AD-A076 342 IBM FEDERAL SYSTEMS DIV GAITHERSBURG MD F/G 5/8
INTERACTIVE DIGITAL IMAGE PROCESSING INVESTIGATION.(U)
DEC 78 W C RICE , J S SHIPMAN , R J SPIELER DAAK70-77-C-0166
UNCLASSIFIED ETL-0172 NL

1 OF 2
ADA 076342



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ETL - 0172

AD A076342

INTERACTIVE DIGITAL IMAGE PROCESSING INVESTIGATION

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29 December 1978

Final Report

Prepared For

U. S. Army Engineering Topographic Laboratories
Fort Belvoir, Virginia 22060

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 ETL-0172 (12)
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): (6) Interactive Digital Image Processing Investigation
5. TYPE OF REPORT & PERIOD COVERED: Final Report
6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): (10) W. C. Rice, J. S. Shipman, R. J. Spieler
8. CONTRACT OR GRANT NUMBER(s): (15) DAAK70-77-C-0166

9. PERFORMING ORGANIZATION NAME AND ADDRESS
International Business Machines Corporation
Federal Systems Division
18100 Frederick Pike
Gaithersburg, Maryland 20760
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (9) Final repts.

11. CONTROLLING OFFICE NAME AND ADDRESS: (11)
U. S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060
12. REPORT DATE: 29 Dec[illegible] 1978
13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 185
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Remote sensing, pattern recognition, feature extraction, digital image processing, photogrammetry, classification

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
multi page

174 950

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ABSTRACT

Engineer Topographic Laboratories (ETL) Report No. 0172
IBM/FSD
Interactive Digital Image Processing Investigation
December 1979 (Unclassified)

The objective of this investigation was to develop an interactive software package of general utility that can be used to support experiments and evaluate a class of interactive/automatic digital techniques whose goal is feature extraction/exploitation. The initial task was to survey and select techniques, algorithms and supporting functions that were to be included in the system. A maximum likelihood supervised classification algorithm, and an unsupervised classification (clustering) method, ~~based on the ISODATA algorithm were selected~~. These and the associated support and evaluation functions were developed and implemented on the ~~ETL~~ Digital Image Analysis Laboratory ~~(DIAL)~~. Testing of the system was accomplished by performing experiments on areas for which both multi-dimensional images and ground truth were available. Analysis of experimental results validated the system. These experimental results were in good agreement with ground truth and further, supervised and unsupervised classification results were in substantial agreement. This report describes the data processing algorithms/techniques, software system, user guide information, and the experiment procedures used along with their results.

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PREFACE

This is the final report for the Interactive Digital Image Processing Investigation Department of the Army contract number DAAK 70-77-C-0166. The purpose of the investigation was to survey algorithms for extracting features from multi-dimensional digital imagery; to select the most promising algorithms; and to implement them on the DIAL system, where algorithm performance was calculated.

The report was prepared by W. C. Rice, R. J. Spieler, and J. S. Shipman. We would like to thank the following people at ETL for their help during the course of this work:

Samuel Barr
Dave Jenkins
Bob Matos
John Moses (DBA Systems, Inc.)
Dr. Bryce Schrock
James Stilwell

CONTENTS

Section		Page
1	INTRODUCTION	1-1
1.1	Background	1-1
1.2	Report Organization	1-3
2	FEATURE EXTRACTION OVERVIEW	2-1
2.1	Overall Structure	2-1
2.2	General User Information	2-2
3	PROCESSING MODULE DESCRIPTION	3-1
3.1	INTERL Processing Module	3-1
3.1.1	INTERL User Information	3-1
3.1.2	INTERL Engineering Description	3-5
3.1.3	INTERL Control Flow Processing Steps	3-7
3.1.4	INTERL Subroutine Description	3-8
3.2	FIELDEF Processing Module	3-12
3.2.1	User Information	3-12
3.2.2	Engineering Description	3-26
3.2.3	FIELDEF PDL	3-32
3.2.4	FIELDEF Subroutine Description	3-36
3.3	CLASTAT	3-49
3.3.1	User Information	3-49
3.3.2	Engineering Description	3-50
3.3.3	CLASTAT PDL	3-59
3.3.4	Subroutine Description	3-62
3.4	CLUSTER Processing Module	3-64
3.4.1	User Information	3-64
3.4.2	Engineering Description	3-70

Section		Page
3.4.3	CLUSTER PDL	3-91
3.4.4	Subroutine Description	3-93
3.5	MAXLIK Processing Module	3-99
3.5.1	MAXLIK User Information	3-99
3.5.2	MAXLIK Engineering Description	3-113
3.5.3	MAXLIK Control Flow	3-115
3.5.4	MAXLIK Subroutine Description	3-117
4	EXPERIMENT RESULTS	4-1
4.1	Overview	4-1
4.2	Hand County Data Set	4-1
4.2.1	Supervised Classification	4-2
4.2.2	Unsupervised Classification	4-12
4.3	Synthetic Data Set	4-14
4.3.1	Supervised Classification	4-14
4.3.2	Unsupervised Classification	4-15
5	EXPERIMENT CONCLUSIONS AND RECOMMENDATIONS	5-1
5.1	Conclusions	5-1
5.2	Recommendations	5-2
REFERENCES		

LIST OF ILLUSTRATIONS

Figure		Page
2.1-1	Overall Structure of Feature Extraction Package	2-3
2.2-1	Typical Classification Sequence	2-4
3.1-1	INTERL Options Menu	3-2
3.1-2	List of Channels	3-4
3.1-3	Image Channel Correspondence	3-4
3.2-1	FIELDEF Option Menu	3-13
3.2-2	FIELDEF Display Selection Menu	3-14
3.2-3	FIELDEF Image Type Menu	3-16
3.2-4	FIELDEF Red Image Select Menu	3-17
3.2-5	FIELDEF Field/Class-File Menu	3-18
3.2-6	FIELDEF Field/Class-Data-File Menu	3-19
3.2-7	FIELDEF Field Definition Menu	3-20
3.2-8	FIELDEF Image Function Tables Modification Menu	3-21
3.2-9	FIELDEF Area Outline Menu	3-22
3.2-10	FIELDEF Subimage Expansion Menu	3-23
3.2-11	FIELDEF Field Type Selection Menu	3-24
3.2-12	FIELDEF Areal Field Creation Menu	3-25
3.2-13	FIELDEF Field Record Menu	3-27
3.2-14	FIELDEF Linear Field Creation Menu	3-28
3.2-15	FIELDEF Field Modification Menu	3-29
3.2-16	FIELDEF Vertex Modification Menu	3-30
3.3-1	CLASTAT Field/Class-Data-File Select Menu	3-51
3.3-2	CLASTAT Principle Options Menu	3-52
3.3-3	CLASTAT Field Selection Menu	3-53
3.3-4	CLASTAT Class Selection Menu	3-54
3.3-5	Example of Class Statistics Display	3-55
3.3-6	Bhattacharyya Distance Between Field1 and Field5	3-56
3.4-1	CLUSTER Composite Scene and Field/Class-Data-File Selection Menu	3-67

Figure		Page
3.4-2	Display of Selected Fields Data	3-68
3.4-3	CLUSTER Initial Parameters Menu	3-69
3.4-4	CLUSTER Starting Vectors Display	3-71
3.4-5	CLUSTER Interim Statistics Display, First Pass	3-72
3.4-6	CLUSTER Interim Statistics Display, Second Pass	3-73
3.4-7	CLUSTER Interim Statistics, Third Pass	3-74
3.4-8a	CLUSTER Interim Statistics, Fourth Pass	3-75
3.4-8b	CLUSTER Interim Statistics, Fourth Pass (cont'd.)	3-76
3.4-9	CLUSTER Interim Statistics, Fifth Pass	3-77
3.4-10a	CLUSTER Interim Statistics, Sixth Pass	3-78
3.4-10b	CLUSTER Interim Statistics, Sixth Pass (cont'd.)	3-79
3.4-11	CLUSTER Population Statistics Before and After Eliminating Small Clusters	3-80
3.4-12a	CLUSTER Summary Statistics	3-81
3.4-12b	CLUSTER Summary Statistics (cont'd.)	3-82
3.4-13	CLUSTER Field Statistics	3-83
3.5-1	Field Description	3-101
3.5-2	Class Prescription	3-103
3.5-3	Class Pseudocolor	3-104
3.5-4	Processing Parameters	3-106
3.5-5	Results Options	3-107
3.5-6	MLC Subimage Results	3-108
3.5-7	Thresholding	3-110
3.5-8	Field Results	3-112
3.5-9	Subarea Map Results	3-114
4.2-1	Sample Ground Truth Inventory Page	4-3
4.2-2	Ground Truth Overlay	4-4
4.2-3a	Hand County Training Fields	4-5
4.2-3b	Hand County Training Fields (cont'd.)	4-6
4.2-4a	Hand County Classes	4-7

