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LOW-COST DATA ANALYSIS SYSTEMS FOR PROCESSING MULTISPECTRAL SCANNER DATA

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16. Abstract

The basic hardware and software requirements are described for four low-cost analysis systems for computer-generated land use maps. The data analysis systems consist of an image display system, a small digital computer, and an output recording device. Software is described together with some of the display and recording devices, and typical costs are cited. Computer requirements are given, and two approaches are described for converting black-and-white film and electrostatic printer output to inexpensive color output products. Examples of output products are shown.

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LOW-COST DATA ANALYSIS SYSTEMS FOR PROCESSING MULTISPECTRAL SCANNER DATA

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SUMMARY

Most computer-generated land use maps produced to date have been made with expensive, sophisticated, research-oriented systems. Realizing that most potential users of remotely sensed data cannot afford such systems, the NASA Earth Resources Laboratory has developed a modular hardware approach that may be added to existing facilities to establish a low-cost data analysis system for processing Landsat-type multispectral scanner data using supervised spectral pattern recognition techniques. A few modifications are required for use of aircraft-acquired data. Software modules have been developed in FORTRAN IV language that are compatible with most small (and large) digital computers.

The Earth Resources Laboratory has defined the basic hardware and software system requirements for four low-cost data analysis system configurations consisting of an image display system, a small digital computer, and an output recording device. The software consists of a Landsat multispectral scanner data reformatting program, a series of supervised spectral pattern recognition programs, a program to reference the image data to a map base, a data storage and retrieval program, and some applications programs. A modular component designed for reading high-density digital tape recorded data and transferring it into computer memory has been developed but is beyond the scope of this report.

Some image display and output recording devices are described, and typical prices are given. Computer requirements such as word size, memory, speed, and peripherals are presented. Two approaches are described for converting black-and-white film and electrostatic printer output to inexpensive color output products.

INTRODUCTION

The NASA Earth Resources Laboratory (ERL) has developed a sophisticated, research-oriented data analysis system (DAS) for evaluating complex remote-sensor systems and for developing techniques for application of remotely sensed data to solve or monitor resource management problems. The research-oriented DAS has

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the capability for reading and processing data from several multispectral scanner (MSS) systems flown on aircraft and spacecraft, as well as data from ground-based data collection systems on boats and trucks. Most potential users of remote-sensor data cannot afford and do not need such an extensive data analysis capability. Most users will initially receive the data in computer-compatible-tape format. The low-cost data systems have been configured to accept computer-compatible tapes only. A modular component has been designed for reading high-density digital tape (HDDT) recorded data (in biphase-level pulse-code-modulated format) and transferring it to computer memory. Although this type of module is compatible with low-cost data systems, it is beyond the scope of this report. Low-cost data systems as described in this report are designed primarily for processing Landsat-type data. A few modifications are necessary for use with aircraft-acquired MSS data. Because most users do not need a very sophisticated system, the ERL has accepted a challenge to define, assemble, and evaluate several configurations of low-cost DAS's for processing MSS data. Throughout this report, the term "system" is defined to be a set of hardware, a set of software, and a procedure for their use. The procedure used by ERL for processing MSS data with the ERL DAS is described in reference 1. A very similar procedure for use of low-cost DAS's is being prepared.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

MODULAR APPROACH

The ERL low-cost DAS designs are based on a modular approach to take advantage of equipment available in a user's facility and to give the user a choice of components determined by his resource management requirements. The hardware for a low-cost data system can be logically divided into three modules: (1) an image display device, (2) a computer with appropriate peripherals, and (3) an output recording device. The software for the low-cost DAS has also been modularized to include the following: (1) a program-reformatting module for converting the data from their original formats to formats that are easier to use, (2) a spectral pattern recognition module for classification of surface materials, (3) a geographical reference module for converting data from sensor reference systems to a geographical reference system such as the universal transverse Mercator (UTM) projection, (4) a data base module for storage, update, and retrieval of as many as 30 bytes of information from disparate sources describing resource survey units (e.g., 400- by 400-meter (40 acre) plots), and (5) applications modules for extracting information from the data stored in the data base module.

IMAGE DISPLAY SYSTEMS

Printer/Plotters

A number of display systems are now available for displaying digitally encoded imagery data. The simplest display system is a line printer in which symbols are chosen to approximate gray shades. This type of display device requires the support of a computer program called PICTOUT,[1] which can be adapted for use with any existing line printer. Recently, electrostatic printer/plotters have been introduced that are capable of printing a picture element as a character or as a shade of gray. Figure 1 is an example of gray-scale imagery printed by an electrostatic printer. A number of electrostatic printer/plotters are available from computer equipment manufacturers at a cost of $12 000 to $20 000, depending on resolution, printing speed, and gray-scale consistency.

Cathode-Ray-Tube Displays

A portable image display system (PIDS) (fig. 2) was designed and built to ERL specifications by Comtal Corporation in 1974. The PIDS was designed to enable MSS data users to identify the location of known training samples and test fields on tape, and to review the results of surface classification as a color-coded display. The PIDS reads MSS imagery data from nine-track computer-compatible tapes and displays the data as shades of gray or false colors on the screen of a color-television monitor. The input data may contain as many as 2000 elements/scan line, and the flight-line length may be unbounded.

The user has complete flexibility in selecting any one of 64 levels of color or gray to represent any picture element. The scale of PIDS-displayed Landsat imagery is approximately 1:43 000. Any selected group of 256 by 240 elements may be displayed on the PIDS screen. The necessary controls are provided to permit the PIDS user to advance, reverse, or shift laterally in the data set and to read data for display on the PIDS screen.

To enable data users to select training samples and test fields, the PIDS is equipped with the cursor symbol +, which can be positioned anywhere within the screen by rolling a "track-ball" control in the direction of desired cursor movement. The coordinates (scan-line number and picture-element number) of the cursor-symbol position are displayed by light-emitting diodes on the front panel of the PIDS. On command, polygon-shaped training samples or test fields may be defined with the cursor, stored, and transmitted, together with sample identification, to a punched paper-tape output device (or to a keypunch, a card punch, or the bus of a digital computer if appropriate interfaces are provided) for further processing by spectral pattern recognition. The PIDS operates on 60-hertz, 110- to 115-volt alternating current and is mounted on wheels for ease of movement from office to office. Only a few minutes of training are required for learning to operate the PIDS.

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[1]Program PICTOUT was developed by the Laboratory for Applications of Remote Sensing at Purdue University and is a part of their program LARSYSAA.

Figure 1.- Sample output from the STATOS 33 electrostatic printer/plotter.

Figure 2.- Portable image display system.

An image processing system (IPS) (fig. 3), such as the Comtal model 8100, may be hardline connected with a small general-purpose digital computer so that the user may interact with the data processing and analysis steps to a large degree. The purposes of the IPS are to display color-coded MSS imagery for training- or test-field location and to give the user greater flexibility in analyzing the imagery data. The 512 scan lines by 512 picture elements are displayed on the screen to as many as 256 levels of color or gray. The system was designed for easy enhancement of the displayed data.

Data are read from tape into the computer to which the IPS is coupled and are reformatted for display on the IPS display screen. The user may define a polygon-shaped training sample, then have the computer calculate statistics for that training sample before a decision is made to accept or reject the sample. The real-time assessment of training-sample quality is an overall timesaver but results in slightly greater IPS utilization time. A variety of interactive analysis steps is possible, but discussion of these steps is beyond the scope of this report.

Use of the IPS depends on availability of the computer with which it is integrated. It is recommended that the IPS be used in a time-sharing environment in which other tasks can be performed concurrently by the computer because an investigator uses very little of the computer capacity during time-consuming tasks such as training-sample and test-field definition. The IPS must be installed in a fixed location, but it may be physically separated from the computer facility and operated as a terminal.

The hardware cost of the IPS is approximately $40 000. When used in a time-sharing mode, it is necessary to add an operator's console at a cost of approximately $2800.

COMPUTERS

Almost any small (or large) general-purpose digital computer may be used in a low-cost DAS. The software developed by ERL for low-cost data systems may be used on almost any computer having a FORTRAN IV compiler if experienced programers convert certain instructions that may not be compatible with the existing computer. Greater operating efficiency of some small computers may be achieved by adding to the systems software package a few instructions that make imagery data manipulation easier.

The characteristics of minimum and desired computer configurations are shown in table I. The minimum computer capability required for a low-cost data system is shown in the second column. If a computer of the minimum capability is used, the data processing time will be longer. It may be necessary to process the imagery data through the computer two or more times to classify all data. Addition of computer memory is recommended when high throughput rates are required. The third column of table I shows the desired computer configuration, which is adequate for most potential users of remote-sensor data, even for State-sized survey areas.

