UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SUMMARY TABLES FOR SELECTED DIGITAL IMAGE PROCESSING SYSTEMS

by
Virginia Carter, Frederic Billingsley and Jeannine Lamar

Open-File Report 77-414

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By Virginia Carter, U.S. Geological Survey
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1977

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TABLES

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ABSTRACT

The exploration of earth from space has greatly increased the demand for computer systems of great speed and complexity.

Because it has proved difficult to make comparisons between systems in an orderly fashion, a set of five tables have been developed for the comparison of digital image processing systems. The tables have been compiled for six U.S. manufactured hardware/software systems. Three U.S. software systems are included in the tables also.

The tables and the System Summaries have been prepared primarily from information supplied by the manufacturers. While some rewording has been done to make the descriptions parallel, the manufacturers' wording has been retained to a large extent.

INTRODUCTION

The exploration of Earth from space has greatly increased the demand for computer systems of great speed and complexity. Among the many functions of these computer systems is the processing of digital images such as those produced by Landsat (formerly Earth Resources Technology Satellite - ERTS). There has been a proliferation of digital image processing systems, both hardware/software and software, to analyze these data.

Because it has proved difficult to make comparisons between systems in an orderly fashion, a set of five tables have been developed for the comparison of digital image processing systems. The tables have been compiled for six U.S. manufactured hardware/software systems: 1) the General Electric (GE) IMAGE-100, 2) the Bendix Multispectral Data Analysis System (MDAS), 3) the Electronics Systems Laboratory (ESL) Interactive Digital Image Manipulation System (IDIMS), 4) the Comtal Corporation (CC) Series 9 System, 5) the International Imaging Systems, Inc. (I^2S) System 101, and 6) the Interpretation Systems Incorporated (ISI) System 470.

Three U.S. software systems are included in the tables also: 1) the Jet Propulsion Laboratory (JPL) Video Communication and Retrieval (VICAR) System, 2) the Laboratory for Applications of Remote Sensing (LARS) System, and 3) the University of Kansas KANDIDATS System. The tables can be updated rapidly, and other systems may be added using the same tabular format.

Isolated pieces of hardware performing only part of a system function and all single purpose systems where processing is only done as a display function are not included.

These tables are intended for system comparison and <u>not</u> systems evaluation. There are many existing digital image processing systems; each is slightly different in concept or operation. There is not sufficient information in these tables, nor can there ever be, to make them the sole basis for choosing a system for a particular use. The authors have deliberately avoided making subjective judgements on the systems. The selection of a system will have to take into account such parameters as operating speed (especially for the multispectral classification, if that is a prime use of the equipment), the flexibility with which other operations are possible, the ease of communication with the system during operations, the ease of writing and implementing new functions, and the cost of the system.

Finally, the tables have been designed for use by analysts with some degree of familiarity with image processing. They cannot serve as a training course in image processing. The reader desiring additional information is encouraged to refer to the extensive literature on the subject. For clarification, some terms used herein are defined following the tables.

The tables and the System Summaries have been prepared primarily from information supplied by the manufacturers. While some rewording has been done to make the descriptions parallel, the manufacturers' wording has been retained to a large extent.

SYSTEM SUMMARIES

G.E. IMAGE-100

An interactive image analysis system designed for multispectral classification of satellite and aircraft multispectral scanner data, with limited general-purpose processing available. The hardware system includes a PDP11-class computer, an interactive image analysis console containing a hardware classifier and other specialized processing functions, five channels of memory for image processing and display refresh with thematic overlay capability, and a color display.

Sold as a complete system with proprietary software. Can be expanded and(or) reconfigured to meet specialized user requirements.

General Electric Company
Space Division
P.O. Box 2500
Daytona Beach, Florida 32015
(904) 258-2924
Contact: Robert W. Towles
Manager, Image Processing Applications

BENDIX MDAS

A combination hardware-software system designed primarily for multispectral classification of satellite and aircraft multispectral scanner data, with limited general purpose software processing available. The hardware system includes a PDP-11 and an interactive image analysis console containing a hardware classifier and some specialized processing functions. The system can process up to 16 channels of image data simultaneously and has a solid-state refreshed 3-color display with graphic overlay.

Sold as a complete system with proprietary software. Can be expanded to meet user requirements.

The Bendix Corporation
Aerospace Systems Division
3621 S. State Road
Ann Arbor, Michigan 48107
(313) 665-7766
Contact: Mr. Charles L. Wilson
Manager, Earth Resources Applications

I^2S SYSTEM 101

An interactive multi-user digital image processing system including multi-spectral analysis and an expandable set of general purpose algorithms. The hardware consists of a Hewlett-Packard 3000 Series II Computer with disc image storage and user console containing up to 14 channels of refresh memory, with hardware processing at video rate, a programmable floating point image array processor and color displays.

Sold as a specific complete system with proprietary software, configured to user requirements.

International Imaging Systems
Division of Stanford Technology Corporation
650 North Mary Avenue
Sunnyvale, California 94086
(408) 737-0200
Contact: Mr. Paul Papathakis
Director of Marketing

ESL IDIMS

A combination hardware-software system for general purpose interactive, multi-user image processing including multispectral analysis and classification. Hardware includes: Hewlett-Packard 3000 Series 11 computer, interactive processing console including a programmable array processor, 3 or more channels of refresh memory with video color display; refresh memory is CCD or random access. Software can also process collateral data.

Sold as a complete system with proprietary software with configuration tailored to user needs.

Electromagnetic Systems Laboratories, Inc.
495 Java Drive
Sunnyvale, California 94086
(408) 734-2244
Contact: Dr. James E. Burke
Manager, Image Data Systems

COMTAL SERIES 9

A complete stand-alone system designed for both multispectral data classification and general purpose image analysis and enhancement of up to four separate image planes simultaneously. It incorporates a combination of hardware and software functions to provide maximum processing speed and capability while maintaining complete functional flexibility. Changes in algorithms and processing techniques may be implemented by software changes. Major subsystems are magnetic tapes, computer, and 8000 Series display.

