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ERTS - 1 Imagery Interpretation

Techniques in the Tennessee Valley

R. E. Bodenheimer

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# ERTS - 1  IMAGERY INTERPRETATION
# TECHNIQUES IN THE TENNESSEE VALLEY

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16. Abstract

The data processing facility used in support of the ERTS-1 Program at The University of Tennessee was organized about three major systems: (1) an IBM 360/65 batch processing system, (2) a microdensitometer scanning system, and (3) an interactive image processing and recognition system. These systems are described as they were integrated into the overall application of processing ERTS data.

Several significant findings of this study are reported. The feasibility of delineating major soil associations and land uses through computerized analyses is presented. Useful and potential applications in detecting landscape change and landuse mapping are described. Finally, recommendations for improving the data processing effort in a multidisciplinary program are discussed.

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PREFACE

This report describes the data processing facilities provided in support of the ERTS-1 Program for a multidisciplinary group at The University of Tennessee during the period September 1972 - March 1974. Specific objectives for this project were:

- To develop effective techniques for computer processing of ERTS data comenserate with the needs of individual users.

- To conduct research in improved methods for image enhancement and display.

- To coordinate the computer image processing tasks between disciplines.

- To provide the expertise and interface necessary to extend the understanding of data obtained from airborne platforms to that obtained from earth-orbiting platforms.

- To develop pseudo-color image enhancement techniques useful for each discipline.

- To initiate the development of a "fast turn-around" image processing system for data review, analysis, enhancement, and recognition whereby the user interacts directly with the computing facility.

A data processing facility was structured around three major systems--an IBM 360/65 batch processing system, a microdensitometer scanning system, and an interactive image processing and recognition system. The features and data processing capabilities of these systems are described as they were integrated into the overall application of processing ERTS data.

The highlights of useful applications in soil association, soil moisture, and land use evaluations are reported. Major soil association were delineated through the reflectance characteristics of a fairly uniform

cover of vegetation. The ability to group soils into similar categories is of great value in providing for better land use management and development.

Density values derived from the spectral bands of imagery in areas of an intensive raw crop agriculture provides enough information for making general land use classifications such as cropland, pasture, forest, and water. Automated classification using NDPF digital tapes for this type of application was not pursued until late in the study and definitive results using this approach were not obtained.

This project has identified many of the problems typical of a multidisciplinary group. While there is evidence that a central group capable of providing data processing support is an effective approach to image processing, the problem of operating in a multipurpose, computer processing environment is significant. The close communication that must exist between the information processing group and the user, along with the desire on the part of the user to interact with the interpretation process, indicate the need for an on-line, interactive image processing facility.

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# CHAPTER I

## INTRODUCTION

The need for developing effective techniques which lead to the assessment and inventory of our natural resources has clearly been brought to focus during the last decade. The National Aeronautics and Space Administration has recognized this need and, consequently, initiated the ERTS Program. This effort has generated programs which are endeavoring to utilize new technology in solving agricultural, environmental, and energy problems of today.

Three major categories of the ERTS Program are (1) data acquisition and storage, (2) data processing, and (3) data interpretation. The Goddard Space Flight Center has been largely responsible for data acquisition and distribution of the data to user groups. Information processing and interpretation of the data has been the responsibility of the individual investigators. In many cases the individual users have found that a cooperative effort must exist between several technical fields of specialization.

The University of Tennessee is typical of this type of effort in that the Electrical Engineering Department (MMC # 162-6) has provided a data processing service and limited data interpretation to Agriculture (MMC # 139), Ecology (MMC # 162-2), and Geography (MMC # 162-3). The emphasis of this report is placed upon the data processing facilities of the Electrical Engineering Department used for supporting the ERTS Program.

## Background

The University of Tennessee has been involved in research and feasibility studies pertaining to remote sensing of the environment for several years. The Tennessee Valley basin offers an ideal natural laboratory for this work because of its vast and controlled system of rivers and reservoirs, its land-use diversities, its rapidly expanding urban areas, its natural resource potential, and its need for continued resource development.

Project THEMIS for Remote Sensing of the Environment was an interdisciplinary effort at the University between Agriculture, Civil Engineering, Urban and Rural Planning, Geology, Botany, Electrical Engineering, and Geography. This effort was supported by the United States Air Force. The remote sensing THEMIS program was committed to the utilization of photography and thermal imagery as a means whereby the environment is sensed. Diverse systems such as diseased crops, soil surveys, forest inventory, urban planning, and water quality were studied. All of these studies utilized data obtained from an air-borne camera and an infrared scanner [1-3].

The specific tasks of the Department of Electrical Engineering during Project THEMIS were:

- To develop the capability for processing infrared and conventional film data obtained from air platforms

- To develop digital analysis techniques compatible with the processing requirements

- To recommend and develop methods for information storage and retrieval

During the THEMIS program, staff members of the Electrical Engineering Department found that not only must the data processing group

develop systems for processing data, but must also participate in data interpretation to insure maximum benefits to the user groups. In particular, our usefulness hinged upon users being able to define objectives of their work and to relate these objectives to extracting information from bulk data.

## ERTS - 1 Project Objectives

The ERTS-1 multidisciplinary group at The University of Tennessee consists of the departments of Geography, Botany, Agriculture and Electrical Engineering. A principal mission of this group has been to demonstrate useful, potential applications for ERTS imagery. The Electrical Engineering Department was the principal center for computational support and development of software for image processing recognition problems. The scope of this effort ranged from the application of ERTS-1 imagery to detect the state of health of vegetation to the use of this imagery in the study of soil classification in the Tennessee Valley.

The specific objectives of this project in terms of the overall ERTS program at the University has been:

- To develop effective techniques for computer processing of ERTS data commensurate with the needs of individual users.

- To conduct research in improved methods for image enhancement and display.

- To coordinate the computer image processing tasks between disciplines.

- To provide the expertise and interface necessary to extend the understanding of data obtained from airborne platforms to that obtained from earth-orbiting platforms.

- To develop pseudo-color image enhancement techniques useful for each discipline.

- To initiate the development of a "fast turn-around" image processing system (DEC PDP-11 supported) for data review, analysis, enhancement, and recognition whereby the user interacts directly with the computing facility.

In the following chapter a summary is given of the processing facilities used during the ERTS Program from September 1972 to March 1974. Of particular interest is the image processing and recognition system.

# CHAPTER II

## DATA PROCESSING

This project has utilized ERTS-1 data in the form of film imagery as well as computer compatible tapes. The tapes can be processed both on a large storage, moderate turn-around, IBM 360/65 batch processing facility and a fast turn-around, personalized, image processing facility. The 360/65 is a campus-wide processing computer while the personalized facility is developed around a Digital Equipment Corporation PDP-11 model 20 computer located in the Electrical Engineering Department. Figure 2.1 diagrammatically represents the major systems used to process ERTS data.

Film data can be transformed into digital tapes by film scanning with a high-resolution microdensitometer. For coarser processing, the image processing laboratory is equipped with a TV camera which can be used to scan film and store the results on magnetic tape. Processing can then be carried out either by the 360/65 or by the PDP-11/20 image processing system.

The flow chart shown in Figure 2.2 represents the coordinated effort in data analysis and processing. As indicated in this figure, data is received from the National Data Processing Facility (NDPF) as either magnetic tape or film form. Film and photographs are first analyzed visually by the ERTS investigators. If computer processing is desired, the investigator specifies the segments of data and the required format. Processing is performed using either the image processing laboratory or the microdensitometer/ IBM 360 facility.
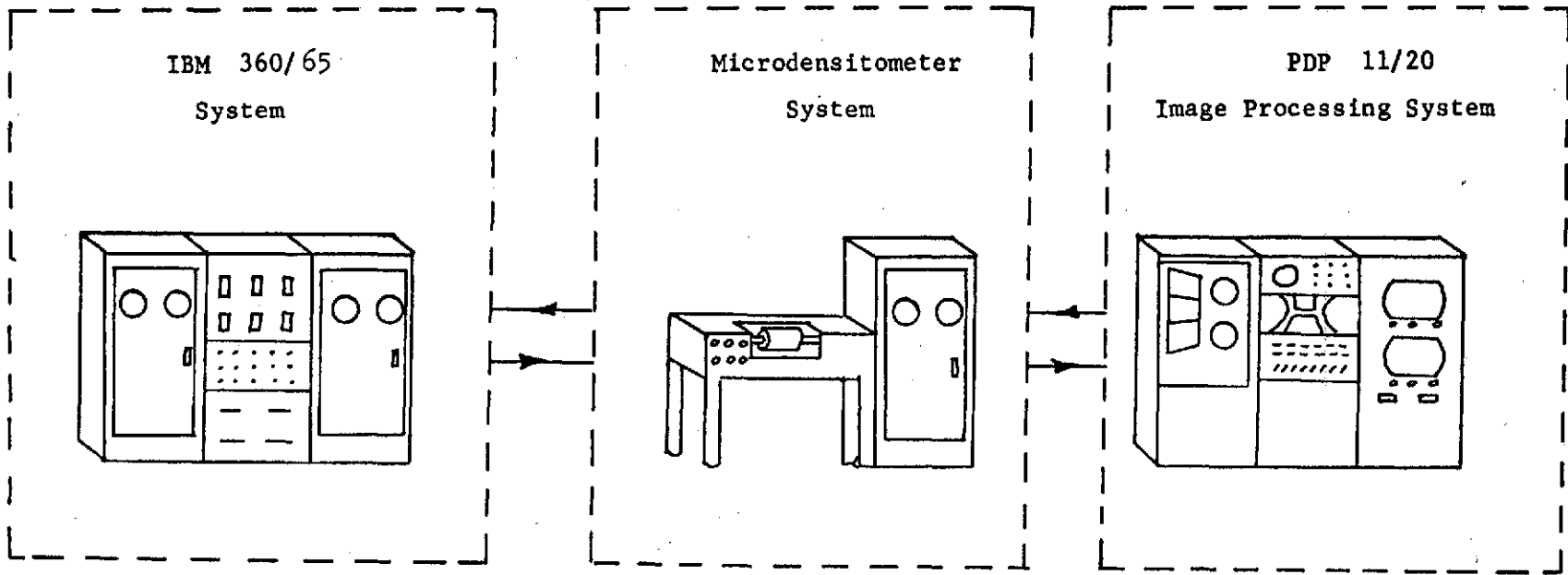
IBM  360/65
System