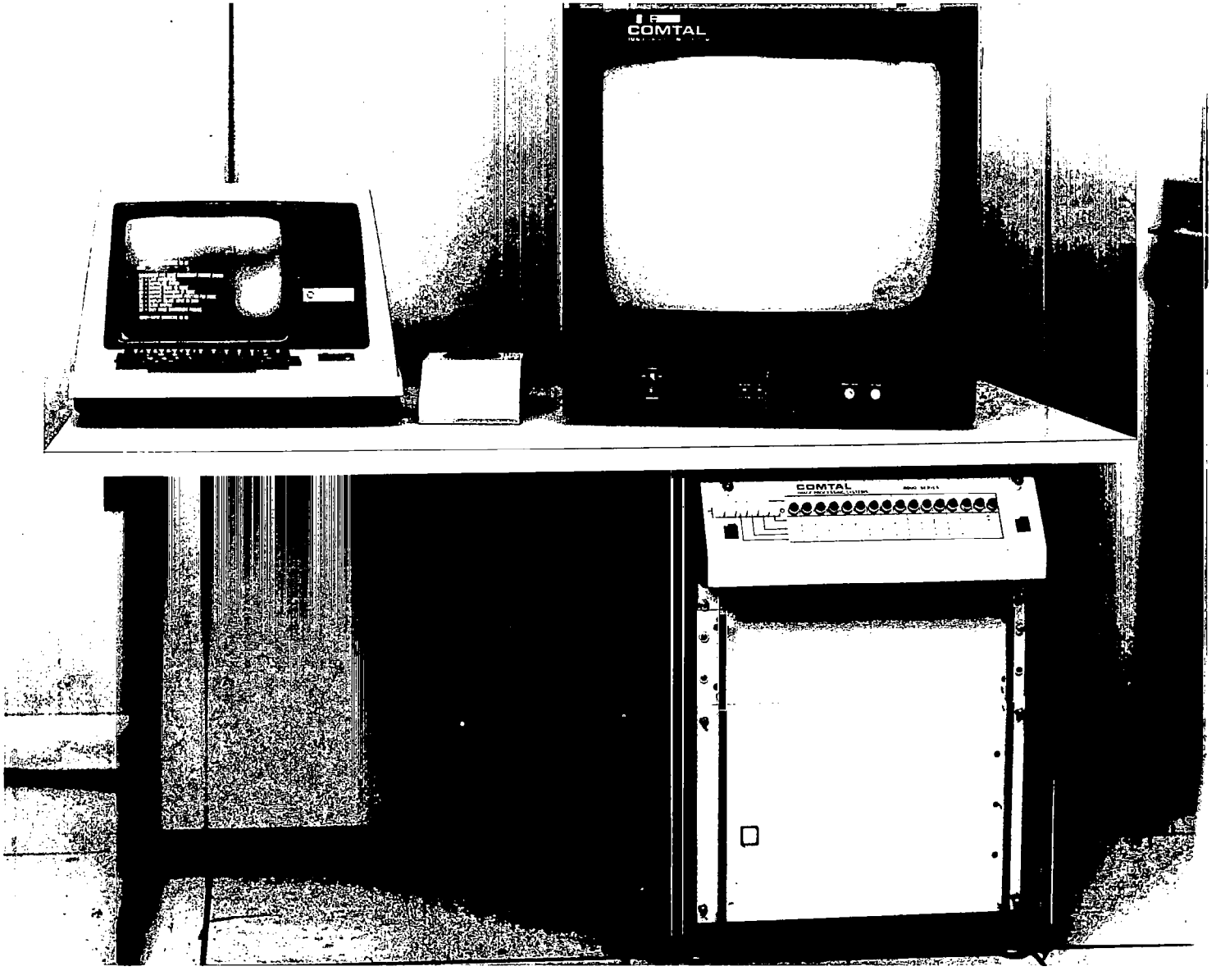


Figure 3.- Image processing system.

TABLE I.- COMPUTER REQUIREMENTS FOR LOW-COST DATA ANALYSIS SYSTEM

Characteristic	Requirements	
	Minimum	Desired
Central processor unit with operator's console	Required	Required
Memory	16 000 16-bit words	64 000 16-bit words (dual port)
Tape drives (computer-compatible tape)	Two 7- or 9-track drives	Two 9-track drives, 3.05 m/sec (120 in/sec), 315 bytes/cm (800 bytes/in)
Disk (rotating memory device)	12 000 000 16-bit words	46 000 000 16-bit words
Line printer	Required	Required
Electrostatic printer	Not required	Required
Card reader	Required	Required
Floating-point hardware	Not required	Required
Microprogrammable writable control storage	Not required	Required
Operating executive system	Not required	Required
FORTRAN compiler	Required	Required
Approximate cost (1975 prices)	$75 000 to $80 000	$150 000

Computer cycle time is not critical in the selection of a candidate computer for a low-cost data system. A cycle time of 1 microsecond is acceptable; but if high-volume throughput is required, cycle times of 660 nanoseconds are recommended. The speed of geographical reference conversion depends on the data manipulation (multiplication and division) efficiency of the computer. Hardware or firmware floating-point processors are recommended if geographical reference conversion (i.e., conversion from Landsat scene coordinates to the UTM projection) is required.

Although computer tape drives of any speed may be used in a low-cost data system, it is recommended that tape speed be as high as possible ($\leq$ 3.05 m/sec (120 in/sec)) because most modern computers can process data very rapidly. The tape drives should be capable of reading 315- and/or 630-byte/cm (800 and/or 1600 byte/in) packing densities.

Disk drives (rotating memory devices) are required in the low-cost data system to store a Landsat-size image during geographical reference conversion. A disk is also very useful for storage and quick retrieval of all software modules used in the low-cost DAS.

Small computers that are adequate for use in a low-cost data system together with all the necessary peripherals may be purchased for $75 000 to $150 000, depending on throughput rates required. The operating costs for these small computers (without equipment amortization or housing) are in the range of $30 to $75 per clock hour.

OUTPUT RECORDING DEVICES

The output recording device for a low-cost data system may be either a computer line printer, an electrostatic printer/plotter, or a black-and-white or color film recorder. The selection of an output device for a low-cost system should be based on the requirements, including output speed, control of scale, quantity of output, dynamic range, and number of copies of output to be produced. Several output recording devices are discussed in the following subsections.

Line Printer

A conventional line printer may be used as an output recording device for a low-cost DAS. The surface classification map is recorded on line-printer paper, and characters represent the surface material mapped on each print position. This type of output recording device is inexpensive to implement and is appropriate for small-scale survey applications. Its application is best when scale is not critical and extensive duplication of products is not necessary. The output can be manually color coded if desired.

Electrostatic Printer/Plotter

The electrostatic printer/plotter produces all the characters available on a standard line printer in various letter sizes and also produces as many as 16 distinct gray levels for a given print position. The output format of the electrostatic printer/plotter may be as wide as 56 centimeters (22 inches). Coordinate lines, scan-line counts, and picture-element numbers may be written over the imagery data for annotation purposes. A sample of gray-scale imagery is shown in figure 1. Electrostatic printer/plotters are available from several sources and are competitively priced at approximately $12 000 to $20 000, depending on speed, resolution (39 or 79 dots/cm (100 or 200 dots/in)), and gray-scale consistency.

Film Recorders

When large volumes of data are to be processed, when good geometric precision is needed, and when multiple copies of the output product are required, it is advisable to incorporate a black-and-white or color film recorder in the low-cost DAS as an output recording device. If only gray-shade map products are required, a simple black-and-white strip or frame film recorder may be used. If a large dynamic range exists in the data and if it is important to display the range, a color-recording output device must be incorporated.

Color Film Recorders

At least two currently available color film recorders are compatible with low-cost DAS's. One such system is manufactured by DICOMED and records its output on 127-millimeter (5 inch) wide color film in frames. The resolution and linearity are good. The system operates in a "stand alone" mode and contains a small digital computer for control purposes. The DICOMED system costs approximately $140 000. The DICOMED system can also be implemented as an "add on" to the computer for approximately $80 000. A stand-alone color film recorder (SACFR) was recently developed for ERL by HRB-Singer, Incorporated. The SACFR is an upgraded version of the ERL DAS film recorder. The SACFR output is recorded on 241-millimeter (9.5 inch) wide color film as a positive or negative image. A sample of the film recorder output is shown in figure 4. The system records high-resolution images in a continuous strip. The SACFR has a built-in capability for expansion (magnification) and, when used with data previously processed with the appropriate computer software routines, can produce precise map scales. Scales of any size may be produced without loss of resolution or geometric degradation. Magnification is accomplished electronically rather than optically. The cost for production versions is estimated to be $115 000. The prototype SACFR was delivered in April 1976.

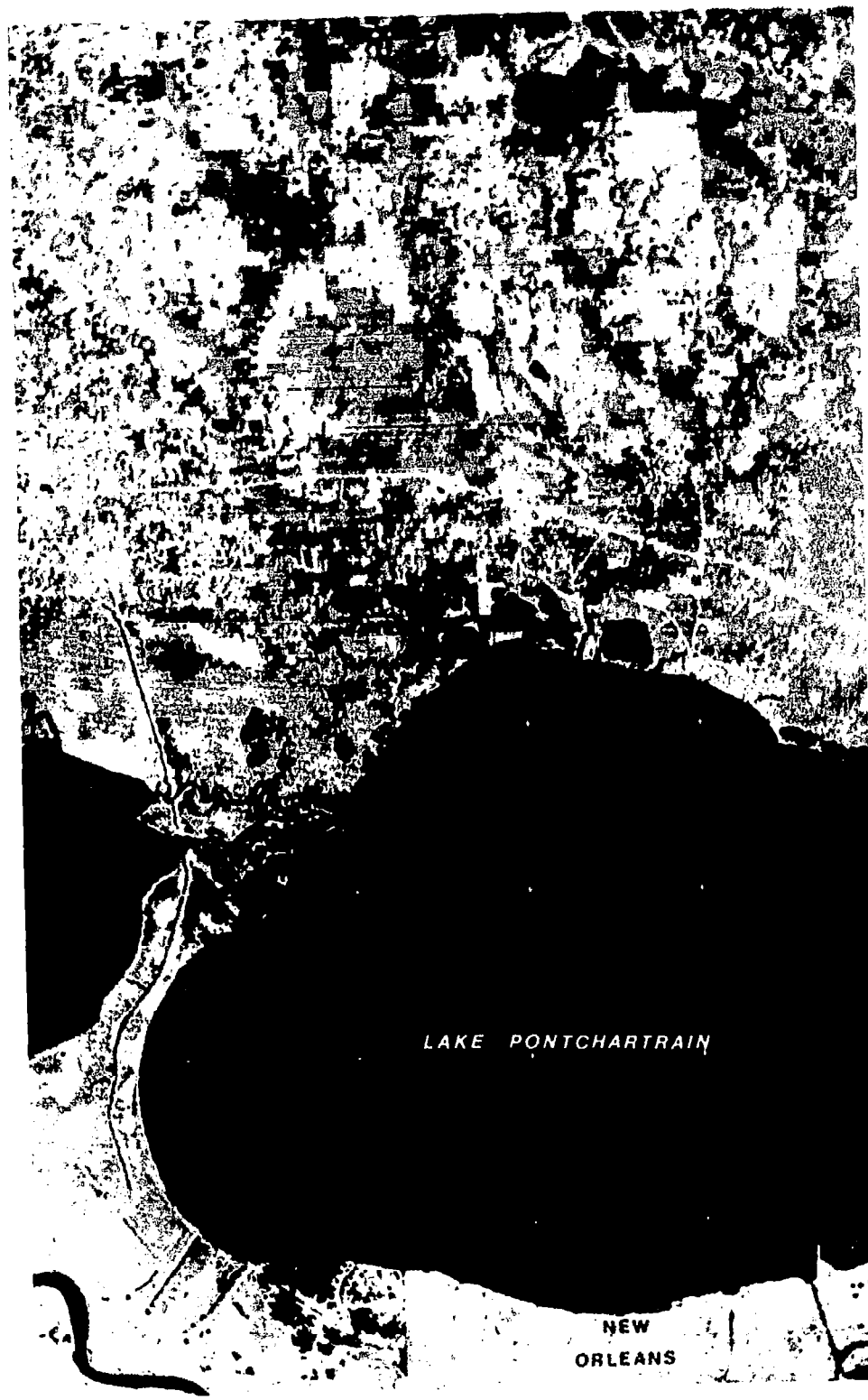


Figure 4.- Sample output from color strip film recorder.

