returns, and scans the next line in the same direction as the first.

(d) The distance between the samples and the size of the samples is also variable.

According to Mr. Fred McCaleb, advances they make within the next few years will bring them closer to complete digitization. He foresees the final product changing from photographs to high density magnetic tape. This tape will store corrected image data that is accurately referenced to geographical coordinates. This type of data will allow computers to not only analyze a single image but also allow them to compare images of the same ground area.

Section 1-4

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1-5 NAVAL OCEAN SYSTEMS CENTER: SENSOR PROCESSING AND ANALYSIS DIVISION

San Diego, California
Contacts: Thomas R. Little, Lee A. Wise

The United States Postal Service (USPS) is sponsoring work at NOSC investigating the possibilities of an Electronic Message Service (EMS). Instead of transporting letters and documents by planes, trains, or trucks, they would be digitized and transmitted electronically to their destinations. The goals that have been set for this research are:

1. The data can be typed, printed, handwritten, or continuous tone form.
2. The text can be most colors on most colors of paper.
3. The scanning technique must be capable of 80 lines per centimeter.
4. Within the limits of resolution, the quality of the reproduced transmitted message must be very nearly equal to that of the original.
5. In order to handle the volume anticipated for the EMS system, the scanning rate must be equivalent to twenty pages (8½" x 11") per second.

The NOSC system at the time of this report is shown in Figure 8.

PRESTORAGE PROCESSING. A great deal of the work done by NOSC has been in the area of prestorage processing. Prestorage processing involves taking a preliminary scan of the image and processing some data in order to optimize the methods used for the final scanning and data collection. Doing this enables them to:

1. Determine the color of illumination in order to get the desired contrast.
2. Distinguish between bi-level data (e.g., a typed page) and continuous tone data (e.g., a photograph).
3. Decide how many data points need to be taken.
4. Decide whether or not to use thresholding. If the brightness is above a certain level, it is white; if not, it is black.
5. Determine the bit precision needed.
6. Determine which compression techniques will be most useful and be able to implement them as the data is collected.
7. Determine which enhancement techniques will be most helpful if any, and be able to implement them as the data is collected. This prescanning process is what will allow them to obtain quality reproductions when scanning at a rate of twenty pages per second. The first set of sensors in Fig. 7 are the prescanning sensors.

IMAGING. The page or photograph is attached to a 40-inch-circumference drum scanner. Illumination is provided with high-brightness fluorescent lamps, and the image is focused through a system of optics onto the surfaces of CCD (charged

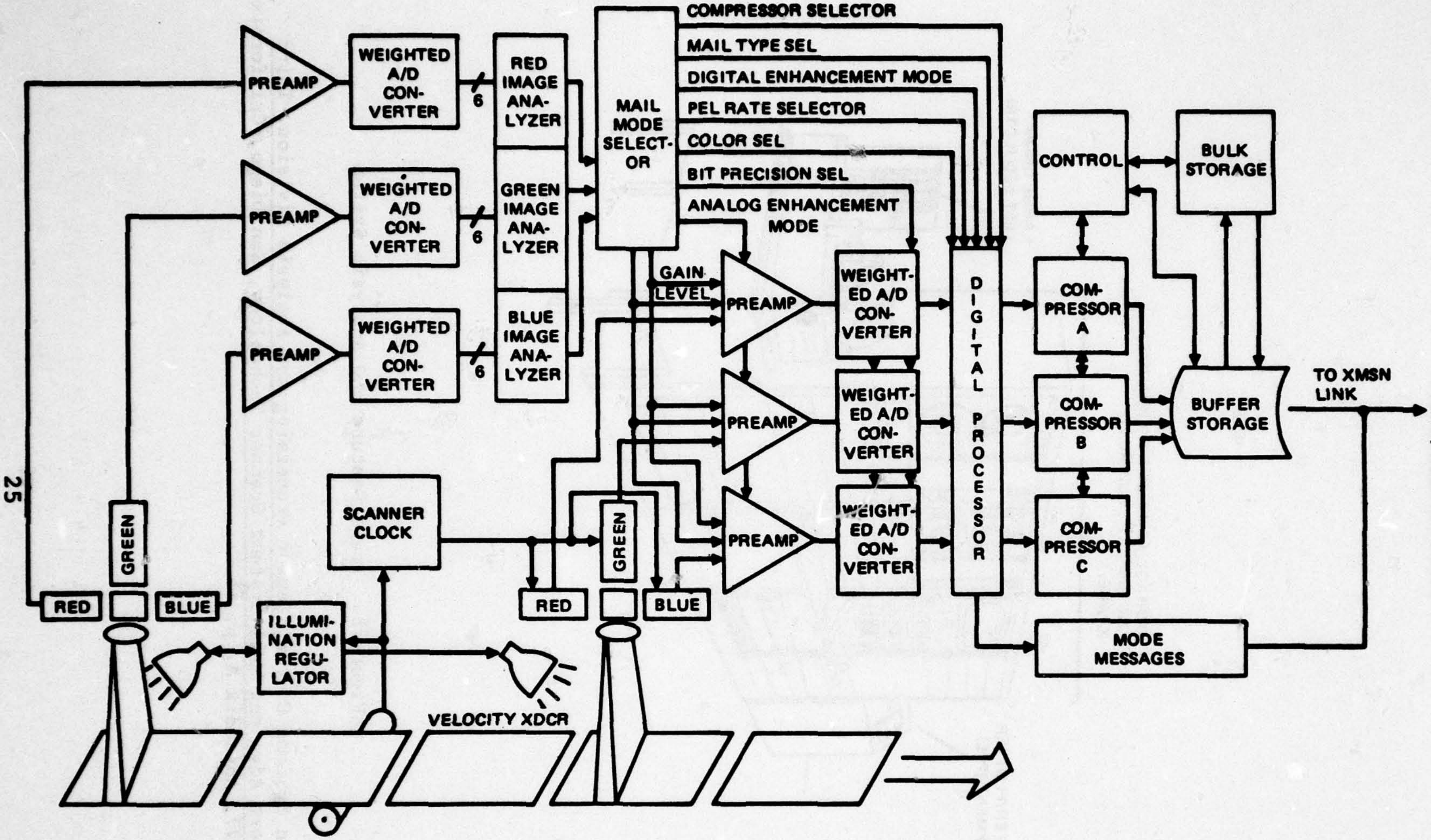


*Figure 7. Advanced Electronic Input Terminal

*Naval Electronics Laboratory Center, Display Division, Second Annual Report Advanced Mail Systems Scanner Technology, San Diego, California, October 1976, Vol. 1, Appendix A, p. 5.

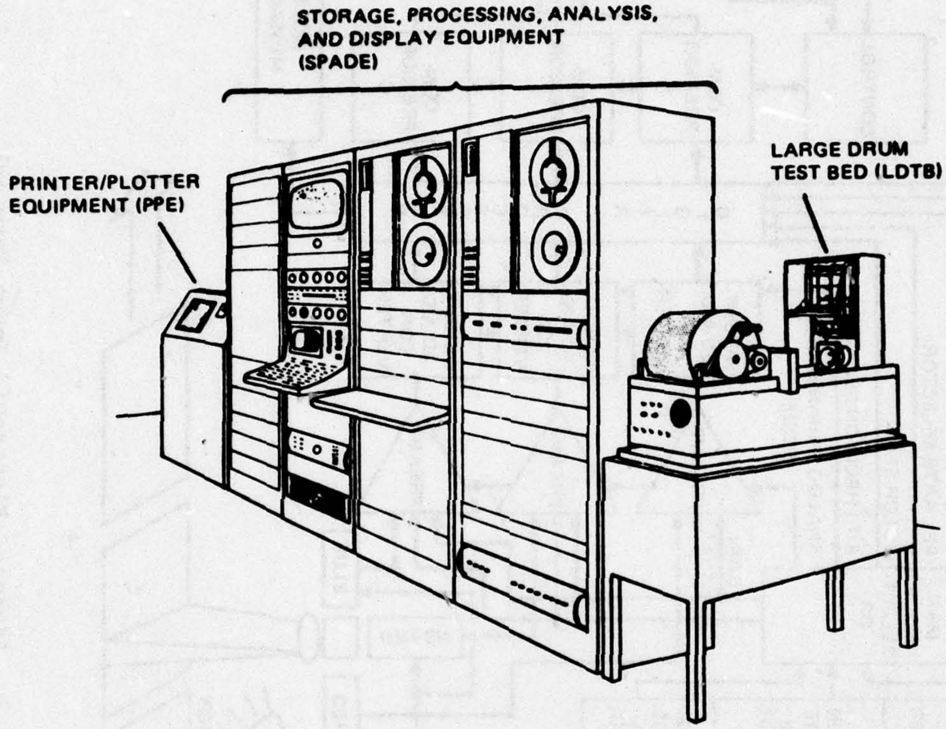


**Figure 8. Image Capture and Analysis System

**Naval Ocean Systems Center, Sensor Processing and Analysis Division, Third Annual Report Advanced Mail Systems Scanner Technology, San Diego, California, October 1977, Appendix A, p. 18.