Microdensitometer
System

PDP  11/20
Image Processing System

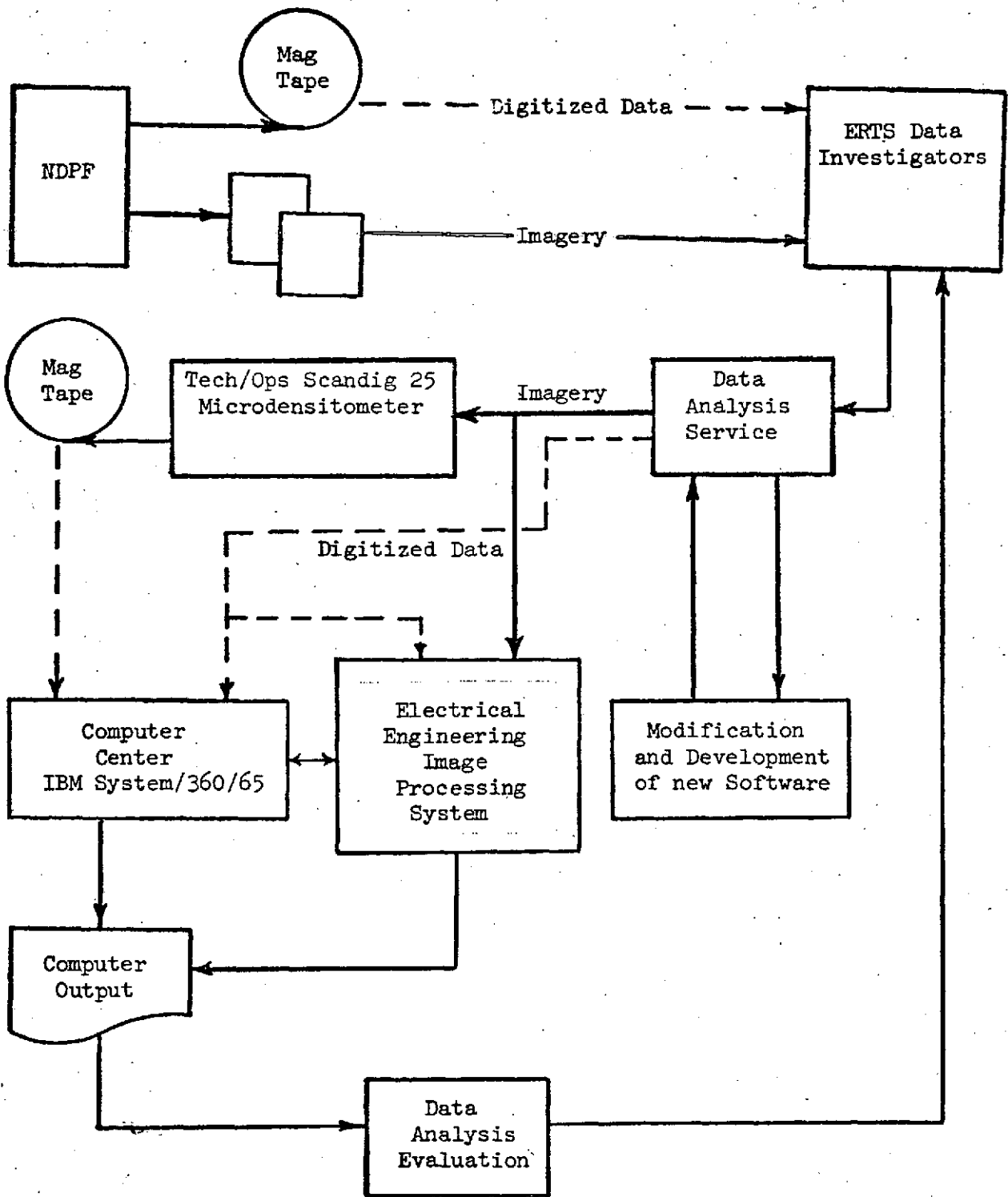Figure 2.1.   Major Systems Used to Process ERTS Data

Figure 2.2. Flow Diagram Showing the Handling and Processing of ERTS-1 Data

## Microdensitometer/IBM Processing

The experience of this group in remote sensing was acquired through the use of aircraft photographic imagery and greatly influenced the approach taken during the ERTS investigation. Image transparencies from the NASA Data Processing Facility (NDPF) were the primary source of acquired data as opposed to the alternate use of digital tapes. Although the intention at the beginning of the investigation was to compare the use of transparencies and digital tapes in achieving the goals of the investigation, this was not accomplished. As a consequence, the loss of radiometric accuracy and multispectral registration in using film transparencies has not been clearly defined. A significant limitation in using NDPF tapes was the lack of familarity with the tape content and file order corresponding to particular scenes.

One way to handle film data digitally is to digitize the film using a microdensitometer. This unit is used as one element of the toal processing capability shown in the block diagram of Figure 2.2. The output of the microdensitometer is a 256-gray-level binary image stored on magnetic tape with compatible format for processing on the IBM 360/65 machine. A variety of software packages are available for processing the tapes. Typical operations that are carried out by the software include density slicing, edge enhancement, histogram generation, statistical analysis, and tonal digital outputs.

## Microdensitometer

During ERTS-1, a Technical Operations Scandig Model 25 high speed, digital, X-Y-scanning microdensitometer was employed to digitize film density information. This information is stored on nine track, 800 BPI magnetic tape. In this system the film transparency is mounted on a rotating

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drum and illuminated from inside the drum by a small light beam. The illuminated point of the transparency is imaged by a microscope objective onto a scanning aperture. Light which is transmitted through the aperture is monitored by a photomultiplier tube coupled through a logarithmic amplifier to an analog to digital converter. The output of the converter is recorded on magnetic tape as successive binary numbers corresponding to the points sampled. Baseline drift is completely eliminated through automatic zeroing at the start of each line scan.

In the scanning process, a rectangular scan window adjustable in 1mm increments is established on the film transparency. The microdensitometer scans the window from top to bottom and advances to the right after each vertical scan as illustrated in Figure 2.3. A vertical scan generated one data block or one record. Each data point in the record represents the density of the film at the sample point and is recorded on 8 channels of magnetic tape as a binary number between zero and 255 (8-bit ADC conversion). The 256 levels quantitize the optical density range from 0 to 3 ODU (optical density units) giving a resolution of 0.012 ODU. Data acquisition rate is 20,000 data points per second during the vertical scan. Records are separated by an automatically inserted interrecord gap. A file is generated as the collection of all records recorded from scanning the rectangular window. The number of data points contained in the file is dependent upon the raster used to scan the window. Lattice scanning of 25μm, 50μm and 100μm rasters can be selected for sampling the transparency. If a 25μm scan raster is used to scan a rectangular window one inch by one inch, approximately one million discrete data points are generated.

The end result of the scanning process is to generate files of data stored on magnetic tape. These files contain the spatial and spectral