Figure		Page
4.2-4b	Hand County Classes (cont'd.)	4-8
4.2-4c	Hand County Classes (cont'd.)	4-9
4.3-1a	Synthetic Data Set, Band 3	4-16
4.3-1b	Thresholded Class Map	4-17
4.3-2	Initial Clustering Parameters for Synthetic Data Set	4-18
4.3-3a	Interim Statistics for Synthetic Data Set, Second Pass	4-19
4.3-3b	Interim Statistics for Synthetic Data Set, Third Pass	4-20
4.3-4	Cluster Map for SYNDATA	4-23
4.3-5a	Cluster Map Results, Synthetic Data	4-24
4.3-5b	Classification Map Results, Synthetic Data	4-25

LIST OF TABLES

Table		Page
4.2-1	Preliminary Classification Results	4-10
4.2-2	Results of Second Classification Run	4-11
4.2-3	Assignment of Classes to Clusters	4-12
4.2-4	Cluster and Training Field Means	4-13
4.3-5	Assignment of Training Field Pixels	4-21
4.3-6	Cluster Statistics Comparison	4-21
4.3-7	Field Statistics Comparison	4-22

Section 1
INTRODUCTION

1.1 BACKGROUND

The Digital Image Analysis Laboratory (DIAL) at the Engineer Topographic Laboratories is one of the most advanced interactive digital image processing facilities in the country. The computer and display subsystems in combination with the large repertory of applications programs enable the user to apply interactively a variety of digital image processing techniques to problems in photointerpretation, stereo compilation, and automatic cartography. A complete range of display operations and many digital image processing techniques such as image rotation and warping are available as callable routines. Several feature extraction algorithms have been implemented to take advantage of the throughput capabilities of the STARAN associative processor. These capabilities include differentiation, mask comparison (which yields information about the direction of edges), and convolution. However, up until the time the effort described in this report was initiated, none of the feature extraction algorithms typified by the maximum likelihood classification method used in NASA's Large Area Crop Identification Experiment (LACIE) was available to DIAL users. It was the purpose of this effort to select several proven feature extraction algorithms of this type from those which have been documented, implement those chosen as DIAL callable program modules (PMs), and test and validate the PMs with multi-channel digital images commonly processed by these algorithms.

Two algorithms were selected for implementation, a supervised classification scheme based on the maximum likelihood approach to pattern recognition, and an unsupervised clustering scheme based on the ISODATA algorithm developed by Ball and Hall at Stanford Research Institute. Supervised classification requires some apriori knowledge of the image data to be classified, known as "ground truth" in the LACIE application, while unsupervised classification does not. On the other hand, supervised classification is usually computationally faster and more accurate than unsupervised classification. The algorithms chosen are, therefore, complementary. In addition, they have been successfully applied to several types of digital imagery, not just Landsat agricultural scenes, and have been implemented in a number of digital image processing facilities of varying hardware configurations. The two algorithms are then natural choices for the DIAL application.

The classification techniques require as supporting capabilities the building of composite (multi-channel) images from single channel source images, the definition of fields in the image to be used as training fields, classes, and fields to be classified, the computation of class statistics (signatures), and the display of class maps and the generation of classification reports. These capabilities are implemented in five PMs callable by DIAL users, INTERL, FIELDEF, CLASTAT, MAXLIK, and CLUSTER which communicate with each other through disk files. The PMs were tested and the algorithms validated on two sets of image data and are now available to DIAL users for application to problems in feature extraction.

1.2 REPORT ORGANIZATION

Section 1 contains background information and the report organization.

Section 2 contains a review of the feature extraction package, which consists of the five PMs INTERL, FIELDEF, CLASTAT, MAXLIK, and CLUSTER, directed toward the user.

Section 3 includes a detailed user's guide to the package, including copies of the menus encountered by the user, and a documentation of the PMs which make up the package. The documentation is in high-level program design language (PDL) for the major programs, with conventional descriptions of the principal subroutines called. Copies of complete commented computer listings have been deposited with J. E. Stilwell of USAETL.

Section 4 discusses the results of the experimentation. The data sets are described, the principal steps in the classification procedure explained, and the classification results interpreted. Copies of the displayed reports and photographs of a set of the class maps are included.

Section 5 presents the conclusions of the investigation, and recommendations for further work to extend and enhance the DIAL feature extraction capability provided by the present package.

Section 2
FEATURE EXTRACTION OVERVIEW

This section presents an overview of the Feature Extraction capability of DIAL. In the overview are discussed the overall structure and general user information. It is assumed that the reader has some familiarity with DIAL.

2.1 OVERALL STRUCTURE

The feature extraction package described in this report, which adds to the DIAL system the capability of performing both supervised and unsupervised classification, consists of five interrelated processing modules (PMs). The PMs communicate thru the use of image and parameter data sets. The five PMs are

INTERL - Builds a composite image of up to 24 channels in the band-interleaved-by-pixel format from images resident on disk, and stores the resulting image on disk.

FIELDEF - Constructs a parameter data set (field/class) of fields associated with a designated composite image. The fields can be closed polygons or connected linear segments of up to twelve sides or segments. FIELDEF includes facilities for displaying a composite image; designating a portion of that image for magnification; and displaying the fields defined superimposed on the composite image.

CLASTAT - Computes the channel means and covariance matrix for previously defined fields to form classes, as well as the Bhattacharyya distance between classes (a measure of their separation).

CLUSTER - Performs unsupervised classification (clustering) of a previously defined composite image according to the ISODATA algorithm. Included are facilities for displaying a channel of the image to be clustered, and the resulting cluster map.

MAXLIK - Performs supervised classification according to the maximum likelihood or Bayes' algorithms.

The interfaces and data sets used by the PMs are shown in Figure 2.1-1. To take advantage of the similarity of functions the PMs perform, a significant set of common subroutines was developed and is used by all PMs.

2.2 GENERAL USER INFORMATION

A typical classification sequence is given in Figure 2.2-1. Clustering and maximum likelihood classification are done on multichannel (composite) images, so that the first step is the construction of an appropriate composite image consisting of the channels to be used. For example, if it were decided that bands 5, 6, and 7 of a four-band LANDSAT MSS image were to be classified, a three channel composite image would be built using the INTERL PM. Once the composite image is made it can be used until it is purged and does not need to be recreated before each classification run.