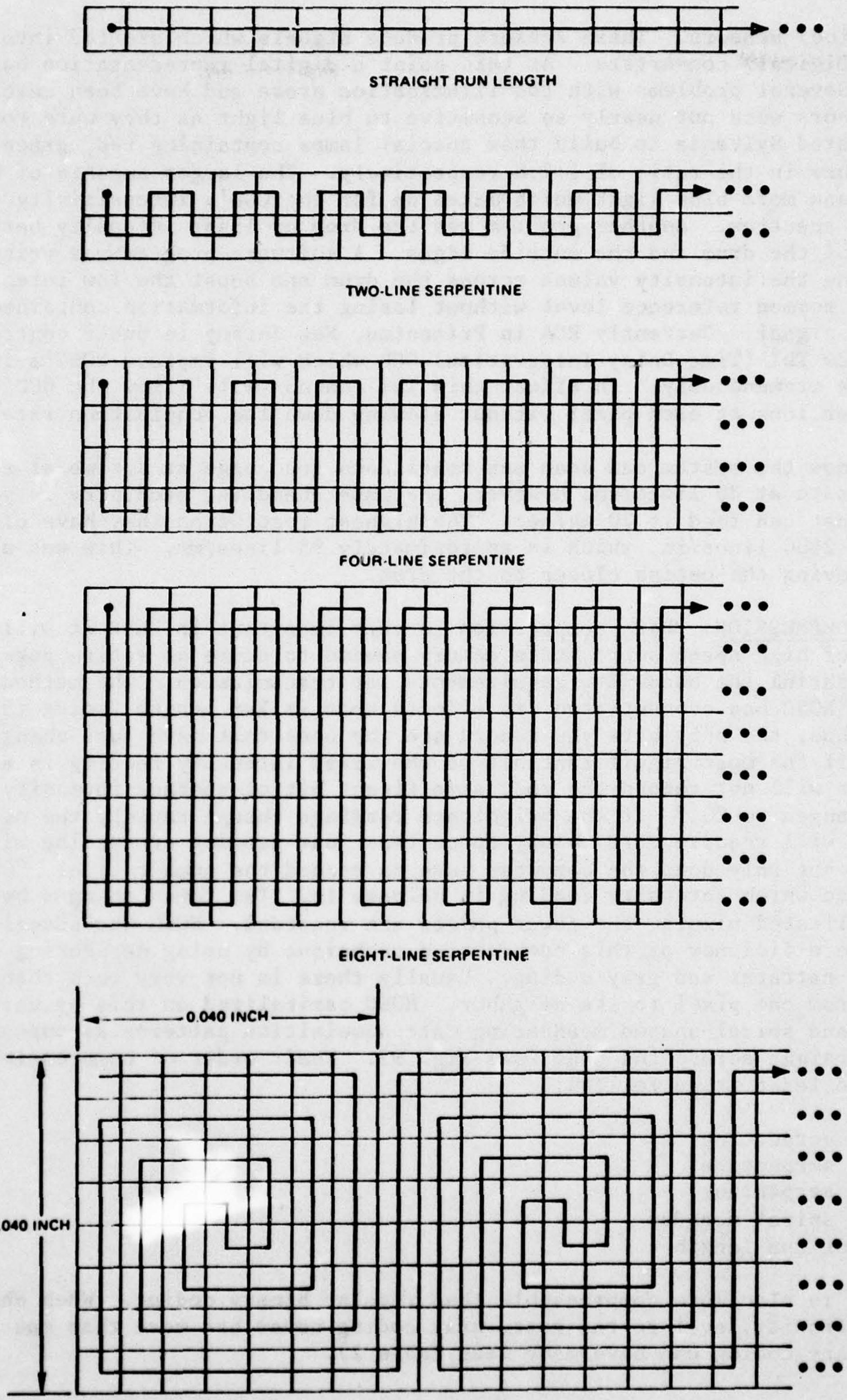
coupled device) sensors. These sensors produce signals which are fed into A/D (Analog to Digital) converters. At this point a digital representation has been obtained. Several problems with the illumination arose and have been resolved. The CCD sensors were not nearly so sensitive to blue light as they were to red, so NOSC contracted Sylvania to build them special lamps containing red, green, and blue phosphors in the ratio of 1:2:8 respectively. The larger amounts of blue phosphors mean more blue light which makes up for the CCD's insensitivity to that part of the spectrum. Another problem was the drop of light intensity between the center of the drum and the outside edges. A software program was written that would examine the intensity values across the drum and boost the low intensity values to a common reference level without losing the information contained in the varying signal. Currently RCA in Princeton, New Jersey is under contract to develop a new TDI (Time Delay Integration) CCD which will improve NOSC's imaging capabilities tremendously. In effect this TDI concept will allow the CCD's to take a longer look at each pixel without slowing down the acquisition rate.

Right now the system can scan one continuous tone page at a time at a 20 pg/sec. rate at 80 lines/cm; however, the paper-handling machinery is yet to be developed that can feed it 20 pg/sec. The highest resolution they have officially obtained is 2400 lines/in. which is approximately 95 lines/mm. This was accomplished by simply moving the optics closer to the drum.

DATA COMPRESSION. Data compression is very important in that it will reduce the amount of high speed solid state memory needed to store an entire page of data as well as shrink the bandwidth requirements for transmission. The method of compression NOSC has concentrated its efforts upon is Run Length Coding (RLC). In this method, the only bits you record are the ones that have just changed. Therefore, if the most significant bit of the first intensity reading is a "1," the computer will not record the most significant bit of another intensity reading until it changes to "0." If the brightness readings change rapidly the use of this method will require more memory space than just storing everything without it, because not only does the computer have to record the number (i.e. "0" or "1") but also which intensity reading it belongs to. The fewer changes between adjacent collected pixels, the fewer points are recorded. NOSC has successfully improved the efficiency of this compression technique by using meandering data acquisition patterns and gray coding. Usually there is not very much change in intensity from one pixel to its neighbor. NOSC capitalized on this by using serpentine-and spiral-shaped meandering data acquisition patterns as opposed to scanning straight across the page (see Fig. 9). Their order of compressibility from most to least is as follows:

8 line serpentine
4 line serpentine
2 line serpentine
Double spiral meander
Straight run length

Gray coding is also more compressible than regular binary coding. When changing from one intensity level to the next, gray coding never has more than one bit change whereas binary coding can have many (see Table 2).



Double-Spiral Meander

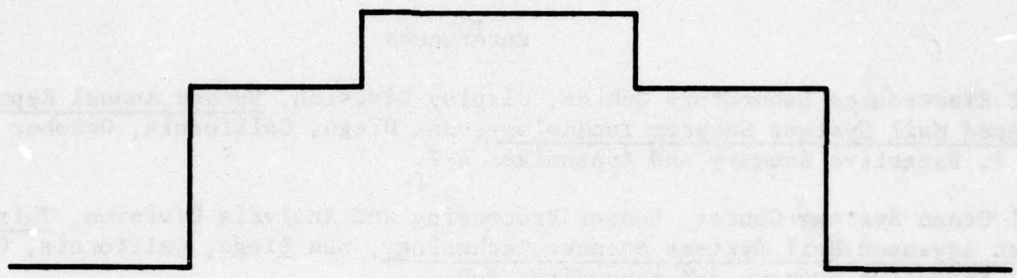
Figure 9 Meander patterns.

Table 2. Compressibility of Binary Code and Gray Code

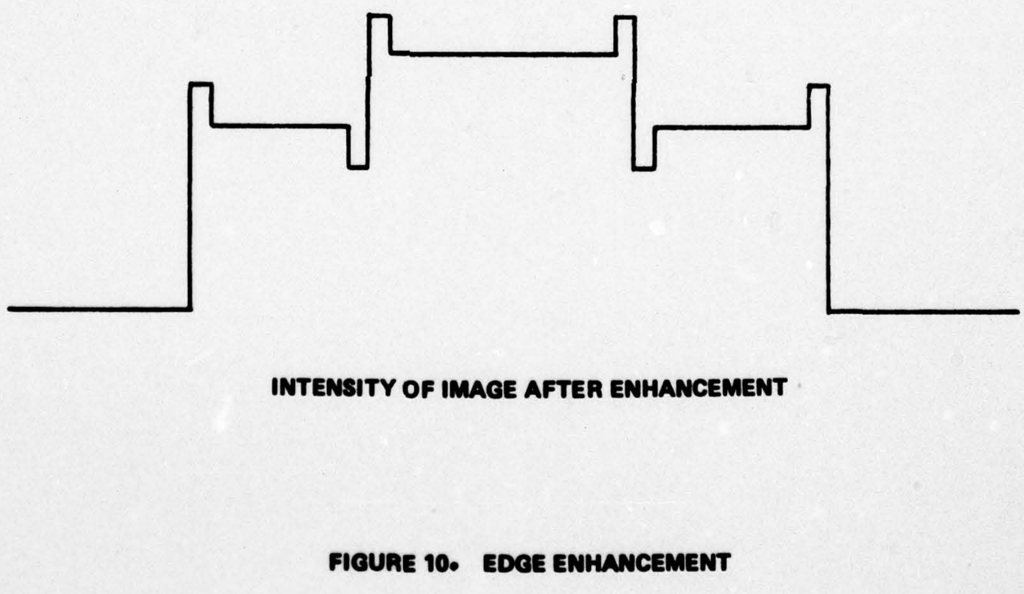
	Base 10	Binary Code	No. of Bit Changes in Binary Code	Gray Code	No. of Bit Changes in Gray Code
Black	0	0000		0111	
	1	0001	1	0110	1
	2	0010	2	0100	1
	3	0011	1	0101	1
	4	0100	3	0001	1
	5	0101	1	0000	1
	6	0110	2	0010	1
	7	0111	1	0011	1
	8	1000	4	1011	1
	9	1001	1	1010	1
	10	1010	2	1000	1
	11	1011	1	1001	1
	12	1100	3	1101	1
	13	1101	1	1100	1
	14	1110	2	1110	1
White	15	1111	1	1111	1
	TOTAL NUMBER OF CHANGES		26		15

ENHANCEMENT. NOSC has worked with several types of image enhancement. When working different color backgrounds, it is often desirable to use color filtering in order to get better contrast. Edges can be enhanced by overemphasizing them (see Fig. 10). The enhancement and data compression is done in software off line, but the programs simulate the actual hardware that when built will be able to perform these functions in real time as the data is acquired.