Comtal Corporation
169 North Halstead
Pasadena, California 91107
(213) 793-2134
Contact: Dr. John Tahl, President

ISI SYSTEM 470 AND SAND

Combination hardware-software systems for general purpose image processing and multispectral analysis. Swing (proprietary) software and digital computer and peripherals are the same in both; 470 contains real-time video processing and 600 image video disc store; SAND is RAM (Random Access Memory)-based for interactive computer graphics applications.

Specific configurations may be tailored to user needs.

Interpretation Systems Incorporated
P.O. Box 1007
Lawrence, Kansas 66044
(913) 842-5678
Contact: Mr. Jerry D. Lent
Director, International Marketing

KANDIDATS

KANDIDATS is a digital image processing system that interacts with the user at the command string level. It includes prompting for parameter input and checks user input for errors. Image analysis programs available in KANDIDATS consist of utility functions, image transform operations, spatial clustering, and Bayesian classification. Programming structure and file structure are modular.

Dr. Robert Haralick
Space Technology Center
University of Kansas
Lawrence, Kansas 66045
(913) 864-3542

JPL VICAR

A Fortran-based expandable general purpose image processing software system. It includes a wide variety of general purpose algorithms including multi-spectral analysis and computation. Implemented at JPL initially on IBM-360/44; recently modified to 360/65. Computer peripherals serviced by the system include: 2 Comtal interactive consoles, a Ramtek refresh memory, a quick look Polaroid hardcopy output, and off-line film recording.

Software system available from COSMIC includes documentation and listings.

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103
(213) 354-5016
Contact: Mr. William B. Green
Section Manager, Science Data Analysis Section

PURDUE LARSYS

Combination hardware-software image processing facility at the Laboratory for Applications of Remote Sensing (LARS) in West Lafayette, Indiana. System is used locally and also supports remote terminals via phone line. The software system (LARSYS) is primarily designed for multispectral classification, but also includes limited general purpose image processing. Hardware is an IBM-360/67 plus an interactive console containing a black-and-white video display with facilities for black-and-white and color photographic output.

System hardware is not for sale, but several terminals are available throughout the country and at West Lafayette. System software is available through COSMIC.

Purdue University
Laboratory for Applications of Remote Sensing (LARS)
Purdue Industrial Research Park
1220 Potter Drive
West Lafayette, Indiana 47906
(317) 749-2052
Contact: Mr. Terry L. Phillips
Deputy Director, System Services

TABLE 1 GENERAL PURPOSE IMAGE PROCESSING

RADIOMETRIC FUNCTION	GE IMAGE 100	BENDIX MDAS	I²S SYSTEM 101*
RADIOMETRIC CORRECTION Landsat debanding, correction for 6-sensor unbalance of MSS	Line by line gain and offset (Optional software, or software/hardware hybrid) Average adjacent lines	No	Average adjacent lines
Correction of photographic data	Hardware shading (for TV camera input)	Shading, when using vidicon option D-log E correction	Shading Focus correction Motion de-blurring
Other	Video averaging software for noise removal	Atmospheric correction by regression analysis	Sun angle correction
DIGITAL LEVEL SLICING Continuum B/W to multiple discrete grey shades	8-level (to theme tracks) N-level (Optional) completely flexible spacing	Φ 24-level: Offset, counts/level Θ Offset, gain (8 levels/band, equal size) Δ N-level with flexible spacing by card input	N-level Completely flexible spacing Linear, high and low limit, # of steps
Assignment of colors to discrete grey shades	64 preset colors, 8 at a time N-level - arbitrary color assignments	Φ 24 preset colors Θ Arbitrary color assignment, Δ 512 colors available (false color mode)	Arbitrary color assignment, 512 colors available Single level color slice on B/W image
CONTRAST STRETCH	Table lookup implementation Linear Equal occupancy Square root Piecewise linear (Opt.)	Table lookup implementation Equal occupancy Square root Piecewise linear (Opt.) Variable gain and offset (planned)	Linear Equal occupancy Logarithmic Piecewise linear Exponential

TABLE 1 GENERAL PURPOSE IMAGE PROCESSING Page 1 of 3 (Continued)

RADIOMETRIC FUNCTION	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
RADIOMETRIC CORRECTION Landsat debanding, correction for 6-sensor unbalance of MSS	Average adjacent lines Notched filtering	No	Average adjacent lines
Correction of photographic data	Shading correction Focus correction Motion de-blurring	No	Shading correction Focus correction (planned)
Other	Atmospheric corrections (planned) Sun angle correction	Replace adjacent line	
DIGITAL LEVEL SLICING Continuum B/W to multiple discrete grey shades	N-level Completely flexible spacing	N-level	8-level (hardware real-time) N-level software Completely flexible spacing
Assignment of colors to discrete grey shades	Arbitrary color assignment, 4096 colors available, 64 at a time for display	Color contouring	Arbitrary level setting (color contouring - SAND)
CONTRAST STRETCH	15 major types of intensity transformations.	Variety of interactive transforms	Table look-up Linear Logarithmic Piecewise linear

TABLE 1 GENERAL PURPOSE IMAGE PROCESSING (SOFTWARE SYSTEMS)

RADIOMETRIC FUNCTION	KANDIDATS	JPL VICAR	LARSYS
RADIOMETRIC CORRECTION Landsat debanding, correction for 6-sensor unbalance of MSS	Average adjacent lines	*Average adjacent lines Convolution filtering Line by line gain and offset Fourier filtering	Gain and offset *Average adjacent lines *Fourier filtering *Scanner angle correction *Convolutional filtering
Correction of photographic data	No	Shading D-log E correction	*Shading
Other	Point correction	Focus correction Average several images for noise correction Individual pixel correction	*Focus correction *Finite aperture correction
DIGITAL LEVEL SLICING Continuum B/W to multiple discrete grey shades	N-level, flexible Grey scale line printer	N-level flexible table Linear-arbitrary endpoints Log Exponential Grey scale line printer	N-level flexible table Grey scale line printer
Assignment of colors to discrete grey shades	Arbitrary, in display memory, 10-color	*Arbitrary (analyst-generated tables in color space)	*Arbitrary (analyst-generated color tables)
CONTRAST STRETCH * Not in COSMIC	Linear Equal occupancy General non-linear	Table lookup implementation Linear, arbitrary end points Equal occupancy Contouring Flexible table Logarithmic Exponential Piecewise linear	Flexible table lookup Equal occupancy