FILM PROCESSING SYSTEMS OR SERVICES

Electrostatic Printer/Plotter Outputs

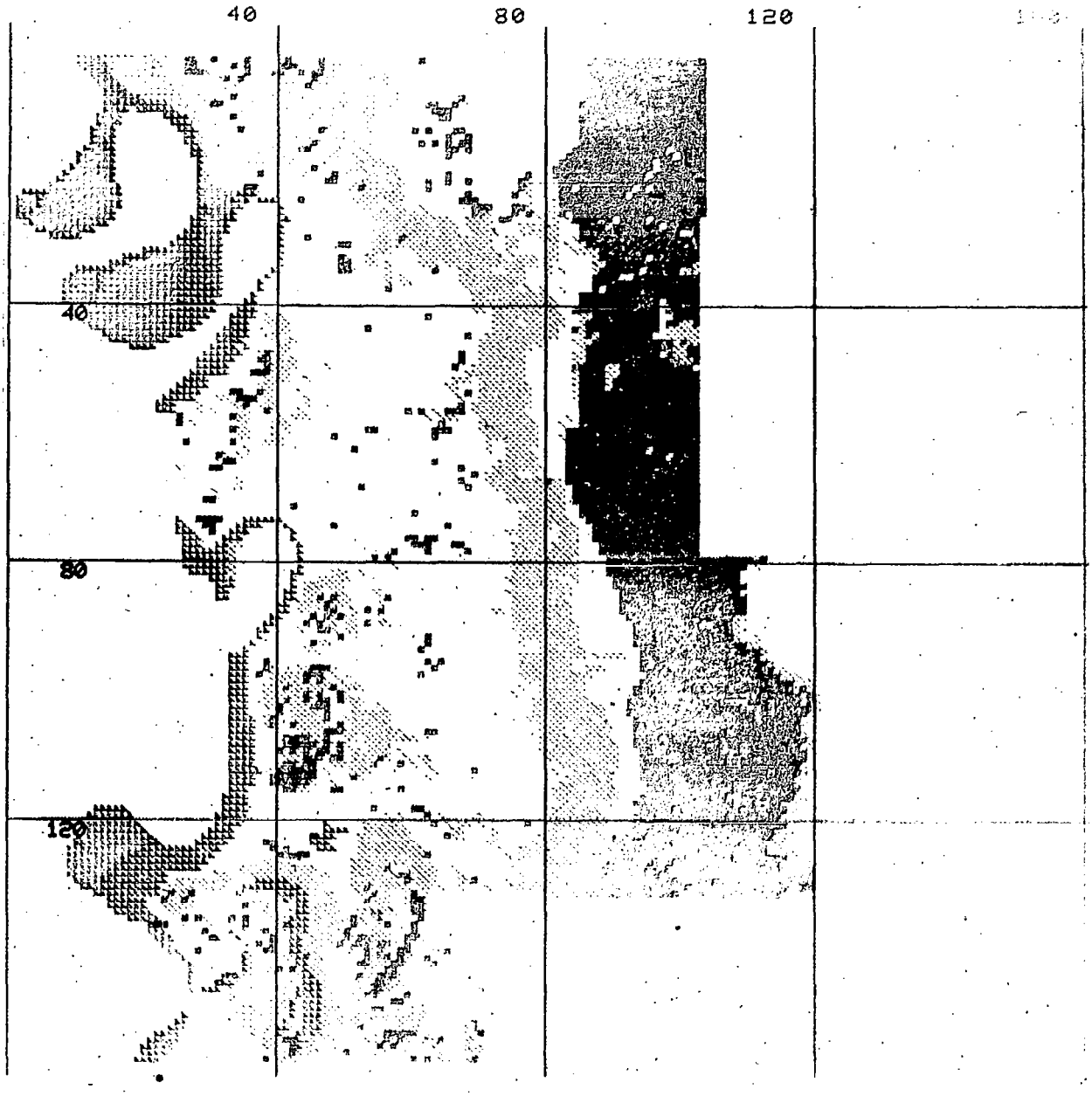
The electrostatic printer/plotter output may be produced as a gray-shade map (fig. 1) through a technique known as level slicing. The computer may be instructed to print out separate plots for each theme (classification category), or the computer may be instructed to subdivide the output into red-green-blue (RGB) components. The thematic maps and the RGB components may be converted to a color-coded map by a very inexpensive process developed for the lithograph industry called Kwik-Proof. First, the electrostatic prints are converted into as many black-and-white negatives as there are themes or components. Then, the image on each negative is transferred to a resin-coated base paper by exposing the negative onto the ink-coated base paper using a different ink color for each negative. The excess ink is removed with a water spray after each exposure to leave the color-coded information transferred from the negative. Figure 5(a) is an example of a color map produced by using the Kwik-Proof technique. The process, equipment, supplies needed, and costs for all components are described in appendix A. It should be noted that the equipment needed for this system is available in the average photographic laboratory.

A similar, higher quality product can be produced on slightly more sophisticated equipment. A Du Pont product known as CROMALIN can be used to produce a very good color-coded map from film positives. The procedure for producing the CROMALIN product is described in appendix B together with the required equipment and costs. Figure 5(b) is an example of a CROMALIN map. If negatives or positives are provided, a number of companies throughout the United States can produce color-coded CROMALIN maps at contact scale quite inexpensively. The current cost for making a four-level color map (e.g., red, green, blue, and black) is approximately $\$86.00/m^2$ ($\$8.00/ft^2$).

The procedures described in appendixes A and B are applicable if few color products are required. The negatives and positives used to generate color products in these two procedures may be submitted to a lithographer to make multiple copies at an economical price. The usual procedure for making large numbers of color products is to provide the lithographer with a color picture. The lithographer's first step is to make color separations. In both the Kwik-Proof and CROMALIN techniques described in appendixes A and B, the electrostatic printer output is converted directly into color separation films. The color separation step is not necessary if the user desires to produce multiple copies by lithography.

Black-and-White Film Recorder Outputs

The output from low-cost DAS's may be recorded on black-and-white film as either a positive or a negative transparency. If the film is 70 millimeters or 127 millimeters (5 inches) wide, many facilities are available for processing the transparency. If 241-millimeter (9.5 inch) wide film is used, a more limited photographic processing capability exists. The transparencies may be duplicated on a



(a) Using Kwik-Proof technique.

Figure 5.- A nine-level digitized soils map produced from three gray-scale plots from an electrostatic printer/plotter.

(b) Using CROMALIN technique.

Figure 5.- Concluded.

black-and-white print paper to make an inexpensive photomosaic. However, to generate color products from black-and-white film, the transparencies may be prepared as themes or RGB components as described in the subsection entitled "Electrostatic Printer/Plotter Outputs." Then, they may be processed using the Kwik-Proof or the CROMALIN procedure described in appendix A or B, respectively.

Color Film Recorder Outputs

The color strip film recorder output may be on 70-millimeter, 127-millimeter (5 inch), or 241-millimeter (9.5 inch) wide transparencies. The DICOMED film recorder produces 70-millimeter or 127-millimeter (5 inch) wide film. The HRB-Singer SACFR produces 241-millimeter (9.5 inch) wide film. Difficulty in finding a suitable color film processing service increases with film width, as does the cost of equipment and service for processing and duplicating. A number of organizations process and duplicate 70-millimeter and 127-millimeter (5 inch) wide film. The 70-millimeter to 241-millimeter (9.5 inch) wide color films are processed at the National Space Technology Laboratory for ERL using an Eastman Kodak Color Versamat, model 1811 RT, to either a positive or a negative color transparency depending on the recording film used. The ERL color film is printed on type RC-37 color paper by an SP-1070C Log-E-Tronic printer. Other similar processors and printers may be used.

SOFTWARE

The software modules for the low-cost DAS were developed on either a Univac 1108 computer or a Varian Data Machines (VDM) V-73 small general-purpose digital computer. All software was written in FORTRAN IV language for ease of transfer to other computer systems. The software modules that were developed on the Univac 1108 computer have been converted by ERL personnel to run on the V-73 computer (using 32 000 memory locations or less). The V-73 systems software package has been extended a modest degree by ERL systems programers to specifically facilitate remote-sensor data processing. These extensions to the V-73 systems package already exist in most larger computer systems.

The software developed for the low-cost DAS consists of the following modules: (1) PATREC module, (2) GEOREF module, (3) data base module, and (4) applications module. A block diagram including elements of these software modules is shown in figure 6.

PATREC Module

The purpose of the PATREC module is to convert Landsat MSS bulk tape recorded data, and other supporting data, into surface classification maps. The PATREC module consists of several computer programs: LANREF, DAPIDS, ISOFLD, STATS, ELLIPSE, and ASSIGN.