HARD COPY OUTPUT. The printer used by NOSC has a bi-level (black and white; not continuous tone) output. Versatek is under contract to develop a black and white electro-static printer that outputs 10 pg/sec. So far they have only achieved an output of about 6 pg/sec.



INTENSITY OF IMAGE BEFORE ENHANCEMENT



INTENSITY OF IMAGE AFTER ENHANCEMENT

FIGURE 10. EDGE ENHANCEMENT

Section 1-5

References

Naval Electronics Laboratory Center, Display Division, Second Annual Report Advanced Mail Systems Scanner Technology, San Diego, California, October 1976, Vol. 1, Executive Summary and Appendixes A-F.

Naval Ocean Systems Center, Sensor Processing and Analysis Division, Third Annual Report Advanced Mail Systems Scanner Technology, San Diego, California, October 1977, Executive Summary and Appendixes A-D.

Kosonocky, W., Angle, R., Carnes, J., Criado, A., Sauer, D., Shallcross, F., CCD Page Reader for Mail-Scanning Applications, RCA Laboratories, Princeton, New Jersey, May 15, 1977.

1-6 NAVAL OCEAN SYSTEMS CENTER: SIGNAL PROCESSING AND DISPLAY DIVISION

San Diego, California
Contact: John A. Roese, Ph.D

NOSC is equipped with a Comtal 8300 digital display system that it uses in conjunction with a Univac 1108 computer to analyze digital images. This section does not have its own image digitizing facilities, so all of this type work is done out-of-house. The digital display is a 512 x 412 array of points which does not completely fill the entire screen of the monitor. This minimizes error introduced into the picture by the curvature of the screen and also lets one see all of the data, as opposed to a regular television which loses all of the outer points off the edges of the screen. The data remains in digital form until just before being put onto the screen. This eliminates virtually all smear between pixels, allowing each pixel to be totally different from its neighbors. A digital television has remarkably better quality images than a conventional television.

ANALYSIS OF PICTORIAL DATA. The images examined do not necessarily have to be photographs or x-rays. Much of the work down at NOSC has been on data correlation images. In the correlation displays gray scale of color assignments can be used to represent the range of correlation values displayed. The Comtal system plus the software implemented by NOSC has many outstanding capabilities for image analysis.

It is able to display a histogram of the intensity distribution of the image (i.e., how many pixels of each possible intensity appear in a particular image). This is often very helpful in determining how one wants to shape the response curve of the display. If all of the pixels fall in a small intensity range, one is able to stretch that small range across the entire intensity range of the screen. In order to obtain more detail in the highlight, shadow, or medium intensity area/s they may be stretched or compressed into as much of the total intensity range as wished.

The human eye is only capable of distinguishing ten to fifteen shades of gray, but with six bits of precision in the D/A converter the display presents sixty-four levels. The computer can pick out any intensity or intensity range and assign any designated color to it. This makes these points stand out from the rest of the image. It is also possible to color code the entire intensity range. These colors assigned to the intensity values can be changed to the most helpful arrangement.

Programs have been developed that take the Fourier and Hadamard transforms of an image and then display them on the screen. The Fourier transform allows one to identify the major frequency components of the image. Individual frequency components can be studied by filtering everything else out and then taking the inverse transform. The image can be studied with particular components excluded by filtering them out and then taking the inverse transform. The Hadamard transform is used to enhance lines in time vs. frequency displays.

The system is also capable of using computer graphics to give one a perspective view of the image. The high intensities are represented by peaks and the low intensities by valleys. This perspective view can be rotated giving almost any point of view one wishes. This feature combined with color coding gives an excellent display of the data.

All of these methods combined make many image patterns and characteristics that were once difficult or impossible to recognize, very obvious. They are all done in real time so that a person can work interactively with the computer.

3D TELEVISION. NOSC has also developed a stereoscopic television system (see Fig. 11). An everyday television set shows us thirty frames (pictures) per second. Each frame is produced by two field scans of the screen by an electron beam. One field scan fills in the odd lines and the other fills in the even lines. This system uses two cameras to obtain two different perspective views of the object. The odd scan lines come from one camera while the even scan lines come from the other, producing two separate images on the screen. Each has only half the vertical resolution of a normal television image making the overall images a little grainy. The viewer wears a pair of PLZT (lead lanthanum zirconate titanate) ceramic glasses that receive electrical pulses from the vertical retrace sync pulse of the television monitor. These glasses act as shutters, only permitting one's left eye to see the image produced by the left camera and one's right eye the image produced by the right camera. This system differs from other stereoscopic systems in that it allows many people to observe the screen at once and the viewers are not bound to looking through bulky optical devices but may move freely about the room without changing the stereo effect.

The effectiveness of the stereoscopic effect depends greatly upon how the cameras are set up. The most important factors are:

(a) The angle between the central rays of the two cameras. This is dependent upon the distance from the object to the cameras and the separation distance between the two cameras. In order to get a good effect the cameras generally must be greater than 2.5 inches (normal distance between a person's eyes) apart.

(b) The distance between the ray intercept and the object.

It is not absolutely necessary to have two television cameras in order to get a stereoscopic image. The image can be obtained from a moving camera or an optical device can be used to provide one television camera with two different views.

A computer driven display unit also has the capability of a cursor that will not only move in the x and y but also in the z direction. This overall system literally and figuratively adds a new dimension to video viewing.

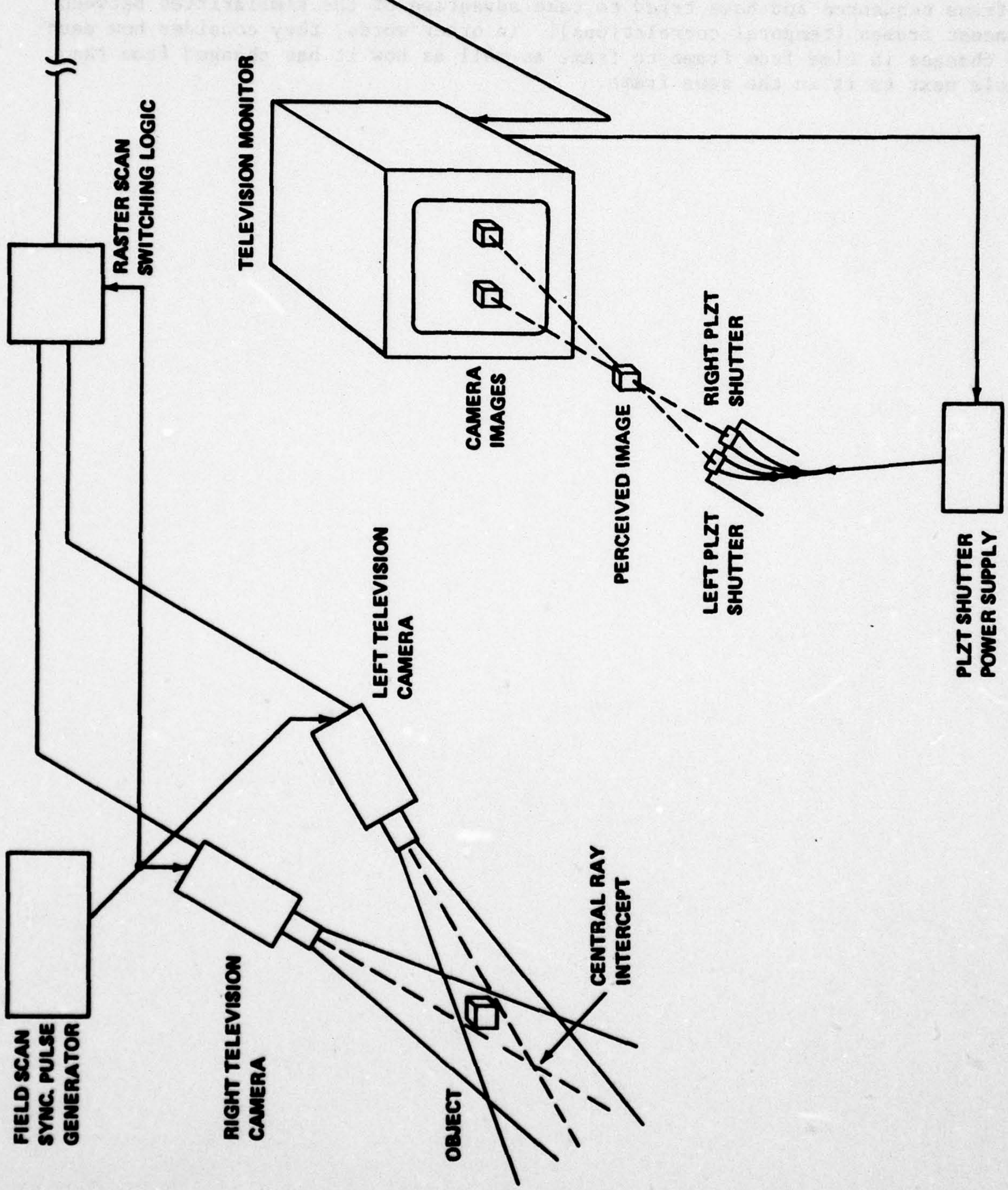


FIGURE 11. TWO-CAMERA PLZT STEREOSCOPIC TELEVISION SYSTEM

<u>INTERFRAME CODING OF DIGITAL IMAGES</u>. Motion pictures involve series of very similar images. John Roese has also been involved in developing techniques for compressing the number of bits needed to store and transmit digital images of this variety. Basically they have extended single frame coding (compression) techniques to frame sequences and have tried to take advantage of the similarities between adjacent frames (temporal correlations). In other words, they consider how each bit changes in time from frame to frame as well as how it has changed from the pixels next to it in the same frame.