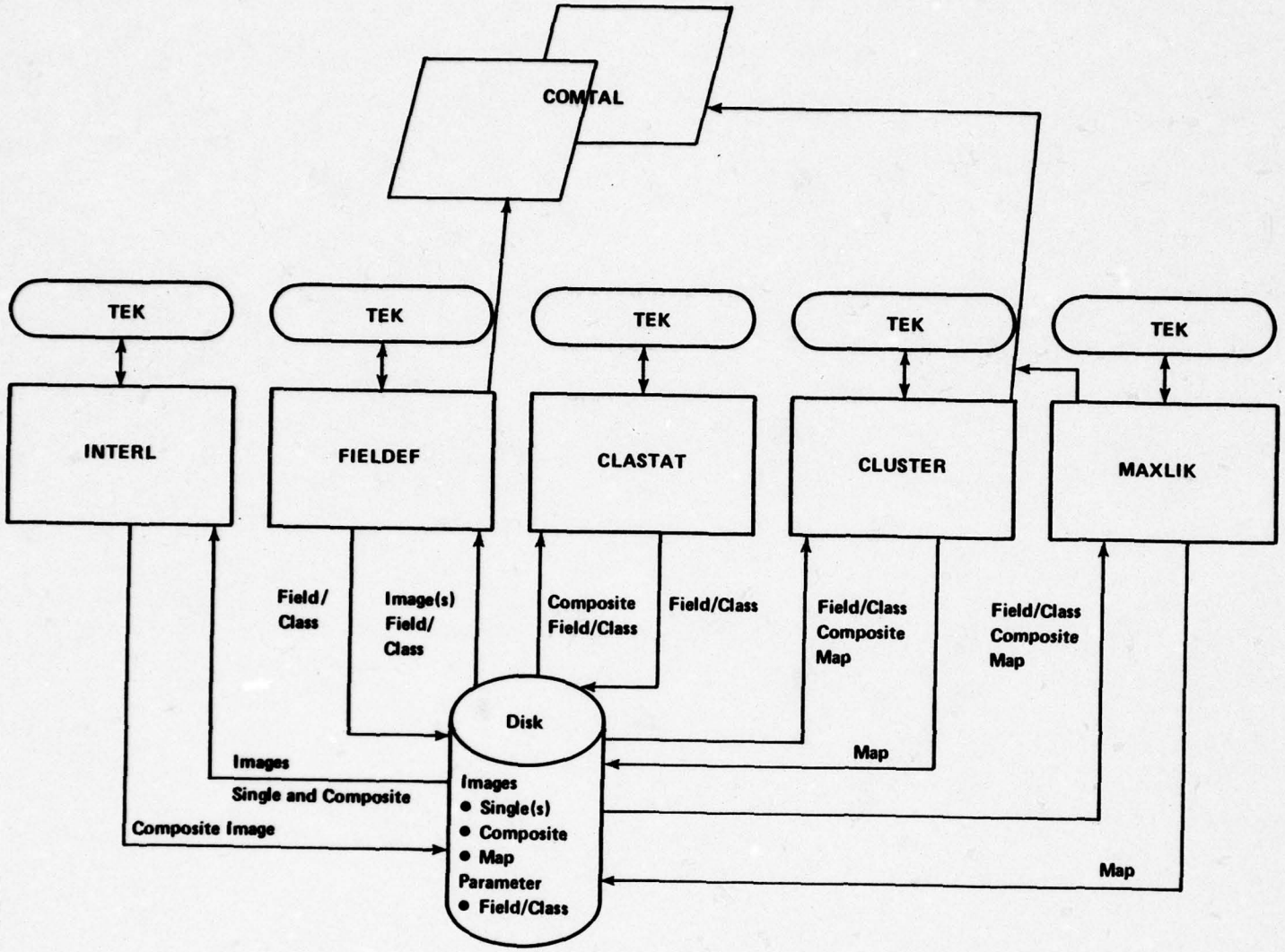


Figure 2.1-1 Overall Structure of Feature Extraction Package

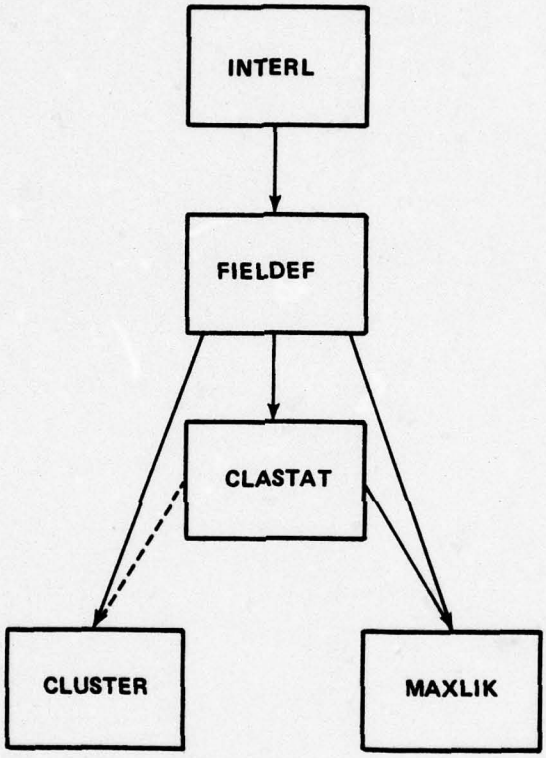


Figure 2.2-1 Typical Classification Sequence

Next comes field definition (FIELDEF). The fields defined there serve two purposes. Some will be used to define the area to be classified or clustered, while others will become classes (training fields) for which statistics will be computed in CLASTAT. Further, both the MAXLIK and CLUSTER PMs perform on the minimum rectangle encompassing all the fields selected.

If supervised classification (MAXLIK) is to be performed CLASTAT would be called next to compute class signatures (the use of classes is optional in unsupervised classification). Finally MAXLIK or CLUSTER would be initiated. In many applications it is advantageous to classify a given image by both supervised and unsupervised algorithms. In such cases MAXLIK and CLUSTER would be called one after the other and both results would be analyzed. This process in many cases leads to further runs.

In general, each PM is self-explanatory through the menu sequence, which requests the user to make certain choices and to enter certain parameters. If a user has some knowledge of the principles of pattern recognition he should have no difficulty using this package for his application.

Section 3
PROCESSING MODULE DESCRIPTION

3.1 INTERL PROCESSING MODULE

INTERL is the processing module by which single channel DIAL images are composed into multi-channel, band-interleaved-by-pixel, DIAL images. The image/scene that results from the process will be called a composite image; this definition is used throughout the report. Composite images can have up to 24 channels, and all the channels are assumed to be registered.

3.1.1 INTERL User Information

Upon entering the INTERL processing module (PM) the user is asked if a new composite image is to be created or if channels are to be added to an existing composite image. If a new composite image is to be created, then requests are made to

- o name the image
- o enter an image specification, and
- o enter the pixel size (number of bits per pixel) which can be different from that of the input images.

When using an existing composite image, the user enters the image name or a carriage return and selects from the library. Upon completing the above the menu given in Figure 3.1-1 is displayed and the processing is controlled by the option selected. This menu is redisplayed upon completion of processing for the selected option. The exception is option

```
INTERL          12/06/73 13.20.05.
GENERATES A COMPOSITE IMAGE

AVAILABLE OPTIONS ARE
---------------------

1 LIST OF COMPOSITE IMAGE CHANNELS
2 LIST OF CHANNEL IMAGE CORRESPONDENCE
3 ADD IMAGE TO COMPOSITE
4 DELETE IMAGE FROM COMPOSITE
5 BUILD COMPOSITE IMAGE
6 TERMINATE PM

ENTER OPTION NUMBER 3
```

Figure 3.1-1 INTERL Options Menu

six which terminates processing.

1. List of Composite Image Channels
   This option displays on the Tektronix a list of all the channels associated with the composite image. "Associated" means that if the next option selected is Build Composite Image, then the composite would have the channels displayed. The reason "associated" is used is that it is possible to delete or add images to this composite before a build is performed. See Figure 3.1-2 for an example of the display this option generates. It states that composite image ERIMSYN has 6 channels; the names and sequence are as given in the figure.

2. List of Channel Image Correspondence
   Like Option 1, this option gives the user information about the composite image to be built. It differs in that a user may add composite images to the composite being created. Under this situation, the user needs to know the channel/composite image correspondence because when composite images are added or deleted all channels of the composite are included in the operation. Figure 3.1-3 gives an example of the display.

3. Add Image to Composite
   This option just requests an image name to be added to the composite. This can be accomplished by either typing in a name or hitting carriage control (CR) and selecting from the library. A maximum of 8 images can be accumulated before it is necessary to either delete images or build a composite. This restriction is due to the number of permanent files that can be attached.

```
COMPOSITE IMAGE-----ERIMSYN

 LIST OF CHANNELS ASSOCIATED WITH COMPOSITE
CHAN  1   ERIM1A
CHAN  2   ERIM2A
CHAN  3   ERIM3A
CHAN  4   ERIM4A
CHAN  5   ERIM5A
CHAN  6   ERIM6A

 TO SELECT ANOTHER OPTION ENTER (CR)
```

Figure 3.1-2 List of Channels

```
COMPOSITE IMAGE-----ERIMSYN
 IMAGE -- CHANNEL CORRESPONDENCE
 IMAGE NAME                CHANNEL NAME(S)
ERIM1A                     ERIM1A
ERIM2A                     ERIM2A
ERIM3A                     ERIM3A
ERIM4A                     ERIM4A
ERIM5A                     ERIM5A
ERIM6A                     ERIM6A

 TO SELECT ANOTHER OPTION ENTER (CR)
```

Figure 3.1-3 Image Channel Correspondence

4. Delete Image From Composite

   After this option is selected a numbered list of the images associated with the primary composite are displayed on the Tektronix, and the user enters the number of the image (single channel or multi-channel) to be deleted. Again, if one is deleting a composite image from the primary composite, all channels of that image are deleted.

5. Build Composite Image

   This option is selected when the user is satisfied with the set of images making up the composite and their sequence. At this time, the actual building of the label and writing the image to disk takes place. Because this process can take a considerable amount of time, a status message is displayed on the Tektronix. Also, the composite image is closed and not cataloged which means that the user must save the image via DIAL routines or it will be deleted at LOGOFF.

