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Interim Report

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ORSER-SSEL Technical Report 15-75

REMOTE SENSOR DIGITAL IMAGE DATA ANALYSIS USING THE GENERAL ELECTRIC
IMAGE 100 ANALYSIS SYSTEM (A STUDY OF ANALYSIS SPEED, COST, AND
PERFORMANCE)

General Electric Company, Space Division (on subcontract to ORSER)

ERTS Investigation 082
Contract Number NAS 5-23133

INTERDISCIPLINARY APPLICATION AND INTERPRETATION OF ERTS DATA
WITHIN THE SUSQUEHANNA RIVER BASIN

Resource Inventory, Land Use, and Pollution

(E76-10017)	REMOTE SENSOR DIGITAL IMAGE	N76-10549
	DATA ANALYSIS USING THE GENERAL ELECTRIC	
	IMAGE 100 ANALYSIS SYSTEM (A STUDY OF	
	ANALYSIS SPEED, COST, AND PERFORMANCE)	Unclas
Interim Report (Pennsylvania State Univ.)	G3/43	00017

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Date: August 1975

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REMOTE SENSOR DIGITAL IMAGE DATA ANALYSIS

USING THE

GENERAL ELECTRIC IMAGE 100 ANALYSIS SYSTEM *

(A STUDY OF ANALYSIS SPEED, COST AND PERFORMANCE)

prepared for

Office for Remote Sensing of Earth Resources (ORSER)
The Pennsylvania State University

by

General Electric Company
Space Division
Valley Forge Space Center
P.O. Box 8555, Philadelphia, Pa. 19101

November 1974

* An evaluation of the Image 100 system by ORSER personnel is given in ORSER-SSEL Technical Report 4-75.

ABSTRACT

ORSER-SSEL Technical Report 15-75

REMOTE SENSOR DIGITAL IMAGE DATA ANALYSIS USING THE GENERAL ELECTRIC IMAGE 100 ANALYSIS SYSTEM (A STUDY OF ANALYSIS SPEED, COST, AND PERFORMANCE)*

General Electric Company, Space Division (on subcontract to ORSER)

The objective of this investigation, conducted jointly by the General Electric Company and the Office for Remote Sensing of Earth Resources, was to integrate the results of digital data analysis using 1) the highly interactive Image 100 system having a moderate digital computer capability, and 2) the less interactive, but large, high-speed computer capability at The Pennsylvania State University. The task encompassed both ERTS and aircraft multispectral data and conventional and canonically transformed multispectral data (all transformations were implemented by ORSER at the University). The following Image 100 pre-processing and analysis modes were employed: 1) various geometric and radiometric scale factors for analysis, 2) 1-D training and classification, 3) N-D training and classification, 4) level slicing, 5) clustering, and 6) manual interpretation of multiband composite displays. A brief description of some applicable Image 100 operations is given.

It was found that the high-speed man-machine interaction capability is a distinct advantage of the Image 100; however, the small size of the digital computer in the system is a definite limitation. The system can, therefore be highly useful in an analysis mode in which it complements a large general purpose computer. For example, the Image 100 was found to be extremely valuable in the analysis of aircraft MSS data where the spatial resolution begins to approach photographic quality and the analyst can truly exercise interpretation judgements and readily interact with the machine, but where the volume of data requires a larger computing capability, such as that found at ORSER. A summary of results for each scene processed is given, and an analysis of cost and time effectiveness for the Image 100 processing is provided.

* An evaluation of the Image 100 system by ORSER personnel is given in ORSER-SSEL Technical Report 4-75.

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I

REMOTE SENSOR DIGITAL IMAGE DATA ANALYSIS
USING THE
GENERAL ELECTRIC IMAGE 100 ANALYSIS SYSTEM

I. INTRODUCTION

The investigation reported here has been conducted jointly by the General Electric Company and the Office for Remote Sensing of Earth Resources (ORSER) of the Pennsylvania State University. It represents one task of an ERTS data investigation being performed by ORSER for Goddard Space Flight Center under contract NAS 5-23133. The ORSER ERTS data investigation is entitled Interdisciplinary Applications and Interpretations of ERTS Data Within the Susquehanna River Basin. Howard L. Heydt is the principal investigator for General Electric.

The heart of the plan for the task involving General Electric is to begin with remote sensor image data previously analyzed by ORSER personnel using computing facilities and programs at the Pennsylvania State University, and then re-analyze the same data using the General Electric Image 100 analysis system. Image 100 is a real-time man-machine interactive analysis system in which the image analysis is performed somewhat differently than at the University where a large general purpose computer is used. The principal task objective is to compare analysis results using (1) the highly interactive Image 100 system having a moderate digital computer capability, and using (2) the less interactive, but large, high-speed computer capability at the University. The objective includes comparing, where possible, the time and costs associated with similar analyses performed using the two systems. This objective was adhered to for most sub-tasks of the investigation. But as the program proceeded, other sub-tasks were performed in which the Image 100 analyses supplemented those previously undertaken at the University.

The scope of the General Electric task has encompassed both ERTS and aircraft multispectral scanner digital data analyses, analyses of conventional and transformed multispectral data (transforms implemented by ORSER at the University), several data analysis applications focused on the Susquehanna River Basin in Pennsylvania, and the use of several Image 100 pre-processing and analysis modes, such as:

- 1) Various geometric and radiometric scale factors for analysis
- 2) 1-D training/classification
- 3) N-D training/classification
- 4) Level slicing
- 5) Clustering
- 6) Manual interpretation of multiband composite displays

A detailed description of the Image 100 system will not be provided as a part of this report. However, a brief description of certain system operations and terminology follows in Section II. It may be noted, however, that the Image 100 system, while continually undergoing improvements, is an image data analysis system in production by the General Electric Company. In addition, one model of the system is in operation at the General Electric Earth Resources Image Processing and Analysis Center (IPAC) located in the G.E. facility at Beltsville, Maryland. At IPAC, the Image 100 and other processing and analysis functions are operated as a service facility for a broad range of image data users. Essentially all of the Image 100 analyses reported here have been conducted at IPAC in the Beltsville facility.

The schedule of major events in this General Electric - ORSER investigation has been as follows:

February 9-10, 1974	Initial tests on Image 100 at GE/Daytona Beach, Fla.
June 7	Heydt meets with ORSER personnel to review plans
June 12-13	Image 100 tests at Beltsville
July 1-2	Image 100 tests at Beltsville
July 12	Heydt meets with ORSER for preliminary review of results
September 26	Image 100 tests at Beltsville

II. DESCRIPTION OF SOME APPLICABLE IMAGE 100 OPERATIONS II

A. Read-in, and the Analysis Frame

Scene data read-in refers to filling the Image 100 video disk from a digital tape with scene picture elements (pixels) each of which may have associated with it four channels of 8-bit (256 level) data. An array of up to 512 x 512 pixels are stored on the disk for analysis and display. The fact that all pixel data in this array may be accessed at high speed is key to the real-time man-machine interactive capability of Image 100.

B. Geometric and Radiometric Scale Factors

Data associated with one pixel of the source data may be placed in two or more adjacent pixel cells on the video disk. This sets the geometric scale factor. The signal level information (radiometric data) may be placed on the disk with a multiplying scale factor relative to the source radiometric data. For example, a signal level of 52 in a data source having a maximum level of 256, may be stored on the video disk as a level of 104 on a 256-level scale (i.e., radiometric scale factor of 2:1).

C. Radiometric Resolution for Analysis

Although the pixel radiometric data is or can be stored on the video disk with a granularity of 256 levels from minimum possible to maximum possible level in each channel, it may be analyzed with a radiometric granularity of 128, 64, 32, etc., levels, as selected by the operator.

D. 1-D Training

For this operation the analyst first defines a training area in the scene by appropriately locating an electronic cursor in the TV display of the scene, and by setting the size and shape of that cursor. The system then examines the radiometric data in four channels (4-space) for all pixels in the training area and determines the maximum and minimum actual signal levels in the four channels. These eight values may be envisioned as the eight plane surfaces of a parallelepiped in 4-space.

NOTE: More sophisticated training areas may be employed, but these are not discussed here.

E. 1-D Alarm and Classification

When the four-channel radiometric data for all pixels in the analysis frame are systematically searched, every pixel whose four-channel radiometric location in 4-space (i.e., signature) falls within the four-dimensional parallelepiped established from 1-D training then will be "alarmed". A

distinctive binary alarm signal is available which can be displayed to show the location of alarmed pixels. The alarm signal may be counted to obtain a measure of the alarmed area in terms of number of pixels. Pixels anywhere in the analysis frame which have been alarmed as indicated here are considered to be classified as falling in the same category as the training area. If the training area pertains to a particular type of vegetation, then alarmed pixels are considered to be classified as that same type of vegetation. This is a 1-D classification.

F. Theme, and Theme Track

The binary alarm signal comprises, for the complete analysis frame, a binary map or theme. Such a theme may be stored on the video disk along with the four-channel radiometric data for each pixel. The theme stored on a theme track may be displayed or accessed rapidly for other purposes.

G. 1-D Threshold Adjustment

1-D thresholds are the eight values corresponding to the eight parallelepiped surfaces in 4-space resulting from 1-D training. These values or surfaces may be considered to be thresholds in the classification process since pixels whose signatures fall within the parallelepiped are alarmed, and pixels whose signatures fall outside are not alarmed. As part of the Image 100 1-D training procedure (a real-time, interactive, and iterative procedure), the analyst may alter the thresholds which were obtained in the initial 1-D training process. He does this after making interpretation judgements while viewing the alarmed areas in the scene display, and while studying 1-D histograms displayed for each channel of radiometric data pertaining to the training area.