Section 1-6

References

Roese, J. A., and Khalafalla, A. S., "Stereoscopic Viewing with PLZT Ceramics," Ferroelectrics, 1976, Vol. 10, pp. 47-51.

Roese, J. A., Interframe Coding of Digital Images Using Transform and Hybrid Transform/Predictive Techniques, NUCTP 534 Naval Undersea Center, San Diego, California, June 1976.

Roese, J. A., McCleary, L. E., and Khalafalla, A. S., "3-D Computer Graphics Using PLZT Electro-Optic Ceramics," Society for Information Display International Symposium Digest of Technical Papers, Paper 4.2, 1978.

1-7 SRI INTERNATIONAL: DATA BASES

Menlo Park, California
Contacts: Daniel Sagalowicz, Gordon Novak

The broad goal of SRI International in its work on data bases has been to minimize the impositions put on us by the computer/s we work with. The major imposition the computer puts on us is that of language. If one wishes to use a computer one must either learn the language and structures of the computer or work through a programmer.

SRI International's LADDER system (Language Access to Distributed Data with Error Recovery; see Fig. 12) which is in operation over ARPANET (a network of computers spread across the country under the control of the Advanced Research Projects Agency) for the most part eliminates this imposition. It is comprised of three major components: the Natural Language Interface, Intelligent Data Access, and File Access Management. The Natural Language Interface allows the user to ask the computer questions in his own natural language. The question does not necessarily have to be in proper English and the program can even correct minor spelling errors. The Intelligent Data Access breaks the question down into smaller queries and determines which files must be accessed in order to obtain the answer. Two methods can be used to do this operation. The program can then determine the first query, obtain an answer, then determine the next query, determine its answer, and so on, or it can first determine all the queries and then find the optimal way to access all the required files in order to get the overall answer. The former method is approximately an order of magnitude faster but it occasionally cannot answer answerable questions. The File Access Management component uses a model of the entire data base to determine the files requested by the Intelligent Data Access component. It establishes a connection with the correct file in the correct computer, monitors the response, and recovers from most errors that may occur. If the computer goes down it tries to find another computer containing the same information. If it is wrong about what is stored in the files of a computer, it corrects its model of the data base and again tries to locate another computer containing the information it is looking for.

A K-NET (Knowledge Network) forms a real life model that classifies all the data stored. All the so-called reasoning that the program does is hinged on this format. A K-NET is a set of nodes connected by arcs. The nodes represent entities and situations, etc. The outgoing arcs represent such things as a "subset of" or an "element of" while incoming arcs represent such things as "owner of" or "builder of." One of the characteristics of a K-NET that makes it so useful is the ability to have subnets where a node in one K-NET can be an entire K-NET in itself. An example of a simple K-NET is shown in Fig. 13.

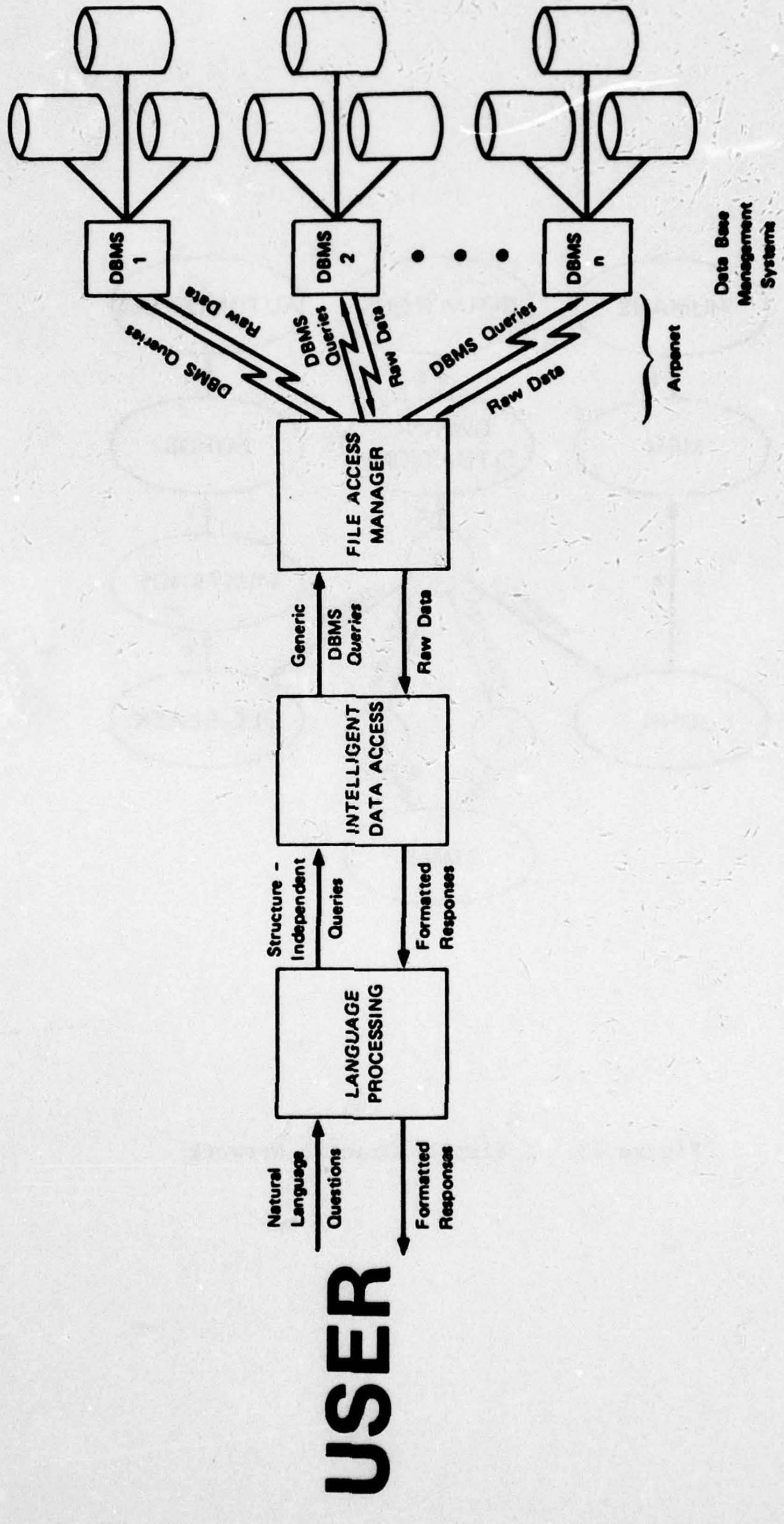


Figure 12. Overview of the LADDER System

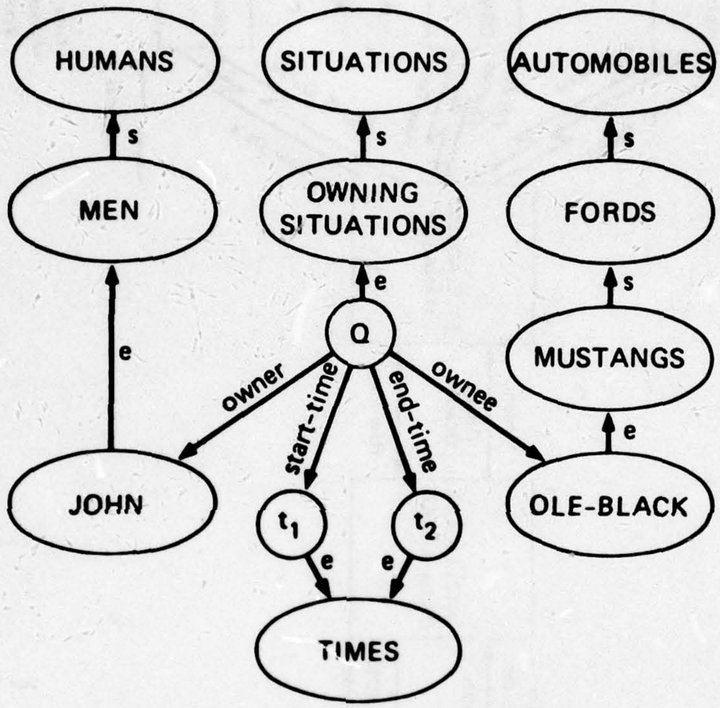


Figure 13. A Simple Semantic Network

This overall system is able to give answers to one's untranslated questions in real time. In order to do this, it only makes two assumptions. First, that you know what type of information you can get from it; and second, that you are asking relevent questions.