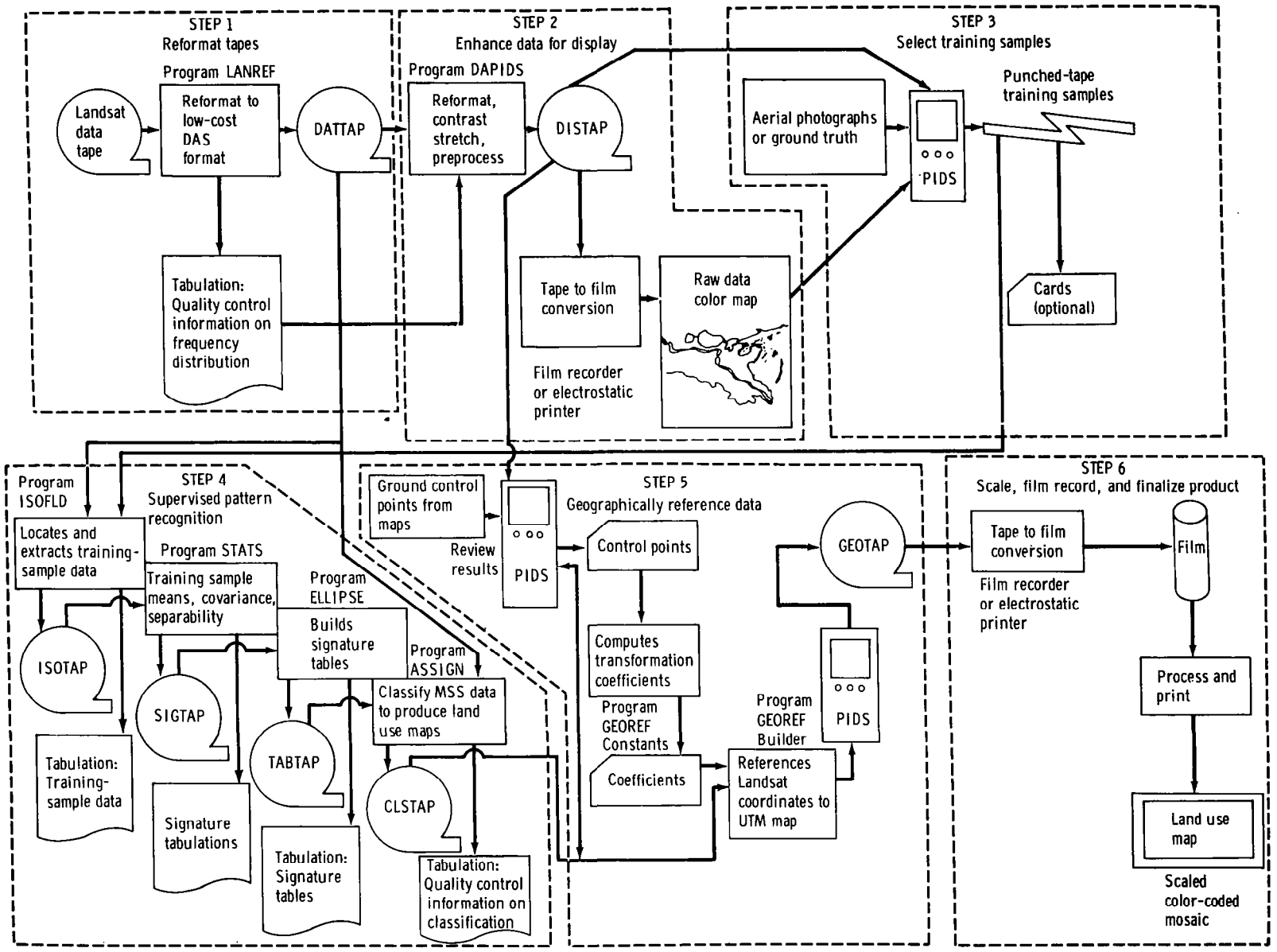


Figure 6.- Low-cost data analysis system data flow (specifically for configurations 2 and 3).

Program LANREF accepts the original Landsat bulk tape and converts it to a format called DATTAP (data tape). The DATTAP format is more convenient to read and manipulate than the original Landsat format.

Program DAPIDS (data tape to PIDS tape conversion) accepts the DATTAP format and converts it to a DISTAP (display tape) format, which is the format expected by the PIDS. Basically, the DISTAP format consists of general header information (including scan-line count), and each picture element of the imagery is expressed as 6-bit words (64 levels). This format is flexible in that scan lines of imagery data may contain as many as 2000 picture elements.

Program ISOFLD accepts as input the Landsat imagery data in the DATTAP format, cards containing the coordinates of polygon-shaped (n-sided, where $n \leq 100$) training samples, and sample identification as defined by the user on the PIDS. The purposes of program ISOFLD are to isolate and extract training-sample data from Landsat data tapes and to produce a new tape in the DATTAP format that contains only training-sample data.

Program STATS accepts training-sample data from program ISOFLD in the DATTAP format only. Program STATS produces tabulations of histograms, means, standard deviations, covariance matrices, and spectral plots for each training sample. Based on a divergence criterion, program STATS also calculates the relative separability of materials to be classified. Program STATS produces signatures for each material in the form of means and covariance matrices in the SIGTAP format.

Program ELLIPSE reads signatures as determined by program STATS in the SIGTAP format, then converts each of the signatures into elliptically shaped, four-dimensional decision boundaries. The boundaries are written onto tape as decision tables in the TABTAP format for use in program ASSIGN. Programs ELLIPSE and ASSIGN are also known as program ELLTAB. These two programs were described by Jones (ref. 2), and their theory was described by Eppler (ref. 3).

Program ASSIGN reads decision tables for each classification category and stores them in computer memory. Program ASSIGN also accepts, as input, the bulk Landsat imagery in the DATTAP format, classifies all data by a table look-up procedure based on maximum-likelihood spectral pattern recognition, and produces a surface classification map in the DISTAP format. Program ASSIGN runs very rapidly and can classify an entire Landsat scene into 24 classification categories in approximately 1 hour, depending on the computer system used.

GEOREF Module

The GEOREF module converts a Landsat scene from sensor coordinates (scan lines, picture elements, and latitude and longitude of the scene center) to a geographically referenced system, the UTM projection. Ground control points are identified on the PIDS and are inputted to the GEOREF program by cards together with the Landsat imagery in the DISTAP format. The geographically referenced image is outputted on tape in the DISTAP format to a precision of approximately 100 meters root-mean-square error at 1:250 000 scale. The GEOREF module is made up

of two programs, GEOREF Constants and GEOREF Builder. Program GEOREF Constants computes a set of constants based on ground control points and is a required input to program GEOREF Builder. Program GEOREF Builder rescans the Landsat data and converts it from scene coordinates to UTM coordinates, northings and eastings.

To implement the GEOREF module on a small-scale digital computer, it is recommended that the system contain a disk with at least 12 000 000 words of 16-bit/word storage. A disk of this size, with its controller, costs approximately $13 000 for small computers. The GEOREF programs may be implemented on a computer using tape as a storage medium when small area surveys are required but would run much slower than when using a disk-oriented system.

Data Base Module

The data base module is a highly specialized information storage and retrieval system. The objective of program Data Base is to store as much as 30 bytes (8 bits/byte) of geographically referenced information describing each 400- by 400-meter (40 acre) unit for an entire state. The most predominate land cover for each unit may be stored in one byte, the soil type in another, and so forth. Two versions of the program are being developed. One program references data to a regular 400- by 400-meter grid and is recommended for use in areas where surveys are conducted by metes and bounds. The other version references data to an irregularly shaped grid of "forties" (one-sixteenth of a section) and is recommended for use in areas surveyed by the Public Land Survey System.

Program Data Base accepts geographically referenced land cover maps generated by program GEOREF in the DISTAP format. Other types of information, such as soil type, rainfall, terrain slope, and census data, are entered into the program by punched cards or tape. The program maps the input information into the appropriate set of bytes describing each unit. Provisions are made for correcting errors in the stored data down to the byte level.

If the data base module is established for a State the size of Mississippi (approximately 129 500 square kilometers (50 000 square statute miles)), and if the plots of real estate are selected to be 400- by 400-meter (40 acre) units, then 30 bytes of information for each plot may be stored on three nine-track, 315-byte/cm (800 byte/in) computer-compatible tapes. There are approximately 1 000 000 400- by 400-meter (40 acre) plots in the State of Mississippi.

Information may be retrieved from the data base module by entering on punched cards an ordered set of UTM coordinates that describe an n-sided polygon. The program will retrieve the 30 bytes of data from each plot contained within or on the boundary of the polygon-shaped region. The retrieved information will be used as input data by a family of applications programs to extract management information.

Applications Module

The applications module is a series of computer programs that extract data from the data base module to derive management information for practical applications. Short descriptions of application programs under development are as follows.

1. Program ACREAGE computes the acreage for each classification category (theme) within a polygon-shaped region and prints acreages of each for all materials. This program may use output from the data base module or from the GEOREF module.

2. Program CROP PRODUCTION ESTIMATE computes production estimates for selected crops in a polygon-shaped region based on crop type (land cover) and soil type from the data base module and from tables of yield/crop soil type/rainfall. Outputs are presented in bushels, bales, etc., as appropriate for the crop type.

3. Program EROSION CONTROL provides data for erosion control by "reforestation need inventory." Maximum slope, soil type, rainfall, and current land use are the required input data, and they are all extracted from the data base module. The output from this program is an erosion hazard map showing units in need of reforestation.

4. Program WILDLIFE HABITAT ASSESSMENT is designed to calculate the capacity of a given region for sustaining whitetail deer. The inputs are retrieved from data base storage (land cover, crown cover, soil type, aspect, and elevation). The capacity may be calculated from a habitat assessment of each unit on a scale of 1 to 10.

5. Program SITE SELECTION locates land units that meet a specified criterion (e.g., for a recreation site).

LOW-COST DAS CONFIGURATIONS

Several low-cost DAS configurations have been defined. These configurations, which represent various levels of complexity and capability, are composed of the hardware and software modules described previously.

Configuration 1

Configuration 1 (fig. 7) is composed of an electrostatic printer/plotter as an image display device and output recording device and a small general-purpose digital computer. This configuration is a very inexpensive system and may be implemented on most existing facilities without the purchase of additional equipment. If such a hardware system were purchased new, the total cost would be approximately $97 000 to $155 000, depending on the computer peripherals and memory.