H. N-D Training and Classification

If, for example, the radiometric resolution for analysis has been set at 256 levels in each of four channels, 4-space will consist of $256 \times 256 \times 256 \times 256$ elemental cells each of which is a parallelepiped. The signature vector for any pixel in the scene must fall in one of the elemental cells of 4-space. Obviously, for an analysis frame of 512×512 pixels, there will be a large number of 4-space cells which are not occupied. In the N-D training operation, the specific elemental cells in 4-space which are occupied by the training area pixels are identified. Then, in the N-D classification step, pixels in the total scene are alarmed if their signatures fall in any one of the identified elemental 4-space cells. This is a more sophisticated but also more powerful training and classification procedure than the 1-D method. A parameter in the N-D training operation is the population threshold for the 4-space elemental cells. For example, only those 4-space cells may be identified which have n or more pixels associated with each of them. Here, $n = 1, 2, 3$, etc., and the value is set by the analyst.

I. Window Mode

In any scene being analyzed, a selected area within the analysis frame may be reconstructed so that each original pixel will appear as 2×2 , 3×3 , ..., or 9×9 pixels. This provides an electronic magnification of a portion of the scene to assist the analyst in the interpretation of the display of the video scene and themes.

J. Level Slicing

This refers to setting thresholds (analogous to 1-D thresholds described in G) in one selected channel of the four channels. Two methods are available. In one method the system will automatically set thresholds to provide eight equal slices between the minimum and maximum actual signal levels in that channel. In the second method the analyst may set the individual thresholds at any desired level so that non-uniform or arbitrarily located slices may be specified when desired. In either method the resulting slices produce alarms (themes) during the classification process.

K. Clustering

In this operation the analyst first uses the cursor to define a training area in the scene. He also specifies his interest in the N most dense clusters in 4-space for the training area. (Loosely, a cluster may be considered as a concentration in 4-space of occupied elemental 4-space cells). Through an iterative process, Image 100 identifies the clusters (i.e., identifies the 4-space elemental cells in each cluster). Then, each pixel is alarmed in the analysis scene if its signature falls into one of the 4-space elemental cells for a given cluster. The system causes a theme to be entered onto a theme track in the classification process associated with each cluster. If six clusters were identified, six classification themes are produced. This overall procedure is essentially an unsupervised training and classification operation.

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In this operation the analyst first uses the cursor to define a training area in the scene. He also specifies his interest in the N most dense clusters in 4-space for the training area. (Loosely, a cluster may be considered as a concentration in 4-space of occupied elemental 4-space cells). Through an iterative process, Image 100 identifies the clusters (i.e., identifies the 4-space elemental cells in each cluster). Then, each pixel is alarmed in the analysis scene if its signature falls into one of the 4-space elemental cells for a given cluster. The system causes a theme to be entered onto a theme track in the classification process associated with each cluster. If six clusters were identified, six classification themes are produced. This overall procedure is essentially an unsupervised training and classification operation.

III. IMAGE 100 ANALYSES ~~III~~

A. Shamokin Area - ERTS MSS Data

1. General Information

- a. Shamokin scene from ERTS MSS frame 1350-15190
- b. Analysis frame: 2:1 geometric scale factor
256 x 185 ERTS pixels (9 mi x 9 mi) spread over
512 x 370 analysis/display cells
and
1:1 geometric scale factor
512 x 370 ERTS pixels (18 mi x 18 mi) spread over
512 x 370 analysis/display cells
- c. Analysis radiometric resolution: 64 levels from the minimum possible signal to the maximum possible signal in each spectral band.

2. Analysis Procedure

- a. For the 2:1 geometric scale factor, read scene digital data into Image 100 from tape.
- b. Training/Classification
Window; set training area; 1-D (4 band) signature extraction; observe alarm and single band histograms; compare with ground truth; adjust 1-D threshold limits; iterate; store final alarm as a theme on a theme track; record (on paper) the 1-D signature (threshold limits for four bands).
- c. For the 1:1 geometric scale factor, read scene digital data into Image 100 from tape.
- d. Use the signatures developed in b. to classify this 1:1 scene. Store results as themes on theme tracks.
- e. Photograph the TV display of the scenes and themes.
- f. Print out themes on printer.
- g. Record scenes and themes on digital product tape.

3. Themes and Signatures

<u>Theme</u>	<u>Themes Having Some Signature Overlap*</u>	<u>MSS 4[#]</u>	<u>MSS 5[#]</u>	<u>MSS 6[#]</u>	<u>MSS 7[#]</u>
1. Conifer	4,5,7	17-19	11-15	21-28	21-29
2. Hardwood, unshaded	4	16-17	8-11	29-34	35-40
3. Hardwood, shaded	4	16-17	8-11	26-28	32-35
4. Agricultural Woodland	1,2,3	17-20	11-15	25-33	29-36
5. Grass	1	19-21	15-17	23-25	24-25
6. Wheat stubble	8	21-23	21-24	25-30	26-27
7. Corn	1,8	19-20	15-17	25-27	26-27
8. Alfalfa	6,7	20-24	16-23	27-31	26-30
9. Strip Mine	10,12	16-19	11-15	11-14	8-10
10. Coal pile	9,12	16-17	10-12	10-12	7-8
11. Urban	-	19-22	14-19	14-21	12-20
12. Water with some vegetation	9,10	15-16	9-11	12-18	7-20

*Overlap refers to the overlap in 4-space of the established theme classification boundaries which are the plane surfaces bounding a four-dimensional parallelepiped. For the cases listed, the overlaps generally are minor.

#The listed numbers are the lower and upper classification signature threshold limits in that spectral band.

4. Operation Time/Cost

	<u>Train: 1 scene at 2:1 geometric scale factor Classify: 1 scene at 1:1 *</u>	<u>Train: 1 scene at 2:1 geometric scale factor Classify: 2 scenes at 1:1 **</u>	<u>Train: 1 scene at 2:1 geometric scale factor Classify: 4 scenes at 1:1 **</u>
Read in training scene from tape	10 min.	10 min.	10 min.
1-D training for 8 themes	180 min.	180 min.	180 min.
Read in scene(s) for classification	10 min.	20 min.	40 min.
Scene classification - 8 themes	16 min.	32 min.	64 min.
Photograph or print out the 8 classification themes	10 min.	20 min.	40 min.
Record the 8 classifica- tion themes on digital product tape	6 min.	12 min.	24 min.
Total Image 100 time	232 min.	274 min.	358 min.
Image 100 User Cost at \$250/hour#	\$967	\$1142	\$1492
Square miles classified (8 themes)	327 mi ²	654 mi ²	1308 mi ²
Cost per square mile (8 themes)	\$2.96	\$1.75	\$1.14

* Numbers in this column pertain to actual tests using Image 100

** Numbers in these columns are predictions based on the test data

Includes Image 100 operator time, but excludes labor cost of user
(discipline specialist)

4. Operation Time/Cost

	<u>Train: 1 scene at 2:1 geometric scale factor Classify: 1 scene at 1:1 *</u>	<u>Train: 1 scene at 2:1 geometric scale factor Classify: 2 scenes at 1:1 **</u>	<u>Train: 1 scene at 2:1 geometric scale factor Classify: 4 scenes at 1:1 **</u>
Read in training scene from tape	10 min.	10 min.	10 min.
1-D training for 8 themes	180 min.	180 min.	180 min.
Read in scene(s) for classification	10 min.	20 min.	40 min.
Scene classification - 8 themes	16 min.	32 min.	64 min.
Photograph or print out the 8 classification themes	10 min.	20 min.	40 min.
Record the 8 classifica- tion themes on digital product tape	6 min.	12 min.	24 min.
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Includes Image 100 operator time, but excludes labor cost of user
(discipline specialist)

5. Comments

- a. The accuracy of the classification was judged to be satisfactory by D. Wilson of Pennsylvania State University. (Wilson directly supervised all Image 100 operations in this analysis.) However, a comparison was not made, pixel by pixel, of Image 100 themes vs ground truth or vs themes previously produced using University algorithms and computing facilities.
- b. Analysis cost per square mile depends on many factors, conditions and requirements. For example: The complexity of the signatures for the selected themes; the acceptable level of classification accuracy; and the size of the region which can be classified once signatures have been developed in a training area (this is partly a property of the scene). With regard to this last factor, the three columns in Section 4 above assume that signatures developed in the 2:1 geometric scale factor scene are applicable over nearby areas having respectively 4, 8 and 16 times the area of the training scene.

B. Lancaster Area - ERTS MSS Data

1. General Information

- a. Lancaster scene from ERTS MSS frame 1350-15190.
- b. Analysis frame: 1:1 geometric scale factor
512 x 370 ERTS pixels (18 mi x 18 mi)
spread over 512 x 370 analysis/display cells
- c. Analysis radiometric resolution: 64 and 128 levels from the minimum possible signal to the maximum possible signal in each spectral band.

2. Analysis Procedure

- a. For the 1:1 geometric scale factor, read scene digital data into Image 100 from tape. Set up 64-level radiometric resolution for analysis.
- b. Training/Classification - Series I
Set training area for "Forest"; perform N-D training using 4-space color cell pixel count thresholds of 1, 2 and 3; alarm the total scene for each threshold case; store alarms as themes on theme tracks; perform an area measurement (pixel count) for the three themes corresponding to the three selected thresholds.
- c. Training/Classification - Series II
Repeat b. using the same training area and same threshold values but this time using 128-level radiometric resolution for analysis in MSS bands 4, 5 and 6 and 64-level resolution in MSS Band 7.
- d. Training/Classification - Series III
Using 128-level radiometric resolution and a threshold of 1, perform N-D training and classification for Limestone Quarry, Brush, Bare Soil and Water. Store themes on theme tracks.
- e. Photograph the TV display of the scene and themes.