SCAN ADVANCE ◆

IMAGE
ORIGIN

|← XO →|

TOP OF IMAGE

|← WINDOW X-LENGTH →|

YO

WINDOW
ORIGIN

START SCAN LINE

SCAN

WINDOW

WINDOW
Y-LENGTH

RECORD 1  RECORD 2  RECORD N-1  RECORD N

◆

DRUM
ROTATION

STOP SCAN LINE

IMAGE

BOTTOM OF IMAGE
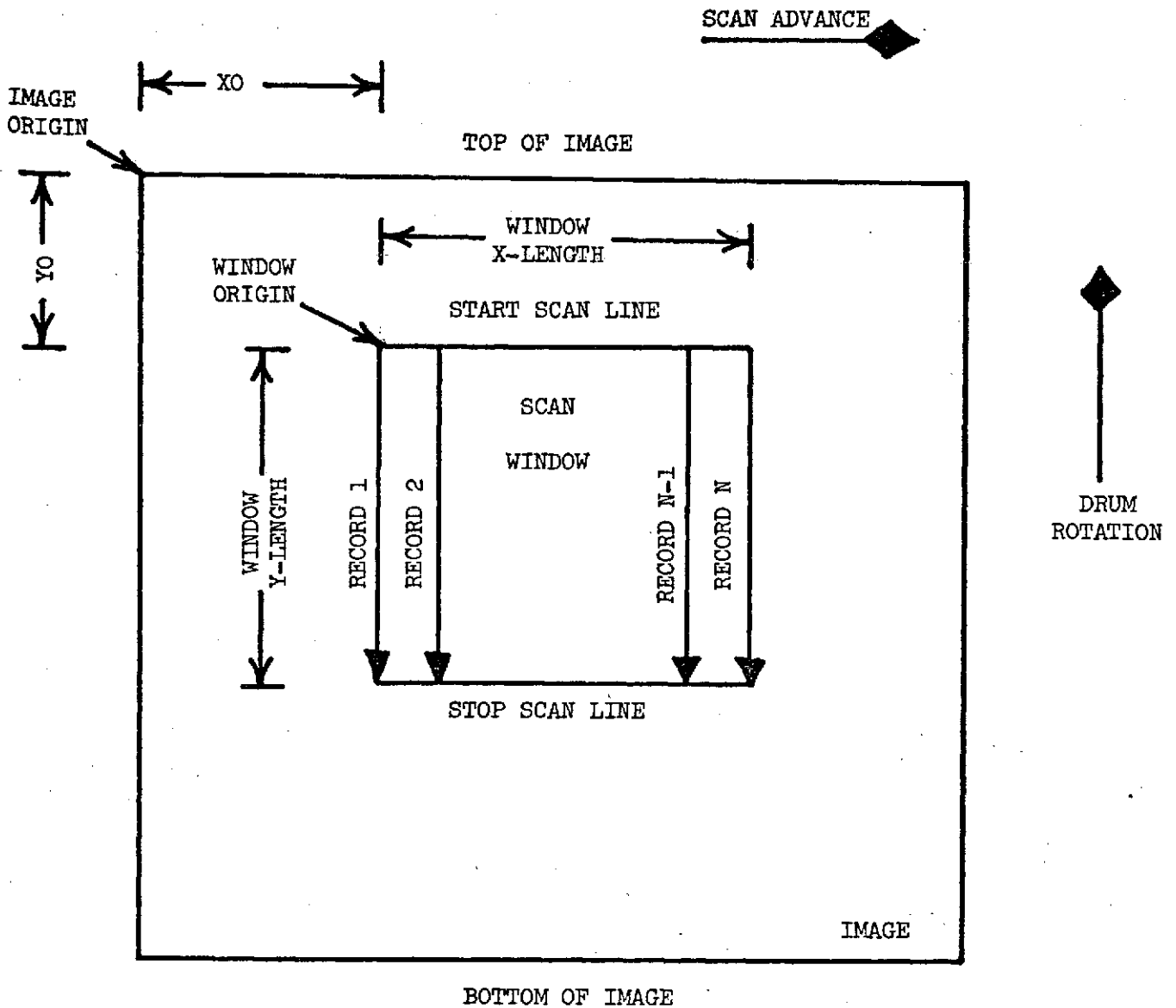
Figure 2.3. Microdensitometer Scan Window Showing the
Relative Position on the Image During the Scanning Process.

information obtained from the film transparency within the scan window. The

information is now in a format which is convenient for data analysis and

data interpretation techniques using a general purpose digital computer.

The microdensitometer is not usually tied directly into a digital

computer but rather, as discussed above, stores data on magnetic tape which

may be processed at a later date. In some applications this offers the

advantage of the large storage capacity and data processing facilities of
computer centers, in contrast to the limited capabilities of a small dedi-
cated computer [4,5].

Computer Software for Processing Tape Data

The software package OPSCAN was designed around the capabilities of
the IBM Operating System/360 and the PL/1 programming language. A prime
consideration given to the development was to create a program which could
be easily controlled by the user and easily expanded to embody an even
wider range of data processing capabilities. Specific objectives in devel-
oping this software package were: (1) to provide a wide range of data pro-
cessing capabilities, (2) to create an efficient program which would require
a minimum of computer time, (3) to create a program that would be easily
controlled by the user, and (4) to create a program that could easily be
extended by another programmer to provide an even wider range of data pro-
cessing capabilities.

The OPSCAN package was originally developed for processing tapes
derived directly from the SCANDIG microdensitometer. The format for the
microdensitometer tapes are not the same as the bulk and the precision
tapes supplied by the National Data Processing Facility. In order to use
the OPSCAN software, the NDPA tapes are stored on disk and new tapes are
generated so that that format is compatible to the OPSCAN Program. This
procedure prevents the necessity of rewriting software for processing NDPA
tapes.

Data editing facilities, chain printer compensation, outline and
first gradient output operations, histogram output and gray-scale manipu-
lation are a few of the features which have been included in the OPSCAN

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software. A brief description of the salient capabilities follows [6,7].

Gray-tone Picture Output. The user may select from any one of three, fixed, gray-scales for use in computer print-out. For example, if GRAYSCALE 1000 is selected, 12 gray-tones are linearly distributed over the 256 levels of density. Each gray-tone is generated from a character set using one to six overstrikes. When this gray-scale is used to reproduce photographic imagery, a high quality reproduction results. An example of a six-tone gray-scale is:

Character Set = {blank, -, X, 0, =, A, B, V}

Overstrike Combinations

| blank | - | X | 0 - | 0X= | 0XBVA |
|-------|-----|-------|-------|-------|---------|
|       | - - - | X X X | θ θ θ | ⊞ ⊞ ⊞ | ⊠ ⊠ ⊠ ⊠ |
|       | - - - | X X X | θ θ θ | ⊞ ⊞ ⊞ | ⊠ ⊠ ⊠ ⊠ ⊠ |

Added capability is obtained through the specification of a threshold density (lowerbound) and a saturation density (upper bound). When these bounds are specified, the selected grayscale will be linearly distributed over the range between the two density values.

Hybrid Picture Output. User specified gray-scale may be added to the program. These gray-scales may be linearly or nonlinearly distributed over a desired density range. Coded gray-scales have been generated which not only provide partial gray-toning, but project quantitative information as well. An example of a coded gray-scale is:
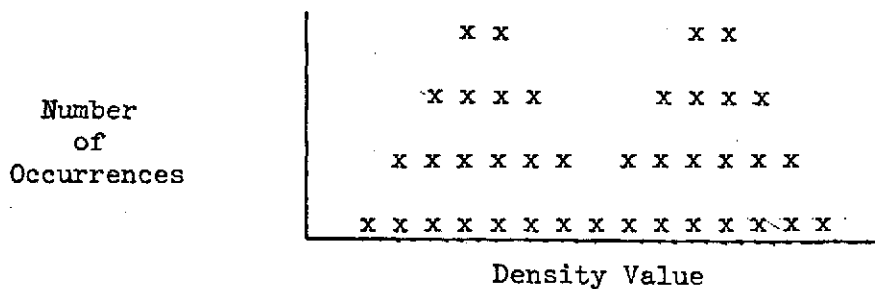
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Overstrike Combinations

| | | | A _ | B _ | C _ | A _/ | B _/ | C _/ |
|---|---|---|---|---|---|---|---|---|
| AAA | BBB | CCC | AAA | BBB | CCC | AAA | BBB | CCC |
| AAA | BBB | CCC | AAA | BBB | CCC | AAA | BBB | CCC |

Each combination may be associated with a unique numerical value.

Outline Output Operation. The data points are analyzed horizontally and vertically to detect sharp contrasts between adjacent data points. An "output sensitivity" is specified by the user. When a contrast equal to or greater than the value specified is detected, the denser of the two adjacent points is designated for further processing. The designated densities are translated into gray tones or numerical density codes and printed in pictorial form. All other data points are assigned a value of zero density and translated accordingly.

Histogram Output Operation. The histogram graphically represents the number of occurrences of each density level measured. A simulated histogram is shown below in which each x represents a specified number of times the particular density occurs.

```
              |       x x            x x
  Number      |     x x x x        x x x x
    of        |
Occurrences   |   x x x x x x    x x x x x x
              |_ x x x x x x x x x x x x x x x x
                          Density Value
```

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When a histogram output is requested, the number of occurrences of each density level is recorded along the ordinate and the 256 density levels along the abscissa. In addition to being able to specify the range of density levels for histogram processing, statistical information such as mean, median and mode is output.

First Gradient Output Operation. The spatial gradient is the first derivative in two-dimensional space of the density surface. In the discrete domain the first derivative is analogous to the first difference. The gradient is given by

$$|\text{Gradient}| = G_1 = \sqrt{(D_1-D_2)^2 + (D_1-D_3)^2}$$

where $G_1$ is the magnitude of the density gradient at point 1, $D_1$ is the density at point 1, $D_2$ is the density point immediately to the left of point 1, and $D_3$ is the density point directly above point 1.

The output operations described above are printed only upon the request by program control. Another type of printed output, which is always performed, is the control card listing. Before the control cards are processed by the program, each card is listed to provide a permanent record of the program execution. Comment cards can include dates, tape serial numbers, department names, operator names, etc. Errors in the control cards can be located easily with the aid of this listing and the error messages which follow the listing.

Applications are included in Chapter III which utilize the OPSCAN software.

## Image Processing System

The previous procedure for processing tapes offers the user flexibility with respect to large storage facilities, a standard software package, and moderate CPU speed. However, batch processing inherently requires one to two days turn-around time. Furthermore, the user plays a passive role in this mode of processing in that the results from one computer-run must first be observed before reasonable decisions can be reached for submitting additional runs. This approach for processing tapes can be extremely time consuming.