1-8 SRI INTERNATIONAL: DESCRIPTIONS OF PHOTOGRAPHS

Menlo Park, California
Contact: Martin A. Fischler

The work discussed here has been directed towards providing the computer with a description of an image (photography or other) without knowing in advance what kind of questions the computer will be asked about it. This problem is yet to be solved in its entirety, but its study has uncovered a mass of interesting material to think about when attempting to describe images.

Most of the work done has involved studying how we humans describe images and what kind of information we store about them. There are several natural methods we use when describing images:

1. Central focusing-the main object of the picture is picked out first and then the rest of the picture is described in relation to it.

2. Descriptor approach-key words are picked that bring out the main points of the picture.

3. Partition approach-the picture is broken into sections (thirds or quarters etc.) and each section is described individually.

4. Classification approach-the areas of interest such as lakes, shopping centers, or docking areas are identified and described individually.

5. Unorganized listing-the picture is looked over and observations are listed as they are made.

There are also several different purposes we can have in mind when describing pictures. Some narrow purposes would be:

1. Reconstruction-the picture would actually be reformed from this description. It would have to include very thorough and accurate information concerning the size, shape, color, texture, etc. of the picture.

2. Classification-the picture would be put into a distinct category. The describer would have to know which categories are possible and the characteristics of each category.

3. Retrieval-the user would be able to determine the content and meaning of each picture.

4. Comprehension-this would aid in the understanding of the picture.

Broader purposes would be things like:

1. Painting a mental image-this would give the user a good mental image of what the picture looked like.

2. Answering questions-this would answer questions directly without showing the picture to the user.

We also have widely varied backgrounds. Are you familiar with the subject matter? What type of experience have you had with it? The answers to these questions affect our descriptions of images very much. Oftentimes much of our description comes from assumptions we make based on our background and not on the actual information obtained from the image. As you can see, the number of possible descriptions for one image is almost unlimited. Our descriptions vary not only because we use different methods of description and different purposes for describing, but also because we all have different backgrounds.

A substantial amount of the variation in descriptions can be eliminated by providing proper training of the describers. This will assure that all of them will be using the same methods for the same purpose, and will give them more similar backgrounds.

Some types of work that require descriptions of images are:

1. Photointelligence

2. Publishing house art library

3. Broadcasting corporation picture library

4. University library

5. TV or movie studios

Section 1-8

References

Sacerdoti, E. D., Mechanical Intelligence: Research and Applications, SRI International, Menlo Park, California, December 1977.

Firschein, O., Fischler, M. A., "Describing and Abstracting Pictorial Structures," Pattern Recognition, Pergamon Press, Great Britain, 1971, Vol. 3, pp. 421-443.

Firschein, O., Fischler, M. A., "A Study in Descriptive Representation of Pictorial Data," Pattern Recognition, Pergamon Press, Great Britain, 1972, Vol. 4, pp. 361-377.

SECTION 2

WHO'S WHO

2-1 GOVERNMENT INSTALLATIONS

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
Advanced Research Projects Agency		Military	Sponsoring research in the areas of image understanding and image processing	
EROS Data Center U.S. Geological Survey Sioux Falls, S. Dakota 57198	Frederika A. Simon (605) 594-6511	Data Base for LANDSAT, Apollo, Gemini, Skylab, etc. imagery	Computer index shelf storage of images	
NASA Goddard Space Flight Center Greenbelt, Md.	Kevin Gilson (contractor) (301) 982-6251 Fred McCaleb (301) 982-2819	Production of ERTS, LANDSAT imagery	Vidicon cameras Multispectral scanners Electron beam recorders Laser recorders CRT recorders Scanning microdensitometer Obtain original ERTS images, enhance & correct images output hard copy images	
NAMRL Bldg. 420 Michond Assembly Facility 13800 Old Gentilly Rd. New Orleans, La. 70189	Ronald Tognetti (Ampex field service engineer) (301) 982-2826			Dick Irons (chief of Data Branch) (504) 255-4890

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
Naval Ocean Systems Center (NOSC) Sensor Processing and Analysis Division Code 732 San Diego, Ca. 92152	Frank Martin (714) 225-2773 Autovon 933-2773	USPS Advanced Mail Systems Electronic Message Service (EMS)	Large & small drum images Conrac display Image computer	
	Thomas Little Autovon 933-6169		Utilize CCD & TDI imaging techniques Image Acquisition rate of 20 pages/sec.	
	Lee Wise Autovon 933-6169		Automatic film Data Reduction	
Naval Ocean Systems Center (NOSC) Signal Processing and Display Division San Diego, Ca. 92152	John A. Roese Autovon 933-2391	3-D Television correlation of Data	Comtal image display system Univac 1108	
			Image analysis Image compression PLZT ceramics	
Naval Research Laboratory (NRL) Washington, D.C. 20375	David R. Barbe (202) 767-2408	Periscope imagers RPV Mortar reconnaissance Low light level imaging	CCS's Theoretical as well as applications	Ken Ferrous (Mortar reconnaissance)

2-2 PRIVATE INDUSTRIES

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
Ampex Corporation 401 Broadway Redwood City, Ca. 94063	William F. Justus (Product Manager Audio-Video Systems Division)	Electronic Still Store (ESS) image data base for television broadcasting industry	Quick recall data base Manufacture & sale of equipment	
Comtal Corporation P.O. Box 5087 Pasadena, Ca. 91107	Lovell C. Chase (Vice President Marketing) (213) 793-2134	Image processing & analysis	High resolution digital monitors & image computer Manufacture & sale of equipment	
Dicomed Corporation 9700 Newton Ave. So. Minneapolis, Minn. 55431	Wayne A. Huelskoetter (Vice President) (612) 888-1900		Image digitizers Soft copy displays CRT recorders Manufacture and sale of equipment	
DS America, Inc. Suite 405 10 Gould Center Rolling Meadows, Ill. 60008	Thomas Jeffers (Vice President of Marketing) (312) 640-6560		Scanner digitizers scanner recorders Manufacture and sale of equipment	
Environmental Research Institute of Michigan (ERIM) Box 8618 Ann Arbor, Mich. 48107 (313) 994-1200	Ronald Fairchild X489	Remote Sensing LANDSAT High-resolution radar imaging	Radar and optics Infrared and optics	Rod Dallaire X507
	Stan Sternberg X338	3-D sensor	Research oriented	

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
General Electric Space Division Valley Forge Space Center P.O. Box 8555 Philadelphia, Pa. 19101		LANDSAT, ERTS	Computer processing of imagery	
Hughes Aircraft Co. 1950 East Imperial Highway El Segundo, Ca. 90245 Space & Communications Group		Built sensors (MSS) for ERTS satellite		
IBM Federal Systems Division 10215 Fernwood Rd. Bethesda, Md. 20034	John F. Timmins (301) 840-6908 or X0111	Processing of LANDSAT ERTS imagery	Development of Soft & Hardware computer systems. Image Correction of Platform, Sensor, Atmospheric, & Scene effects Produce very pretty images	

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
Image Systems, Inc. P.O. Box 2488 Culver City, Ca. 90230 (213) 390-3378 Dealer in Wash. D.C. CRW Inc. 901 N. Washington St. Alexandria, Va.	Stan Rosen (703) 836-7120	Quick recall computer linked microfiche data base systems	I.S.I.-Manufactures equipment & computer software CRW-Sells equipment, makes microfiche	CRW Martin Chase Robert Chase
Interpretation Systems, Inc. P.O. Box 1007 Lawrence, Kansas 66044 (913) 842-5678		Processing of LANDSAT & other digital data	Image digitizers (camera) Monitors Image processing system Manufacture & sale of equipment	
I^2S Image Processing Systems Stanford Technology Corp. 650 N. Mary Ave. Sunnyvale, Ca. 94086 (408) 737-0200		Processing of LANDSAT, ERTS & other digital imagery	Image computer & monitors	
Jet Propulsion Lab. California Institute of Technology 4800 Oak Grove Drive Pasadena, Ca. 91103	William B. Green (213) 354-5016	Mariner & Viking Imaging systems & Image processing	Vidicon cameras Diode sensors Image processing computers Monitors Laser recorders	

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
Lockheed Missiles & Space Company Space Systems Division 1111 Lockheed Way Sunnyvale, Ca. 94088	Charles R. Lomax (manager of marketing support & Administrator of Space Systems Division)	SEASAT imagery Space Telescope		
Log E/LogEtronics, Inc. 7001 Loisdale Rd. Springfield, Va. 22150 (703) 971-1400			Automatic variable dodging printer Automatic variable dodging enlarger Manufacture and sale of equipment	
Optronics International 7 Stuart Road Chelmsford, Mass. 01824 (617) 256-4511	Alan S. Barrett (Sales Dept.) Stan Goodman (516) 921-3737	Scientific image processing	Digital microdensitometers Drum scanner digitizers Drum recorder	
	Glenn G. Coppelman		Manufacture and sale of equipment	
Perkin-Elmer Electro-Optical Div. 916 Meridian Ave. South Pasadena, Ca. 91030 (213) 682-3391			Microdensitometer digitizers Manufacture & sale of equipment	