3. Are Measurement Results

For the "Forest" theme and same training area in all cases:

Radiometric Resolution for Analysis				Alarmed Area (Pixel Count) in Total Scene		
MSS 4	MSS 5	MSS 6	MSS 7	N-D Thres.=1	N-D Thresh.=2	N-D Thres.=3
64	64	64	64	92,842	52,626	46,516
128	128	128	64	48,983	36,282	29,374

NOTE: Radiometric read-in scale factor was 1 in all cases.

4. Operation Time

<u>Operation</u>	<u>Analysis Procedure Steps Involved</u>	<u>Approximate Operation Time</u>
Read in scene from tape	2.a	8 min.
N-D train (6 cases); alarm; store themes on theme tracks; measure theme areas	2.b.,c.	24 min.
Photograph 6 themes and scene	2.e	8 min.
N-D train (4 cases); alarm; store themes on theme tracks	2.d	14 min.
Photograph 4 themes and scene	2.e	6 min.

6.7
min.
per
theme

7 min.
per
theme

5. Comments

The N-D operation times obtained here cannot be compared with the 1-D operation times obtained in A. for the Shamokin scene. The scene itself, the scene features to be classified, and the geometric scale factors are some of the differences in the two cases.

C. Texas Scene - ERTS MSS Data

1. General Information

- a. Several combinations of radiometric read-in scale factor and radiometric resolution for analysis are used.
- b. Objective is not to determine analysis time. Rather, it is to study 1-D and N-D analysis performance as parameter values are changed.

2. Analysis Procedure

- a. Read scene digital data into Image 100 from tape. Use radiometric read-in scale factors of 1, 1, 1, 1 and use analysis radiometric resolution of 64, 64, 64, 64 for MSS Bands 4, 5, 6, 7 respectively.
- b. With the cursor define a training area in the scene which is reasonably homogeneous and which contains enough pixels to provide useful statistical data.
- c. Perform 1-D training and record the mean value and variance obtained by Image 100 in the four channels corresponding to MSS Bands 4, 5, 6 and 7.
- d. Proceed to N-D training using the same training area. Record the number of 4-space color cells which are searched by Image 100 and the number of those cells having pixels in them from the training area.
- e. Repeat a, b, c, d using same training area but radiometric scale factors and resolutions of 1, 1, 1, 1 and 256, 256, 256, 256.
- f. Repeat e for 2, 2, 2, 2 and 64, 64, 64, 64.
- g. Repeat e for 1, 1, 1, 2 and 64, 64, 64, 64.
- h. Repeat e for 1, 1, 1, 2 and 128, 128, 128, 128.

3. Results for 1-D Training

Case No.	Radiometric Scale Factor	Radiometric Resolution For Analysis		MSS 4		MSS 5		MSS 6		MSS 7	
				Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
(1)	1,1,1,1	64	Each Band	* → 8.4	0.4	11.5	1.0	11.7	0.8	5.5	0.3
				# → 13.1	1.0	18.0	2.4	18.2	1.9	8.6	0.7
(2)	1,1,1,1	256	Each Band	** → 34.9	4.6	47.2	13.6	48.2	11.2	23.5	2.4
				# → 13.7	0.7	18.5	2.1	18.9	1.7	9.2	0.4
(3)	2,2,2,2	64	Each Band	* → 17.2	1.5	23.0	6.0	23.5	4.5	11.3	0.8
				# → 26.9	3.6	36.0	14.6	36.8	10.9	17.7	1.9
(4)	1,1,1,2	64	Each Band	* → 8.4	0.5	11.3	1.6	11.5	1.3	11.3	0.8
				# → 13.1	1.2	17.7	3.9	18.0	3.2	17.7	1.9
(5)	1,1,1,2	128	Each Band	** → 17.2	1.5	23.0	5.8	23.5	4.6	23.1	3.1
				# → 13.4	0.9	17.9	3.6	18.3	2.8	18.0	1.9

*Mean and variance values derived by Image 100 and pertaining to a signal scale for which the maximum possible signal value is 64.

**Mean and variance values derived by Image 100 and pertaining to a signal scale for which the maximum possible signal value is 128.

***Mean and variance values derived by Image 100 and pertaining to a signal scale for which the maximum possible signal value is 256.

#Mean and variance values normalized to a signal scale for which the maximum possible signal value is 100.

4. Results for N-D Training

Case No.	Radiometric Scale Factor	Radiometric Resolution For Analysis		No. Signal Levels Between Min. Signal And Max. Signal In The Training Area				No. Cells in 4-Space To Be Searched	* No. Occupied Cells in 4-Space	% Occupied Cells in 4-Space
				MSS 4	MSS 5	MSS 6	MSS 7			
(1)	1,1,1,1	64	Each Band	4	6	7	3	504	40	7.9%
(2)	1,1,1,1	256	Each Band	14	24	23	12	92,736	#	-
(3)	2,2,2,2	64	Each Band	8	15	14	6	10,080	92	0.9%
(4)	1,1,1,2	64	Each Band	5	8	8	6	1,920	50	2.6%
(5)	1,1,1,2	128	Each Band	8	15	14	11	18,480	102	0.6%

* For cell population threshold of 1 pixel.

Image 100 search time in 4-space was predicted to be lengthy, so search was aborted.

D. McElhatten Area - Aircraft MSS Data

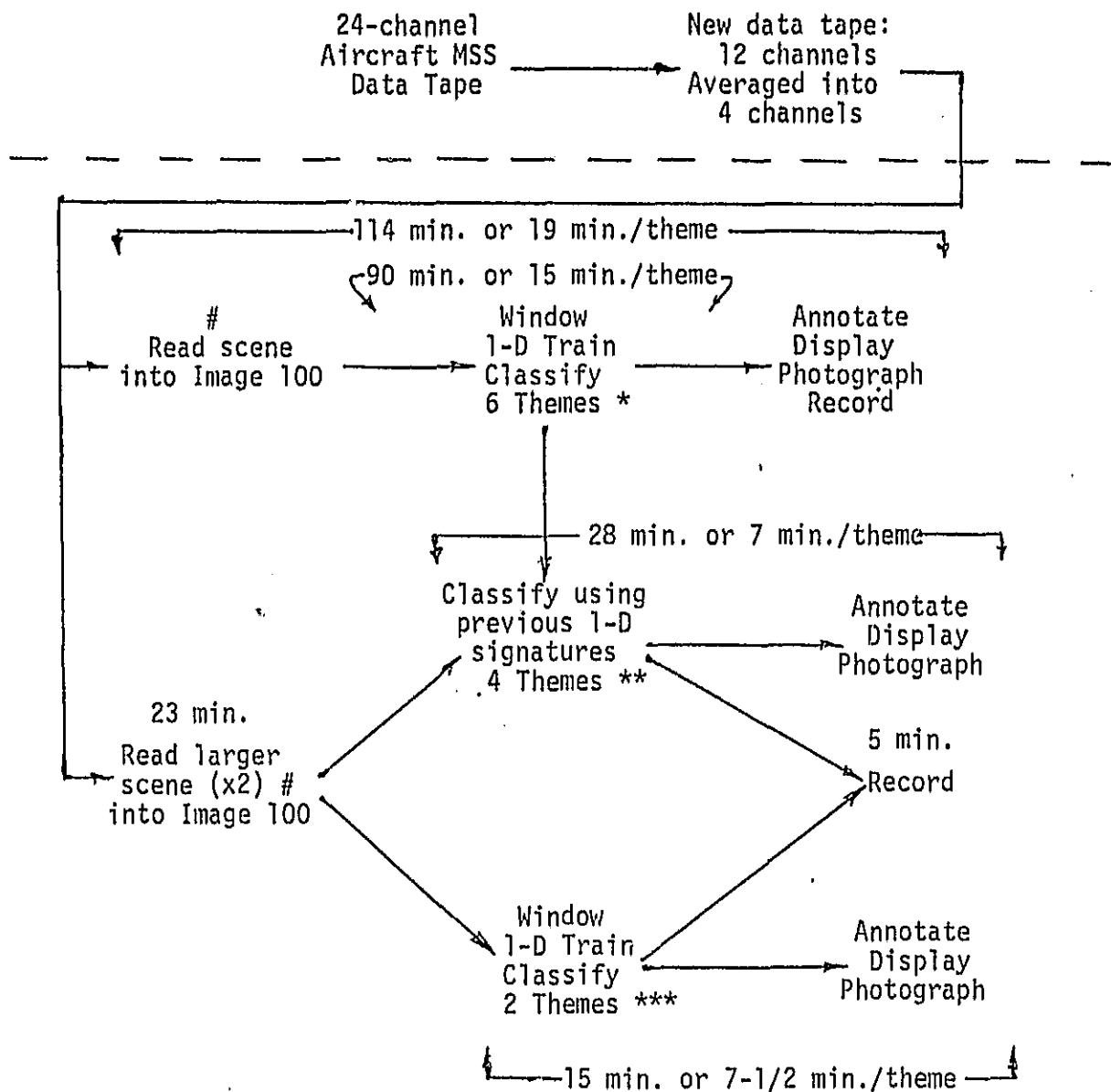
1. General Information

- a. Data source is the 24-channel aircraft multispectral scanner.
- b. The digital data from source a were processed in two forms at Pennsylvania State University:
 - (1) 12 channels of the data were combined ("averaged") to produce a new digital tape containing four-channel data spectrally similar to ERTS MSS Channels.
 - (2) 12 channels of the data were transformed onto four canonical axes using an algorithm developed at Penn State. A four-channel digital transformed data tape was produced.
- c. Analysis frame: Initial scene is 500 rows from a long strip which is 250 pixels in width, analyzed and displayed at 1:1 geometric scale factor. Larger scene is composed of the initial scene plus a similar sized additional scene from the same strip, with the two placed side by side for analysis and display.
- d. For the averaged data, analysis radiometric resolution is 128 levels from the minimum possible signal to the maximum possible signal in each spectral band, and the radiometric scale factor during read-in from tape is 2:1 for each band.
- e. For the transformed data, radiometric resolution and scale factors are 256 and 1:1 in each band.