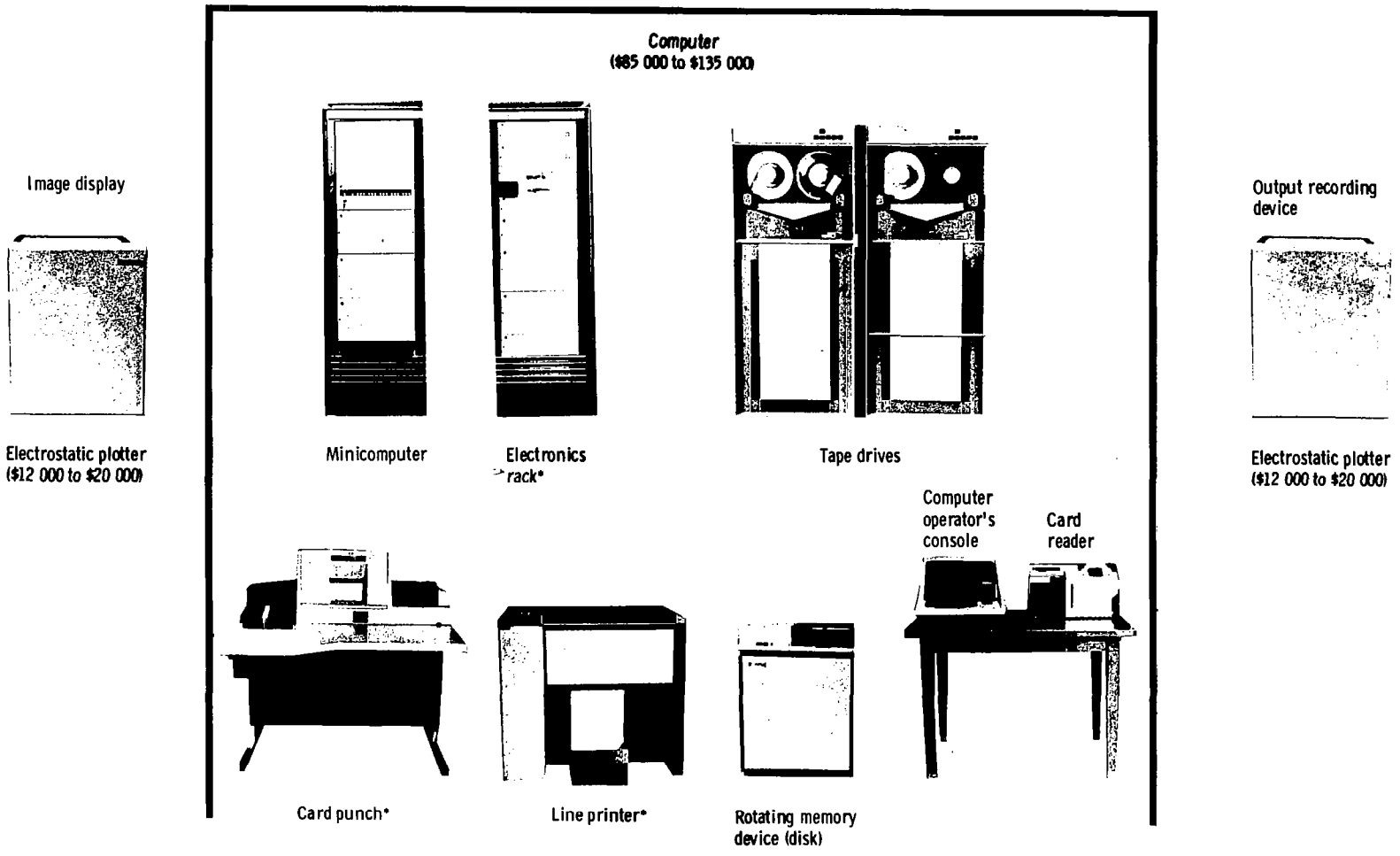


Figure 7.- Configuration 1 of the low-cost data analysis system.

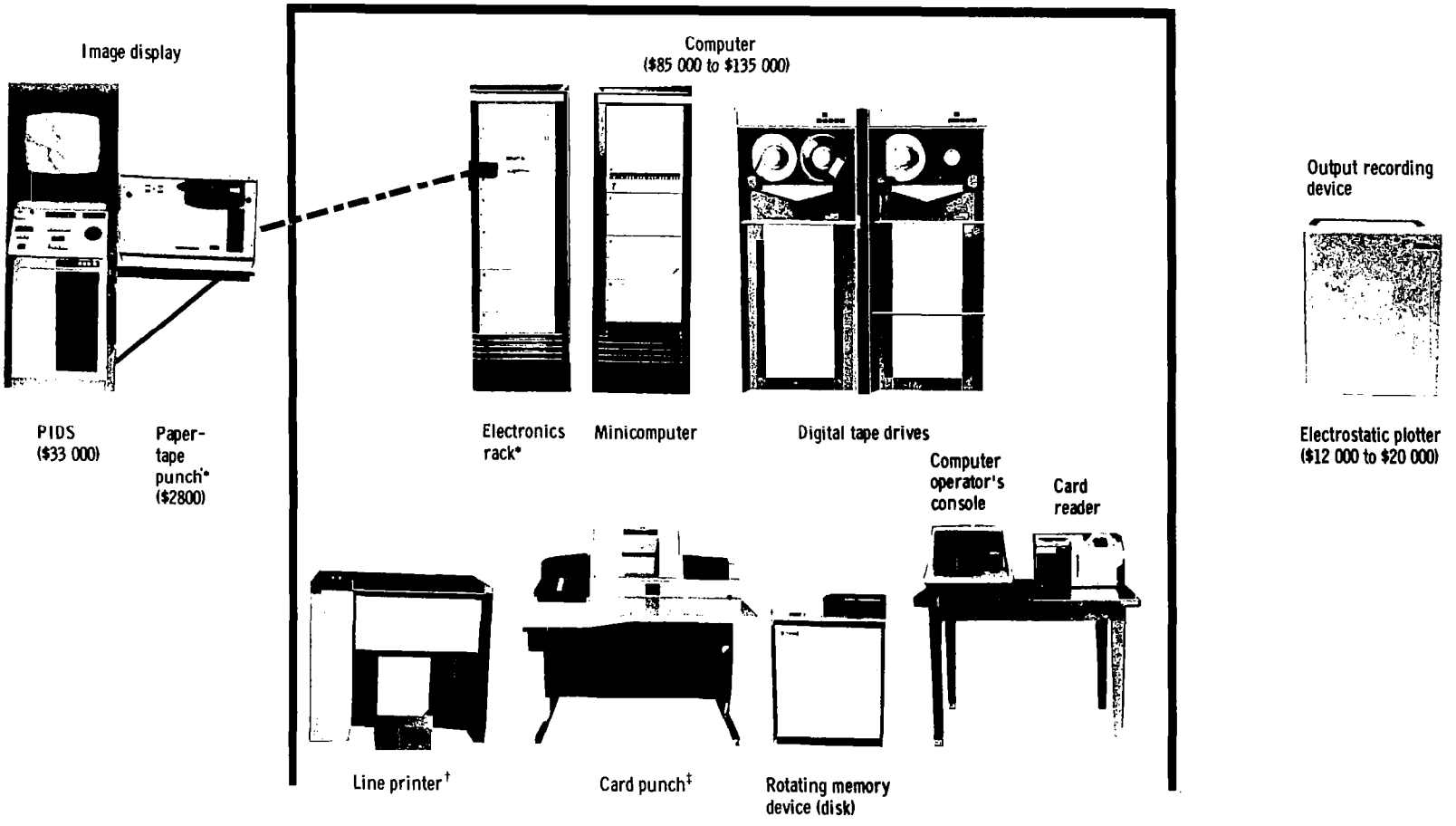
The primary expenditure for implementation of configuration 1 by most potential users is the cost of manpower for software conversion of existing documented programs. The configuration 1 system is most appropriate for small-area, special-purpose surveys, but it is also a building block that enables the user to begin operation before adding more expensive display and output modules. The output from the electrostatic printer/plotter can be converted to color products by using the procedures and equipment described in appendix A or B.

Configuration 2

Configuration 2 (fig. 8) is composed of a PIDS, a small general-purpose digital computer, and an electrostatic printer/plotter. This hardware configuration is quite inexpensive and may in some cases be implemented by purchasing only a PIDS and implementing ERL software on existing equipment. If the entire system is purchased, the component costs will be $33 000 for the PIDS, $2800 for the paper-tape punch, $85 000 to $135 000 for the computer, and $12 000 to $20 000 for the electrostatic printer/plotter, or a total system cost of $132 800 to $190 800. If a computer with an electrostatic plotter exists in the user's facility, the cost would be only $33 000. Configuration 2 is characterized by efficient data-screening and training-sample-selection procedures, efficient data processing, and a highly usable gray-scale map output capability. The gray-scale map may be outputted in red, green, and blue components or as thematic breakouts for conversion to a color output product. In either case, the gray-scale outputs may be converted to a color map by the procedures described in appendix A or B. The PIDS display screen is very useful for reviewing the results of pattern recognition classification and may be photographed to create a color-coded map of a small survey area. The only significant expenditures for implementation of configuration 2 are the purchase of the PIDS and the cost of manpower to adapt ERL software to the user's computer facilities.