GEOMETRIC CORRECTION & REGISTRATION	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
CORRECTIONS Internal sensor distortions	Mirror scan velocity profile (Opt.) Roll, pitch, yaw (Opt.) Ephemeris (altitude and velocity) (Opt.) Skew Aspect ratio and scaling Std.: By line selection Opt.: By interpolation	Mirror scan velocity profile Roll, pitch, yaw Ephemeris (altitude and velocity) Skew Aspect ratio by nearest neighbor Scaling	Mirror scan velocity profile Roll, pitch, yaw Skew Aspect ratio Scaling - remove synthetic pixels
External - projective geometry distortions	Map Projections: Space oblique Mercator (Opt.)	Map Projections: UTM Lat/Long State plane	Map Projections: UTM Space oblique Mercator Albers equal area Polar stereographic State plane Lambert conformal North American polyconic Flexible rubber sheet stretching (Array processor planned) Image rotation (Array processor planned) Perspective correction
REGISTRATION Development of registration parameters	Cursor designates line and pixel of selected features	Interactive selection of control points (Includes displayed GCP's from maps) One pixel dot for GCP location (blinking)	Interactive selection of control points from subscenes, merged for full scene correction (Up to 100 GCP max.)
Mapping of ground control points to entire scene or subscene	Least squares fit to a maximum of 16 GCP's (Opt.) Translation only with standard software	Least squares fit to a maximum of 99 GCP's	Computed surface fit by nth order polynomial
Digital temporal and mapping overlay Image to image	Subscene only (Opt.) Full scene (Opt.)	Full scene	Full scene
Image to map	Variable scales (Opt.)	Variable scales	Variable scales

GEOMETRIC CORRECTION & REGISTRATION	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
CORRECTIONS Internal sensor distortion (Landsat MSS)	Skew Aspect ratio to 79x79 meter IFOV Scaling for line printer to specified scale Mirror scan velocity profile, roll, pitch, yaw, detector sampling delay (planned).	No	Mirror scan velocity profile Roll, pitch, yaw Skew
External - projective geometry distortions	Image rotation Map projection (planned) Rubber sheet stretching	No	Image rotation Round earth Flexible rubber sheet
REGISTRATION Development of registration parameters	Interactive cursor selection of control points	Interactive cursor location of control points	Manual selections of points by coordinates Cursor selection of GCPs
Mapping of ground control points to entire scene or subscene	Least squares fit to polynomials (up to cubic)		Least squares fit per 512x512 sub-image
Digital temporal and mapping overlay Image to image	Full scene	Yes	Entire image by mosaic of sub-images
Image to map	Variable scales		Variable scales

TABLE 1 GENERAL PURPOSE IMAGE PROCESSING (SOFTWARE SYSTEMS)

GEOMETRIC CORRECTION & REGISTRATION	KANDIDATS	JPL VICAR	LARSYS
CORRECTIONS Internal sensor distortions (Landsat MSS)	Skew Scale by nearest neighbor Vertical skew also available	*Mirror scan velocity profile *Roll, pitch, yaw *Skew Aspect ratio Scaling - by interpolation	*Skew Aspect ratio Scaling
External - projective geometry distortions	Flexible rubber sheet by function Rotation, translation, skew, scale by matrix coefficients	*Space oblique Mercator Image rotation *Projection to standard map Flexible rubber sheet stretching	*Image rotation *Rubber sheet stretching
REGISTRATION Development of registration parameters	Manual control points	*Manual or interactive selection of control points *Cross correlation of areas around selected control points	*Manual selection of control points *Computed block correlations for 12-30 blocks per scene
Mapping of ground control points to entire scene or subscene	2x2 transformation matrix	Triangular facet surface fit	*Biquadratic fit to GCP's
Digital temporal and mapping overlay Image to image	Partial scene, limited by computer size	Full or partial scene	*Full scene
Image to map	By control point	Variable scales	*Yes

*Not in COSMIC

OTHER SYSTEM FUNCTIONS	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
GEOMETRIC INTERPOLATION TECHNIQUES	Nearest neighbor (Opt.) Cubic convolution (Opt.) Bilinear (Opt.) Lagrangian (Opt.) Hardware/software implementation allows any 4x4 technique to be used	Nearest neighbor Software implementation of any 4x8 technique including restoration, cubic convolution, bilinear Lagrangian (Opt.)	Nearest neighbor Bilinear Cubic convolution (planned)
FILTERING	High pass, low pass, Laplacian (Opt.) Theme filtering via Golay surrounds (Opt.) Sin x/x filter software for window display (Standard), hardware for full screen (Opt.)	"Restoration" (Bendix proprietary technique) Any linear filter (Sin x/x, high pass, low pass, Laplacian)	Convolution; Gaussian High pass Low pass Wiener Homomorphic Directional Fourier transform Hadamard transform
TRANSFORMS Fourier	No	Yes	Yes (hardware and software)
Hadamard	Yes (hardware/software	Yes	Yes (hardware and software)
Other		Categorical transform	Slant

TABLE 1 GENERAL PURPOSE IMAGE PROCESSING

OTHER SYSTEM FUNCTIONS	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, 6AND
GEOMETRIC INTERPOLATION TECHNIQUES	Nearest neighbor Bilinear Cubic convolution	Nearest neighbor Bilinear	Nearest neighbor Bilinear Cubic convolution
FILTERING	Convolution - using arbitrary kernal Wiener Homomorphic Directional Ten different routines for filter generation Fourier transform	No	Convolution - using arbitrary kernal LaPlacian Robert's gradient Theme filtering by Grow/Shrink and generalized template match
TRANSFORMS Fourier	Yes	No	Yes
Hadamard	Yes	No	Yes
Other			Discreet cosine Discreet Linear Basis Slant