2. Analysis Procedure and Operation Time

- a. Several different types of analysis are performed. These include training/classification of the "averaged" data for the initial and larger scenes. Also included are level slicing of the transformed data for both scenes. Finally, 1-D training/classification is performed on the transformed data.

b. Analysis of the "averaged" data:



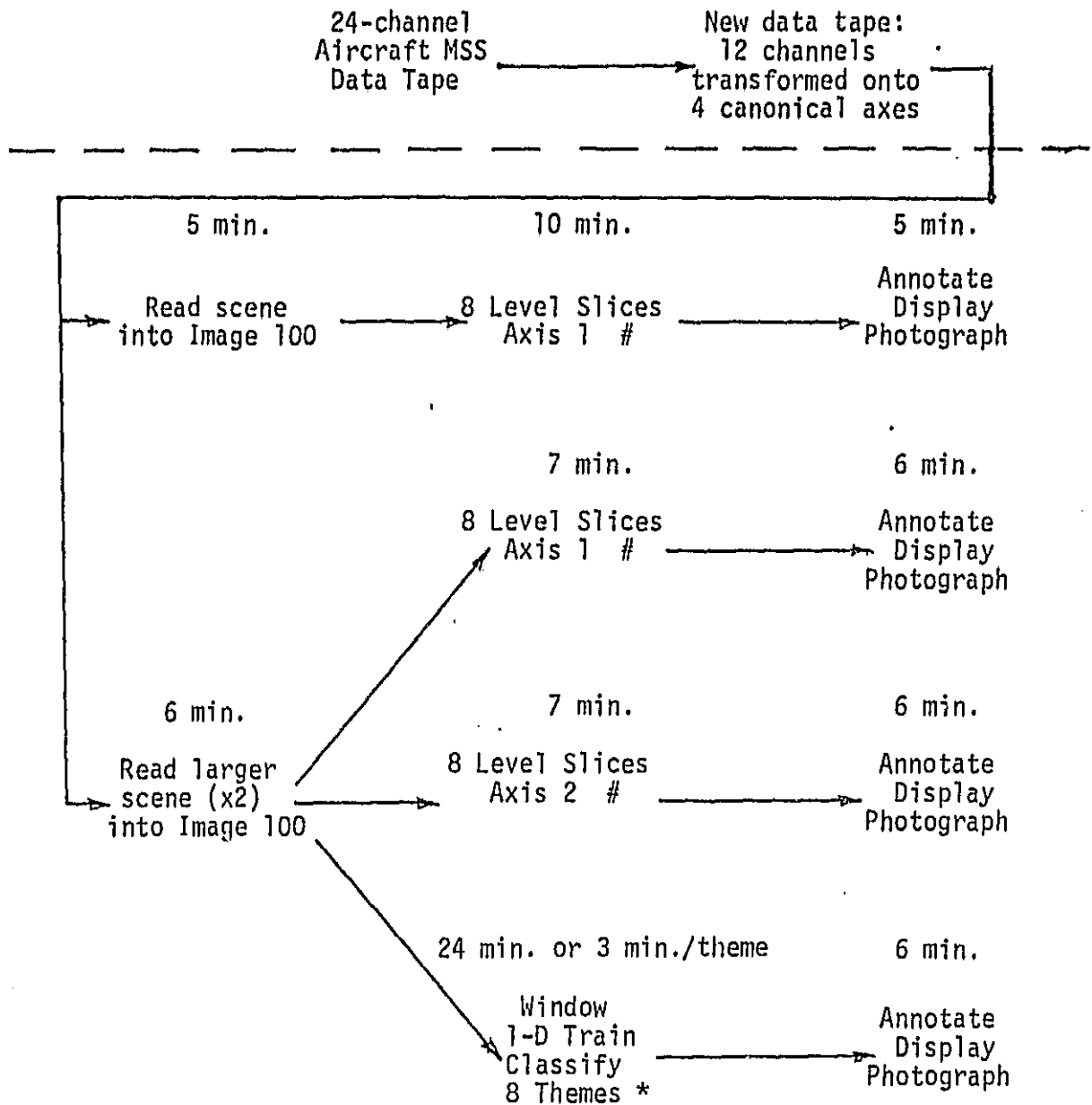
*Flood plain
 Bare soil
 Terrace vegetation
 Terrace bare soil
 Polluted water
 Clean water

**Flood plain
 Bare soil
 Terrace vegetation
 Terrace bare soil

***Corn
 Wheat

#Relatively long read-in time attributable to analyst coordinate selection process, not to Image 100

c. Analysis of transformed data:



8 equal slices between the minimum and maximum actual signal levels. Themes produced by level slicing (unsupervised training) do not necessarily correspond to themes resulting from supervised training.

* Flood plain sparse vegetation, bare soil, terrace sparse vegetation, terrace bare soil, polluted water, clean water, wheat, forest.

3. Comments

- a. Comparisons of operation time/cost for analysis of averaged data on Image 100 vs analysis of transformed data must take into account the time/cost for producing the transformed data tape. (such time/cost data are not shown in 2c.)
- b. Level slicing the transformed data generally resulted in themes which appeared to conform fairly well with features in the scene. However, Axis 1 did not always have all the key scene features; some will be on Axis 2. Even considering Axes 1 and 2, not all the possible scene features of interest will emerge with the eight equal slices used. Some non-uniform slicing may be required.
- c. The variety of test conditions employed make it difficult to compare time/cost for different types of analyses. One comparison of interest is that between level-sliced transformed data (unsupervised analysis) and analyst-supervised training/classification of averaged data. Much of the data is available for that comparison, except that the resulting themes are not all identical in the two cases. Results do tend to indicate, however, that supervised analysis of the transformed data is 2 to 5 times faster than supervised analysis of the averaged data for the same scene.