The Image Processing System shown in Figure 2.3 avoids lengthy turn around time and, moreover, allows the user to make on-line decisions in processing both photographic film and digitized tape. The system consists basically of a Digital Equipment Corporation's PDP-11 computer with a 9-track industrial compatible magnetic tape unit, 16k of 16 bit storage, hardware multiply/divide and standard A/D, D/A, converters. Special purpose peripherals include a TV camera for scanning photographic film, a scan converter which converts digital information into video output, monochrome and color TV monitors, and an image analyzer for general density slicing and edge enhancement. This system is capable of handling almost any processing, with slightly less resolution, which is carried out using OPSCAN and the IBM 360/65. In addition, however, the system has the capability of displaying the processed images in either the monochrome or color TV monitor. This capability is extremely powerful since a semi-real time basis can be used. One application to this project, for example, is to scan a film image using the TV camera. The scanned image is stored on magnetic tape. This image is then enhanced and displayed in pseudo color
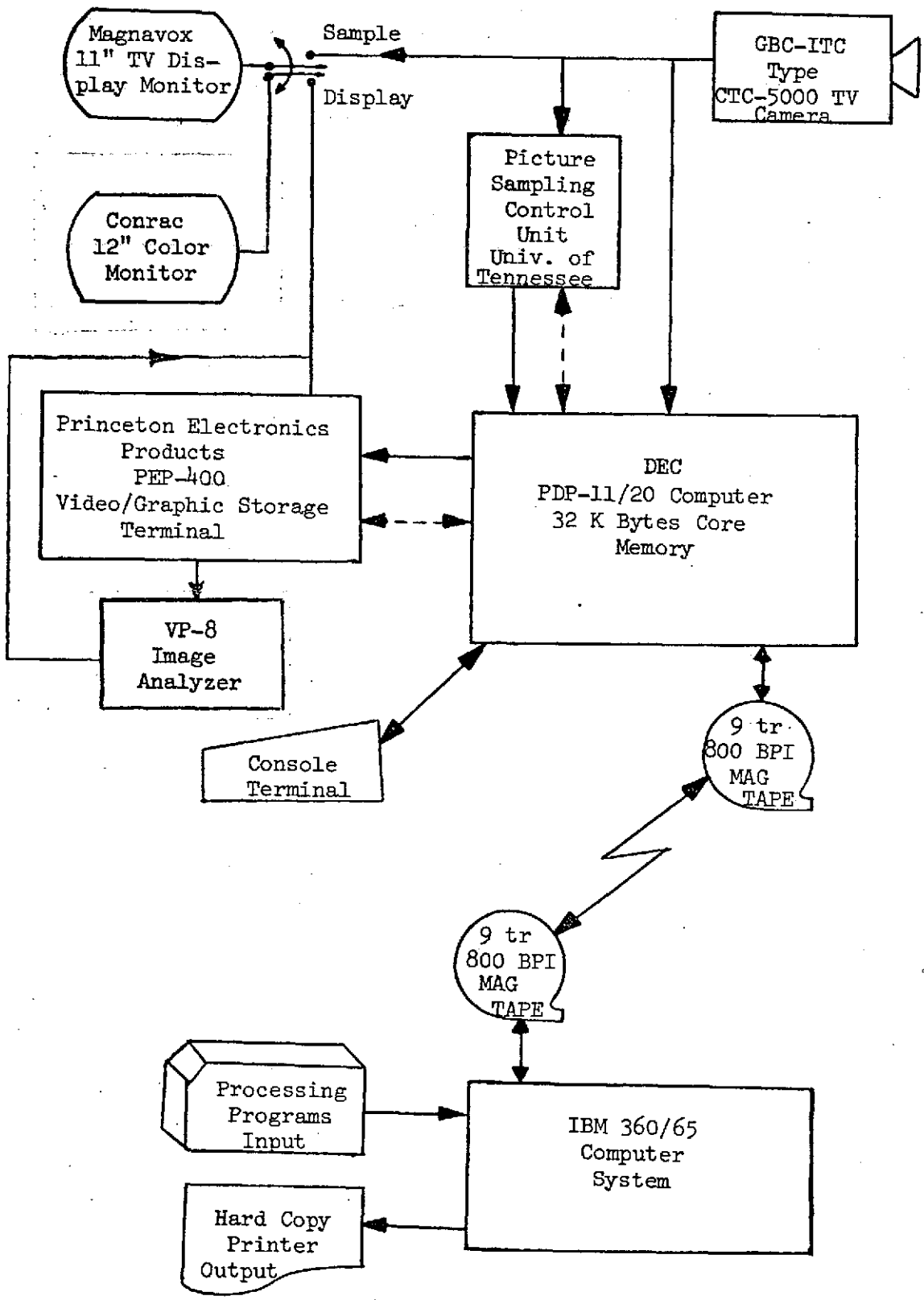
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Figure 2.4. Block Diagram of The University of Tennessee's Computer Image
Processing and Recognition Laboratory

via the scan converter and TV monitor. The color combinations can be changed almost instantaneously and the image displayed again in order to accent events of interest. A computer compatible tape unit links the IBM System/360 and the image processing system. Any processing for which the PDP-11 proves inadequate can be carried out on the System/360 and the results displayed on one of the monitors. A more detailed description of the Image Processing System hardware and software is given below [8-10].

Hardware. The hardware portion of the system consists of the video equipment, the computer, and the instruments which interface the video units to the computer.

Picture input to the system is provided by a GBC TV CORP. CTC-5000 monochrome closed circuit television camera. In order to properly adjust the camera before taking a picture, and also to view the results of processing, there is a Magnavox 11 inch monochrome TV monitor. This monitor expects a composite video input signal, while the rest of the video system is designed for a composite sync signal separate from the video signal. Therefore, a composite video generator was designed to eliminate this problem. A color monitor with RCB inputs (World Video CR-6210), which can be fed from one of three sources via a color source switch, is also part of the system. However, this monitor requires inverted video signals at the RGB inputs necessitating three video inverter amplifiers.

Another video unit in the system is the real time video analyzer (INTERPRETATION SYSTEMS INC. VP8 IMAGE ANALYZER) capable of taking a monochrome video signal, and dividing the signal into eight variable width bands. The outputs of this unit can then be a monochrome video signal with a particular gray level associated with each band, or a set of RGB video

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signals such that each of the above bands is indicated by a particular color.  This image analyzer can also provide an isometric projection of the video input on an XYZ display monitor (HEWLETT-PACKARD HP-1300A).  Relative levels and picture areas contained within a band can also be determined using the built-in panel meter.

Provision has also been made to include a color mix circuit (monochrome input-RGB output to color source switch).  All of these components are interconnected through a manual master select switch which has twelve combinations available to the user for maximum utilization of the video equipment.

The computer being used is a Digital Equipment Corporation PDP-11/20 with 16K words of core memory, console teletype, extended arithmetic unit (KE-11A), programmable clock (KW-11P), sixteen bit general purpose digital interface (DR11A), industry compatible 9-track magnetic tape controller and driver (TM11/TU10), three channels of digital to analog conversion (AA-11D), a one of four channel analog to digital converter (AD01-D) with an external input used to initiate conversion, and a high speed paper tape reader punch (PC11).  The computer is tied to the video equipment using some of the above peripheral devices connected with the equipment to be discussed in the next few paragraphs.

Taking a picture requires the use of the SAMPLER, a digital device designed at The University of Tennessee for this purpose.  This device accepts as inputs the horizontal and vertical pulse trains from the camera, two digital signals which specify picture size, and one digital signal which initiates sampling.  Two signals are generated as outputs, one which initiates analog to digital conversion at the proper times and one which

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indicates that sampling is complete. The unit samples horizontal line by horizontal line in one column, then moves to the next column, and continues until a complete picture has been sampled. Picture sizes available using this device are 128 points per side, 256 points per side, or 512 points per side. This sequence of sampling also specifies that picture data be stored in the same format, so data elements in a picture data block start with the upper left corner and proceed down the column, then start at the top of the next column to the right, continuing in this manner through the complete picture.

A video signal must also be provided when taking a picture. Due to loading and line termination considerations, the actual input video signal to be digitized is fed to a video buffer amp which provides a high impedance tap on the video line to minimize loading effects. This amp also provides line impedance conversion from the standard 75 ohm video line to a 50 ohm line as required to feed the A/D converter. The amp also adds a DC offset to the video signal in order to use the maximum portion of the A/D input range.

Re-creation of a picture is accomplished using the Princeton Electronic Products PEP-400R Video-Graphic Storage Terminal. An analog signal for each of the X-, Y-, and Z-axes is required by this unit, and these signals are generated using the D/A converters of the computer. However, loading constraints required that a buffer amp be installed between the D/A outputs and the axis input for each axis. A video signal and a composite sync signal are generated by the PEP-400R, and are fed to the other video equipment. Control of the storage terminal is done by a set of digital signals generated by the computer, and fed to the terminal via the general purpose

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digital interface.

Throughout the hardware portion of this system, three things stand out as more important than anything else. First, everything must be tied to a very good local ground to eliminate noise problems. Second, all high-frequency signals, mainly video lines, must be terminated for proper operation. Third, timing considerations are very critical, both in the hardware, and in the software.

Software. Software for the Image Processing System can be split into two sets of programs, i.e. those concerned with the interaction of the video units and those concerned with processing the images. Programs are stored as files on mag tape, as are pictures. Each file consists of a 4K byte label record followed by additional data records. In program files, the additional records contain core images of the program, while the label record indicates where each additional record is to be loaded into memory, along with the starting address. The additional records contained in a picture file contain the actual picture data, and are required to be 4K byte records. Every label record contains the file number, the file name, the file type, the number of records excluding the label record, a title field, and any other necessary information for the programs.