TABLE 1 GENERAL PURPOSE IMAGE PROCESSING (SOFTWARE SYSTEMS) Page 3 of 3 (Continued)

OTHER SYSTEM FUNCTIONS	KANDIDATS	JPL VICAR	LARSYS
GEOMETRIC INTERPOLATION TECHNIQUES	Nearest neighbor	Nearest neighbor Bilinear *Cubic convolution *Spline *Sin x/x	*Nearest neighbor *Cubic *Spline *Sin x/x
FILTERING	Theme cleanup by grow-shrink Rectangular box filter 3x3 median filter Gradient, Generalized Laplacian 3x3 linear filter	Wiener Convolution - function selected by parameter input (eg. low pass, high pass, Laplacian, directional) Fourier transform	*Convolution *Optimum constrained restoration *Laplacian *Gradient *Fourier transform
TRANSFORMS Fourier	Yes	Yes	*Yes
Hadamard	Yes	*Yes	*Yes
Other	Slant Discrete cosine Discrete linear basis	*Various color space transforms	
*Not in COSMIC			

TABLE 2 MULTISPECTRAL CLASSIFICATION

MULTISPECTRAL CLASSIFICATION	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
SUPERVISED CLASSIFIER	Parallelepiped (single-cell) Table lookup (multi-cell) Nonparametric maximum likelihood (Opt.) Hardware/software implementation Hardware bulk classifier, including table lookup and parametric maximum likelihood (Opt.)	Bayesian maximum likelihood Gaussian or aggregate Gaussian standard	Maximum likelihood Parallelepiped Table lookup (hardware and software)
UNSUPERVISED CLASSIFIER Spectral space clustering	Semi-supervised software(Opt.)	Yes (Opt.)	Yes - software - can be done on cursor-designated polygon
Region growing in image space			
MENSURATION Pixel count of strata	Full screen Subareas by thematic mask	Total scene Cursor enclosed area Interactive manual digitizer Multiple scene areas	Subscene defined by cursor or rectangular window
INTER-BAND MANIPULATION Inter-band functions	Ratioing, difference-over-sum, normalization (hardware)	Ratioing (software)	+ - x ÷ (hardware and software)
Spectral analysis	Eigenvector (software)	Eigenvector Regression Factor	Eigenvector (hardware and software)
Spectral Axis Rotations	Karhunen-Loeve (hardware/software) General Axis Rotation (hardware)	Karhunen-Loeve General Axis Rotation	Karhunen-Loeve (hardware and software) General Axis Rotation

TABLE 2 MULTISPECTRAL CLASSIFICATION (SOFTWARE SYSTEMS) Page 1 of 2 (Continued)

MULTISPECTRAL CLASSIFICATION	KANDIDATS	JPL VICAR	LARSYS
<u>SUPERVISED CLASSIFIER</u>	Bayesian table lookup with spatial neighbor backup	*Bayesian *Parallelepiped table lookup *Parallelepiped table lookup with Bayesian secondary classifier *Stored table Bayesian	Maximum likelihood for each pixel Sample (per field) classifier *Multiimage layered classifier
<u>UNSUPERVISED CLASSIFIER</u> Spectral space clustering	Euclidian distance in measurement space	Not at present	Yes
Region growing in image space	Boundaries by Roberts gradient and adaptive thresholding		*Automatic boundary finding/sample classification
<u>MENSURATION</u>		Yes, subareas by binary mask	Yes
<u>INTER-BAND MANIPULATION</u> Inter-band functions	Algebraic operations	+ - x ÷ averaging Any Fortran-writable function	Ratioing
Spectral analysis	Eigenvector, by training areas or on all data	*Eigenvector	*Eigenvector
Spectral axis rotations	Karhunen-Loeve. Also fast K-L General Axis Rotations	*Karhunen-Loeve General Axis Rotations	*Karhunen-Loeve

*Not in COSMIC

TABLE 2 MULTISPECTRAL CLASSIFICATION Page 1 of 2 (Continued)

MULTISPECTRAL CLASSIFICATION	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
SUPERVISED CLASSIFIER	Advanced stored table (Bayesian) Maximum likelihood (array processor) Minimum distance (Euclidian)	Parallelpiped	Parallelpiped Bayesian Table look-up Non-parametric (hardware/software implementation - SAND)
UNSUPERVISED CLASSIFIER Spectral space clustering	ISOCLS (iterative) classifier - can be done on cursor-designated sub-area	No	
Region growing in image space			Iterative spatial clustering based on homogeneous regions, edge detection and enhancement and thresholding
MENSURATION	Yes - by strata binary mask, cursor-designated area, or interactive manual digitizer. Stereo mensuration (opt.)	Yes - hardware 1/30 sec.	Total scene or arbitrary sub-area (optional real-time mensuration hardware)
INTER-BAND MANIPULATION Inter-band functions	Sum, Difference, Product, Ratio	Sum, Difference, Product, Ratio and combined functions	Ratio Array and scalar arithmetic Logical operations Algebraic functions
Spectral analysis	Eigenvector	Eigenvector	Eigenvector
Spectral axis rotations	Karhunen-Loeve General axis rotation		Karhunen-Loeve General axis rotation

MULTISPECTRAL ANALYSIS	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
STATISTICAL OPERATIONS Training field selection	Single pixel (cross-hair), rectangle, 45° rotated rectangle Polygon cursor (Opt.)	Any shape quadrilateral as small as 1 pixel with any orientation	Full scene Any shape designated Interactive selection
Derivation of training field statistics	Covariance matrices Histograms Hardware/software implementation Time independent of size	Covariance matrices Histograms (Opt.)	Covariance matrices
Maximum number of spectral bands analyzed simultaneously	4; 5 with ratioing Up to 16 (Opt.)	16	14 - Display processor or 36 - Central processor
Maximum number of classes	Any number, 8 themes displayable at one time superimposed on video.	50, display handles any number simultaneously	64
Optimum band selection	Optional interactive feature selection software - ≤4 out of 16 max.	All input data channels processed unless operator overridden	Ratios and divergence analysis
Classification speed (per 512x512 pixel 4-band scene)	Nominally 3-5 seconds per class (multicell signature)	CCT-limited (I/O limit) 20 min. total ¼ scene	10 class - 2 min. with array processor (linear with number of classes)