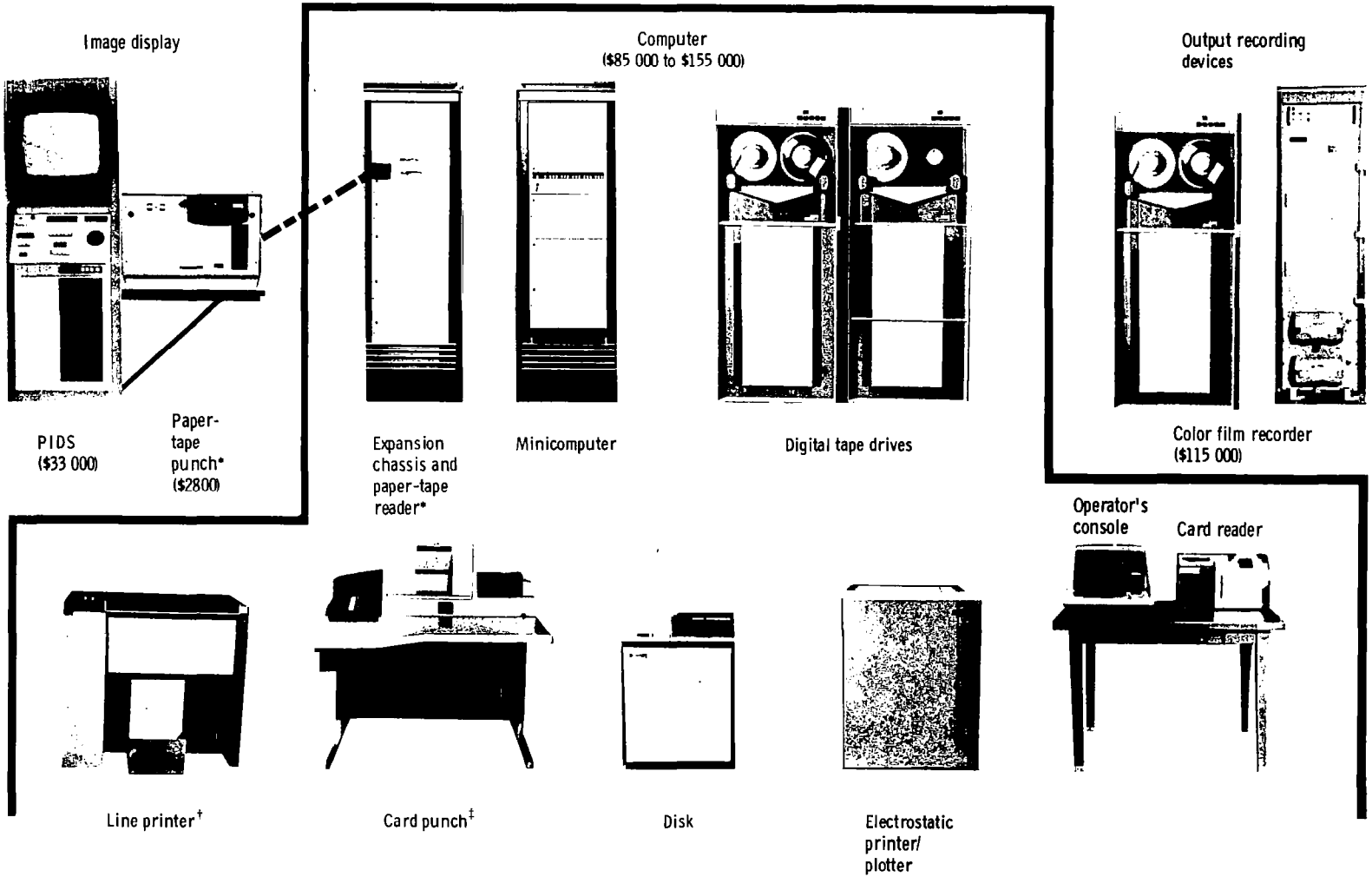
Configuration 3

Configuration 3 (fig. 9) is composed of a PIDS, a small general-purpose digital computer, and a stand-alone color strip film recorder. This hardware configuration is fairly inexpensive for its capabilities. The system may be implemented by using existing computer facilities and purchasing a PIDS and a color strip film recorder. In this case, the user would be required to spend only $148 000. The components of the system may be purchased for a cost of $33 000 for the PIDS, $2800 for the paper-tape punch, $85 000 to $155 000 for the computer, and $115 000 for the color strip film recorder, or a total hardware cost of $235 800 to $305 800. Configuration 3 is capable of efficient data screening and training- and test-field definition; efficient, high-volume data processing; and generation of high-precision, color-coded output products of the type shown in figures 10 and 11. To implement configuration 3, most users must purchase the PIDS and the film recorder but may convert the ERL software for use on their existing computer. A film processing service capable of handling 241-millimeter (9.5 inch) wide film is required to support the color strip film recorder.



*May be deleted but makes the system more manual
†May be deleted; electrostatic printer/plotter can be used instead
‡May be deleted if other tape-to-card capability is available

Figure 8.- Configuration 2 of the low-cost data analysis system.



*May be deleted but makes the system more manual
†May be replaced by electrostatic printer/plotter
‡May not be needed if other tape-to-card capability exists

Figure 9.- Configuration 3 of the low-cost data analysis system.

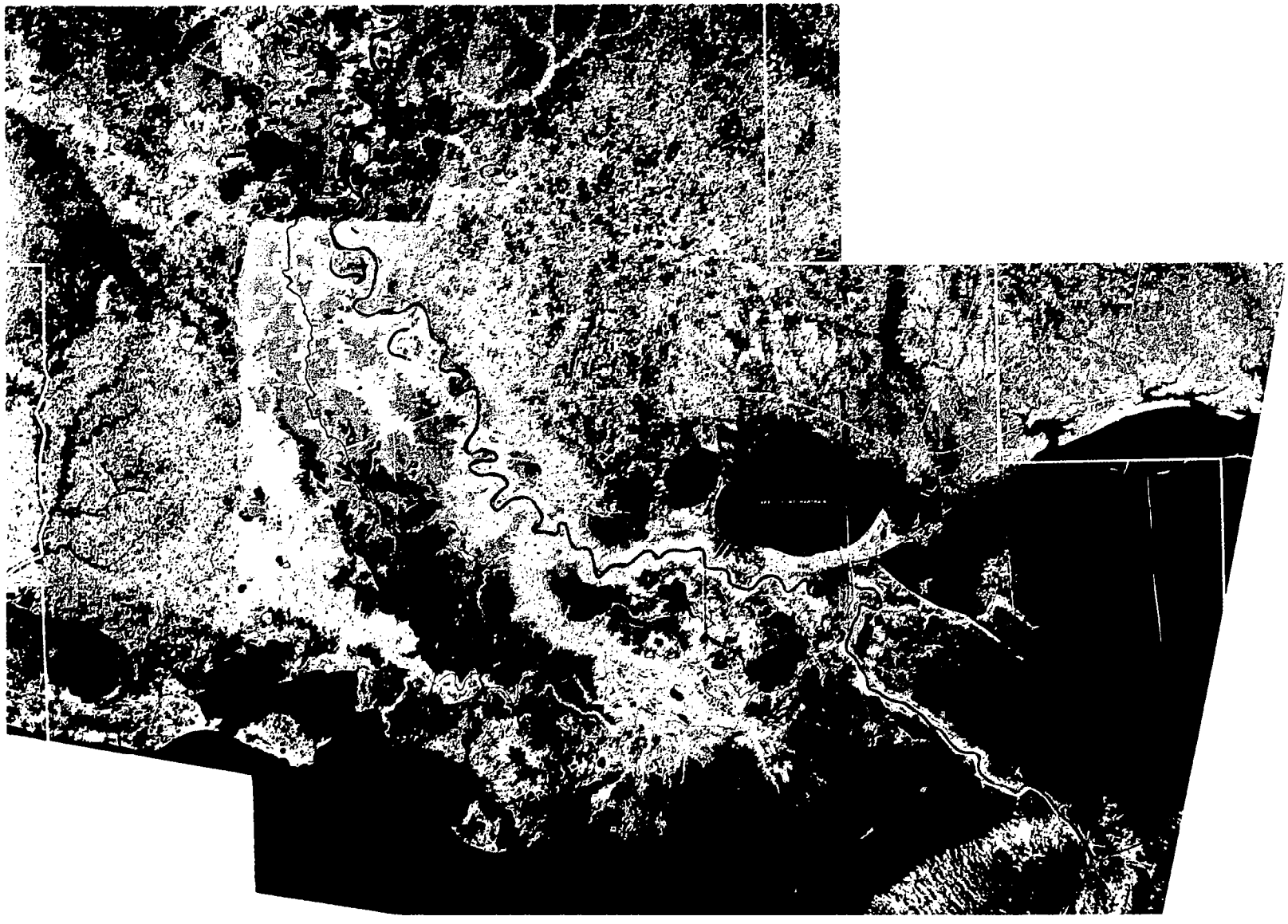


Figure 10.- Simulated color-infrared photomap using Landsat-1 digital data acquired in 1973 and 1974; scale of original, 1:250 000.

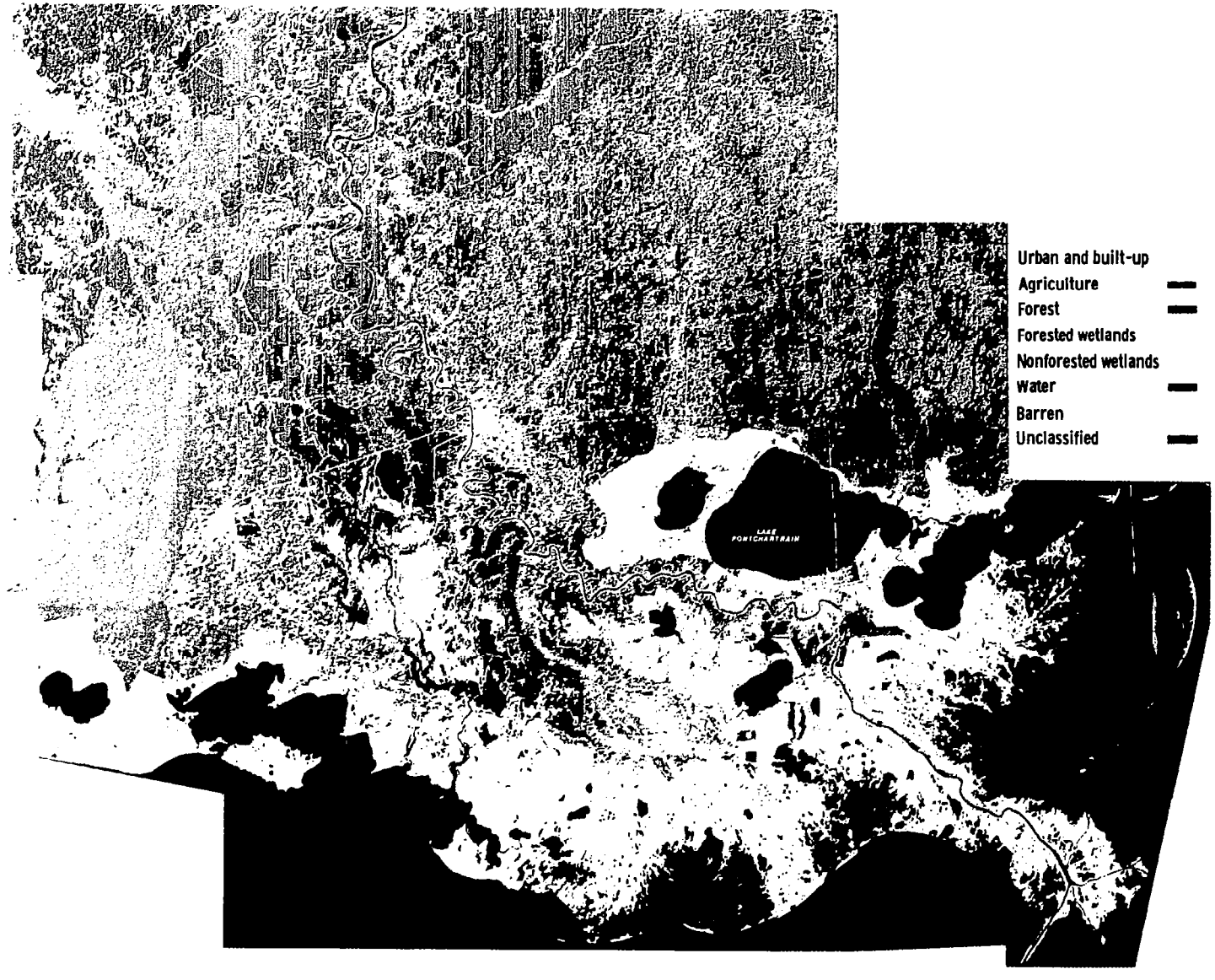


Figure 11.- Computer-derived land use classification using Landsat-1 digital data acquired in 1973 and 1974; scale of original, 1: 250 000.