E. Pine Creek Area - Aircraft MSS Data

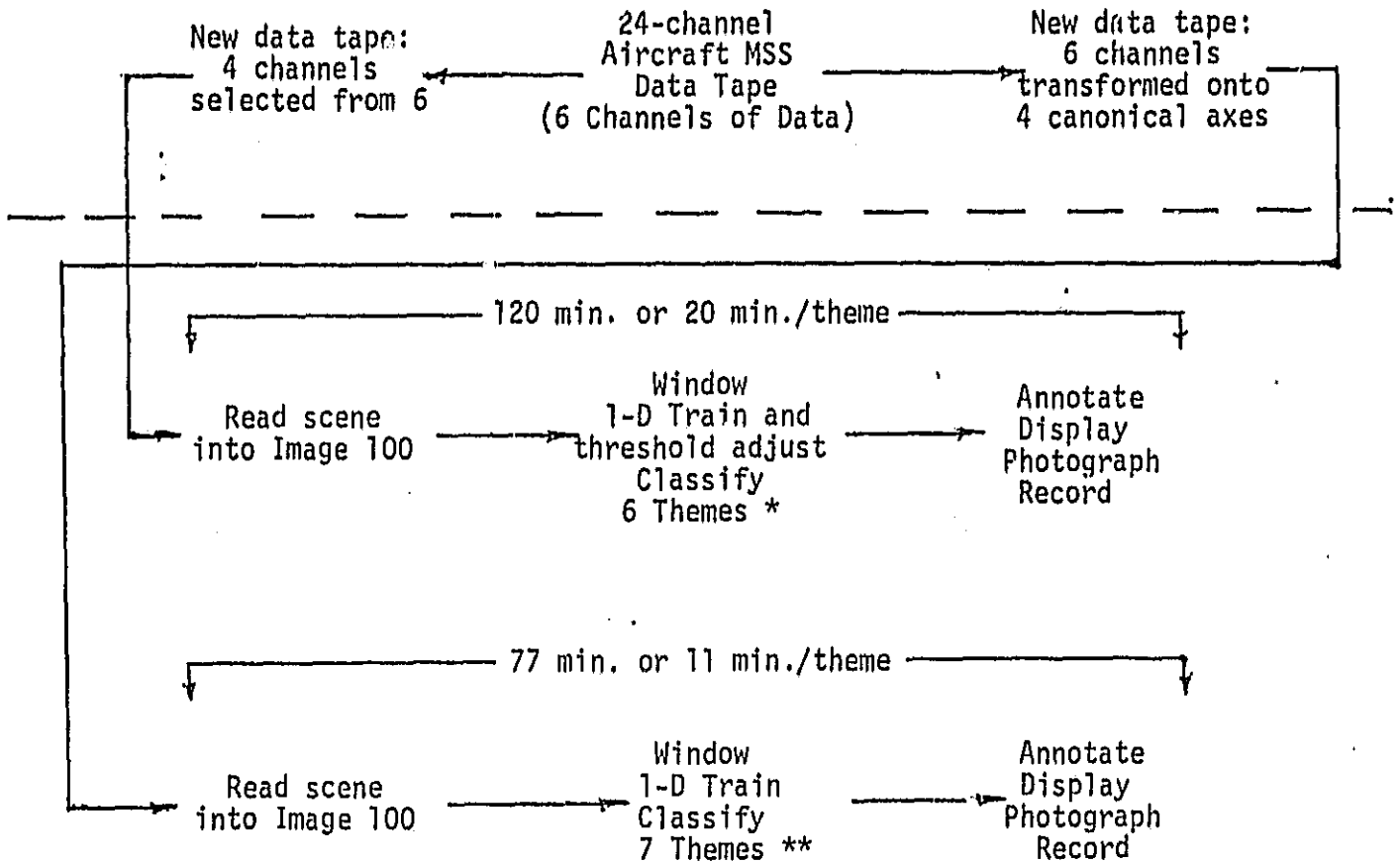
1. General Information

- a. Data source is six channels of 24-channel aircraft multispectral scanner.
- b. The digital data from source a were processed in two forms at Pennsylvania State University.
 - (1) From the six channels of data four channels were selected and used to produce a new four channel digital tape with a format similar to an ERTS CCT.
 - (2) The six channels of data were transformed onto four canonical axes using an algorithm developed at Penn State. A four-channel digital transformed data tape was produced.
- c. Analysis/display geometric scale factor is 1:1 using 500 rows of scanner data along the flight path.
- d. For the non-transformed data, radiometric read-in scale factor and radiometric resolution for analysis are 2,2,2,2 and 128,128,128,128.
- e. For the transformed data, radiometric scale factor and resolution are 1,1,1,1 and 256,256,256,256.

2. Analysis Procedure and Operation Time

a. Several different types of analysis are performed. These include supervised training and classification of non-transformed and transformed data. Also included are uniform and non-uniform level slicing for two axes of the transformed data.

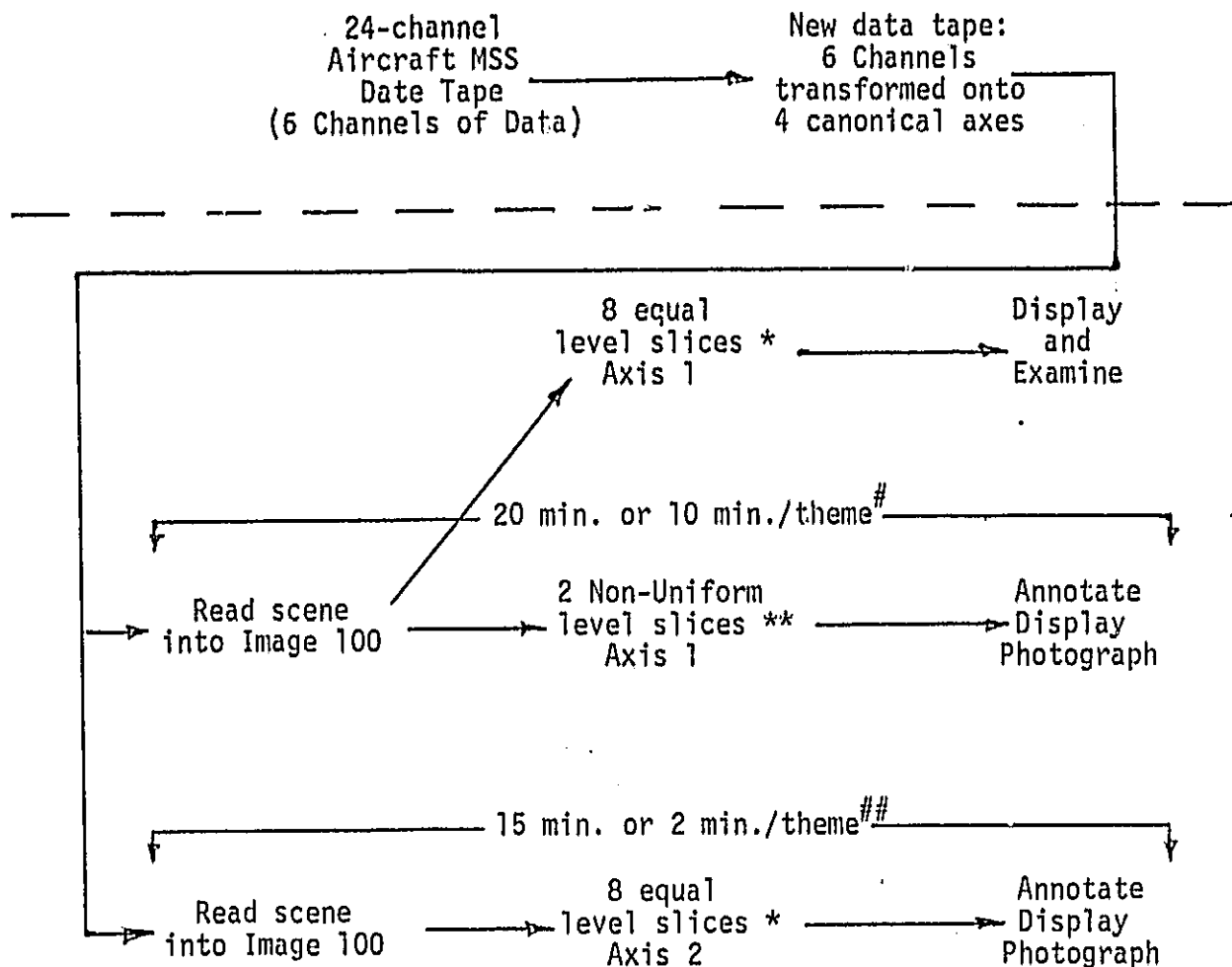
b. Analysis involving supervised training/classification:



* Bare soil - flood plain
Plowed soil
Bare soil - upland
Winter wheat
Pine Creek
Susquehanna River

** Bare soil
Recently plowed
Bare soil - terrace
Winter wheat
Pine Creek
Susquehanna River
Wheat stubble

c. Analysis involving level slicing the transformed data:



* Between the minimum and maximum actual signal levels.

** Supervised analysis producing themes for Vegetation and Bare Soil.

Since only two slices (and two resulting themes) were produced, the fixed read-in time makes analysis time per theme abnormally high.

Themes from the slices in this operation may not correspond to themes from supervised analysis.

3. Comments

- a. The comments under D.3. for the McElhatten scene tests generally apply here also.
- b. Supervised training and classification for the non-transformed data compared with similar operations using the transformed data, exhibits a 2 to 1 speed-up in analysis time on Image 100 when the transformed data is used and when very similar themes are developed in both cases.
- c. The supervised analysis of the transformed data, via iterative adjustment of the level slicing bounds by the analyst, leads to the development of good quality themes in categories chosen by the analyst. This is achieved at some expense in analysis time, however. The time per theme for such analysis is longer than when uniform level slicing (essentially automatic) is applied to the transformed data, but is similar to the time per theme to perform supervised training and classification on the transformed data.