File type is a two character code indicating what is contained in the file. The first character specifies data format, while the second character specifies certain information, such as size, relative to the format. A "P" format file indicates a program file and the second character specifies which of the system programs is contained in the file. Picture files generated when sampling are defined as "0" format, where picture elements are all real quantities stored as eight bit 2's

complement bytes.  The complex formats were created with respect to the data format used by the Fast Fourier Transform subroutine.  These formats consist of a real part and an imaginary part for each picture element, where either part is a 16 bit 2's complement binary number considered as a fraction with the binary point between the sign bit and the next most significant bit.  In a complex format record the first half contains the real parts, while the second half contains the corresponding imaginary parts.  Complex format files appear as being either "F", "C", or "T" format, where "F" is for frequency data generated as the result of executing a forward Fourier Transform, "C" is for time (or spacial) data generated by an inverse Fourier Transform, and "T" indicates a temporary data file as generated by the two transform programs since only one sequential mass storage device is available in the system.  In "O", "F", "C", or "T" format files, the only acceptable second characters are "S" for 128 size pictures, "M" for 256 size pictures, or "L" for 512 size pictures, where size indicates the number of picture elements per side of the picture.  There is also a special "S" format for special picture sizes, which is limited to the same kind of data as in an "O" format file.  Here, the second character can be "3" for $8 \times 8$ pictures, "4" for $16 \times 16$ pictures, "5" for $32 \times 32$ pictures, or "6" for $64 \times 64$ pictures.  The 3-dimensional display program, to be discussed below, is the only program in the system which recognizes "S" format files as valid.  Files are delimited by tape marks, and logical end-of-tape is indicated by two consecutive tape marks.  Mag tape errors cause the programs to halt.

Interface Programs. This set of three programs are used to convert pictures from visual to numerical form or from numerical to visual form. A picture is converted from visual to numerical form using the hardware SAMPLER unit, and the program known as SAMPLE (also READ). SAMPLE positions the mag tape where the user requests, writes the proper label record using user supplied information, initializes the A/D converter and the SAMPLER, and then sends the start signal to the SAMPLER. The SAMPLER starts initiating A/D conversions, and the program controls the transfer of data from the A/D to the mag tape using a double buffer system. When the SAMPLER sets the sampling done flag, the program checks that all data transfers are complete, and then closes the file by writing a double tape mark. A message is also generated to let the user know that sampling is complete, and indicates in which file the data is contained. The data format for this file is "O" format.

Conversion from numerical to visual pictures is accomplished using the PEP-400R storage terminal and either the DISPLAY (or DISP) program, or the 3-dimensional display (DIS3) program. DISPLAY generates a normal visual image of a picture file, while DIS3 generates an XYZ type image display. Both of these programs will handle any of the standard data format files. If a picture file is in one of the complex formats ("F", "C", or "T"), the user has the option of displaying the real part, the imaginary part, or the $\log_2$ of the magnitude squared for each picture element. A planned modification will also allow display of the phase angle for each picture element. These two programs allow the user to specify the characteristics of each display run, locate the data file on mag tape, and then proceed to write the image on the storage terminal. Writing is accomplished by controlling

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the three analog signals generated by the D/A converters, and also by the proper sequence of digital signals to the storage terminal actions.

Processing Software. The second set of system programs consists of those which process data files in order to modify pictures. Included in this set are the Fast Fourier Transform programs, the filtering programs, and other incidental processing programs.

There are two Fast Fourier Transform programs due to the difference between "O" format files and complex format files. Tape movement and positioning is slightly different during the first pass of the Transform programs, as is data handling. These two programs were written around a one dimensional Fast Fourier Transform subroutine, which expects that the data values used as input are 16 bit 2's complement binary fractions with the binary point positioned between the sign bit and the next most significant bit. Therefore, if the source file is "O" format, the 8 bit data elements must be converted to 16 bits before passing them to the subroutine. This conversion is written into the first pass of the real transform program known as FFTR. Since more information can be seen easier if the average value, i.e. the origin, of the frequency plane is in the center of the picture, there is a provision to multiply the input data element by minus one raised to the power equal to the sum of the position indices for the element. This multiplication shifts the frequency plane origin from the upper left corner to the center of the plane. The first pass reads blocks of data, converts the data, multiplies by minus one if desired, calculates the forward transform for each column, and outputs the result to a "T" format file, saving the scale factors. In the second pass, the results of the first pass are read back in, scaled to keep the complete transform relative,

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the rows and columns are transposed so that the transform of the rows will be calculated. The results of this pass are then output to a second "T" format file in transposed form and the new set of scale factors are saved. At this point, transforming is complete but the data is transposed and not properly scaled. Pass three, therefore, reads the data from pass two, scales it, transposes so data is in normal form, and outputs the result on a third file which is in "F" format. FFTR can only produce a forward transform.

In order to generate an inverse transform, the complex Fast Fourier Transform program must be used. This program, known as FFTC, will calculate either an inverse transform given a "F" format data file, or a forward transform given a "C" format data file. For the inverse transform, the final output file will be in "C" format, while the forward transform generates a "F" format file. No data modification is necessary, since data is already in the proper form. If an origin shift via multiplication by minus one is requested, the multiplication occurs in pass one prior to transforming when calculating forward transforms, or in pass three when calculating inverse transforms. Operation of FFTC is the same as for FFTR in all other respects.

To actually modify a picture, the other programs must be used. Principal among these are the two filtering programs. Both of these programs will accept either "F" or "C" format data files as input, and generate an output file of the same type. Filtering is normally applied to frequency data. The first filtering program, known as FILTER or FILT, uses rectangular shaped filters which can be positioned as desired in horizontal-vertical orientation, if care is taken to not overlap adjacent filters. The user can

specify up to thirty-two real and thirty-two imaginary filters to be applied to the picture.  If the same set of filters is to be applied to both real and imaginary elements, the user can specify duplication in order to eliminate having to enter filter parameters twice.  After specifying the number of filters, the user enters the parameters for each filter.  Each rectangular filter is specified by the X and Y coordinates of the upper left corner, the length in the X and Y directions, and the gain to be used for multiplication inside the filter area.  Acceptable gain values lie in the range from -512.0 to +511.9 with the only allowable fractions being tenths.  After all filter parameters have been entered, the program requests verification, so that the user can respecify the filters if a mistake was made on entry.  Once the parameters are correctly entered, the program proceeds to read the source data, multiply by either a specified gain or by unity, and then writes the filtered data out in a new data file.  This program was originally intended to be able to use different geometrical shapes defined by subroutines as the filters, but these have not been implemented since the processing scheme was changed to filtering in a radial manner.

The latter filtering scheme uses the radial filtering program, known as RADFIL or RADF.  RADFIL operates similarly to FILTER, with the main difference in the filters themselves.  In RADFIL, the user specifies a one dimensional gain versus frequency function as the filter.  The program determines the radius from the center of the picture for each data element, and uses this radius to determine the proper gain to multiply by from the filter function.  The picture center is defined as one-half of the picture size plus one.  Valid input gains are the same as in FILTER.  RADFIL will accept up to ninety-nine values for the filter function.  The values to be entered

are a coordinate paired with a gain for that coordinate. Coordinates should start with zero, increase monotonically, and the last one should be greater than or equal to three-quarters of the picture size. The program, after verification as in FILTER, proceeds to generate a filter gain table using straight line approximation between each adjacent pair of coordinate-gain values entered by the user. Then the source data is read, multiplied by the proper gain, and output to a new file. With the zero coordinate at the center of the picture, the filter function is rotated around the center.

The procedure which uses these filters is known as homomorphic filtering and requires the logarithm and antilog of the data. The program known as LOGO takes the natural log of the original picture data, and generates a new file containing the logarithm values. Since LOGO only accepts "0" format files, the input data consists of 8 bit 2's complement binary numbers. The data bytes are first made positive by an additive constant, since the log of a negative number is undefined, and then they are used to index a lookup table for the proper logarithm value. Since zero is a valid input value, whose log is minus infinity, the table entry used is the maximum negative number available in 16 bits. The logarithm table consists of word quantities for the logarithms, and therefore the program generates a "C" format output file where the real parts are the logs, and the imaginary parts are forced to zero. Only the source and destination files need be specified by the user. The ratio of the number of negative values versus the number of positive values generated this way, is determined by where the binary point is assumed to be in the 8 bit data byte. Presently, the most optimum choice appears to be between the third and fourth bits from the left, giving a range between zero and seven and thirty-one/thirty-seconds, with the smallest increment being one

thirty-second.

In order to restore processed pictures to the normal data form, anti-logs are taken using the exponentiation program known as EXPO. This program uses a table also in order to determine the antilogs, though this table is accessed using the binary search method. The table is generated in a manner similar to the table used in LOGO in order to generate the proper anti-logs. Each entry in the table is actually a pair of words, the first being the logarithm of a value halfway between the previous original value and the current original value, while the second word is the actual offset antilog expressed in 16 bits instead of 8 bits. EXPO accepts as input a "C" format data file, and outputs a second "C" format file containing antilogs in the real parts, and zero in the imaginary parts. Program execution only requires source and destination files from the user.

The programs discussed above are the main processing programs currently in use. There are four additional system programs available also. Three are simply data manipulation programs, while the fourth is a simple compiler-monitor.