Configuration 4

Low-cost DAS configuration 4 (fig. 12) is composed of an IPS, an operator's console, a small general-purpose digital computer, and a color strip film recorder. In this configuration, the IPS is hardline connected with the computer so that information, commands, and data may be transferred between the computer and the IPS. The color strip film recorder is a stand-alone device. The computer is also equipped with an electrostatic printer/plotter for producing gray-scale plots or for producing color-coded outputs as described in appendix A or B. The computer is equipped with an operating executive that enables performance of multiple tasks on a time-sharing basis. The IPS is a commercial system, and interface units have been designed for a number of widely available small digital computers. The IPS costs $36 100, the operator's console costs approximately $2800, the computer costs $155 000 (including the electrostatic printer/plotter), and the film recorder costs approximately $115 000. The hardware cost for implementing configuration 4 is only $153 900 if the user's computer is adequate and $308 900 if a new computer must be purchased. Configuration 4 enables a user to read data from a Landsat tape, display the imagery on the IPS screen, adjust colors to enhance the data, select training samples, develop statistics for the sample, analyze the sample for adequacy as a training sample, and then accept or reject the sample in near real time. The system can then classify the data by pattern recognition and quickly generate color-coded surface classification maps. Every step required to process a set of data on the configuration 4 system is interactive, and high-priority investigations may be completed quickly and accurately. To implement configuration 4, most users must purchase an IPS and a film recorder but may convert ERL software for use on their existing computer. Figures 10 and 11 are also examples of products obtainable using configuration 4. A film processing service capable of handling 241-millimeter (9.5 inch) wide film is required to support the color strip film recorder.

OPTIONAL MODULE FOR PROCESSING AIRCRAFT-ACQUIRED MSS DATA

Any of the four low-cost DAS configurations previously described may be adapted to process aircraft-acquired MSS data (such as Bendix modular MSS data, Daedalus scanner data, Texas Instruments RS-18 MSS data, and 24-channel multispectral scanner and data system data) by adding an HDDT front-end module to the system. The HDDT module will consist of an analog tape drive (Ampex 3010 or equivalent), bit synchronizers (EMR model 720 pulse-code-modulated bit synchronizer or equivalent), and an electronic interface section. The cost of these components may vary from $50 000 to $100 000 depending on the quality of the bit synchronizers. The reliability of the HDDT module is directly proportional to the quality of the bit synchronizers. The ERL can provide additional information relative to the HDDT module to interested readers.

If this system is adapted to accommodate aircraft-acquired MSS data, the following computer programs must be added. A program is needed to control the HDDT module. Obviously, a different, but similar, reformat program will be used in lieu of program LANREF. If the aircraft MSS collects a large number of data

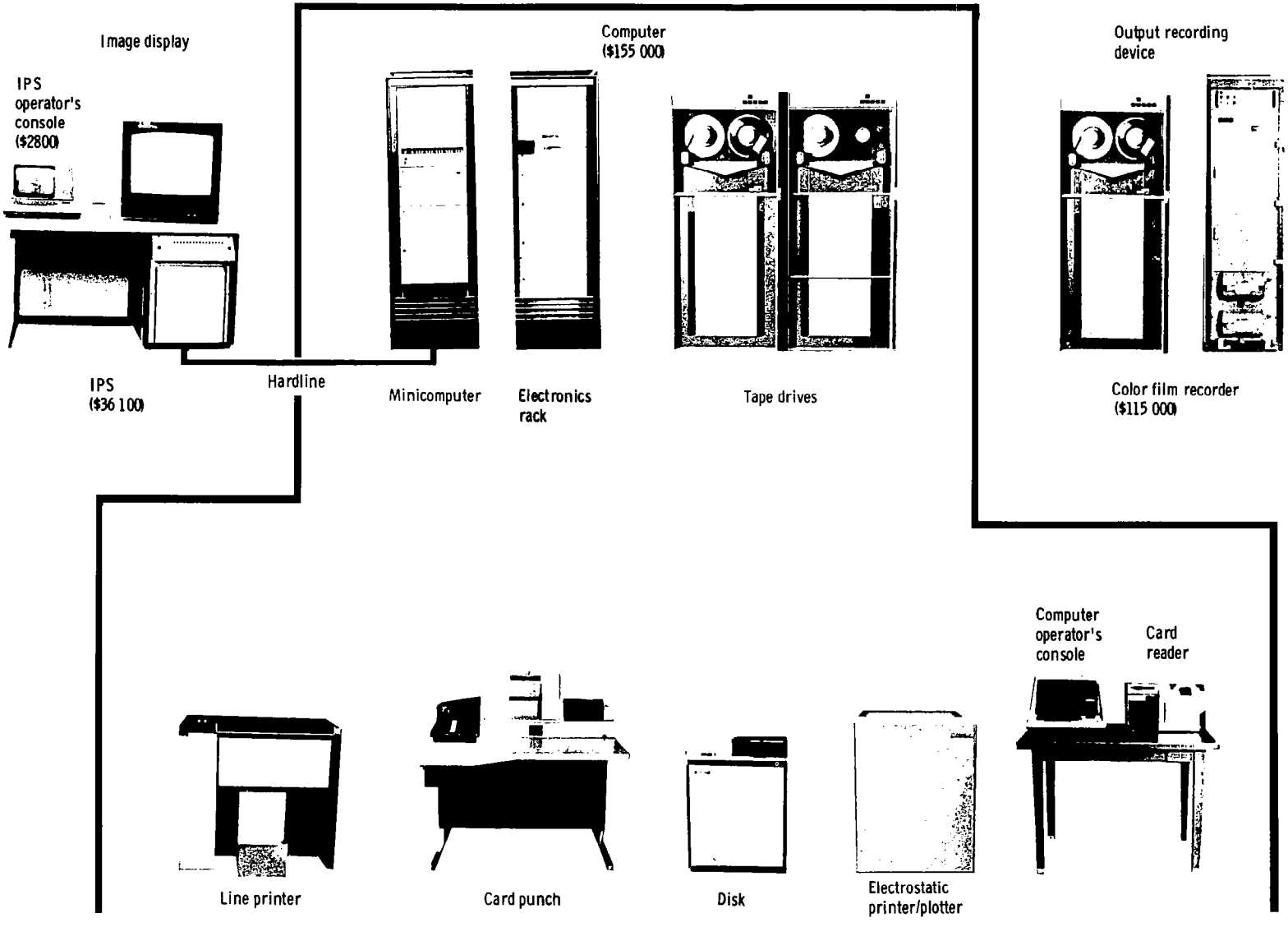


Figure 12.- Configuration 4 of the low-cost data analysis system.

bands, it will be necessary to add a feature selection program to identify the best subset of four data bands for pattern recognition classification. The GEOREF module was designed specifically for converting Landsat data to fit a UTM projection. No equivalent geographical reference conversion program has been developed for correcting the geometry of aircraft-acquired MSS data.

All hardware components described in this paper are commercial and readily available. If desired, specifications can be provided by the ERL. The nine computer programs described are operational on either a Univac 1108 computer or a VDM V-73 small general-purpose computer. All programs are, or will be, available to the public through the Computer Software Management and Information Center, University of Georgia, Athens, Georgia 30602.

CONCLUDING REMARKS

Current land use maps are a recognized necessity for programs and studies related to more effective land use. This requirement is enhanced by dynamic economic growth and sudden environmental changes. In contrast to the conventional mapmaking techniques, the computer-generated land use maps provided the current land use data; but they could be produced only with the expensive and sophisticated computer systems that were available at a few research facilities.

The NASA Earth Resources Laboratory has developed, defined, and verified four low-cost data analysis system configurations that may be added to existing user facilities for the processing of multispectral scanner data. In this report, the four low-cost systems and their various components have been described, particular components have been suggested, and approximate costs have been given.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, August 20, 1976
177-32-83-00-72

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3. Eppler, W. G.: An Improved Version of the Table Look-Up Algorithm for Pattern Recognition. Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Vol. II, Environmental Research Institute of Michigan, Ann Arbor, Mich., Apr. 1974, pp. 793-812.

APPENDIX A

KWIK-PROOF METHOD FOR PRODUCING COLOR PRODUCTS FROM FILM RECORDER OR ELECTROSTATIC PRINTER OUTPUTS

The gray-scale outputs from either a black-and-white film recorder or an electrostatic printer/plotter may be converted into color-coded land use maps using equipment that is available in the average photographic laboratory together with an inexpensive graphics kit. Fewer steps are required to produce a color map if one starts with a black-and-white film negative; therefore, the step-by-step procedure for producing color maps from electrostatic printer plots is given here. To produce color products from film recorded data, start with procedure step 4.

Before using the electrostatic printer/plotter for recording products to be converted to color, the roller of the electrostatic plotter should be cleaned, the toner and concentrate should be replenished, and the system should be checked for correct performance. The system should be loaded with vellum paper to produce high-contrast film negatives.