F. North Bend Area - Aircraft MSS Data

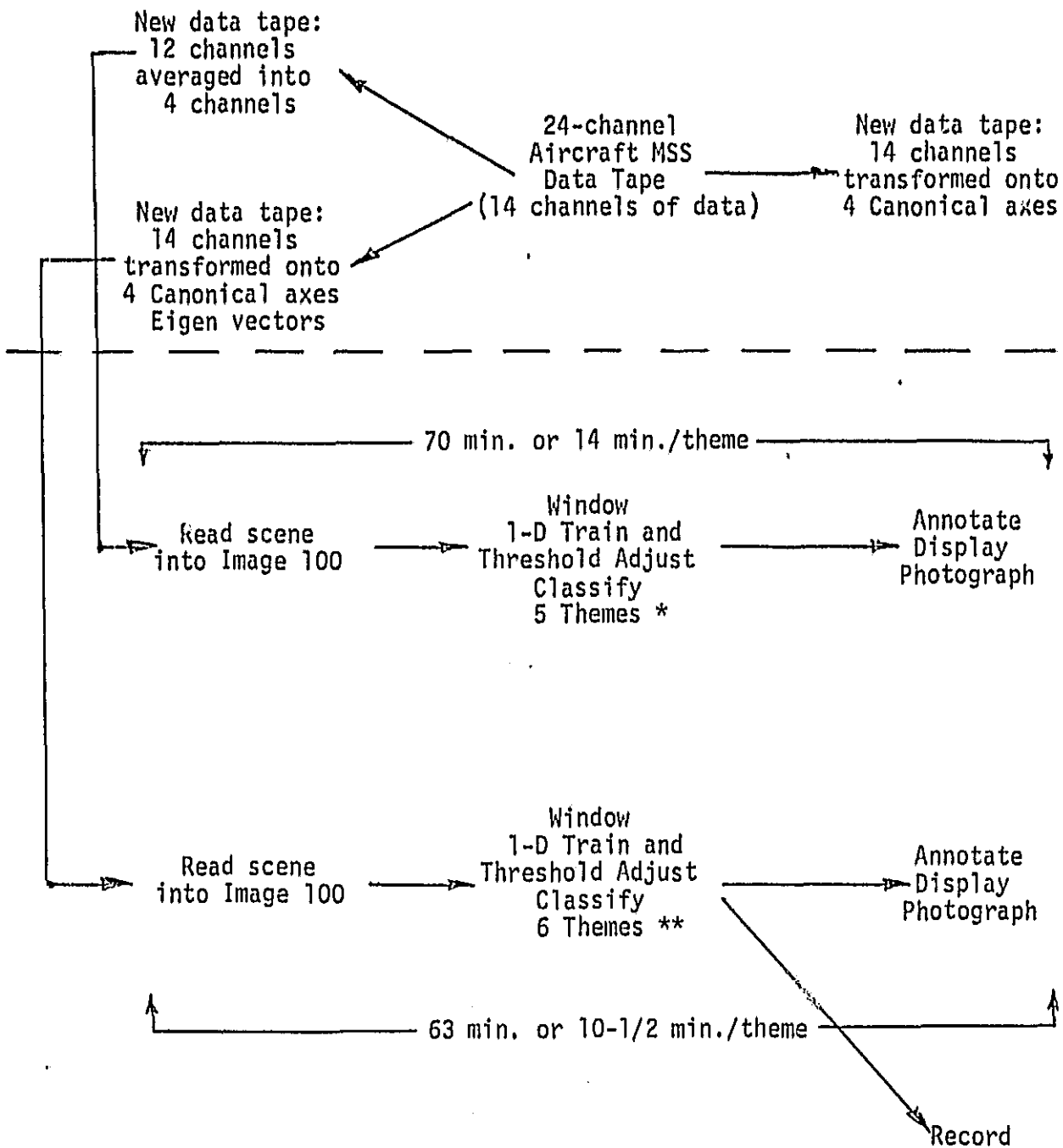
1. General Information

- a. Data source is 14 channels of the 24-channel aircraft multispectral scanner.
- b. The digital data from source a were processed in three forms at Pennsylvania State University.
 - (1) Twelve channels of the data were combined ("averaged") to produce a new digital tape containing four-channel data in ERTS CCT format.
 - (2) 14 channels of the data were transformed onto four canonical axes using an algorithm developed at Penn State. A four-channel digital transformed data tape was produced.
 - (3) Similar to (2), with the axes representing Eigen vectors.
- c. Analysis/display geometric scale factor is 1:1 using 500 rows of scanner data along the flight path. One pixel has been estimated to be about 10 ft x 10 ft in the scene.
- d. For the averaged data, radiometric read-in scale factor and radiometric resolution for analysis are 2,2,2,2 and 128,128,128,128.
- e. For the transformed data, radiometric scale factor and resolution are 1,1,1,1 and 256,256,256,256.

2. Analysis Procedure and Operation Time

- a. Several different types of analysis are performed. These include supervised training and analysis of averaged and transformed data, and uniform level slicing in two axes of the transformed data.

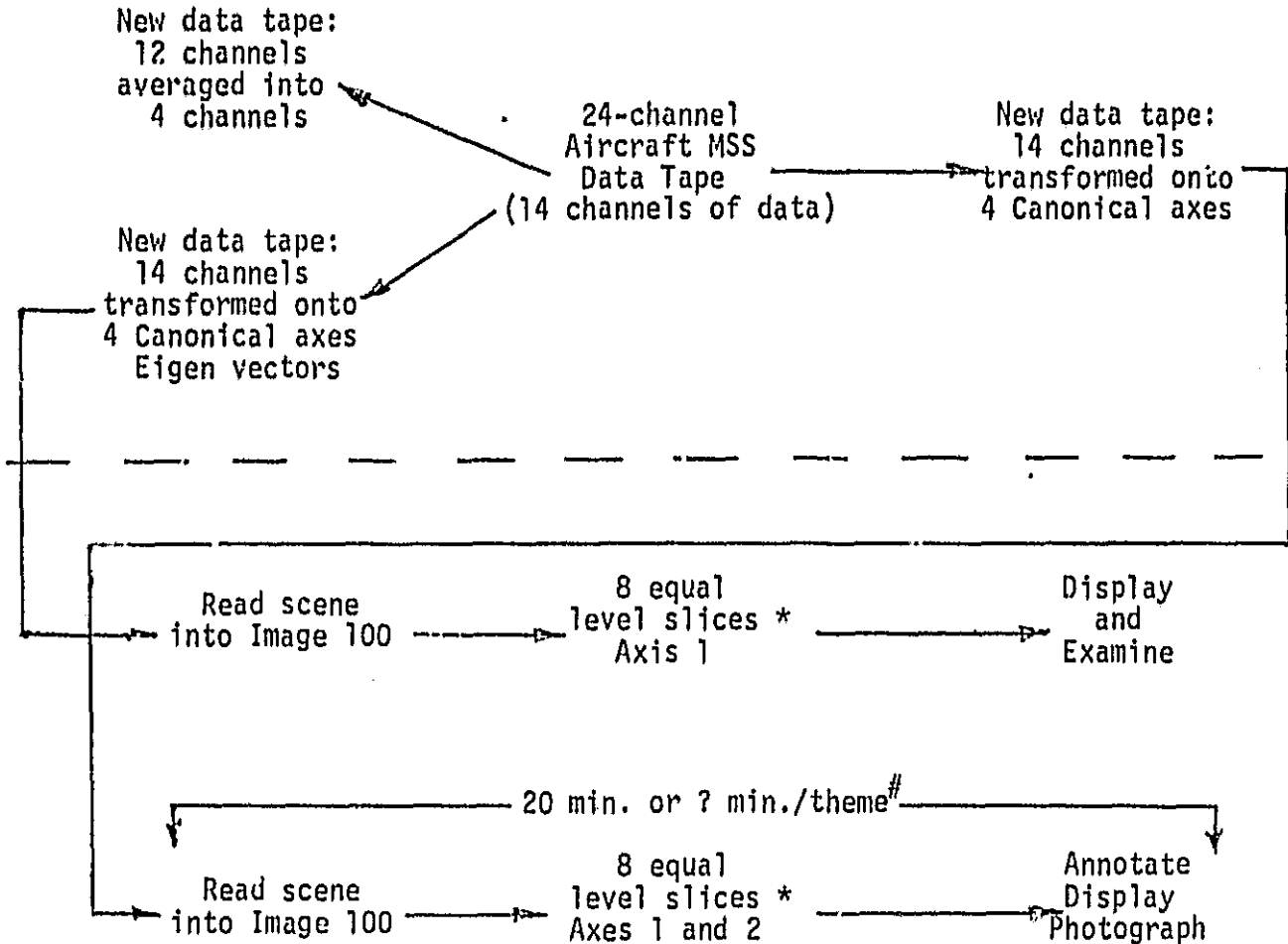
b. Analysis involving supervised training/classification:



* River birch
 Sparsely vegetated clearing
 Rock (along river)
 Abandoned fields
 Susquehanna River

** River birch
 Sparsely vegetated clearing
 Rock
 Abandoned fields
 Susquehanna River
 Creek

c. Analysis involving level-slicing the transformed data:



* 8 equal slices between minimum and maximum actual signal levels.

2-1/2 min./theme, assuming a total of 8 themes of interest. In the analysis the level slicing produced themes for River Birch and Abandoned Fields plus themes which are sub-classes of river water and woodland.

3. Comments

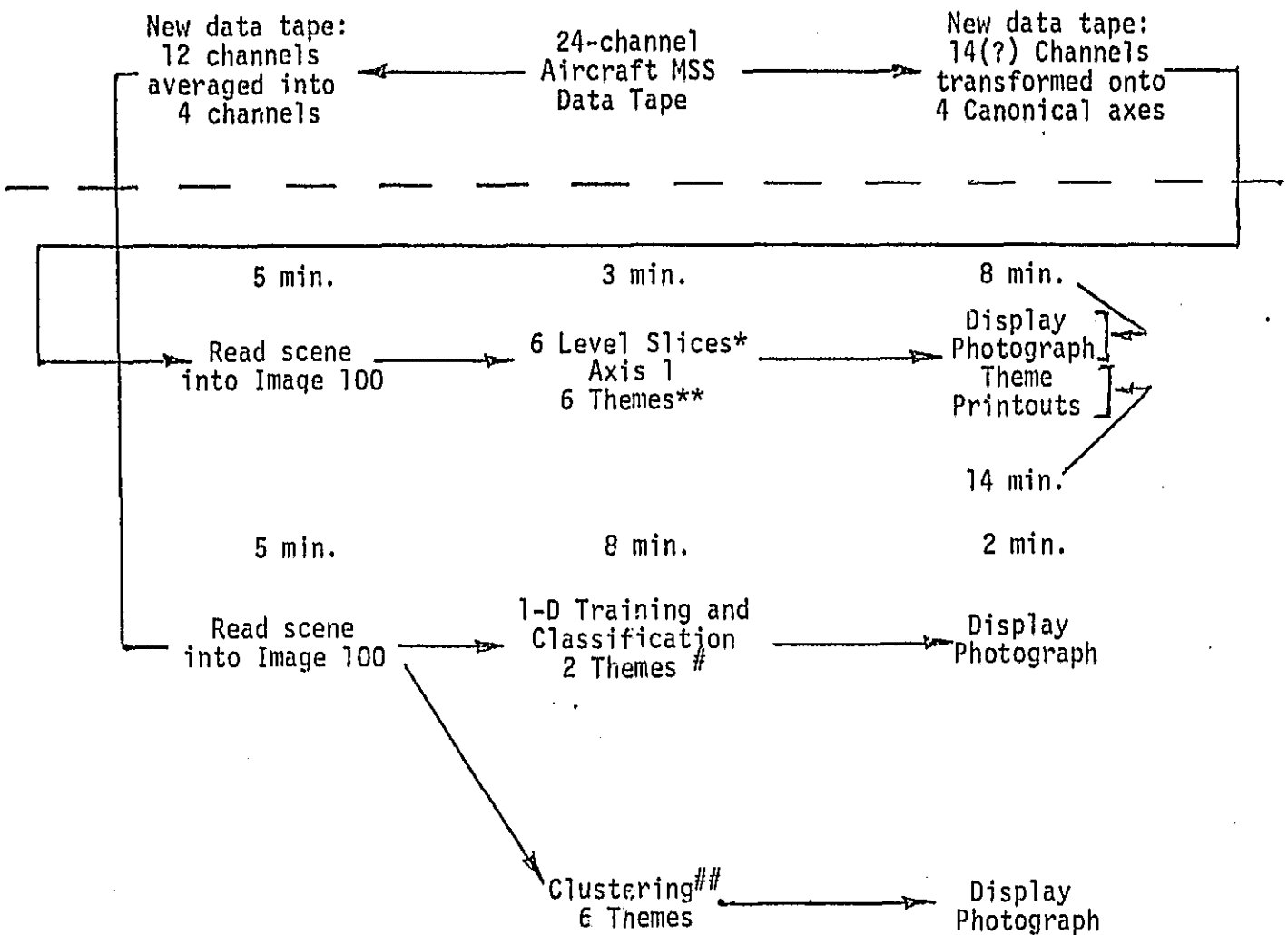
The comments under D.3 for the McElhatten scene generally apply here, except that here the supervised Image 100 training and classification of transformed data is accomplished for very similar themes in about 75% of the time required using averaged data.