3.1.2 INTERL Engineering Description

INTERL's main function is the generation of a composite image in a band-interleaved-by-pixel format. Each record contains one packed image line of data. In this format the unpacked line contains n channel values from pixel 1, followed by n channel values for pixel 2, etc., where n is the number of channels in the composite image.

As an example the buffer containing an unpacked record of a four channel by M pixel composite image would be as given below.

Word		
1	Pixel 1	Channel 1
2	Pixel 1	Channel 2
3	Pixel 1	Channel 3
4	Pixel 1	Channel 4
	.	
	.	
	.	
4*M-3	Pixel M	Channel 1
4*M-2	Pixel M	Channel 2
4*M-1	Pixel M	Channel 3
4*M	Pixel M	Channel 4

The maximum number of channels for a composite is 24 and the actual number of channels is stored in word 365 of the DIAL label. The label contains standard DIAL type information; also there is a photogrammetric parameters record that contains the channels and images making up the composite. The number of 60-bit words in a record is

$$NWDS = (NCHAN*NPIX*NBIT+59)/6$$

where:

NCHAN = Number of channels
NPIX = Number of pixels per image line
NBIT = Number of bits/channel
NWDS = Number of 60-bit words in a record.

Another important consideration is that all the images making up the composite must be registered.

3.1.3 INTERL Control Flow Processing Steps

The control flow of INTERL is determined by the options selected by the user. There are two option menus, the first of which is only displayed once, and the second is displayed after each selected option completes its function or until the user terminates the PM. The control flow/ processing steps are given below along with the subroutines used. DIAL subroutines and system routines are not identified.

Control Flow	Subroutines Used
1. Initialize processing.	
2. Display first option menu	
A. Create a new composite image	
B. Use an existing composite image	FETEKSC
3. Display second option menu	
A. List of composite image channels	LISTCH
B. List of channel image correspondence	LISTCH
C. Add image to composite	ADDIMG
D. Build composite image	PIXINT
	BLDCOM
E. Terminate PM	

3.1.4 INTERL Subroutine Description

This section describes all the subroutines identified in the prior section with the exception of FETEKSC, which is described in Section 3.2.4.

3.1.4.1 Subroutine ADDIMG

Purpose

Develops arrays containing descriptions of the images to be included in the composite.

Usage

CALL ADDIMG (IREF, IRENAM, MAXPFN, MAXCH, IERROR)

Description of Parameters

IREF - Input flag indicating if the first image is a reference image.

=0 NO

=1 YES

IRENAM - Input flag indicating if renaming of image files should take place.

=0 NO

=1 YES

MAXPFN - Input variable describing the maximum number of PFN's that can be attached (8).

MAXCH - Input variable describing the maximum number of channels (24).

IERROR - Output error flag

=0 No errors

=1 Rename error

=2 Create error

=3 Label read error

Method

Based upon the flag IRENAM renaming of the composite already in existence can take place. The new composite is given the selected name while the old composite is named REFERENCE. This is needed when channels are added to an existing composite. A request to the user for the name of the image to be added is made and upon entry the image is attached and checked to determine if it contains the same number of pixels and lines as the base image. After validation, the image characteristics are stored in arrays and the counters are updated.

Common Areas Used

LINE, ECS, PARAMS, COMIMG, ASSIMG

3.1.4.2 Subroutine BLDCOM

Purpose

Performs file functions and builds label for composite image.

Usage

Call BLDCOM (IREF, IERROR)

Description of Parameters

IREF - Input flag indicating if first image is a reference image

=0 NO

=1 YES

IERROR - Output error flag

=0 No errors

=1 Cannot write composite image label

=21 through 24 Error in PIXINT Routine

=3 Cannot close composite image

=4 Cannot read new composite label

Method

Builds and writes composite image label. Returns to the system all images used in building the composite and purges the reference image if there was one. All the above is accomplished with DIAL routines.

COMMON Areas Used

LINE, ECS, PARAMS, COMIMG, ASSIMG

3.1.4.3 Subroutine DELIMG

Purpose

Deletes images from list to be used for composite.

Usage

CALL DELIMG (IREF)

Description of Parameters

IREF - Input flag indicating if the first image is a reference image.

=0 NO

=1 YES

Method

Requests user to enter an image name. If the name is not the reference image name, the image characteristics are removed from the tables, the tables are compressed and the image is returned to the system.

COMMON Areas Used

LINE, ECS, PARAMS, COMIMG, ASSIMG

3.1.4.4 Subroutine PIXINT

Purpose

Generates a composite band-interleaved-by-pixel image file.

Usage

Call PIXINT (IERROR)

Description of Parameters

IERROR - Output error flag

=0 No errors

=1 Insufficient central memory

=2 Pixel count is not equal to reference image

=3 Line count is not equal to reference image

Method

This routine is given a set of images which have been located, attached, and validated. From the image characteristics the routine determines how to divide the available central memory and ECS. A result of the above is number of lines to store in ECS and this number of lines is read from the disk for each image and stored in ECS. A line of the composite image is generated by unpacking the corresponding lines from each image and storing the values in appropriate locations of ECS. When the building of the line in ECS is completed, the line is read into central memory where it is packed and written to disk. This is continued until all lines have been processed. Since some of the images can be multichannel

(composite) images, more than one value from an image can be stored for a given pixel. The output line is in the band-interleaved-by-pixel format.

COMMON Areas Used

LINE, ECS, PARMS, COMIMG, ASSIMG

3.2 FIELDEF PROCESSING MODULE

FIELDEF permits the user to define areas to be used for training the classifier, to be used for classification, or to be used for clustering. The areas are termed "fields." Fields can be defined as a polygon with up to 12 sides, with all of the pixels interior to the polygon considered as the field, or fields can be defined as a series of up to 12 connected straight line segments, with all of the pixels intersected by the line segments considered as the field.

3.2.1 User Information

It is possible for the user to operate FIELDEF without entering a specific name of any of the entities that must be selected to provide information to FIELDEF (except for 2 letters for display selection, and the names of the new fields). The first menu (Figure 3.2-1) that the user sees provides him with a choice to define new fields by displaying the image and interacting with the COMTAL display and trackball to specify field vertices, or to modify or delete existing field definitions. If the user selects to define new fields, the next choice is to specify the display(s) upon which the images will be located (Figure 3.2-2). The first letter specifies the display on which the full image, or possibly an expanded subimage, will be shown to permit

```
FIELDEF      12/12/78  16.56.29.
FIELD DEFINITION FOR CLASSIFICATION/CLUSTERING

                                        SELECT OPTION

    1. DEFINE FIELD(S) USING IMAGES
    2. MODIFY/DELETE FIELD(S) WITH KEYBOARD INPUT

(ENTER A VALUE FROM 1 TO  2)
```

Figure 3.2-1. FIELDEF Option Menu

```
SELECT DISPLAY(S)

-ENTER TWO DISPLAY NAMES, A,B,C, OR D. (LETTERS ONLY)
 -FIRST NAMED WILL DISPLAY FULL IMAGE WITH CHOICE OF EXPANSION
 -SECOND NAMED WILL DISPLAY FIELD DEFINITION (SUB)IMAGE
  (E.G. A C, B B, D A)
```

Figure 3.2-2 FIELDEF Display Selection Menu

the user to locate the area to be used for field definition. The second letter specifies the display on which the subimage used for field definition will be shown (if necessary, both letters may be the same). The next option menu (Figure 3.2-3) permits the user to select a single image data file and display it in gray, or select three image data files and display the images overlayed in red, green, and blue. The assumption is that the three images are different but registered bands that add information to the red/green/blue display for the user to choose fields. The next request (Figure 3.2-4) will be for the individual data set(s) that contain the image(s) to be displayed. If the user does not remember the name, a (CR) will provide a prompting list. The next option menu (Figure 3.2-5) permits the user the option to select an existing file to add additional field definitions, or to create a new file. If the user selects the existing file (Figure 3.2-6) he will be prompted for the name of the field/class-file. As with the image file, if the user does not remember the name, a (CR) will provide a prompting list. If the user selects to create a new file, he will be prompted for the file name, and a file description. The next selection menu (Figure 3.2-7) is the main set of options for defining fields. The first option the user would normally select is #1, to display the subimage used for defining fields. FIELDEF will display the full image automatically. Next, the user has the option to modify the brightness and contrast by using the trackball, or to leave the image alone (Figure 3.2-8). Subsequent to this a subarea must be selected by the user (Figure 3.2-9). This subarea may be expanded to further examine the area, or expanded on the second COMTAL to be used for field definition (Figure 3.2-10). After a subimage has been displayed for field definition, Selection 2 (Figure 3.2-7) will begin the sequence of defining fields. The first option menu (Figure 3.2-11) permits the user to define areal or linear fields, or to save a field just defined. Instructions (Figure 3.2-12) prompt the user on how to define the field. After a field has been defined, the field name and

```
                    SELECT OPTION

    1. GRAY IMAGE (ONE DATA FILE TO SELECT)
    2. RED/GREEN/BLUE (THREE DATA FILES TO SELECT)

(ENTER A VALUE FROM 1 TO  2)
 2
```