PROCEDURE

The following procedure should be followed for producing Kwik-Proof color images from electrostatic printer outputs.

Step 1: The tape-recorded land use maps produced by low-cost data analysis system (DAS) programs ASSIGN and GEOREF consist of an array of numbers. These tape-recorded maps may be converted to gray-shade color component maps by low-cost DAS program SYS 203, which permits the user to specify a gray shade for each color component (red, green, blue, etc.) or material type (theme). To produce maps from the basic colors red, green, and blue, the user runs program SYS 203 three times to produce the color components, or as many times as there are themes. It has been found that the Varian Data Machines STATOS 33 electrostatic printer/plotter used by the NASA Earth Resources Laboratory is geometrically repeatable and registerable. The STATOS 33 plotting bed is 55.88 centimeters (22 inches) wide. If wider plots are needed, multiple passes may be made and mosaicked together.

Step 2: Using a 102- by 102-centimeter (40 by 40 inch) vacuum-frame printer with a tungsten light source, each printer/plotter sheet or mosaic is exposed onto high-contrast black-and-white negative film at contact size. Exposure time may require some experimentation and is dependent on film used and light characteristics.

Step 3: Develop, fix, wash, and dry negatives. This process requires the use of sinks for the chemicals and water. With adequate sinks, this process should require 15 minutes for each negative, including drying time.

Step 4: Place all negatives on a light table and register. If grids or tick marks are recorded in the data, it is easiest to register at these marks; otherwise, one must register on the basis of data content. Punch the registered negatives using a pin registration punch. The pinholes will be used for registration in the remaining steps.

Step 5: Select any resin-coated base material that is as large as or larger than the image being recorded. (Kodak type RC print paper works well.) The paper must be resin coated to prevent absorption of the inks used in the following steps. Coat the resin-coated paper evenly on one side with the color of ink to be used as the first color component or the first theme. Let the ink dry. (A fan will help speed the process.)

Step 6: Place the first negative over the ink-coated paper. Register at the pin marks punched in step 4. Actuate the vacuum to hold the base material and the negative flat. Expose the negative to an ultraviolet (UV) light source. (The recommended exposure time of 3.5 to 4 minutes may require adjustment for your light source.)

Step 7: Remove the negative from the base material. Over a 102- by 102-centimeter (40 by 40 inch) sink, spray off the ink with tapwater using a spray nozzle. All ink will be washed away by the spray except the image of the color component or theme that was transferred from the negative.

Step 8: Return to step 5 and coat the base material with the color of ink for the next color component or theme to be transferred to the base material. Four basic ink colors (black, yellow, red, and blue) are provided in the Kwik-Proof kit. Formulas are provided for producing an adequate number of other colors by mixing these basic colors. Equal exposure time is used for each negative.

Step 9: After the last color component or theme is completed, spray the image (map) first with water and then with a 28-percent ammonia solution. Let the material dry. The product is completed.

EQUIPMENT AND COSTS

The following equipment is needed for producing Kwik-Proof color products from electrostatic printer outputs.

1. A 102- by 102-centimeter (40 by 40 inch) vacuum-frame contact printer with UV and tungsten light sources - The tungsten light is used to expose the negative materials, and the UV light is used to expose the ink. (Cost: approximately $2000)

2. A 102- by 102-centimeter (40 by 40 inch) sink with tapwater and spray nozzle (Cost: approximately $800)

3. Four 102- by 102-centimeter (40 by 40 inch) tray sinks for developing and fixing chemicals (Cost: approximately $1150)

4. A pin registration punch (Cost: $600)

5. A fan for drying negatives and inks (optional)

FACILITY NEEDED

A darkroom for exposing and processing negatives is the only facility needed. The ink is exposed by a UV light source in daylight.

SUPPLIES NEEDED

The following supplies are needed.

1. High-contrast negative film material, black and white, 1.02-meter (40 inch) wide by 30-meter (100 foot) long roll (Cost: $150)

2. An A-B high-contrast developer (Cost: $45/151.5 liters ($45/40 gallons))

3. Eastman Kodak fixer (Cost: $12/94.6 liters ($12/25 gallons))

4. Applicator pads

5. Resin-coated paper or water-resistant paper (base material)

6. Kwik-Proof ink, four colors, and image brightener

Items 4, 5, and 6 are available in an inexpensive ($25) Kwik-Proof graphics kit. Enough materials are included for experimentation. Users may purchase component supplies at a low unit price for larger quantities.

APPENDIX B

CROMALIN METHOD FOR PRODUCING COLOR PRODUCTS FROM FILM RECORDER OR ELECTROSTATIC PRINTER OUTPUTS

The gray-scale outputs from either a black-and-white film recorder or an electrostatic printer/plotter may be converted into color-coded land use maps using equipment available in the average photographic laboratory together with a CROMALIN 2700 laminator and a CROMALIN 3042 console and appropriate supplies. Fewer steps are required to produce a color map if one starts with black-and-white film positives; therefore, the step-by-step procedure for producing color maps from electrostatic printer plots is given here. To produce color products from film recorded data, start with procedure step 4.

Before using the electrostatic printer/plotter for recording products to be converted to color, the roller of the electrostatic plotter should be cleaned, the toner and concentrate should be replenished, and the system should be loaded with vellum paper to produce high-contrast film positives.

PROCEDURE

The following procedure should be followed for producing CROMALIN color images from electrostatic printer outputs.

Step 1: The tape-recorded land use maps produced by low-cost data analysis system (DAS) programs ASSIGN and GEOREF consist of an array of numbers. The tape-recorded maps may be converted to gray-shade color component maps by low-cost DAS program SYS 203, which permits the user to specify a gray shade for each color component (red, green, blue, etc.) or material type (theme). To produce maps from the basic colors red, green, and blue, the user runs program SYS 203 three times to produce the color components, or as many times as there are themes. It has been found that the Varian Data Machines STATOS 33 electrostatic printer/plotter used by the NASA Earth Resources Laboratory is geometrically repeatable and registerable. The STATOS 33 plotting bed is 55.88 centimeters (22 inches) wide. If wider plots are needed, multiple passes may be made and mosaicked together.

Step 2: Using a 102- by 102-centimeter (40 by 40 inch) vacuum-frame printer with a high-intensity light source, each printer/plotter sheet or mosaic is exposed onto a high-contrast positive-to-positive film (Du Pont type DP-4 CRONALAR) at contact size.

Step 3: Develop, fix, wash, and dry film positive. This process requires the use of sinks for the chemicals and water. With adequate sinks, this process should require 15 minutes for each film positive, including drying time.

Step 4: Place all film positives on a light table and register. If grids or tick marks are recorded in the data, it is easiest to register at these marks; otherwise, one must register on the basis of data content. Punch the register film positive using a pin registration punch. The pinholes will be used for registration in the remaining steps.

Step 5: Using the CROMALIN 2700 laminator, overcoat a white coated (Chromkote) paper material with CROMALIN photopolymer, CROMALIN color display film, which includes a protective coating. Punch the base paper material with the pin registration punch to be used for registration in the remaining steps.

Step 6: Place the first film positive over the photopolymer-coated base material in the vacuum-frame printer and register at the pin marks. Actuate the vacuum to hold the base material and the film positive flat. Expose the film positive to high-intensity light as directed by the manufacturer's instructions.

Step 7: Remove the positive and the exposed photopolymer-coated base material from the vacuum-frame printer. Transfer the base material to the CROMALIN 3042 console and strip away the protective coating. The desired color component or theme will be tacky or sticky, whereas all other areas are smooth.

Step 8: Select one of the 40 available colored powders and apply to all tacky areas. This will produce an image of the first theme or color component. The powder should be applied with the CROMALIN applicator, and only on the CROMALIN 3042 console. The console is equipped with a vacuum system and filters to prevent the fine colored powders from floating in the surrounding air. Clear off all excess powders.

Step 9: Coat the base material with another coat of photopolymer in the CROMALIN laminator as described in step 5. Repeat steps 6 to 8 for each color component or theme. In step 8, select a different colored powder for each color component.

Step 10: After the last color component or theme has been applied, run the base material through the CROMALIN 2700 laminator again as described in step 5.

Step 11: Expose the photopolymer applied in step 10 directly to high-intensity light.

Step 12: At the CROMALIN 3042 console, strip away the protective coating from the exposed photopolymer. A smooth waterproof surface will remain. The product is completed. Approximately 20 to 30 minutes are required to produce a three-component color product (steps 5 to 12).

EQUIPMENT NEEDED

The following components are needed for producing CROMALIN color products from electrostatic printer outputs.

1. A 102- by 102-centimeter (40 by 40 inch) vacuum-frame contact printer with a tungsten light source and a high-intensity ultraviolet (UV) light source - The tungsten light is used to expose the film positive materials. The high-intensity UV light is used to expose the photopolymer coating (Cost: approximately $2000)

2. Four 102- by 102-centimeter (40 by 40 inch) tray sinks for water and chemicals used in processing the film positive materials (Cost: approximately $1150)

3. A pin registration punch (Cost: approximately $600)

4. Fan for drying positives (optional)

5. CROMALIN 2700 laminator (Cost: approximately $1600)

6. CROMALIN 3042 console (Cost: approximately $400)

FACILITY NEEDED

A darkroom for exposing and processing film positives is the only facility needed. The CROMALIN printing steps are accomplished in daylight.

SUPPLIES NEEDED

The following supplies are needed.

1. High-contrast positive material, black and white, 51- by 102-centimeter (20 by 40 inch) sheets (Du Pont CRONALAR DP-4) (Cost: $114/50-sheet box)

2. An A-B high-contrast developer (Cost: $45/151.5 liters ($45/40 gallons))

3. Eastman Kodak fixer (Cost: $12/94.6 liters ($12/25 gallons))

4. CROMALIN color display film (photopolymer coating), 69-centimeter (27 inch) wide by 90-meter (300 foot) long roll (Cost: $550/roll)

5. Applicator pads

6. Base material

7. Colored powders, as many as 40 colors available (Cost: $1/28.35 grams ($1/ounce) when purchased in 226.8-gram (8 ounce) lots)

Items 5, 6, and 7 are available in a CROMALIN starter kit at a cost of $135. Sufficient quantities are included to experiment with CROMALIN printing. Users may purchase component materials at a lower unit price for larger quantities.