G. Susquehanna River Scene - Aircraft MSS Data

1. General Information

- a. Data source is the 24 channel aircraft multispectral scanner.
- b. The digital data from source a were processed in two forms at Pennsylvania State University.
 - (1) Twelve channels of the data were combined ("averaged") to produce a new digital tape containing four-channel data in ERTS CCT format.
 - (2) 14(?) channels of the data were transformed onto four canonical axes using an algorithm developed at Penn State. A four-channel digital data tape was produced.
- c. Analysis/display geometric scale factor is 1:1 using 500 rows of scanner data along the flight path.
- d. Radiometric read-in scale factor and radiometric resolution for analysis are 1,1,1,1 and 256,256,256,256 in all cases.

2. Analysis Procedure and Operation Time



*Slice levels pre-determined at Penn State. Two slices were changed at Image 100

Open fields
River Birch

**Themes and slices in Axis 1:
 0-36 Rocks and Roads
 37-64 River and Plowed Fields
 65-102 Borders
 103-140 Open areas
 141-170 Flood plain
 171-255 Forest

Clustering was only partially accomplished in this test. See comments, Section 3.

3. Comments

- a. For the level slicing of the transformed data note that some of the resulting themes are not clear-cut categories of interest such as those usually obtainable when supervised training and classification is performed. For example, themes from some of the slices are Rocks and Roads, River and Plowed Fields, and "Borders" (to land features in the scene). The Image 100 analysis time for training and classification is longer, however, than for level slicing.
- b. This was the first time the Image 100 clustering algorithm had been applied to aircraft digital MSS data. Apparently because of the high spatial resolution (compared to ERTS), pixel signatures were distributed throughout a very large number of cells in 4-space, making clustering a long and slow process. Initially, a radiometric resolution was used having 256 levels in each band. To reduce clustering time the process was re-started using a radiometric resolution of 128. Finding this also would be too big a task for the Image 100 computer, the cursor defining the clustering training area was made smaller and relocated to encompass a spectrally less diverse part of the scene. Again the clustering operation was re-started. Results were as follows:

(1) N-D training	6 min.
(2) Clustering. 14 iterations performed, but clustering not complete. Process stopped at this point	15 min.
(3) Generate the display of 6 themes corresponding to the 6 partially determined clusters in 4-space.	28 min.

Presumably because the clustering was incomplete the displayed themes did not appear to cleanly represent scene features.

H. Susquehanna River Scene - Aircraft Thermal IR Scanner Data

1. General Information

- a. The aircraft flight path for this remote sensing mission along the Susquehanna River includes coverage of the Lock Haven, Pine Creek and McElhatten areas. The four-channel data tape prepared by Pennsylvania State University contains three channels of the digitized thermal IR scanner data (all three channels are identical) and one calibration data channel.
- b. The objective of the test is simply to read-in and display the data, and to study the quality of the displayed data..

2. Analysis Procedure and Operation Time

- a. The data corresponds to a long, narrow strip of scanner coverage along the aircraft ground track, with many lateral (cross-track) rows of scanner data. Three separate 500-row sections of the data are read into Image 100 and placed side by side in the analysis/display frame.
- b. The composite scene is displayed by Image 100, and studied. 24 minutes were consumed in the total test, much of that time associated with the selection and entering of position coordinates for the source and displayed data.

3. Results

The composite image data was recognizable and interpretable from the display. Most evident was the lesser contrast of this thermal data compared to multispectral scanner data for bands in the visible-near infrared region.

I. Pennsylvania State Forest Scene - 2-Date ERTS MSS Data, Transformed

1. General Information

- a. Data source is ERTS MSS data for a scene in central Pennsylvania in the vicinity of Whipple Dam State Park.
- b. Data for the same scene for two dates, October and May, are used.
- c. At Pennsylvania State University, eight channels of the source data (4 channels each date) were transformed onto four canonical axes and a four-channel data tape produced.
- d. Analysis/display frame: 512 x 370 pixels at 2:1 geometric scale factor (i.e., corresponding to 256 x 185 ERTS pixels).
- e. Radiometric read-in scale factor is 1,1,1,1 and the radiometric resolution for analysis is 256,256,256,256.

2. Analysis Procedure and Operation Time

- a. Read scene data into Image 100. 5 minutes
- b. Level-slice the Axis 1 data using eight non-uniform slices whose boundaries were pre-established at Penn State. 7 minutes
- c. Display, study, photograph and print out the eight themes resulting from the slicing. 8 minutes to print, 5 minutes to photograph

3. Results

From interpretation of the display, the slicing themes corresponded to land features as follows (slicing levels are shown for each theme):

0-13	Water	77-84	Bottomland conifer
14-36	Ridge Top	85-105	Bottomland hardwood
37-59	Conifers	106-145	Unshaded hardwood
60-76	Shaded hardwood	146-255	Agricultural land and clouds

J. Pennsylvania State Forest Scene - 2-Date ERTS MSS Data, Transformed, With Uniformity Mapping

1. General Information

Essentially the same as described in I.1 for the preceding test except the Penn State uniformity mapping algorithm UMAP, also is employed.

2. Analysis Procedure and Operation Time

- a. Read scene data into Image 100.
- b. Display Channel 1 (un-normalized).
- c. Display Channel 2 (un-normalized)².
- d. Display Channel 3 (normalized).
- e. Display Channel 4 (normalized)².
- f. Study each displayed channel.
- g. Photograph the display of individual channels and a 3-channel composite display.
- h. Total operation time for a through g: 13 minutes.

K. Pennsylvania Gypsy Moth Scene - ERTS MSS Data

1. General Information

- a. Scene is in northeastern Pennsylvania in vicinity of East Stroudsburg. Vegetation in the scene has been affected by Gypsy Moths.
- b. Data source is ERTS MSS digital data. The data have been transformed onto four canonical axes at Pennsylvania State University, and a new four-channel data tape produced.
- c. Analysis/display frame: 512 x 370 pixels at 2:1 geometric scale factor (i.e., corresponding to 256 x 185 ERTS pixels).
- d. Radiometric read-in scale factor is 1,1,1,1 and the radiometric resolution for analysis is 256,256,256,256.

2. Analysis Procedure and Operation Time

- a. Read the scene data into Image 100. 5 minutes
- b. Level slice the Axis 1 data using five non-uniform slices whose boundaries were pre-established at Penn State. 8 minutes
- c. Display, study, photograph and print out the five themes resulting from the slicing. 14 minutes

3. Results

From interpretation of the display, the slicing themes correspond to scene features as follows (with slicing levels shown for each theme):

0-26	Swampy
27-82	Healthy Vegetation
83-105	Moderate Defoliation
106-166	Heavy Defoliation
167-255	Water

IV. ORSER COMMENTS ON IMAGE 100 ANALYSES ~~IV~~

After several ORSER personnel had the opportunity to perform analyses of digital image data using the Image 100 system on three different occasions, the following comments were offered by these ORSER personnel during a meeting with H. L. Heydt of General Electric at the Pennsylvania State University on July 12, 1974:

1. The small size of the digital computer in the Image 100 system is a definite limitation. There is a lack of easily programmable analytical procedures, and the analysis speed in several operations (for example, searching through color space) is slow.*
2. There is a lack of satisfactory analysis capability in the system for many situations. 1-D is the weakest classifier. With the 1-D method, the 1-D radiometric data range will vary with the size of the training area. A small training area must be used to keep the range down. If two photointerpreters independently performed the same analysis, they would get different results (unless exactly the same training area was used).*
3. The color display of the scene synthesized in good quality from multispectral digital data (un-processed and/or processed), and the high-speed man-machine interaction capability are definite advantages to the Image 100 system.
4. Image 100 is highly suitable for the analysis of aircraft remote sensor data because spatial resolution begins to approach photographic quality. An analyst in this situation can truly exercise interpretation judgments and readily interact with the machine.
5. The Image 100 system needs a capability to input ground truth data in a format which can overlay the analysis results.*
6. Image 100 currently operates with a maximum of four channels of data. By using suitable data pre-processing, a much larger number of channels (e.g., 12 channels) can be transformed into four-channel data for Image 100 analysis.*
7. The Image 100 system can be highly useful in an analysis mode in which it complements a large general purpose computer. This is particularly true if an investigator is starting analysis in a new scene. Using the Image 100 initially, followed by analysis with the large computer, would be an effective approach.
8. There may be an advantage in having the capability to make certain corrections in a simple analog manner (e.g., certain geometric corrections) which are then converted and used digitally in the Image 100 system.*
9. The field-of-view for the Image 100 display (and the analysis frame) can be too small for some applications.*

10. It would be desirable to have a display of currently selected 1-D threshold values to indicate regions of classification overlaps or underlaps in 4-space.*

* The improvements suggested here, or the need for solutions to the problems identified here, have also been recognized by General Electric and specific actions are either planned or are being considered.