MULTISPECTRAL ANALYSIS	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM-470, SAND
STATISTICAL OPERATIONS Training field selection	Interactive selection of polygonal areas with cursor (21 subcommands) Random sampling	Any shape quadrilateral up to 8 active	Interactive selection via cursor or manual specification by polygon vertices Designated by arbitrary irregular boundary
Derivation of training field statistics	Covariance matrices Statistics file editor	Covariance matrices	Histograms Covariance matrices (Hardware/software implementation - SAND)
Maximum number of spectral bands analyzed simultaneously	255	4	14 256 with speed penalty
Maximum number of classes	256 in one pass	4	255 in one pass (8 per pass at maximum speed)
Optimum band selection	Yes	Manual	Non-parametric Bhattacharyya
Classification speed (per 512x512 pixel 4-band scene)	10 class - 52 sec. with ASAP (linear with number of classes)		470 - Bayes, up to 16 classes, disc I/O limit, <20 secs. SAND - from memory, <2.5 secs.

TABLE 2 MULTISPECTRAL ANALYSIS (SOFTWARE SYSTEMS)

MULTISPECTRAL ANALYSIS	KANDIDATS	JPL VICAR	LARSYS
STATISTICAL OPERATIONS Training field selection	Manual on display - rectangular area	Any shape designated *Polygon vertices (may be from maps)	Rectangle by line and column
Derivation of training field statistics	Smoothed Gaussian Mean and covariance matrix by class	*Covariance matrices or manual parallelepiped limits	Covariance matrices from training field or clustering results
Maximum number of spectral bands analyzed simultaneously	Depends on memory available and length of line	16	30
Maximum number of classes	18	50	60
Optimum band selection	Operator selection Bhattacharyya coefficients	*Yes, including ratios	Yes - transformed divergence (average over class pairs, maximized minimum pairwise)
Classification speed (per 512x512 pixel 4-band scene) (Very machine-dependent. Included as illustrative only.) * Not in COSMIC		10 classes - CPU time 45 seconds - parallelepiped only Approx. 1.5 minutes - parallelepiped with 2 class Bayesian resolution - all pixels 12 minutes - parallelepiped with 10 class Bayesian resolution - all pixels	

TABLE 3 SYSTEM INPUTS

INPUT DEVICE	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
TV CAMERA or equivalent (imagery)	Yes, silicon vidicon	Optional vidicon	Yes, vidicon
MICRODENSITOMETER Drum scanner	Optronics (Opt.)	Optronics (Opt.)	Optronics
Other			Perkin-Elmer 1010A can be used with system
DIGITAL TAPES	NASA Landsat Skylab S192 (Opt.) LARSYS (Opt.) INPE Landsat (Opt.) Aircraft scanner (Opt.) CCRS Landsat (Opt.) JSC Universal (Opt.) HDDT to CCT conversion for aircraft scanners (under construction)	Landsat Bendix M^2S scanner \$ Skylab S192 \$ INPE (Brazil) MSDS (24 channel scanner) \$ ERIM scanner \$ \$ (CCT and HDDT)	Landsat
ANALOG TAPES	FM tape to CCT converter for Daedalus analog scanner (developed and operating) (Opt.)	Optional	No

TABLE 3 SYSTEM INPUTS

INPUT DEVICE	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
TV CAMERA or equivalent (imagery)	Not at ESL facility (system option)	Special system option	Yes, vidicon
MICRODENSITOMETER Drum scanner	Optional - user choice	No	Optional (high speed 8-bit video digitizer is included as standard component)
Other	Perkin-Elmer 1010A	No	No
DIGITAL TAPES	Landsat Skylab S192 Aircraft scanner PCM	Landsat VICAR	Landsat JSC Universal Skylab S192 Swing (ISI software std.)
ANALOG TAPES	FM at ESL facility	No	No

TABLE 3 SYSTEM INPUTS (SOFTWARE SYSTEMS)

INPUT DEVICE	KANDIDATS	JPL VICAR	LARSYS
TV CAMERA or equivalent (imagery)		Interface software for: CRT scanner *Dicomed image dissector scanner	*Interface software
MICRODENSITOMETER Drum scanner			*Optronics
Other		Interface software for: Perkin Elmer 1010	
DIGITAL TAPES	Landsat Skylab S192 LARSYS JSC Universal	*Landsat *Skylab S192 *Bendix M^2S *NASA 24 channel VICAR	LARSYS *Landsat *Aircraft scanner *Skylab S192 *CCRS *JSC universal *VICAR
ANALOG TAPES	No	No	*Yes

* Not in COSMIC

TABLE 4 SYSTEM OUTPUTS Page 1 of 2

OUTPUT	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
VOLATILE DISPLAY Graphics	Tektronix	Yes	Yes
Two-dimensional graphic display	Covariance matrix Cluster plotting Histograms Intensity profiles Statistical numerical outputs Mensuration output	Tables of: Categorization group accuracy Means separation in feature space Areas and contents Covariance matrix Transformation coefficients Cluster plots (planned) Histogram (Opt.)	Categorization accuracy table Status monitor Histograms (hardware and software) Intensity profiles Cluster plots (planned)
CRT display - grey scale or color image	512x512 (480 lines visible) Four 8-bit channels superimposable with eight 1-bit themes Bias, gain, invert for all CRT guns Moving window (Opt.) Time-lapse display (Opt,) Large-screen display (Opt.) Additional channels (Opt.) High resolution display, 850X 870 (Opt.)	320x240 "moving window" 3 channels, 3 bits/channel 3 bits/color	512x512 "moving window-scroll" color
Annotation	Yes, in various colors	Yes	Yes

TABLE 4 SYSTEM OUTPUTS Page 1 of 2 (Continued)