Figure 3.2-3 FIELDEF Image Type Menu

```
TO SELECT RED   IMAGE TO BE DISPLAYED ON THE COMTAL-

 -ENTER IMAGE-DATA-FILE NAME
 -OR (CR) TO DISPLAY IMAGE-DATA-FILE SELECT LIST
 ●
```

Figure 3.2-4 FIELDEF Red Image Select Menu

```
                                    SELECT OPTION

                1. SELECT EXISTING FIELD/CLASS FILE
                2. CREATE NEW FIELD/CLASS FILE

                (ENTER A VALUE FROM 1 TO  2)
```

Figure 3.2-5 FIELDEF Field/Class-File Menu

```
TO SELECT FIELD/CLASS-DATA-FILE TO BE USED-

 -ENTER FIELD/CLASS-DATA-FILE NAME
 -OR (CR) TO DISPLAY FIELD/CLASS-DATA-FILE LIST
 ●
```

Figure 3.2-6 FIELDEF Field/Class-Data-File Menu

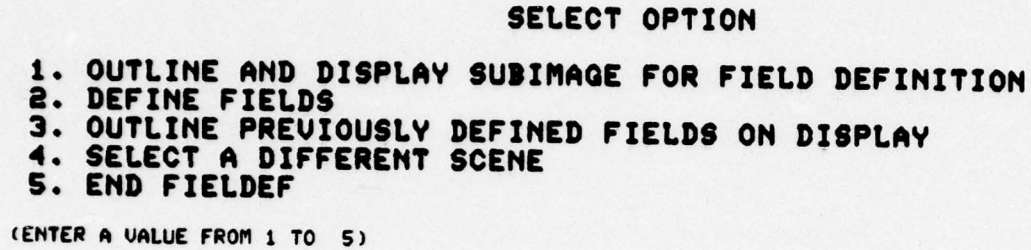


Figure 3.2-7 FIELDEF Field Definition Menu

```
SELECT OPTION

1. MODIFY IMAGE FUNCTION TABLE(S) BY TRACKBALL
2. NO MODIFICATION

(ENTER A VALUE FROM 1 TO  2)
```

Figure 3.2-8 FIELDEF Image Function Tables Modification Menu

TO OUTLINE THE AREA TO BE USED FOR FIELD DEFINITION
OR TO EXPAND A SELECTED AREA FOR FURTHER EXAMINATION-

-BEGIN BY CENTERING THE CURSOR WITH THE TRACKBALL IN
THE SELECTED AREA AND PRESS *S* OR *D* TO FIX THE LOCATION

-NEXT, USE THE TRACKBALL TO EXPAND A SQUARE AROUND
THE CENTER AND PRESS *S* OR *D* TO FIX THE SQUARE

Figure 3.2-9 FIELDEF Area Outline Menu

```
                    SELECT OPTION

  1. FURTHER EXPAND OUTLINE (SUB)IMAGE
  2. EXPAND AND DISPLAY FIELD DEFINITION (SUB)IMAGE

(ENTER A VALUE FROM 1 TO  2)
2

                  20 PERCENT COMPLETE
```

Figure 3.2-10 FIELDEF Subimage Expansion Menu

```
                    SELECT OPTION

1. DEFINE POLYGON FIELD TO ENCLOSE PIXELS
2. DEFINE LINE-SEGMENT(S) THAT INTERSECT PIXELS
3. SAVE FIELD/LINE-SEGMENT(S) DEFINITION
4. END DEFINITION PROCESS

(ENTER A VALUE FROM 1 TO  4)
```

Figure 3.2-11 FIELDEF Field Type Selection Menu

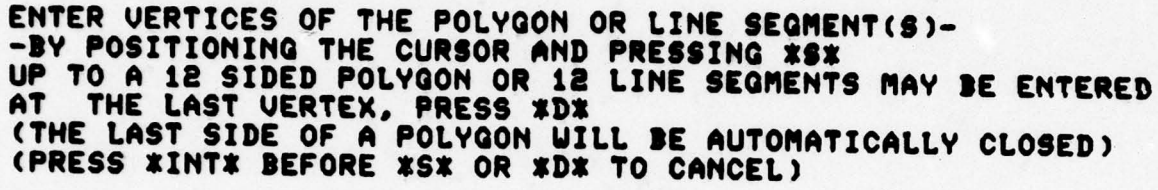


Figure 3.2-12 FIELDEF Areal Field Creation Menu

description will be requested (Figure 3.2-13). The user must remember to save the field defined (Figure 3.2-11) at the end of definition.

If the user chooses option 2 on the first menu (Figure 3.2-11), then the next option menu that appears is the one shown in Figure 3.2-14. The user then has the choice to modify the vertices of an existing field record, to replace the original record with the modified record, to delete selected records, or to delete a field/class-file. If the user chooses option 1, the modification of the vertices of an existing field, the next menu displayed is shown in Figure 3.2-15. This is the standard field record selection menu. After a single field is selected and option 3 chosen, the field modification display (Figure 3.2-16) is shown. One dimension of a vertex may be modified at a time. If, after a modification, the field has a segment that crosses another segment, an error message will appear at the top of the screen. This means simply that the field cannot be saved in the state that it is in. The user may continue to modify and complete the modification process. The modified record must be saved (replacing the original) as shown in Figure 3.2-14, option 2.

3.2.2 Engineering Description

FIELDEF has the capability to display an image and permit the user to define "fields" that correspond to areas of interest. These field definitions may be utilized later as areas that specify the pixels to be used to gather statistics for "training" the MAXLIK classifier, pixels to be classified, or pixels to be clustered with the CLUSTER program.

Fields may be of two types, areal or linear. An areal field consists of a polygon with up to a maximum of 12 sides. It may be either a

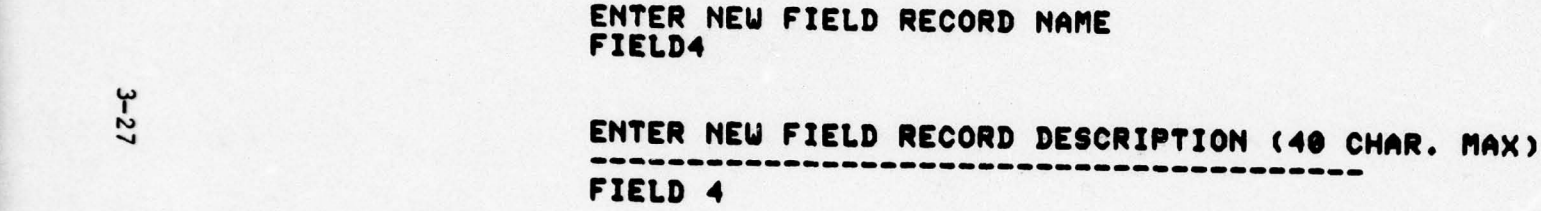


Figure 3.2-13 FIELDEF Field Record Menu

```
                                SELECT OPTION

1. MODIFY FIELD/LINE DEFINITION
2. SAVE MODIFIED FIELD OR LINE-SEGMENT(S)
3. DELETE FIELD/LINE-SEGMENT RECORD
4. DELETE FIELD/CLASS-FILE
5. END FIELDEF

(ENTER A VALUE FROM 1 TO  5)
```

Figure 3.2-14 FIELDEF Linear Field Creation Menu

```
                    SELECT OPTION

 1. SELECT FIELD(S)  (1) FOR MODIFICATION OF VERTICES
 2. DROP FIELD(S)  FROM THE SELECTED LIST
 3. FIELD SELECTION COMPLETED

(ENTER A VALUE FROM 1 TO  3)
```