Multiplication by minus one allows the user to form the negative image of a picture. The program which does this is known as CMPLMT or COMP, and will accept any "O", "F", or "C" format data file as input, and generates a new file in the same format.

Two files can be added using the program known as ADD or ADDF, if the file types and sizes are compatible. "O" formats cannot be added to complex formats. The output file type depends on the input file types.

Multiplication of two source files is accomplished using the program MULT. Two "O" format files multiplied give a "C" format output file with

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zero imaginary parts. An "0" format file times a complex format file gives an output file with the same complex format. Here, multiplication of 8 bits times 16 bits gives a 24 bit result of which the most significant 16 bits are retained as the result. Two complex files multiplied give a 32 bit result with the most significant 16 bits being retained as the result for the complex data file being written. In each case, multiplication is done on an element by element basis. These three programs are not currently in use because they were not written in standalone form as the other system programs.

The final program available to the system is the PICTURE PROCESSING LANGUAGE (PPL) compiler-monitor. All other system programs are intended to run under PPL. The monitor program provides some auxiliary tape handling routines such as tape indexing, file label listing, deletion of unwanted files beyond a certain file number, and driving a tape offline. Definition of variable names and entry into the PPL compiler are also monitor functions. The compiler allows the user to write a simple series of statements which form a program. These statements are compiled into calls to the system programs necessary to execute the user's statements. Even though the system programs are intended to run under the compiler monitor, there are modifications necessary for this type of operation. Most of the programs are now debugged sufficiently to allow this modification to be made as time permits. The modifications necessary are mainly to allow file numbers to be passed to the programs on a compiler stack, proper loading and starting of the programs, and the proper return to the compiler monitor with indication of successful or unsuccessful completion of the program. Unsuccessful completion causes an abnormal end and return to the monitor.

CHAPTER III


DATA INTERPRETATION


A principle mission of the ERTS-1 Program has been to study the feasibility of assessing natural resources from satellite imagery and to demonstrate useful or potential applications of this imagery. This chapter presents the highlights of useful applications in soil association, soil moisture, and land use evaluations.

Delineation of Major Soil Associations

The reflectance characteristics of soils are conditioned by many factors. Soil color and soil moisture content are two major factors that greatly influence soil reflectance. The medium textured soils of the southeast generally have a reddish or yellowish hue while the reflectance from these soils generally reaches a minimum at a moisture content of 16 to 18 percent by weight (about 2 bars tension). As the moisture content increases or decreases, the soil reflectance increases. Maximum soil reflectance is obtained at a moisture level near or slightly below field capacity (1/3 bar tension).

If soils are to be delineated through the use of aircraft or ERTS imagery, the best conditions for delineation exist when the soil is void of vegetation and, preferably, in a freshly tilled state. This condition is generally found only in areas of intensive row crop agriculture or areas where all vegetation is removed from the land each year, as in sections of developing countries with extremes in yearly rainfall distribution.

Another means for soil identification is where the soil is covered

with a vegetative cover characteristic to a particular soil association or soil group. This characteristic occurs in many forested areas but may also be found in other types of vegetative cover. In such cases the soil associations are delineated through the reflectance characteristics of a reasonably uniform type of vegetation possessing the same boundaries as the soil associations. The identification of vegetation types through reflectance characteristics is quite widely known and used.

The example reported herein is a case of soil association delineation through the reflective characteristics of a fairly uniform cover of vegetation. In this particular case the Memphis soil association may be identified in Obion County using ERTS imagery. This Memphis soil association occurs in the western edge of the loess that covers most of West Tennessee. The region is known as the "bluffs" and occurs at the break between the loess soils and the delta soils of the Mississippi floodplain.

Figure 3.1 shows a photograph from Channel 7, ERTS-1 imagery taken on October 1, 1972 (OBSERVATION ID 1070-16055) and a soil association map of Obion County. The orientation features in the photograph are Reelfoot Lake and the Mississippi River in northwest corner and the Obion River that crosses the county from northeast to the southwest. The map and picture scale is 1 inch equals approximately 8.5 miles.

The Memphis soil association is the large block (No. 3) in the western portion of the county. A small block of the Memphis association is found in the northwest portion of the county and extends across the state line into Kentucky. The area has a fairly uniform vegetative cover of pasture grasses and this characteristic permits its delineation through ERTS-1 imagery. Small cultivation and wooded areas are found throughout the area

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Figure 3.1. ERTS-1 Imagery and Soil Association Map of Obion County, Tennessee, Showing Delineation of the Memphis Soil Association an Three Other Major Soil Group

but most of these are not of sufficient size to be detected. The areas east of the large Memphis block is one of intensive row crop agriculture.

The computer printout of the large block of the Memphis association is too large to be adequately shown in one photograph. Figure 3.2 shows a small portion of the computer printout that separates Reelfoot Lake, the Adler-Convent-Falaya, and the Memphis soil associations. Figure 3.3 shows the computer printout of the Obion River and the adjacent Waverly-Swamp association.

These findings demonstrate the feasibility of delineating major soils through vegetative cover characteristics common to the soils in question [10]. Channel 7 has provided the most information for studies of this type.

Soil Moisture and Land Use Evaluations

Locating small cropland areas and correlating aerial photos of these areas with prints of satellite imagery has been difficult. This problem has been resolved by using enlargements of satellite imagery and carefully examining the various color shades of the satellite imagery with aerial photos and computer printouts of the satellite imagery. Due to cloud cover, haze, and similar related problems, only about one image of four is sufficiently clear to use for comparison purposes. This has created a time differential resulting in comparison problems since drastic changes in crop maturity, soil moisture, and soil temperature have sometimes occurred.

Two primary West Tennessee target sites, the West Tennessee Experiment Station and the Ames Plantation, have been definitely located on satellite imagery and correlated with aerial photos. Crops on these areas and surrounding areas have been determined by ground surveys. This information

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Figure 3.2. Computer Printout from ERTS-1 Imagery Evaluation Separating
Reelfoot Lake, the Adler-Convent-Falaya, and the Memphis
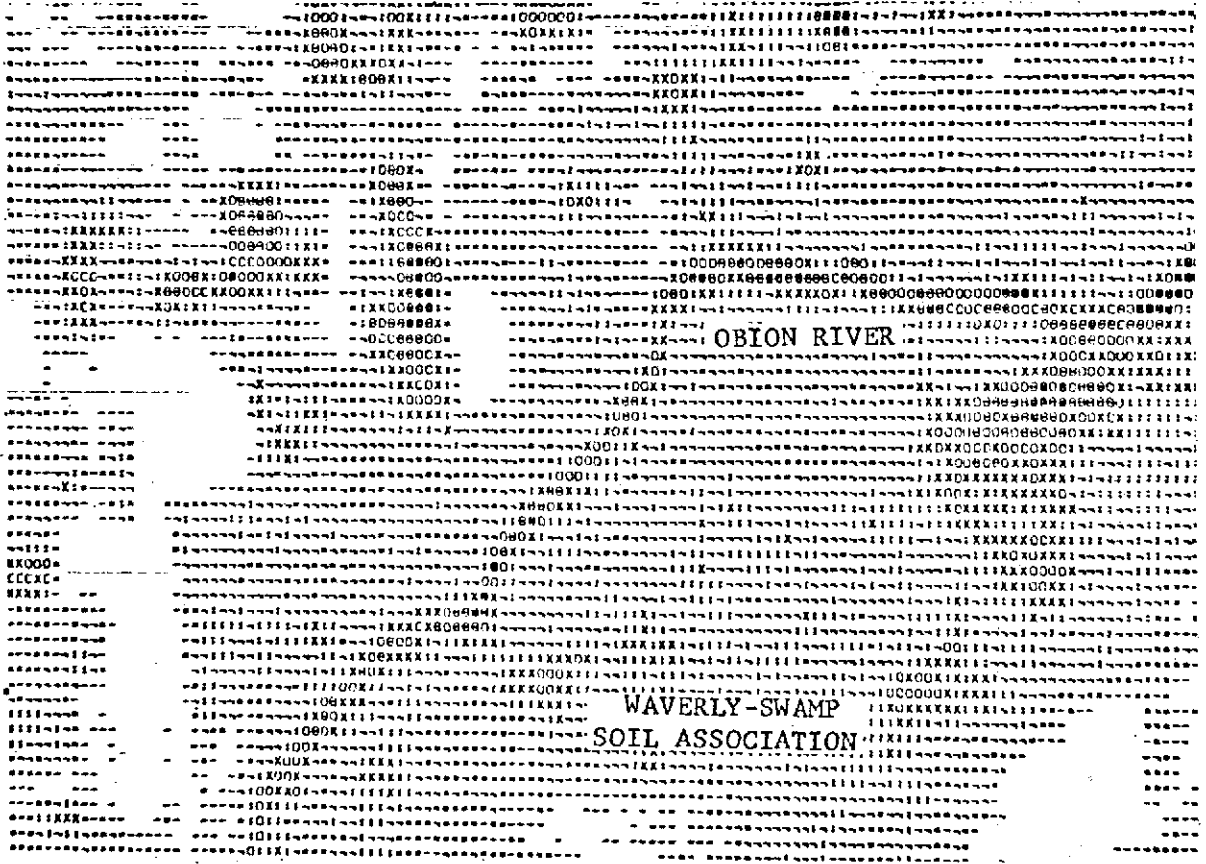Soil Associations.