OUTPUT	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
VOLATILE DISPLAY Graphics	Tektronix (T) Grey level display (D)	Yes (Optional)	Yes
Two-dimensional graphic display	Cluster (T) Histograms (D) Intensity profiles (D) Strata boundaries from ext. digitizer (T, D) Scattergrams (T)	Histogram Covariance matrix	Covariance matrix Cluster plots Scattergrams Most other system tables
CRT display - grey scale or color image	512x512 3, 8-bit images 4, 1-bit graphics, color "Scrolling" Alternate - field TV stereo viewing with 3-D mensuration software (Opt.) Flexible Isometric Display (Opt.)	512x512 4 8-bit images 4 1-bit graphics "Scrolling"	640x480 7 8-bit channels (512x512 4 8-bit channels with 8 1-bit overlays, dynamic translation, scaling) Scrolling, sub-image selection and reversal (SAND) Pseudo 3-D isometric display with variable rotation, relief, inclination and 5x mag. (depth cueing - SAND) Large screen display (Opt.) "Movie Mode" available with video disc store (470)
Annotation	Yes - Color	Yes	Yes - limited to operator entered free-hand overlays (via video mask) (fully software supported - SAND)

TABLE 4 SYSTEM OUTPUTS (SOFTWARE SYSTEMS)

OUTPUT	KANDIDATS	JPL VICAR	LARSYS
VOLATILE DISPLAY Graphics	No	No	No
Two-dimensional graphic display	Pseudo 3-D	*Covariance matrix Cluster plotting	No
CRT display - grey scale or color image	Yes	*512x512 color Comtal *1024x1024 B/W Comtal *640x512 B/W RAMTEK	Yes (at LARS and in cosmic software) No (at terminals via land line)
Annotation	No	Yes	No
* Not in COSMIC			

TABLE 4 SYSTEM OUTPUTS

OUTPUT	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM 101
HARD COPY OUTPUTS Line printer	Gould printer/plotter	Gould printer (Opt.)	Yes
High quality film - grey scale, color	Dicomed (Opt.) Halftone by dot matrix on Gould printer	Optronics	Interface for Optronics available
Overlays (Raster)	Geometrically corrected and scaled transparencies (Opt.) Dicomed film recorder (Opt.)	Geometrically corrected and scaled Optronics	Geometrically corrected and scaled - Tape output for Dicomed D163 (planned)
Maps (Line Plotter)	Xynetics plotter (Opt.)	Calcomp	Planned
Photographs of display	Yes	Yes	Yes

TABLE 4 SYSTEM OUTPUTS

OUTPUT	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
HARD COPY OUTPUTS Line printer	Yes Also printer/plotter	No	Electrostatic printer/plotter Laser recorder (Planned)
High quality film - grey scale, color	Yes - ESL drum recorder Interface (B/W) software to Dicomed, Optronics	Yes	Optional - user-specified brand
Overlays (Raster)	Up to 8x10 transparencies geometrically corrected and scaled		Up to 8x10 transparencies
Maps (Line plotter)	Off-line Xynetics	No	Printer/plotter std. Xynetics optional
Photographs of display	Optional	Optional	Yes

TABLE 4 SYSTEM OUTPUTS (SOFTWARE SYSTEMS)

OUTPUT	KANDIDATS	JPL VICAR	LARSYS
HARD COPY OUTPUTS Line printer	Grey scale by overprint	Yes	Yes
High quality film - grey scale, color	Interface software for Dicomed color via tape	Interface software for; *Dicomed color PDS flatbed - Model 1010 Optronics drum scanner	*Yes
Overlays (Raster)		Up to 8x10 transparencies (off-line)	
Maps (Line Plotter)		Calcomp	*Yes
Photographs of display * Not in COSMIC		Separate high-quality polaroid output	*Yes

TABLE 5 — OTHER SYSTEM FEATURES

	GE IMAGE 100	BENDIX MDAS	I^2S SYSTEM-101
MICROPROGRAMMABLE PROCESSOR	Planned: Spectral proprocessing Classification Training Spatial video filtering Theme filtering	Yes (MCP - the Bendix hardware processor)	Planned array processor for: Supv. classifier Geometric resampling
PRESENT COMPUTER	PDP 11/35, 11/45 PDP 11/70 (Opt.) 32K word/DOS/35 or 45 64K word/RSX11/35 or 45 Up to 1 Mw RSX/11/70 (1 word = 2 bytes)	PDP 11/35 (11/45, 11/70) 32K/DOS Up to 128K core words RSX11M (Opt.) (1 word = 2 bytes)	HP 3000 128K bytes core min
SOFTWARE Language	FORTRAN IV (90%) PAL (10%)	FORTRAN IV (80%) MACRO (20%)	FORTRAN IV (applications) SPL (system)
Modular	Yes,	Yes	Yes
Interface mode to analyst	Batch (Opt.) Interactive Menu	Batch Interactive Menu	Batch Interactive Menu (Opt.) Command
Supports multiple users?	Yes, multiple complete user stations		Yes
SPECIALIZED FEATURES	Fast I/O for displayed data storage on tape - 8 sec. for 512x512, 4 channel	Area table output - Land use by designated area Digital tape images E-W rescanned by Topo. quad. Nearest neighbor scan to user specified resolution Proprietary interpolation	

TABLE 5 OTHER SYSTEM FEATURES Page 1 of 1 (Continued)

	ESL IDIMS	COMTAL SERIES 9	ISI SYSTEM 470, SAND
MICROPROGRAMMABLE PROCESSOR	ASAP: ESL's programmable array processor 1) Maximum likelihood 2) Fourier 3) Resampling 4) Clustering 5) Spectral ratios	No	No - System 470 (yes, vector, matrix and neighborhood operations - SAND)
PRESENT COMPUTER	HP 3000 Series II 128K- bytes core min. HP 21Mx also required with ASAP as a controller 50 MBy disc min. recomm.	PDP 11/35	PDP - 11/35 32K words 11/70 optional (1 word = 2 bytes)
SOFTWARE Language	FORTRAN IV SPL (HP-3000)	MACRO 11	FORTH high level (85%) code (15%)
Modular	Yes	Yes	Yes - User extensible
Interface mode to analyst	Batch Interactive Menu Command	Interactive Command	Batch Interactive Command (Menu - SAND)
Supports multiple users?	Multiple complete user stations		Multiple complete user stations (Opt., SAND)
SPECIALIZED FEATURES	Interactive resource inventory system (Opt.) Map data from external coordinate digitizer Image catalog & retrieval systems (Opt.)		Tree-structured directory for images and data 2 - 80MB discs standard