V. GENERAL ELECTRIC PROGRAM SUMMARY . V

A. Analysis Time, Cost and Effectiveness

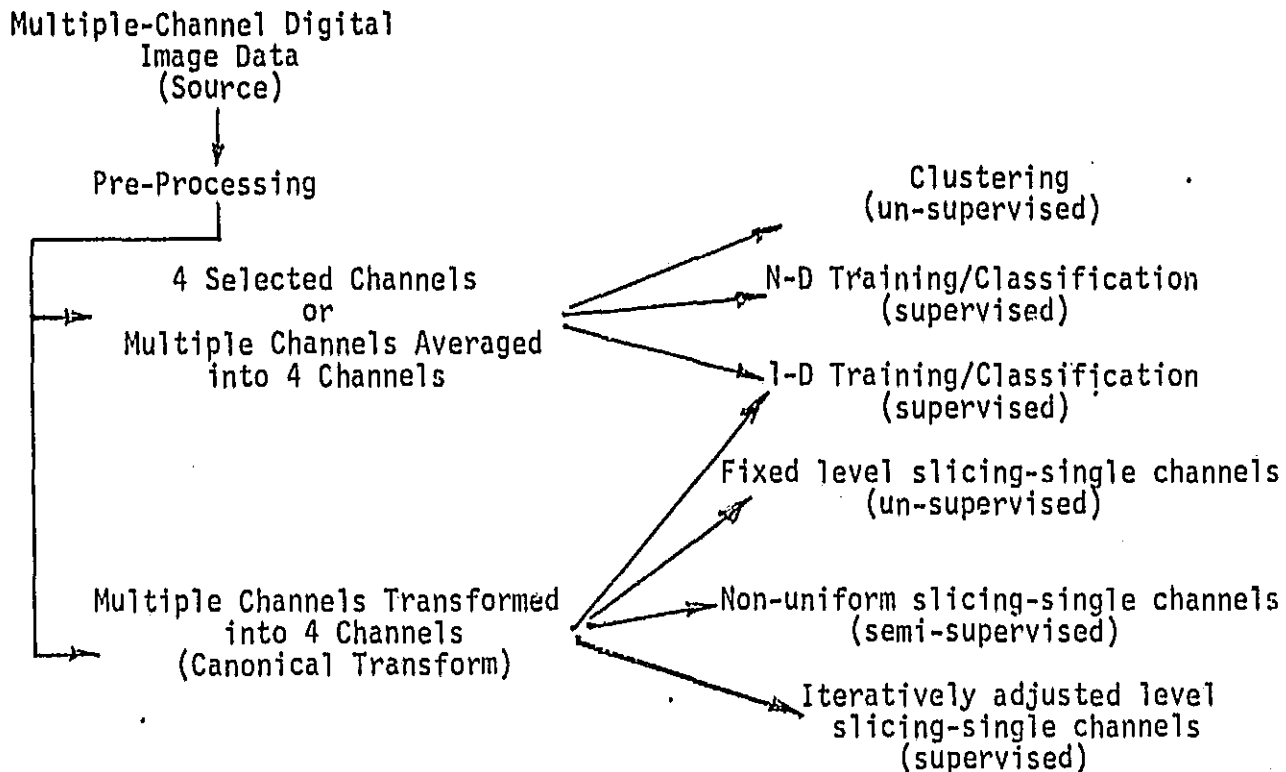
1. It would be beyond the scope of this investigation to attempt to arrive at a broadly applicable relationship between the image analysis job to be performed and the time or cost to accomplish that analysis using machine aids such as the General Electric Image 100 system or a large general purpose computer. First, a more specific set of controlled tests would be necessary than was conducted on this program. Second, a principal difficulty in generalizing from the time/cost data obtained on this program is that the data were obtained for conditions which more than likely will not be exactly the same as those for a new situation where time/cost estimates are desired. Conditions such as the specific categories of features to be classified, the acceptable level of classification accuracy, the scene complexity, the availability of ground truth samples, analyst familiarity with the scene, the image data source (satellite or aircraft), and the size of the area to be classified are some of the factors which make each situation different. Therefore, the tests which have been reported here show analysis time or cost for specific situations. Others may use these data, each as he feels is appropriate in his case, to predict analysis time or cost for different sets of conditions.

2. In the test described in III.A. (Shamokin scene - ERTS MSS Data), it was estimated that complete Image 100 ERTS digital data analysis cost exclusive of the user's labor cost could range from \$1.14 to \$2.96 per square mile for eight classification categories. The estimate is believed to be conservative, with the cost range depending upon different amounts of scene area which are to be classified from one training exercise. The cost includes data read-in, training (signature extraction), classification, printout and recording of results.

If it can be assumed that the signatures developed in one training exercise (in a 9 mi. x 9 mi. portion of the scene) are applicable over the entire ERTS MSS frame (100 nm x 100 nm), then the total estimated analysis cost would drop to about \$.40 per square mile. There is evidence in some applications that such an assumption would be valid.

3. The time and cost for training (i.e., careful signature extraction in an iterative man-machine process) is a key element in the time or cost for the complete analysis. For the case in which the total analysis cost is estimated at \$2.96 per square mile, the training process accounts for 75% of the total cost. If this same training is applicable for the entire MSS frame, then the training process contributes only 14% of the \$.40 cost per square mile. While an analogous cost structure would pertain for any type of digital data analysis (e.g., Image 100 or a general purpose computer), it is readily concluded that analysis using Image 100 becomes very cost effective when there is a sizeable amount of training involved in the analysis task. This results from the fact that good signature extraction requires an efficient man-machine interactive operation - which is a key feature of Image 100. There may be situations where it would be desirable to perform signature extraction using Image 100 followed by bulk classification using a general purpose machine. It is well to remember, however, that using Image 100 to perform the classification over large areas has the advantage that an analyst can monitor classification results essentially as they take place. If obvious errors arise, he may stop the process and make adjustments with no wasted machine time.

4. The following is a summary of the different overall analysis procedures employed on this program. Analysis speed/cost and performance are different for each procedure. There are still other procedures which could be employed but which were not studied here.



B. Observation on Image 100 Analyses in this Investigation

1. Refer to ORSER comment IV,2. pertaining to 1-D classification. Although 1-D may be the weakest classifier, the General Electric experience has been that it is entirely adequate for a large number of applications. When a more powerful classifier is required, the N-D capability in Image 100 is available for use.

ORSER also noted that if two analysts independently used the 1-D process for analyzing the same scene, results are likely to be different. This assessment is based on the fact that the two interpreters probably would use training areas having different sizes. The assessment is indeed valid for a one-step training process. However, most training using Image 100 involves an iterative man-machine interactive process - which is so readily accomplished with the Image 100 system. In the interactive process the interpreter/analyst, who is familiar with ground truth in the training area, observes initial classification results and continues the training when errors are apparent. He can change the training area, or proceed to a 1-D threshold adjustment operation, until he is satisfied with the extracted signature and the initial classification results. In this mode of analysis, similar interpreters are likely to achieve similar results.

2. Subsequent to the time when most of the Image 100 analyses were performed in this investigation, certain improvements were incorporated into Image 100 which would alter some of the operation time results indicated in III. New methods, with a speed-up in operation time, are now available for entering or adjusting 1-D threshold limits and for accomplishing N-D training. In addition, a half-tone printer is now in operation for the themes and scenes. This is an alternative, with better geometric properties, to photography of the TV display.

3. Refer to comments in III.G.3 concerning the test involving the Image 100 clustering algorithm. It was noted for some test conditions that the clustering required more memory than was available. Then, for the condition in which the memory was adequate, the clustering time was long. Two observations are made here. First, using ERTS digital data General Electric has found the clustering algorithm to perform well and with reasonable operation times. The higher spatial resolution of aircraft data undoubtedly contributed to the problem noted. Second, by reducing the radiometric resolution to a value coarser than 128 levels, satisfactory Image 100 clustering performance should be possible with the aircraft data. This was not tried in the test of III.G due to a lack of time.
4. The 1-D training and classification procedure in Image 100 appeared to provide good quality classification in most of the tests in this investigation. This has been the General Electric experience on many other programs as well. However, it should be noted that the N-D procedure really was not thoroughly studied and exploited in tests reported here. Adequate time for thorough N-D tests was not available, so this remains a matter for investigation in the future.
5. The N-D analyses described in III.B and III.C provide some data on the number of occupied cells in 4-space and the number of alarmed scene pixels as a function of radiometric resolution and the N-D threshold setting. The data suggest that higher radiometric resolution leads to higher classification accuracy.
6. The 1-D signature extraction for a fixed (presumably homogeneous) training site, as described in III.C, provide data on individual channel mean and variance values as a function of radiometric resolution and radiometric

scale factor. Test results generally conform to what would be expected. The variances associated with different radiometric resolutions again suggest that higher radiometric resolution leads to higher classification accuracy.