Figure 3.2-15 FIELDEF Field Modification Menu

```
TO CHANGE AN ELEMENT-
-ENTER ELEMENT NUMBER(NUMBER IN PAREN), FOLLOWED BY (CR)
-THEN, ENTER NEW VALUE, FOLLOWED BY (CR)
TO EXIT FROM MODIFY, ENTER (CR)

FIELD NAME -FIELD4
DESCRIPTION-FIELD 4
TYPE--------AREAL

          VERTEX        LINE          PIXEL

            1  ( 1)-   130  ( 2)-     33
            2  ( 3)-   140  ( 4)-     34
            3  ( 5)-   140  ( 6)-     27
            4  ( 7)-   131  ( 8)-     26
            5  ( 9)-   130  (10)-     33
            6  (11)-     0  (12)-      0
            7  (13)-     0  (14)-      0
            8  (15)-     0  (16)-      0
            9  (17)-     0  (18)-      0
           10  (19)-     0  (20)-      0
           11  (21)-     0  (22)-      0
           12  (23)-     0  (24)-      0

          NUMBER OF VERTICES (25)- 4

          ENTER ELEMENT NUMBER-
```

Figure 3.2-16 FIELDEF Vertex Modification Menu

convex or a concave polygon. The pixels defined are those whose centers are on the polygon boundary or interior to the polygon. Linear fields consist of series of one or more connected straight line segments, up to a maximum of 12 segments. The pixels defined are those which are intersected by a field line segment.

Fields are stored simply as a series of integer vertices with the areal definitions always including the closing segment. A standard method is provided to analyze which pixels are included in the field by using the FEUTLLA subroutine. FEUTLLA returns the line segment or segments included in the field for any particular line passed to it.

The user specifies the field vertices by cursor position and pressing the cursor button (normally "select," with "done" as the last vertex). FIELDEF automatically enters the last vertex and closes the polygon when the user presses "done."

The subimage upon which the user specifies the location of the field is obtained in a two-step process. First, the entire image is displayed on one COMTAL. By positioning the cursor, the center of a square and the size of the square area to be displayed is specified. This magnifying process can continue on the original COMTAL until the area of interest is clear. Then, a final magnification is transferred to a second COMTAL to be used for field definition.

Additional functions available in FIELDEF are:

1. Outline previously defined fields.

2. Modify field definition vertex locations.

3. Delete field record(s).

4. Delete field/class file.

3.2.3 FIELDEF PDL

```
FIELDEF:BGNSEGMENT (MAIN)
TEKDISPLAY FIELDEF TITLE MENU
CALL FETEKSO TO SELECT IMAGE OR KEYBOARD OPTION
CASENTRY (IMAGE-DEFINE, KEYBOARD-DEFINE)
CASE 1 (IMAGE-DEFINE)
     DO UNTIL NO IMAGE TO BE DISPLAYED
          CALL FETEDSD TO SELECT DISPLAYS
          CALL FETEKSO TO SELECT GRAY OR R/G/B IMAGES
          CASENTRY (GRAY, R/G/B)
          CASE 1 (GRAY)
               CALL FETEKSI TO SELECT GRAY IMAGE
               CALL FECOMIV TO SET DISPLAY VECTORS
          CASE 2 (R/G/B)
               CALL FETEKSI 3 TIMES TO SELECT R/G/B IMAGES
               CALL FECOMIV TO SET DISPLAY VECTORS
          ENDCASE
          CALL FETEKFC TO SELECT FIELD/CLASS FILE
          DO UNTIL NO FURTHER OPTION
               CALL FETEKSO TO SELECT 1 OF 5 MAIN OPTIONS
               CASENTRY (OUTLINE DEF IMAGE, DEFINE FIELD, OUTLINE FIELDS,
                         ANOTHER IMAGE, END OF FIELDEF)
               CASE 1 (OUTLINE DEFINITION IMAGE)
                    IF NO IMAGE DISPLAYED
                       CALL FECOMDI TO DISPLAY FULL IMAGE
                    ELSE
```

```
      CALL FETEKSO TO SELECT PRESENT IMAGE OR FULL
         IMAGE
      CASENTRY (PRESENT IMAGE, FULL IMAGE)
      CASE 1 (PRESENT IMAGE)
         CALL FECOMDI OR FECOMFS TO DISPLAY PRESENT
         IMAGE
      CASE 2 (FULL IMAGE)
         CALL FECOMDI TO DISPLAY FULL IMAGE
      ENDCASE
ENDIF
CALL FETEKSO TO SELECT FUNCTION TABLE MODIFY OR
   SKIP MODIFY
IF FUNCTION TABLE MODIFY
THEN CALL GRAYMAP TO MODIFY FUNCTION TABLE
ENDIF
DO UNTIL ENOUGH EXPANSION ON COMTAL 1
      SELECT CENTER AND SIZE OF SQUARE TO BE EXPANDED
      CALL FETEKSO TO EXPAND ON COMTAL 1 OR END
      CASENTRY (EXPAND ON COMTAL 1, END)
      CASE 1 (EXPAND ON COMTAL 1)
         EXPAND ON COMTAL 1
      CASE 2 (END EXPANSION ON COMTAL  1)
         SET NO EXPAND SW.
      ENDCASE
ENDDO
EXPAND ON COMTAL 2
CALL FETEKSO TO SELECT FUNCTION TABLE MODIFY OR
   SKIP MODIFY
IF FUNCTION TABLE MODIFY
THEN CALL GRAYMAP TO MODIFY FUNCTION TABLE ON
   COMTAL 2
ENDIF
```

```
CASE 2 (DEFINE FIELD)
     DO UNTIL NO MORE FIELDS TO BE DEFINED OR CANCELLED
          CALL FETEKSO TO SELECT OPTION
          CASENTRY (POLYGON, LINE, SAVE, END)
          CASE 1 (POLYGON OR LINE)
             IF FIRST POINT
             THEN ADD POINT TO FIELD RECORD
             ELSE CALL FEFDTAD TO CHECK FOR ERROR
                IF OK
                THEN ADD POINT
                ELSE CALL FETEKEM TO DISPLAY ERROR MESSAGE
                ENDIF
             ENDIF
             ENTER FIELD NAME
             ENTER FIELD DESCRIPTION
          CASE 2 (SAVE)
             IF FIELD IS VALID
             THEN CALL FEUTILLA TO SAVE RECORD
             ELSE CALL FETEKEM TO DISPLAY ERROR MESSAGE
             ENDIF
          CASE 3 (END)
             SET NO FIELDS SW
          ENDCASE
     ENDDO
CASE 3 (OUTLINE FIELDS)
     CALL FETEKSO TO SELECT IMAGE TO OUTLINE FIELDS
     CALL FETEKOF TO SELECT FIELDS TO DISPLAY
     DISPLAY ALL FIELDS COMPLETELY CONTAINED ON DISPLAY
CASE 4 (ANOTHER IMAGE)
     SET NO FURTHER OPTIONS SW
CASE 5 (END OF FIELDEF)
     SET NO FURTHER OPTIONS SW
     SET NO FURTHER IMAGE SW
```

```
                ENDCASE
            ENDDO
            ENDDO
CASE 2 (KEYBOARD DEFINE)
    DO UNTIL NO FURTHER OPTION
        CALL FETEKSO TO SELECT OPTION
        CASENTRY (MODIFY FIELD,SAVE,DELETEFIELD,DELETE F/C FILE,END)
        CASE 1 (MODIFY FIELD)
            CALL FETEKFC TO SELECT F/C FILE
            CALL FETEKDF TO SELECT FIELD RECORD
            CALL FEUTLFC TO RETRIEVE RECORD
            DO UNTIL (CR) ENTERED
                ENTER FIELD ITEM
                ENTER ITEM VALUE
                IF NOT (CR)
                THEN MODIFY AND TEST FIELD
                ENDIF
            ENDDO
        CASE 2 (SAVE)
            IF FIELD IS OK
            THEN CALL FEUTLLA TO DELETE OLD RECORD
                CALL FEUTLLA TO SAVE NEW RECORD
            ELSE CALL FETEKEM TO DISPLAY ERROR MESSAGE
            ENDIF
        CASE 3 (DELETE FIELD)
            CALL FETEKFC TO SELECT F/C FILE
            CALL FETEKDF TO SELECT FIELDS TO BE DELETED
            CALL FEUTLFC TO DELETE RECORDS
        CASE 4 (DELETE F/C FILE)
            CALL FETEKFC TO SELECT F/C FILE
            CALL DPURGE TO DELETE FILE
        CASE 5 (END)
            SET NO FURTHER OPTION SW
        ENDCASE
```

```
    ENDDO
ENDCASE
ENDSEGMENT
```

3.2.4 FIELDEF Subroutine Description

3.2.4.1 Subroutine FECOMDI

Title - Transmits a gray or red/green/blue image to a COMTAL display and displays the image.