TABLE 5 OTHER SYSTEM FEATURES (SOFTWARE SYSTEMS) Page 1 of 1 (Continued)

	KANDIDATS	JPL VICAR	LARSYS
MICROPROGRAMMABLE PROCESSOR		IBM 2735-MSP for convolution	No
PRESENT COMPUTER	PDP-15 at KU Could go on any mini-computer 24K core minimum	IBM 360/44 128K core 360/65 1000K core	360/67 under CP 67 500K minimum
SOFTWARE Language	Fortran	Fortran IV (70%) Assembly (30%)	Fortran IV (80%) System/360 Assembler (20%)
Modular	Yes	Yes	Yes
Interface mode to analyst	Batch Interactive Menu and Command String	Batch *Interactive Command	Batch Interactive Command
SPECIALIZED FEATURES	Interactive image editor	*Image Based Information System (IBIS)	Available for remote terminal operation Well documented software, with training aids

* Not in COSMIC

DEFINITIONS

These definitions are generally arranged in the order in which they occur in the tables. Definition of all the terms used is not possible within the scope of this paper.

GENERAL PURPOSE IMAGE PROCESSING (Table 1): The entire gamut of possible operations on a picture, including radiometric and geometric alterations, various diagnostic procedures and displays, image analysis, and enhancements such as contrast stretching and spatial filtering. This includes all of the processes leading to the extraction of useful information from an image such as mapping, radiometric information extraction, multispectral analysis and classification, calibration and application of calibration data (rectification), change detection, and image data base operations. This does not imply that all systems have all of these functions, nor that the list is necessarily complete.

<u>Radiometric Correction</u> - Application of calibration data or cosmetic cleanup to remove visible radiometric artifacts.

* Landsat debanding - Landsat imagery generally suffers from a banding effect due to unbalance in the various sensors. This may be mitigated by application of calibration data or by line-by-line cosmetic cleanup.

* Photographic Correction - Framing cameras produce non-uniformity of radiometric response over the face of the images. This shading may be removed if calibration data is available.

* Other - Pixel noise may be removed by frame-to-frame averaging.

Atmospheric radiometric distortions require special procedures to estimate and correct.

Digital Level Slicing - Conversion of the brightness or digital number (DN) continuum to series of steps in each of which an assigned DN is substituted for a range of original DN. Each step may later be assigned a unique color.

Contrast Stretch - An alteration of the DN scale, usually to convert an input restricted DN range to an expanded output DN range. This may be linear or non-linear, as desired. Usually done by table lookup for computer efficiency.

Geometric Corrections - All sensors will produce images with some geometric warping. A primary example is the Landsat MSS, which, being a line scanner, requires 14 types of corrections.

* Internal - The principal MSS corrections required are those for inter-sensor pixel displacements, non-linearity of the scan itself and horizontal/vertical unequalities in the pixel spacing. Also, for framing cameras, raster, film, and lens distortions must be corrected.

* External - Correction for external effects such as spacecraft attitude and altitude, projection onto the round Earth, Earth rotation, and the various warpings required to register images to maps or to other images.

Geometric Warping - The geometric warping process is broken into two parts: determination of the warping function required over the face of the image, and the interpolations of DN required to generate the matrix of output pixels.

Registration - Determination of the geometric warping function.

* Registration Parameters - Determined either by a mathematical modeling of the warping desired, or by locating a series of control points (CP) for which the true locations (e.g., on the ground "Ground Control Points, (GCP)" or in a reference scene or framework "Relative Control Points, (RCP)") are known both externally and by line and pixel.

* Mapping CPs to Scene - Specific location of the source of data for each output pixel is required. The relatively sparse group of CP locations over the face of an image are used, generally by some sort of interpolation or mathematical formulation, to generate the required continuous function.

* Temporal and Mapping - For temporal overlay, CPs are often determined by cross-correlation of areas in the new and reference scenes. For mapping, image-type references are not normally available, and CP selection must be manual.

Geometric Interpolation Techniques - Source location for an output pixel is rarely precisely at an input pixel location, so that some form of interpolation using a group of input pixels surrounding the required source location is required to estimate the DN of the scene at the source location.

Filtering - Spatial filtering is used to restore the high spatial frequencies which have been attenuated in the imaging process, to sharpen visible edges, to determine areas of high or low DN variance, to soften noise effects, to remove banding, or for numerous other functions. Spatial filtering is generally done by convolution, but may be accomplished by multiplication in spatial frequency space via a Fourier transform. Golay filtering minimizes isolated pixel noise in homograms (thematic maps).

<u>Transforms</u> - Normal image coding records the brightness at each discrete instantaneous field of view, IFOV, in the scene as the DN in each pixel. However, the energy in the scene may be grouped in other ways: the Fourier transform displays the two-dimensional energy content of the various spatial frequencies present in the scene; the Hadamard transform displays a related quantity based on square-wave decomposition of the image. Other transforms are possible and sometimes used.

MULTISPECTRAL ANALYSIS (Table 2): That set of operations involving the analysis of multispectral data utilizing the spectral information. "Multispectral analysis" is often used synonomously with "multispectral classification," although it properly covers all of the required operations involving multispectral data. Multispectral classification is the recognition of areas of uniform ground cover through recognition of the spectral signatures (the multispectral vector of DN for a given material). Classification usually results in the substitution in each pixel of a "name" or color representing the ground cover class in place of the original data.

<u>Supervised Classifier</u> - The computer is instructed as to the identification of certain known materials in the scene by the use of "training areas". It is then given decision rules, and instructed to display all pixels matching the series of materials by unique codes (or colors).

Unsupervised Classifier - The computer first groups into a series of classes all of the pixels in the scene by measuring the tendency of pixels of a given material to cluster around a given location of multispectral space. Following this, the analyst identifies each material.