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Figure 3.3. Computer Printout from ERTS-1 Imagery Evaluation Showing the Obion River and the Adjacent Waverly-Swamp Area.

has been used in attempts to predict crops on unsurveyed areas which have corresponding color shades to those of the surveyed areas. Computer densitometer printouts are currently used in the development of crop "signatures" based on the density information of the imagery as determined from the scanning microdensitometer. This procedure involves comparisons of various stages of crop maturity for each MSS Band. Of the imagery received and analyzed to date, only the October 1, 1972 imagery has been sufficiently clear to use in signature development. Results from the study of October 1 imagery are promising.

MSS Channels 4, 5, 6 and 7 were scanned, and a corresponding density printout for each was analyzed. If density values appearing on each transparency are divided into four groups, the following results are found to hold true for each channel. Water has the highest density value. Forest land occupies the next highest level. Cropland (mainly soybeans and cotton) has the third highest density level. Pasture and similar grassland has the lowest density value. Results of printout analyses by MSS Channels for Ames Plantation are given in Table 3.1 [12]. Further refinement of scanning and printout techniques is expected to enable further differentiation of areas into types of crops on cropland and types of trees in forested areas.

Attempts to extend the results from one set of imagery to an unsurveyed, unrelated set of imagery has proven, at most, discouraging. Even attempts to apply the results from one set of imagery to a time-differentiated set of imagery of the same scene produces ambiguity because of haze and cloud cover.

Future work in this area should include pattern identification techniques applied to band 4, 5, 6, and 7. Spectral information from each of

TABLE 3.1   Results of Computer Printout Analysis for October 1, 1972
Imagery of Ames Plantation

| MSS Channel | Density Subrange | Land Use, Terrain Features, or Crops |
|---|---|---|
| | Density Range 140-190 | |
| 4 | 140-153 | Pasture |
| 4 | 154-169 | Cropland |
| 4 | 180-188 | Forest |
| 4 | 190 | Water |
| | Density Range 150-240 | |
| 5 | 168-196 | Cropland |
| 5 | 218-238 | Forest |
| 5 | 240 | Water |
| | Density Range 115-160 | |
| 6 | 115-133 | Cropland |
| 6 | 124-133 | Pasture |
| 6 | 133-144 | Area Around House & Barn |
| 6 | 144-157 | Forest |
| 6 | 159-160 | Water |
| | Density Range 100-140 | |
| 7 | 105-120 | Cropland |
| 7 | 121-132 | Forest |
| 7 | 140 | Water |

these bands should be used to form a 4-dimensional vector. Vectors so formed should be compared with ground truth studies and appropriate classification algorithms developed for computer processing.

## Landscape Change

Studies in landscape change from a geographic perspective require large area coverage on a periodic basis in order to analyze aggregate changes over an extended period of time. The analysis of landscape change in Eastern Tennessee from ERTS-1 imagery utilized three avenues of experimentation and analysis: (1) a multi-stage sampling procedure utilizing field data and aircraft imagery for ground truth and control, (2) a densitometric and computer analytical experiment for the analysis of gray-tone signatures and comparisons for landscape change detection and monitoring, and (3) an ERTS image enhancement procedure for the detection and analysis of photomorphic regions [13].

A small test site on the Cumberland Plateau was monitored for forest alterations and landform disturbances associated with surface strip mining for coal. Ground observations were made and photographed to illustrate the internal characteristics of the surface mines. Revegetation and reclamation work in the form of reseeded spoil banks was verified for the area. An experiment was conducted in which the microdensitometer and OPSCAN software package were used to analyze the ERTS imagery for gray-tone signatures, comparisons, and ultimately, for landscape change detection and monitoring. The experiment consisted of scanning band 5 imagery in which strip mines appeared as light tones against a dark forested background. A computer generated map and histogram (frequency distribution) were developed from the digitized information. By comparing such machine analyzed data from

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different dates of satellite observations, one should be able to conclude that forest cover has been altered and strip mines have been increasing because of the increased frequency of light toned signatures.

Experiments of this nature are very dependent upon the clarity of the observation as well as the registration of the test area. Only one clear observation of the area was obtained, from ERTS data. During other overflights, cloud cover was significant enough to seriously affect the validity of histogram type comparisons for detecting landscape change. Given time and clearer observations, more definitive results could be obtained. In concept, the experiment is justified and represents a potential application of ERTS imagery [14].

Landuse Mapping

The density level slicing and pseudo-color enhancement capabilities of the Image Processing System have provided useful techniques in landuse mapping. Through the manipulation and assignment of color codes to the desired density levels, a landuse display based on level I land categories can be generated. For example, forest cover which corresponds to dark-toned signals on band 5 imagery can be coded with a dark or heavy density color such as brown or purple. Another color such as green can be assigned to the next highest density level which corresponds to agricultural areas. If a water signature is present, a yellow code can be used. The final density slice representing high density settlements and transportation networks is coded bright red or orange. Utilization of these color assignments generates a pseudo-color landuse map.

Using the techniques as described above requires an interaction between the interpreter and the system. Tonal variations reflect densities

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which are measured, sorted, (or sliced) and displayed by the Image Processing System. A human interpreter assigns these levels to landuse categories. The interpretation is only as good as the interpreter since his subjective and objective knowledge of the area enters a bias into the color assignments for different densities as well as the spatial distribution of density levels.

Color transparencies of ERTS imagery have been used to detect and map high density settlements such as central business district areas, shopping center complexes, and suburban subdivisions. High density settlement features reflect from ERTS imagery in bright returns. By selecting only the brightest signatures for an urban scene, identification and mapping of high density settlements are achieved. Since airport runways return signals similar to high density settlements, the interpreter's knowledge of the area and choice of bright signal returns interact in generating the landuse map [15].

The applications presented in this chapter exemplify the types of interdisciplinary studies this project has supported during the ERTS-1 Program.

# CHAPTER IV

## CONCLUSIONS

Results have been obtained during the period of this study which show the feasibility of using satellite imagery in certain types of agricultural and geographical studies - primarily soil association and general land use evaluations. One aspect of the investigation which has not generated definitive results is whether or not point-by-point classification algorithms are more suitable than photomorphic analysis techniques (a study of the structure of the photograph in terms of tone, texture, and pattern) for identification purposes. Additional research must be conducted in these areas before a conclusive answer is obtained.

Certain aspects of interdisciplinary cooperation are quite clear. Various technical groups are searching for information from the data structures which is unique to their particular group. In the final analysis, the interpretation of processed data is very much dependent upon the user's ability to describe the features to be extracted from the data. Close communication must exist between the information processing group and the user of the data as the system software is developed and refined.

Dedicated systems for processing data have definite advantages over multipurpose systems. Turnaround time in bulk processing tasks generate considerable span between the initiation and conclusion of a job. Most researchers still require considerable of interaction with the interpretation process. On-line processing seems to provide the best alternative for satisfying these needs.

The impact of the ERTS-1 program on the remote sensing program of The University of Tennessee is significant. Considerable insight was gained

into the research objectives and data processing problems which are typical of an interdisciplinary group. A nucleus of technical fields exists for continuing the cooperative effort into the future. These endeavors will be strongly oriented toward image enhancement and image recognition techniques as described in the Appendix.

Past experience of this group greatly influenced the approach taken during this investigation. Image transparencies were the primary source of acquired data. An effort was made in the latter stages of the project to correlate information from film data with bulk and precision data tapes. Unfortunately, difficulties were encountered in this effort primarily in that NDPF tape formatting was not compatible to either the Image Processing System or the OPSCAN/360 software. Consequently, special set-up requests for batch processing were necessary and resulted in low priority with the IBM MVT system. Therefore, with slow turnaround time, only a small sampling of dual tapes (one tape derived from film scanning, one tape supplied from NDPF) were processed. Preliminary results show favorable agreement between information obtained from the density values of the two tapes [12].

APPENDIX

Future efforts of the multidisciplinary remote sensing program of
The University of Tennessee will be directed toward the application of
image enhancement techniques and image recognition techniques to satellite
imagery. The specific approaches are described below as integrated into
the image processing system.

## Image Enhancement Techniques

Image enhancement plays a central role in the high-lighting and de-
tection of significant events. A great deal of our present work on image
enhancement is centered upon the 2-dimensional Fast Fourier Transform (FFT).
The basic technique used is shown in Figure A.1. The function $f(x,y)$ rep-
resents the original input image, where $(x,y)$ are the spatial coordinates
of each point in the image and $f(x,y)$ is the intensity at that point. Ap-
plication of the 2-dimensional FFT to $f(x,y)$ yields its transform $F(u,v)$
where $(u,v)$ are the coordinates of the frequency plane. $H(u,v)$ may be con-
sidered a filter or mask which may be used to alter $F(u,v)$. For example,
if it is desired to enhance edges in the original picture $f(x,y)$ (which are
determined by high frequency components in $F(u,v)$, $H(u,v)$ may be used to
boost the high frequencies in $F(u,v)$. Then, when the inverse transform of
$H(u,v)$ $F(u,v)$ is taken, the result is $g(x,y)$ which is a picture similar to
$f(x,y)$ but with enhanced edges. This approach is seen to be very powerful
due to the tremendous variety of possible $H(u,v)$ that one may choose.

The same approach used in Figure A.1 can be used in a spatial-
frequency pseudo-coloring scheme. A diagram which accomplishes this is
shown in Figure A.2. As indicated in the figure, $f(x,y)$ is transformed.