Installation & Address	Person/s Contacted & Positions if Known	Major Applications	Types of Equipment Used and Type of Work Done	Other Possible Contacts
Photo Digitizing Systems, Inc. 820 S. Mariposa St. Burbank, Ca. 91506	Ed Caplan (Vice President) (213) 849-6251	Automatic film data reduction	Camera image digitizers Digital processors Manufacture and sale of equipment	
Quantex Corp. 252 N. Wolfe Rd. Sunnyvale, Ca. 94086 (408) 733-6730			Camera image digitizers Digital image processor Manufacture and sale of equipment	
Sci-Tex North America Corporation 1450 Broadway New York, N.Y. 10018	Neil Yingling (staff consultant gov't representative) 4430 Willow Run Dr. Dayton, Ohio 45430 (513) 429-0544	Graphics & Textiles	Laser plotter Laser scanner digitizer Color manipulation system Manufacture & sale of equipment	
SRI International Artificial Intelligence Center 333 Ravenswood Ave. Menlow Park, Ca. 94025 (415) 326-6200	Martin Fischler Gordon Novak J. M. Tenenbaum Daniel Sagalowicz	ARPANET Natural language data base HAWKEYE-registration of image with data base image. Automatic data gathering, measurements taken	Data bases Image understanding Representations of images Sponsored by ARPA	Earl Sacerdoti Harry Barlow Lin Qualm
Talos Systems Inc. 7419 Helm Drive Scottsdale, Arizona 85260 (602) 948-6540	Morris Bowles (Microsystems Sales Co. Alexandria, Va.) (703) 971-8982		Image digitizers selected individual points Manufacture and sale of equipment	

SECTION 3

EDUCATION SOURCES

School or Educational Source	Type of Program	Equipment or Resources Available	Applications of Work	Teachers
American University	4 day short course CCD July 11-14, 1978			David F. Barbe
ARPA Conference	Conference discussing work sponsored by ARPA, much of which has to do with Photo-electro-optics		Image processing Image understanding Pattern recognition	
Carnegie-Mellon University Pittsburgh, Pa. 15213	Graduate programs leading to MS or Ph.D degrees in EE EE Research areas: Biomedical Graduate programs leading to Ph.D degrees in CS CS Research areas: Image Understanding Image Data Bases	(2) PDP 11/40 E computers (3) PDP 10 computers Homemade color display (2) B&W monitors Gould B&W dot matrix printer All digitization work done out of house sponsored by ARPA	Natural scene analysis Image understanding Image data bases Biomedical	Raj Reddy (CS) (412) 578-2597 Ken Preston (EE) David McKeown (Research Programmer) (412) 578-2618
CCD Applications Conference				Ken Lagnado (Conference Coordinator) Autovon 933-6878
International Conference on Large Data Bases				

School or Educational Source	Type of Program	Equipment or Resources Available	Applications of Work	Teachers
Massachusetts Inst. of Technology (MIT) Cambridge, Mass. 02139	Graduate Programs leading to MS or Ph.D in EE & CS	PDP 10 computer PDP 10 Computer	graphic arts-printing	William Schriever Donald Troxel
	Research areas: Image encoding Image enhancement Study of human vision Scene analysis	Image digitizing equipment Optronics scanner Special Data Systems homemade scanner -Output (hard copy) Optronics scanner Sponsored by ARPA	Satellite imagery Industrial robot arm controlled by camera	Berthold Horn Patrick Winston
Purdue University School of Electrical Engineering and School of Computer Science Lafayette, Indiana 47907	Short courses held @ Purdue University Digital techniques Image Processing (survey course or in-depth course)	DEC PDP 11/45 computer Optronic digitizing Drum scanner Microscope digitizing scanner	-biomedical analysis of chest radiograms white & red blood cell classification prosthetic arms	Thomas S. Huang (317) 493-3361 Avinash C. Kak O. R. Mitchell
	Graduate Programs leading to MS and Ph.D degrees in EE & CS Research areas: Pattern recognition Image processing Advanced Automation Data bases Computer graphics	TV signal digitizing system Ramtek color display CDC 6500 computer Comtal 3 color Display High-resolution TV camera Sponsored by ARPA	-Industrial data base management natural language computer interface robotic control systems -Remote Sensing LANDSAT imagery tracking moving objects Identification of highways, rivers & bridges. Removal of blur due to optics or motion	K. S. Fu D. A. Landgrebe P. A. Wintz (317) 493-3361 S. K. C. Subas R. C. Kashyap

School or Educational Source	Type of Program	Equipment or Resources Available	Applications of Work	Teachers
Stanford University Stanford, Ca. 94305		Computers Robotic arm controlled by TV cameras	Industrial Robot arm use of two TV cameras for depth perception	Tom Binford (415) 497-4971
University of Kansas Lawrence, Kansas 66045	Graduate programs leading to MS, ME, & Ph.D degrees in EE & CS Research areas: Image data compression Enhancement-making better quality images Image segmentation ME-Master of Engineering project oriented program	PDP-15 computer Homebuilt display digitization done out of house	Remote sensing Scene analysis Military RPV	Bob Haralick (913) 864-4836
University of Maryland Picture Processing Lab Computer Science Center College Park, Md. 20742	Graduate programs leading to MS & Ph.D degrees in CS. Research areas: Geometry of digital images Image processing techniques Models for human visual information processing Development of image analysis software	PDP 11/45 homemade high resolution drum digitizing techniques CRT film recorder Scan converter display terminal to Univac 1108 computer	Remote sensing Map processing Biomedical Character recognition scanner	Azriel Rosenfeld (301) 454-4527 Laveen Kanal

School or Educational Source	Type of Program	Equipment or Resources Available	Applications of Work	Teachers
University of Southern California Image Processing Inst. Powell Hall Los Angeles, Ca. 90007	Short Courses held at USC and in Wash. D.C. in: -Image processing -Pattern recognition and analysis -Optical information processing -Biomedical image processing Graduate programs leading to MS & Ph.D degrees in EE & CS. Research areas: -Digital television bandwidth reduction -Digital image restoration -Digital image coding -Pattern recognition -Coherent & incoherent optical information processing -Biomedical image processing -Image data extraction systems -Image understanding systems -Artificial intelligence applied to imagery -Data structures applied to imagery -Language structures applied to imagery	PDP-10 computer HP-2100 computer PDP-11/40 JER flying spot scanner Muirhead scanner transmitter Muirhead receiver printer Microdensitometer scanner Comtal display system Spectro vision display monitor Advent large screen display Sponsored by ARPA	Earth Resources Biomedical Industrial Military	Harry C. Andrews (213) 741-5514 W.K. Pratt N.E. Nahi W. Frei R. Nevatia R. Ronnds A.A. Sawchuk

School or Educational Source	Type of Program	Equipment or Resources Available	Applications of Work	Teachers
University of Utah Salt Lake City, Utah 84112	Graduate programs leading to MS & Ph.D degrees in EE & CS. Research areas: -Image compression -Perception of Images -Removal of Blurs -Color enhancement	-PDP-10 computer -PDP-11 computer -tied into ARPANET computer network -Flyback drum scanner digitizer -Electron Beam recorder -(4) display monitors Sponsored by ARPA	-Photoreconnaissance for the Air Force -Color printing -Shadows/eye perception vs. camera perception -Medical enhancement X-rays, Radiograms, ultrasound graphs	A. Timothy (801) 581-8224 Craig Rusforth Bren Baxter Mary Ann Kleinhart (questions about admission and courses in CS)

Section 4

TECHNICAL TRENDS

The majority of the progress made in photo-electro-optics has taken place through efforts to electronically transmit images, to allow a computer to control some type of industrial operation by giving it visual information, or to aid in the interpretation of photographs by either increasing the quantity of data that may be extracted or by increasing the speed at which it may be extracted. Digital representations of images form the backbone of these advances. Digital information can be stored in a computer usable form allowing the computer to examine it and make decisions about the image as well as being able to manipulate it with mathematical functions. The following paragraphs describe the various aspects of the advances being made and will show where the technology of photo-electro-optics may be in the next ten years.

DIGITAL IMAGE ACQUISITION

Digital images are produced using television type cameras, CCD (Charge Coupled Devices) and solid state imagers, platform type microdensitometer scanners, and drum type scanners. Various configurations of most of these digitizing devices are commercially available today. (A few manufacturers are listed in the Who's Who section of this report). Almost no two users have the same requirements for digitizers. Many research type operations require highly repeatable digitizations of imagery but are not affected by a two-day wait to obtain one, whereas some transmission applications need to input and output rapidly but do not worry about repeatability. Applications working with just a few images may want very high resolution while others may be limited by their available memory space and will be satisfied with very low resolution.

Television type cameras are the least expensive means of obtaining a digital image. They obtain images quickly (usually in one thirtieth of a second) but are unreliable as far as accuracy and repeatability are concerned. They are known for poor shading characteristics and their inability to totally erase past images. These cameras are one of the most common devices used to capture an original image. (An original image is obtained directly from an object or scene instead of from a photograph.)

CCD's and other solid state imagers are used in both staring (optics and imaging equipment remain motionless) and scanning systems. They are also commonly used to obtain original images. They produce quite accurate and repeatable results since each individual sensor's sensitivity can be tested. Any differences found can be corrected by making appropriate changes in some other part of the system. Their 512 x 320 and 48 x 380 element arrays produce resolutions close to those of today's television images (525 x 525), practically instantaneously. Scanning imagers usually have a mirror which moves the image across the sensors. This allows the imaging of larger areas with higher resolutions. For example, the

Viking Facsimile camera was able to image a 9000 x 512 pixel array covering the entire Martian landscape surrounding the spacecraft. CCD's have come a long way since their development in the late 1960's. As manufacturing processes improve, chips become larger, and their subtle problems begin to be solved,they will continue to play a major role in the future of photo-electro-optic imagery.