Parameters

CALL FECOMDI (FNAMES, IMGGRAY, LBLBUF, IDSP, IXYS)

FNAMES - A (4,3) array that contains the red, green, and blue image-data-file names in that order; or, for a gray image, the single gray image-data-file name.

IMGGRAY - Ø - FNAMES contains R/G/B names
1 - FNAMES contains a gray name

LBLBUF - Label buffer supplied by the calling program, at least 2602 words long.

IDSP - A 21 element COMTAL display control vector supplied by the calling program.

IXYS - A 3-element vector returned to the calling program that includes the XY coordinates of the registration point, and the sampling factor (See subroutine IMGSIZE).

Description - This subroutine provides a standard means of displaying complete images through the facilities of subroutine IMGDSK. The calling program must have specific declaration statements for ECS.

3.2.4.2 Subroutine FECOMFS

Title - Expands or shrinks a square image or subimage to fit a full COMTAL screen through linear interpolation.

Parameters

CALL FECOMFS (FNAME,IPC,ILC,NPL,JPC,JLC,JNPL,LBLBUF,BUF,LN, LAN, IANN)

FNAME - The image-data-file name that identifies the source of image data.

IPC,ILC - The pixel and line location of the center of the image or subimage to be displayed (requested).

NPL - The requested number of pixels and lines to be displayed on the COMTAL full screen.

JPC,JLC, JNPL - The actual pixel and line location of the center, and the number of lines and pixels actually displayed on the COMTAL full screen. This may differ from IPC,ILC, and NPL if the request implies an off-image extraction.

LBLBUF - Label buffer supplied by the calling program, at least 2602 words long.

BUF - Working expansion buffer supplied by the calling program, at least 12,288 words long.

LN - Image plane that receives the 8-bit image.

LNA - Overlay plane that receives the annotation.

IANN - Ø - No annotation
1 - Display annotation

Description - This subroutine provides all of the function needed to extract a square subimage or image from a disk image-data-set and expand or shrink that subimage or image to fit the full screen COMTAL. Linear interpolation is the resampling method. This subroutine does not include invocation of subroutine DISPLAY, which must be done subsequently. The calling program must have specific declaration statements for ECS.

3.2.4.3 Subroutine FECOMIV

Title - Initializes a COMTAL display control vector to a standard set of values.

Parameters

CALL FECOMIV (COMALPH,IMGGRAY,IMGGLN,IDSP)

COMALPH - The selected COMTAL display (A,B,C, or D), left justified and zero-filled.

IMGGRAY - Ø - R/G/B image to be displayed.
1 - Gray image to be displayed.

IMGGLN - Image plane (1,2, or 3) where the gray image is located, left justified and zero-filled.

IDSP - The 21 element COMTAL display control vector returned to the calling program.

Description

This subroutine provides a means to initialize a COMTAL display control vector a standard set of values. IMGGLN is not used when IMGGRAY = Ø, but a dummy entry must be present.

3.2.4.4 Subroutine FETEKCL

Title - Clears the Tektronix screen.

No Parameters

CALL FETEKCL

Description

This subroutine provides a simple means to clear the Tektronix display.

3.2.4.5 Subroutine FETEKDF

Title - Displays the field or class records in a field/class-file, permits the user to select one or more records, and returns a series of pointers that point to the location of the selected records.

Parameters

CALL FETEKDF (FNAME, LBLBFR,IFC,MG1,NC,LOCV,MAXV,NV)

FNAME - Field/Class-file that contains the field or class records to be selected.

LBLBFR - A supplied work area for the label.

IFC - Ø - Display field records only.
1 - Display class records only.

MG1 - A character string to be added to the first line (SELECT FIELD(S) or SELECT CLASS(ES)) as explanation for or about the selection (up to 50 characters).

NC - Number of characters in MG1.

LOCV - A single dimension array of pointers returned that are the indexes of the selected records in the file.

MAXV - Maximum number of record pointers permitted to be returned. If more are selected, the amount will be truncated.

NV - Number of record pointers selected.

Description

This subroutine provides a standard means of displaying the field data or class data in a field/class-file, and permitting the user to select one or more of the fields or classes.

3.2.4.6 Subroutine FETEKEM

Title - Displays a single-line error message on the Tektronix display in a standard format.

Parameters

CALL FETEKEM (MSG,NC,ICLEAR)

MSG - The error message to be displayed--may be up to 81 characters. Formatting control characters should not be included.

NC - The number of characters in the error message.

ICLEAR - Ø - Screen not cleared before display.
1 - Screen cleared before display.

Description

This subroutine provides a standard method to display single-line error messages. The message is displayed with a line of dashes above and below, and the Tektronix horn is beeped.

3.2.4.7 Subroutine FETEKFC

Title - Displays a request for a field/class-data-file name on the Tektronix display, and returns the name to the calling program.

Parameters

CALL FETEKFC (FNAME, IOLINE,NREC,ICLEAR)

FNAME - Field/class-file name returned by the subroutine (40 chars.)

IOLINE - Ø - Select existing file only
1 - User has choice to select existing file, or create new file.

NREC - Number of records in the field/class file

ICLEAR - Ø - Screen not cleared before display
1 - Screen cleared before display

Description

This subroutine provides a display that requests a field/class-data-file name, and uses LOCATE to confirm and return the name to the calling program, or, uses KREATE to confirm, return the name, and create a new file.

3.2.4.8 Subroutine FETEKSC

Title - Displays a request for a composite-data-file name on the Tektronix display, and returns the name to the calling program.

Parameters

CALL FETEKSC (FNAME,NCH,LBLBUF,ICLEAR)

FNAME - Composite-file name returned by the subroutine (40 chars.)

NCH - Number of channels included in the composite file, returned by the subroutine.

LBLBUF - Label buffer supplied by the calling program, at least 2602 words long.

ICLEAR - Ø - Screen not cleared before display.
1 - Screen cleared before display.

Description

This subroutine provides a display that requests a composite-data-file name, and uses LOCATE to confirm and return the name to the calling program.

3.2.4.9 Subroutine FETEKSD

Title - Displays a request for image display selection on the Tektronix screen and reads a pair of letters corresponding to the users request. The letters are returned to the calling program.

Parameters

CALL FETEKSD (DIS1,DIS2,ICLEAR)

DIS1 - The first letter (A,B,C or D) is returned, left justified and zero-filled.

DIS2 - The second letter is returned, left justified and zero-filled.

ICLEAR - Ø - Screen not cleared before display
1 - Screen cleared before display

Description

This subroutine provides a header 'SELECT DISPLAY(S)', followed by an explanation of the entry required by the user. The entered letters are returned via the above parameters. This subroutine is designed to be used with subroutine FECOMIV to build a control vector for the COMTAL display.

3.2.4.10 Subroutine FETEKSI

Title - Displays a request for an image-data-file name on the Tektronix display, and uses LOCATE to return the file name.

Parameters

CALL FETEKSI (FNAME, ICOLOR,ICLEAR)

FNAME - The image-data-file name returned by the subroutine.

ICOLOR - Ø - "GRAY IMAGE"
1 - "RED IMAGE"
2 - "GREEN IMAGE"
3 - "BLUE IMAGE"

ICLEAR - Ø - Screen not cleared before display.
1 - Screen cleared before display.

Description

This subroutine provides a display that requests an image-data-file name, and uses LOCATE to confirm and return the name to the calling program. The parameter ICOLOR changes the display wording only.

3.2.4.11 Subroutine FETEKSO

Title - Displays a list of options on the Tektronix screen and reads a number corresponding to the option list.

Parameters

CALL FETEKSO (MSG,IVAL,NW,NL,ICLEAR,IRESPN)

MSG - A dimensioned array of type integer or real which contains the character data to be displayed as the option list. The character data must consist of display code characters, with each line or option choice starting a new line of the array. Formatting control characters should not be included.

IVAL - A single dimensioned array of integer values that correspond to the count of the number of characters per option description line.

NW - The number of words per row in MSG.

NL - An integer value of the number of option description lines in MSG.

ICLEAR- Ø - Screen not cleared before display.
1 - Screen cleared before display.

IRSPN - The value entered by the user to indicate the option selected, and returned to the calling program.