$f(x,y)$ → | FAST FOURIER TRANSFORM | → $F(u,v)$ → | $H(u,v)$ | → $H(u,v)\ F(u,v)$ → | (INVERSE) FAST FOURIER TRANSFORM | → $g(x,y)$
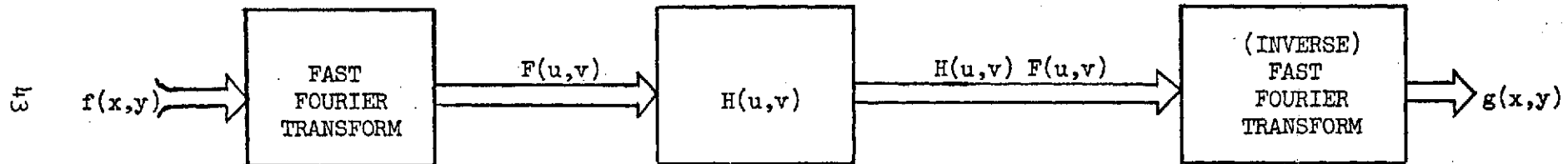
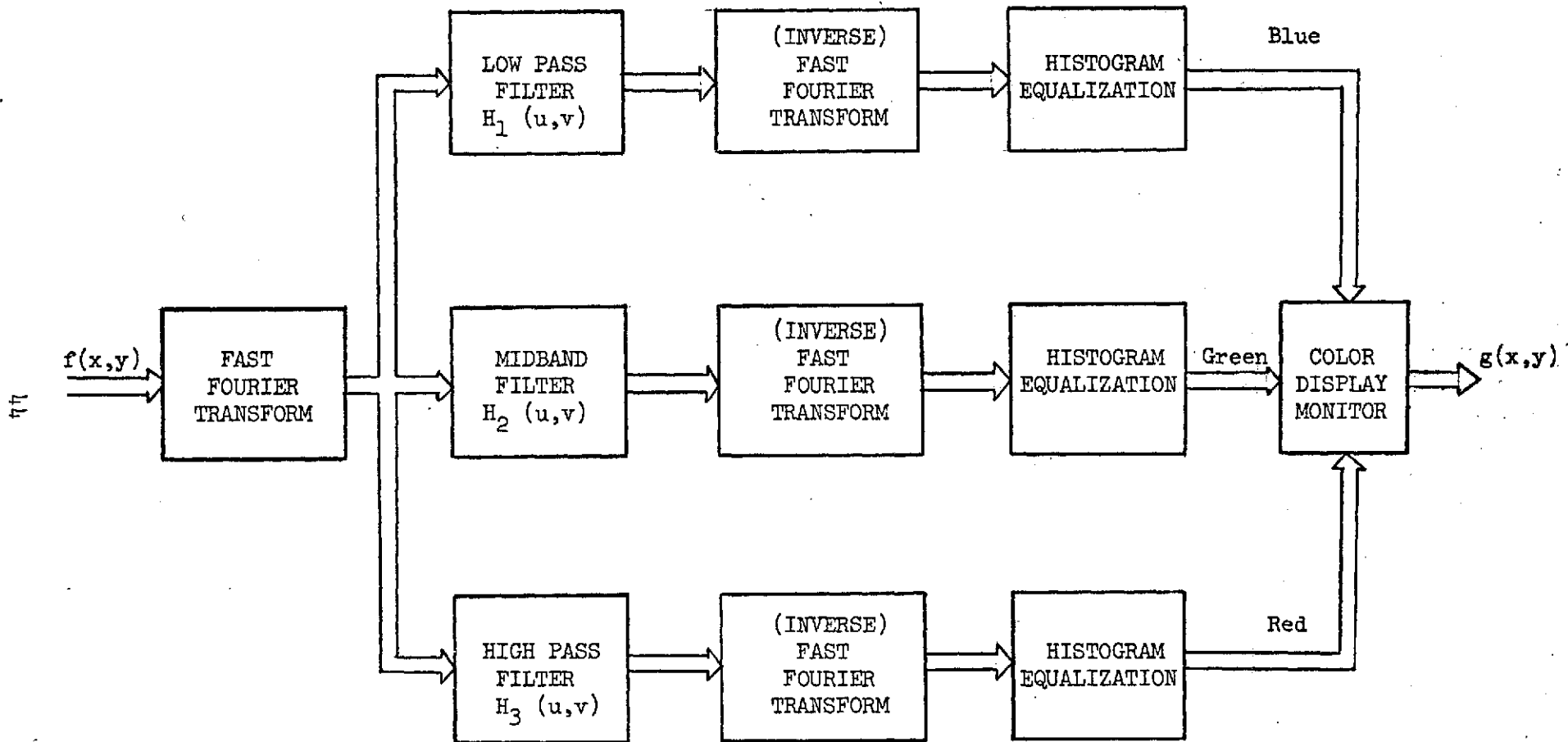Figure A.1. Use of the Fourier Transform for Image Enhancement.

Figure A.2. Frequency-sensitive Pseudo-coloring Scheme.

Then $F(u,v)$ is split into three frequency ranges by using three filters $H_1(u,v)$, $H_2(u,v)$, $H_3(u,v)$. Results of this operation are individually inverse-transformed, equalized (for more uniform color results) and, for example, fed into the Red, Green, and Blue inputs of the color monitor. The result is a picture where each color corresponds to a specific frequency range. This, of course, is only one of many possible color enhancement schemes. Another typical approach is to slice the intensity levels in a picture (density slicing) into several regions and then assign a different color to each region. Qualities which are completely undetectable in a monochrome picture can be convincingly brought out by this method.

Other ad hoc techniques are often useful in image enhancement. Certain types of non-linear transformations can sometimes be used to enhance or restore a specific image. Due to the variability and quality of ERTS data, however, the transform approach to image enhancement is preferred because of its applicability to a great variety of situations and also because of its relative simplicity of implementation.

During ERTS-1 an image analysis system which is capable of performing some image enhancement functions (particularly color) on a real-time basis was evaluated. Although these functions are a subset of the present and projected capabilities, the real-time feature is extremely attractive for a coarse, quick look at significant volumes of data.

Image Recognition Techniques

One of the most important and difficult tasks in this field of research is the automatic recognition of patterns of interest in an image. A well recognized fact is that if users are ever to make substantial use of ERTS data, automated recognition machines capable of processing this

information on a routine basis must be developed.

A general schematic diagram of a pattern recognition system is shown in Figure A.3. The function of the system is to yield a decision which identifies or classifies the input patterns. For example, these input patterns could be a series of multispectral images, and the required recognition task could be to identify regions in the images according to whether they are urban or rural.

The measurement device is generally considered to be the transducer which transforms the input patterns into a form suitable for machine manipulation. For example, in the case of film images, this device is a scanner which transforms an image into digital form.

The preprocessor performs the function of digital noise suppression plus any other functions associated with raw data preprocessing. In addition, specialized functions such as edge enhancement or line thinning may be performed.

The feature extractor is in charge of detecting features required for classification. Its function may be based on mathematical or statistical principles, but very often simply consists of a set of routines designed to perform a specific task.

The classifier is the decision maker. Use is made of the information provided by the feature extractor in order to make these decisions. Its structure may be based on mathematical, statistical, or syntactic principles as well as on ad hoc techniques. A combination of these approaches is not uncommon.

Many of the functions of a pattern recognition system as discussed above are already operational in the image processing system. All the

INPUT
PATTERNS → MEASUREMENT DEVICE → PREPROCESSOR → FEATURE EXTRACTOR → CLASSIFIER → DECISION
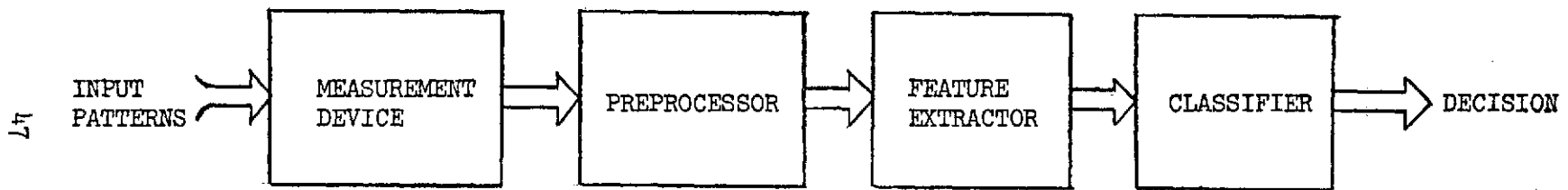
Figure A.3.   General Form of a Pattern Recognition System.

measurement devices are being presently used. Many of the preprocessing routines used for image enhancement are also used for pattern recognition. This also holds true for feature extraction. For instance, histogram generation and boundary extraction are examples of feature extraction operations. The bulk of the work which remains to be done is in connection with classification techniques. Work in this area will be divided into the following principal categories:

- Mathematical
- Statistical
- Syntactic
- Ad hoc

The mathematical approach to classification is normally based on a distance function concept. Cluster-seeking techniques are of particular importance in this approach. These techniques attempt to find clusters in numerical data as a means of establishing measures of similarity. A software package developed at the Stanford Research Institute offers a very attractive approach to cluster seeking. This program, called ISODATA, is presently being implemented at The University of Tennessee.

Based on the data rates at which imagery is currently being acquired and those projected for future space missions, an obvious conclusion is drawn that data handling capabilities must be refined and the research in areas related to this problem intensified. The success of future earth resources programs will be largely dependent on the ability to automatically process information.

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