Most platform type scanners are of the microdensitometer variety. They are highly accurate and have resolutions that lead to micron size pixels. (The scanning microdensitometer being used at NASA in Greenbelt, Maryland is capable of a two micron pixel which produces a resolution of 500 lines per millimeter.) They also produce very repeatable results. These devices are very reliable because all the measurements are made by the same sensor and converted into an electronic signal by the same photomultiplier. Platform scanning devices are also very versatile. You can scan any portion of a print or transparency with any type raster scan, and you also have the ability to vary your resolution. Their drawback is their speed. Literally days are required to make a high resolution scan of a normal sized image, and hours are required to complete lower resolution scans.

Many drum type scanners are again essentially microdensitometers fastened to a drum. These are generally a great deal faster than their flatbed counterparts but some will only scan prints. Some drum type scanners however use arrays of CCD's enabling them to accomplish remarkable speeds and yet retain reasonably high resolutions, very high accuracy and repeatability. NOSC (Naval Ocean Systems Center) in San Diego, California has developed one of these drum scanners that is able to scan twenty 8½" x 11", continuous tone pages per second at a resolution of 8 lines per millimeter, or approximately one page per second at 95 lines per millimeter.

IMAGE STORAGE

After an image is digitized, the data must be stored for either a short time while the computer works on it or for longer periods of time as an archive for future reference. High density magnetic tape is used to store large quantities of images inexpensively. (A standard 200 mm x 200 mm photograph used by NASA occupies approximately five and one half inches of one inch magnetic tape.) However, the time required to locate the proper tape, locate the image on the tape, and play back the image from the tape can often be longer than the time required to locate an image in a standard filing system and load it into a viewer by hand. Disc storage is expensive but it provides real time (less than one second) random access to about eight hundred television resolution images per disc pack as demonstrated by Ampex's ESS system. Solid state memory is even more expensive than disc and therefore is usually only used to store one or two images at a time for refreshing a monitor or for the computer to actually work on. Virtually everyone working with digital imagery is involved in some type of image compression. Image compression reduces the amount of memory space required to store an image. Accompanied by continued reductions in the costs of present-day techniques and devices, developments in image compression and advances in new random access memory devices will cause photo-electro-optical imaging and processing systems to become more and more practical for all applications.

Almost all substantial sized data bases are organized under some type of index. Hierarchical, key word indexes are the most popular. Larger data bases usually store their index in a computer that can either tell the user where to find his image (e.g, EROS Data Center) or actually show the image to him (e.g, Ampex and Image Systems Inc.). The computer is usually programmed to either list the images included under the user's description or at least tell how many images are included before it begins to display them. Quite often the initial description may be too general and include scores of images that the user does not really wish to view. This gives him a chance to add more descriptors, reducing the number of images he will view.

IMAGE UNDERSTANDING

Image understanding projects are involved in trying to discover what kind of image descriptions a computer needs in order to simulate what the human mind recognizes and remembers about an image. This problem stretches further than the realms of computer science and electrical engineering into the domains of the psychological and physiological sciences. We have to try to understand what the human mind does before we can make the computer imitate it. One aspect of image understanding includes the recognition and differentiation of objects and textures. This, for example, would enable the computer itself to distinguish between a car and a building, or between an aerial view of a grassy field and an aerial view of a forest. In several projects, a map or an image of an object is stored in the computer's memory for use as a comparison with any new image of the same object. New images are stretched and warped to appear as though they were obtained at the same angle and object distance as the reference image stored in memory. Differences between these images are now computer detectable, which enables the computer to make accurate physical measurements from the new image. Once these types of image descriptions become more highly developed, they will serve not only as a classification system, but also will enable the computer to answer the user's questions (that had not been anticipated at the time the descriptions were being made) about an image without showing him the image.

IMAGE MANIPULATION

Once an image is in digital form, an almost unlimited number of functions can be performed upon it. The computer can automatically check an image and adjust it for proper contrast or it can display the image to the user, letting him select any contrast he desires. In many systems, the user can actually alter the response curve to any shape he desires (see Figure 14). This in effect can burn in the shadow areas and/or dodge the highlight areas. If the user does not want to alter the entire image but rather just a portion of it, he can outline that portion with a light pen or enclose it in a window and then implement any function he wishes on only that isolated area. Any disturbing background intensity or base fog can be removed. Any specific intensity or intensity range can be assigned another intensity or color. Color images are usually stored as three separate images (red, green, and blue) that are combined when being displayed on a monitor or being made into a hard copy output. This permits any of the above operations to be performed on each color individually. Blurred or otherwise distorted images can be restored to near undistorted quality. Images can be warped, giving the viewer a seemingly different view of the object (e.g., an isometric view can be warped into a side view). Edges can be enhanced so that they stand out clearly or they can actually be traced with a line. Enlargement or reduction is also easily done. Everything that can be done to an image on photographic materials and more can be done to a digital image mathematically.

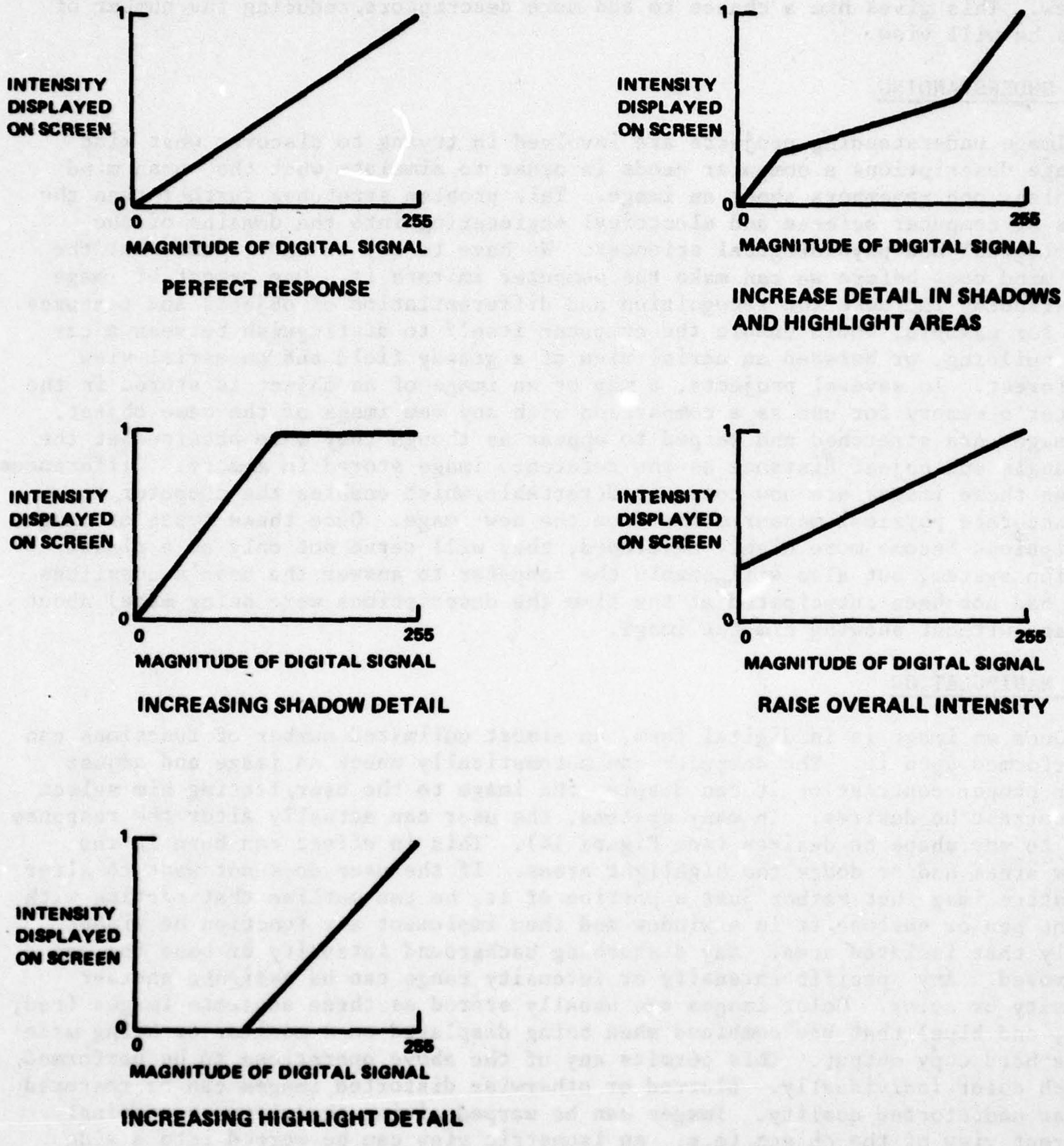


FIGURE 14. SHAPING THE RESPONSE CURVE OF A MONITOR.