* Region growing - Pixels of a given material tend to form a series of groups of contiguous pixels (in image space). Thus, "All wheat pixels in the scene occur in a group of wheat fields, each of which is identifiable." Region growing is the computer process of gathering and displaying the pixels in the identifiable groups, after which the analyst may identify each.

Mensuration - the determination of areas in the image or designated subsection. This normally is done by simple pixel count, although for some purposes intra-pixel mixtures must be estimated.

Inter-Band Manipulation - For multispectral data, each spectral image is a "band." Operations between bands have been found to be useful for certain analyses.

* Functions - Various algebraic functions such as multiplication or division are non-linear, and produce data of a new kind. For example, division of a scene by a reference "flat field" scene, point-by-point, will tend to normalize against variation of sensor response over the face of the scene.

* Spectral Analysis - Analysis of selected data points to determine the optimum processes to be applied to the entire image. Examples are eigenvector analysis to determine the optimum band combinations to

allow multispectral analysis, or the selection of optimum ratios to be used for display.

* Spectral Axis Rotation - Linear combination of bands, pixel-by-pixel, amounts to producing a new projection of the data onto a set of rotated axes. Rotation to the optimum angles following an eigenvector analysis (Karhunen-Loeve) is the most usual, but other rotation angles may be used for other purposes.

<u>Statistical Operations</u> - The set of processes and decisions required to carry out the multispectral analysis.

* Training Field Selection - Operator designation of areas of known materials or ground cover. May be done interactively or by off-line mapping.

* Training Statistics - Characterization of the group of pixels of the training area, usually as mean and variance in multispectral space (covariance matrix). Other measures such as texture could be used as a derived multivariate analysis "band" for use with the multispectral.

* Number of Spectral Bands - Analysis time goes up as the number of bands used increases - but so may the classification accuracy. A tradeoff to be made by the analyst.

* Maximum Number of Classes - For some classifiers, the time for classification goes up with the number of classes. Another tradeoff, since the analyst may group classes together as desired.

* Optimum Band Selection - Some bands, including possible ratios between bands, will give better class identification than will others. Some software is available to aid the analyst in this selection.

* Speed - Schemes using full analysis can be extremely slow; table lookup methods can accomplish much the same task at greatly increased speeds. Decision as to "optimum methods" has not been made, and may not be possible; differences between methods is often secondary to differences caused by variance in the scene or the analyst choice of training.

INPUTS (Table 3): In addition to the computer compatible tape (CCT) input anticipated, other input devices will be useful for other than Landsat MSS data.

TV Camera - For scanning input images, a local TV camera may be useful. This normally will be a vidicon or image dissector.

Microdensitometer - For higher accuracy, either in spatial or in brightness quantizations, various forms of travelling aperture devices are used. These commonly take the form of either drum scanners or flatbed scanners.

Digital Tapes - The tape format expected for most MSS work is the "NASA Landsat." Others, many of which are similar, may be encountered. NASA and USGS are currently trying to define a universal tape format family which will encompass many of the present formats.

Analog Tapes - For some purposes, image data may be recorded on analog magnetic tapes. Special analog-digital conversion is required to utilize this data.

OUTPUTS (Table 4): These may be either volatile on a terminal display, or hard copy via line printer, image film, maps, or tables.

Volatile outputs

* Graphics - A number of graphics displays are available - these are normally used for alphanumeric conversations with the analyst during the analysis process.

* Two-Dimensional Graphics - Some graphics terminals have the ability to display line drawings, graphs, cluster plots, and other diagnostic aids.

* CRT for Image Display - When grey-scale or color images need to be displayed during the analysis, a special television-like terminal display is required. These displays must be continually "refreshed", requiring a special memory in the system to continually generate the required data.

* Annotation - Ability to superimpose grids, alphanumeric data and other information on a displayed image.

Hard Copy Outputs

* Line Printer - The normal computer printer, which may also be used to generate a grey-scale image by character selection and overprinting. For a printer having the normal 10 characters/inch and 6 lines/inch,

a 1/24,000-scale image will be produced if the pixels are interpolated to be 60.96x101.60 meters IFOV.

* Film - For most analysis, the desired output product will be high quality film, either in black/white (B/W) or color. The latter will normally be generated by photographic combination of three B/W films.

* Overlays - Film output requiring the ability to convert some set of data such as polygon vertices to rasters.

* Maps - Output implying the capability of driving line drawing devices.

* Display Photographs - Usually for quick look or reduced-quality permanent copy, limited in quality by the display device.

OTHER FEATURES (Table 5)

Microprogrammable Processor - Some of the analysis steps are very time-consuming, even with fast general purpose computers. A number of special purpose devices are available to perform specified process very efficiently. These are usually used as peripheral devices to the normal computer in the system.

Present Computer - The hardware systems discussed each are based on a modern minicomputer. Depending on the degree of interaction, number of terminals serviced, displays, and other features, the size required may vary considerably.

Software - Most applications programs are written in Fortran. Various higher-level languages may be used for parts of the system programs, and for some of the applications. The feature to look for here is the ability of the user to write and incorporate new programs as he wishes, since all functions cannot be defined at purchase time, and the state-of-the-art is continually advancing.

* Interface Mode to Analyst:

1. Batch - The analyst generates a series of commands, either at an interactive terminal or via card job entry. The entire series is run by the computer as a single job without further interaction with the analyst.

2. Interactive Command - The computer carries out each command as it is entered by the analyst, (usually) displays the results, and waits for the next command. In some cases, it may be possible to assemble or call a short series of commands (a procedure) which will be accomplished before receiving the next command.

3. Interactive Menu - As each command is entered by the analyst, the computer replies with a display which gives the analyst the choice of a number of options. These might be parameter entries, function options such as linear, log, table, or other defined types of contrast stretch, or entries relating to any multiple choice decisions the analyst must make. This mode is of particular value to the analyst unfamiliar with the details of the function being called, as it guides him through the required decisions.

DATE DUE	BORROWER'S NAME	ROOM NUMBER