IMAGE REPRODUCTION

Soft Copy. Digital images are conveniently displayed on television type video monitors. Digital display monitors, however, are capable of producing images with quality far superior to their conventional counterparts. Since digital displays are available with arrays of 1024 lines x 1024 lines, as opposed to televisions which have arrays of approximately 512 lines x 512 lines (varies as a function of bandwidth) and since none of the pixels on the outer edges are lost off the edge of the screen, they are capable of approximately twice the resolution of a televison monitor. Smear between adjacent pixels is virtually nonexistent, allowing each pixel to be totally different from its neighbors. These display monitors are fantastic for fast temporary viewing and are especially helpful in allowing the user to work interactively with the computer as it performs operations on an image.

Hard Copy. Output onto a piece of paper or film still relies heavily on photographic processes. Electrostatic printers have been used for fast output in a number of black and white applications, but the only dry process for color presently available is color xerography and it has not been incorporated into any of the systems investigated during the course of this study. Photographing an image while it is being displayed on a monitor is one of the easiest and most widely used methods of obtaining hard copies of color and black and white images. The hard copy images produced by this method are not overly impressive. Due to the mismatch in hue between the monitor's phosphors and the film's color filters, they are flat and have poor color response. Distortion is also produced in these images by the curvature of the monitor's screen. The highest quality hard copy digital images are produced by either a laser or an electron beam recorder. They expose the image onto film point by point. One image is made for each spectral range and then these spectral images are combined photographically to produce a color image. Hard copy output lags far behind the other aspects of photo-electro-optical imagery in terms of speed because of its reliance on photographic processes. Furthermore, no one seems to be putting any effort into developing new techniques or improving the present ones to overcome this problem.

CONCLUSION

Major advances in technology during the next ten years will probably be in the areas of image understanding and charge coupled devices since major research efforts are being expended in these areas today. Image understanding will aid image compressibility by enabling us to know what type of image information we must record and what type we can disregard in order to store more information in less memory space, and CCD's should continue to improve the resolution, accuracy, and speed of digital image acquisition.

Section 5

RECOMMENDATIONS

The Photographic Branch (E-24) of Naval Surface Weapons Center does have some applications for the present photo-electro-optical technology. E-24 does a substantial amount of motion picture data reduction, determining the speed, angle of attack, and spin of a wide variety of projectiles. Any system designed to aid in the reduction of such a wide variety of data must be extremely flexible. This flexibility would probably be best obtained through a computer system including capabilities for human interaction. Systems are now commercially available (Photo Digitizing Systems Inc.) that will digitize a series of motion picture frames, allow the user to select several reference points in the first frame, and then the computer automatically tracks them from frame to frame. (Point recognition techniques were used at SRI International, JPL, and NASA to aid in the registration of images.) A computer can also be programmed to take measurements between points and their previous positions and perform calculations providing the user with the data desired. This type of system would cost approximately $160,000.

E-24 can also apply this technology to modernize its image filing system. The filing system currently in use permits each user to file his negatives under key words that he originates. An aperture card (similar in size and shape to a computer punch card, but containing a positive transparency and space for written information) is produced for each image or set of images and filed under the project title. A blank aperture card is prepared and filed for each of the remaining key words. These refer the user back to the card containing the image/s. The user removes the aperture card from the file and loads it into a viewer for inspection of the image. Once the desired image is selected or located in the aperture card file, the master negative can be obtained from the negative files by its negative number which is also found on each of the aperture cards. This system is efficient when the user knows the exact key words that the cards were filed under, but often he does not. Occasionally the user simply forgets the key words he provided and more often he is not the originator of the key words. In these circumstances it usually requires 10 to 15 minutes to locate a specific image. Many times a user giving a visual presentation does not know exactly which image he wants and would like to browse through all the images stored of a specific weapon system, test site, etc. in order to decide which one is the most appropriate. This can require hours of searching and viewing.

Some of these problems can be overcome by establishing a hierarchical indexing system. The images E-24 is storing will have to be categorized and some type of K-net (see SRI International facility report) should be established. Instead of formulating a set of key words for each new image, it would be entered into its proper place in the K-net. A well organized K-net will not limit the amount of descriptive information available on each photograph any more than the key word indexing system does, but the descriptive process will produce much more highly repeatable results from different individuals. It will also aid tremendously in rapid location of all images in a specific category. This type of indexing system itself would just be an aid to the aperture card system. Blank cards would not have to be made and the remaining cards could be filed by number. The aperture cards would still definitely be necessary since repeated handling encountered in viewing the images would quickly diminish the quality of the master negatives. The establishment of such an index would require a substantial initial effort during the actual creation of the K-net and would require periodic updating (probably once or twice a year) to ensure that it is including all of the newly acquired images. This hierarchical K-net indexing system would be helpful even if maintained by hand on paper, but it would be much faster and more convenient if it was maintained in a computer. The computer could be programmed to accept subject headings and subheadings from the K-net and to respond with the number of images included under this heading, the subheadings directly under this heading, and/or a list of the images and their locations included under this heading. (See EROS Data Center facility report.) The computerized version of this system would require a teletype or CRT terminal interfaced with a mini/micro computer or interfaced with the CDC 6500 time sharing system owned and run by the White Oak Laboratory. A minicomputer that would more than handle this application can be purchased for around $10,000. The Laboratory's CDC 6500 system already maintains a data base management system so that all E-24 would have to do is enter its hierarchical index and data into its memory and install a terminal. A terminal costs around $3,000 or rents for around $125/month. E-24 would also have to pay for computer time ($15/hour) and storage of the data and indexing system.

A step beyond the computer index would be a system that would also automatically display the images to the user and thus completely replace the aperture card system. At the present time, two systems of this type are known to be available. The first, as manufactured by Image Systems, Inc., stores the images of microfiche cards in a carousel type arrangement. Headings from the K-net are inputted to the system and it responds much like the system described previously did, but then instead of having to manually retrieve the images from the aperture card file and load them into a viewer, the system will automatically load and position the proper microfiche into the viewer. This system can provide instant (less than 3 seconds) random access to approximately 50,000 images. It is also capable of providing low quality copies of the image directly from the microfiche. Including the computer index, a computer capable of handling the index, the microfiche carousel viewer, and a simple microfiche camera (only converts prints to microfiche), this system would cost approximately $50,000. The second type system digitizes images acquired with a conventional camera and stores them on disc memory. (See Ampex facility report.) Ampex's system can store 2442 television images (resolution, approximately 512 x 512 pixels) on three disc drives. Any of these images is randomly accessible in less than 1 second. Although this system is even faster than and provides much simpler image input than the microfiche carousel system, it severely restricts the number of on line images that can be accessed immediately. This system, including a television camera and a computer capable of handling the index system, would cost approximately $200,000.

Utilizing the ultimate state-of-the-art photo-electro-optical reproduction techniques available today, E-24 could also replace some of its manual laboratory work with electronic, mechanized equipment. With a larger computer (not required if using the CDC 6500 time-sharing system), E-24 could enhance imagery in any desired way using today's image processing techniques. E-24 could also output

this enhanced digital imagery directly to film using either a CRT, laser, or drum scanner, leaving only machine lab processing as the final step. These types of systems are not restricted to television resolution but may obtain 80 to 90 lines per millimeter. Although image enhancement can be done much more quickly and easily electronically than it can be done in the dark room, the input and output processes of digital imagery with fairly high resolution are extremely slow. The units of time required for them to be inputted or outputted are hours or days. (NOSC has developed a very fast high-resolution drum digitizer, but it is not commercially available.) The highest resolutions in digital imagery commercially available today (approximately 90 lines/millimeter) are not yet comparable to practical high-resolution photographic systems (300 to 500 line pairs/millimeter or approximately 600 to 1000 lines/millimeter). A digital imagery system with the capabilities as described above would have a cost in the 1/2 to 3/4 of a million dollar range. Although all of these applications are not feasible, they are possible and will continue to become more and more practical.

Section 6

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Section 7

GLOSSARY

accuracy	-Exact reading of the amount of light actually reflected or transmitted
aperture card	-This card contains a positive transparency of an image, identification words, and identification numbers. It is the approximate size and shape of a computer punch card and is usually manually placed in a viewer for inspection.
gray code	-A code using only 0's and 1's that only has one bit change per increment.
original image	-A primary image obtained from the actual scene or object. It is not obtained from another photograph.
pixels	-Picture elements.
registration	-The lining up of two or more images such that their individual points have the proper correlation with one another.
repeatability	-Under the same conditions the same output will be produced.
resolution	-In this paper the units used are lines/mm. In most photographic applications, the units used are line pairs/mm. Each line pair/mm is equal to approximately two lines/mm.
response curve	-As used in Fig. 14 this term refers to the response of the video monitor.
staring	-Optics and imaging equipment remain motionless.
vidicon	-A type of television camera tube.

Section 8

ABBREVIATIONS AND ACRONYMS

A/D	Analog to Digital
CCD	Charge Coupled Device
CRT	Cathode Ray Tube
EBR	Electron Beam Recorder
EMS	Electronic Message Service
EROS	Earth Resources Observation System
ERTS	Earth Resources Technology Satellite
ESS	Electronic Still Store
I/O	Input/Output
JPL	Jet Propulsion Laboratory
K-NET	Knowledge Network
MSS	Multi-Spectral Scanner
MTF	Modulation Transfer Function
NAMRL	Naval Aerospace Medical Research Laboratory
NOSC	Naval Ocean Systems Center
PLZT	Lead Lanthanum Zirconate Titanate
RBV	Return Beam Vidicon
SRI	Stanford Research Institute
USPS	United States Postal Service

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