Description

This subroutine provides a header 'SELECT OPTION', followed by the character data in MSG. The user must enter and integer that ranges from 1 to the number of option choices. The returned value typically could be used directly in a computed GO TO implemented CASENTRY control figure.

```
Example:
DIMENSION MENU1(5,2),IMCL1(2)
DATA IMLC1/32,45/
DATA MENU1(1,1),MENU1(2,1),MENU1(3,1),MENU1(4,1)
$ /1ØH1.ßDEFINE ß,1ØHFIELD(S)ßß,1ØHUSING IMAG,
$ 2HES/
DATA MENU1(1,2),MENU1(2,2),MENU1(3,2),MENU1(4.2)
$ /1ØH2.ßDEFINE/,1ØHMODIFY FIG,1ØHLD(S) WITH,
$ 1ØH KEYBOARDß; 5HINPUT/
CALL FETEKSO (MENU1,IMLC1,5,2,1,ICASE)
CASENTRY (IMAGE-DEFINE,KEYBOARD-DEFINE)
  GO TO (1Ø,2Ø) ICASE
```

3.2.4.12 Subroutine FEUTLFC

Title - Retrieves, adds, or deletes specific records in a field/class-file.

Parameters

CALL FEUTLFC (FNAME,LBLBFR,IFUNCT,ILOC,FCBFR)

FNAME - The field/class-file from/to which data is to be retrieved, added, or deleted.

LBLBFR - A supplied work area for the label.

IFUNCT - Ø - Retrieve record
1 - Add record
2 - Delete record

ILOC - For IFUNCT = Ø - Points to the record to be retrieved.
For IFUNCT = 2 - Points to the record to be deleted.

FCBFR - For IFUNCT = Ø - Retrieved record is placed in this area.
For IFUNCT = 1 - Record to be added is located in this area.

Description

This subroutine provides a standard method to retrieve, add, or delete records in a field/class-file. ILOC must point to the actual record in the file, not to the relative field record, or relative class record. This subroutine along with FETEKDF provides a complete capability to operate on the field/class files.

3.2.4.13 Subroutine FEUTLLA

Title - Determines the maximum and minimum lines involved in a particular field definition, and, for a particular line determines the segment(s) of the line defined by the field.

Parameters

CALL FEUTLLA (IFCR,IRPIX,L1,L2,LINE,NSEG,NSTRT,NEND)

IFCR - Input Field/Class record

IRPIX - Ø - Determine min and max line (L1 & L2) only.
1 - Determine segment(s) of line defined by the Field IFCR.

L1 - Minimum line value defined by the field.

L2 - Maximum line value defined by the field.

LINE - Particular LINE for which segment(s) defined by the field are to be determined.

NSEG - Number of segments defined by the field for this LINE (MAX. 12).

NSTRT - A one-dimensional array of NSEG starting segment values.

NEND - A one-dimensional array of NSEG corresponding ending segment values.

Description

This subroutine provides a method to determine the pixel segment(s) included in a field (areal or linear) for any line included in the field.

3.2.4.14 Subroutine SYMIN

Title - Inverts a symmetric matrix, and calculates the determinant of the matrix.

Parameters

CALL SYMIN (A,AI,DET,N)

A - Symmetric matrix to be inverted.

AI - Inverted matrix.

DET - Determinant of A

N - Row/column dimensions of A.

Description

This subroutine inverts a symmetric matrix and provides the determinant of that matrix. Presumed dimensions are 24 x 24.

3.3 CLASTAT

CLASTAT permits the user to utilize the fields defined by FIELDEF to specify the location of pixels for the gathering of signature statistics. One or more fields may be specified for a single signature, with all of the corresponding pixels utilized for the statistics. A combining function is provided to permit two or more classes to be combined into a single new class. And a distance metric is provided in the form of the Bhattacharyya distance calculation. This provides an indication of the similarity of pairs of classes.

3.3.1 User Information

The user may interact with CLASTAT primarily through simple option selection, except for naming new classes that are created.

The first information the user must enter is the field/class-file name, or select one of the available files (Figure 3.3.1). The next item shown on the Tektronix is the main option menu for CLASTAT (Figure 3.3-2). This gives the user the choice to calculate class signature statistics from one or more fields, to combine statistics from one or more classes into a new class, to delete class records, to calculate the Bhattacharyya distance between two classes, and to print class information on the line printer from a set of selected classes. If the user selects option 1, he will be asked to supply the composite-file name, and the field or fields to be referenced for pixel retrieval (Figure 3.3-3). Subsequent to the calculation the user must enter the new class name and description. If the user selects option 2 to combine classes, he must select the classes and then supply the new name and description. In either case he will be asked explicitly to save the new class. To delete classes, the user simply selects the classes from the class selection menu. To calculate the Bhattacharyya distance between two classes (option 4), the user selects two classes from the class selection menu (Figures 3.3-4, 3.3-5), and the result is displayed as in Figure 3.3-6. To print class data (option 5), the user selects the classes from the class selection menu and the results are printed on the line printer.

3.3.2 Engineering Description

The primary function of CLASTAT is to gather mean and covariance statistics, by channel, from pixels specified by fields. More than one field may be specified, and in this event the statistics will be gathered over all of the pixels in all of the fields. The resultant covariance matrix is stored in the upper half of the class record covariance array, while the correlation matrix is stored in the lower half of the class record covariance array.

```
CLASSTAT      12-12-78  17.20.16.
CLASS STATISTICS FOR CLASSIFICATION

          TO SELECT FIELD/CLASS-DATA-FILE TO BE USED-

           -ENTER FIELD/CLASS-DATA-FILE NAME
           -OR (CR) TO DISPLAY FIELD/CLASS-DATA-FILE LIST
           ●
```

Figure 3.3-1 CLASTAT Field/Class-Data-File Select Menu

```
                    SELECT OPTION

    1. CALCULATE CLASS SIGNATURE
    2. COMBINE CLASSES INTO A NEW CLASS
    3. DELETE CLASS(ES)
    4. CALCULATE BHATTACHARYYA DISTANCES
    5. PRINT FIELD/CLASS FILE
    6. END CLASTAT

(ENTER A VALUE FROM 1 TO  6)
```

Figure 3.3-2 CLASTAT Principle Options Menu

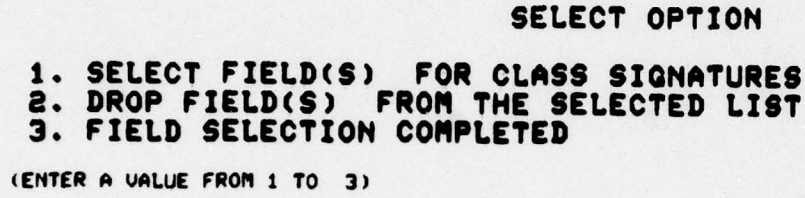


Figure 3.3-3 CLASTAT Field Selection Menu

```
                    SELECT OPTION

 1. SELECT CLASS(ES) (2) FOR BHATTACHARYYA DISTANCE
 2. DROP CLASS(ES) FROM THE SELECTED LIST
 3. CLASS SELECTION COMPLETED

(ENTER A VALUE FROM 1 TO  3)
 1
```

Figure 3.3-4 CLASTAT Class Selection Menu

CLASS-FIELD1

CLASS-FIELD5

BHATTACHARYYA DISTANCE-

.268273E-75

(CR) RETURNS TO OPTION MENU

Figure 3.3-6 Bhattacharyya Distance Between Fieldl and Field5

The resultant mean and covariance data is utilized subsequently by MAXLIK to "train" the maximum likelihood classifier, and also the data may be used by CLUSTER to provide the mean values of a set of starting clusters. CLASTAT also provides the capability to combine the class statistics of two or more classes into a single new class.

Means are calculated by:

$$\mu_c = \frac{1}{N_c} \sum_{k=1}^{N_c} x_k$$

where μ_c and x_k are n dimensional vectors, and

μ_c is the mean for class c,

x_k is the individual pixel vector,

N_c is the number of pixels in class c.

Covariance matrices are calculated by:

$$\sum_c = \frac{1}{N_c - 1} \sum_{k=1}^{N_c} (x_k - \mu_c)\,(x_k - \mu_c)^T$$

To combine 2 classes, the means are calculated as follows:

$$\mu_c = \frac{N_c' \mu_c' + N_c'' \mu_c''}{N_c' + N_c''}$$

where μ_c is the resultant mean vector,

N_c' is the number of pixels in the first class,

N_c'' is the number of pixels in the second class,

μ_c' is the first mean vector,

μ_c'' is the second mean vector.

Covariance matrices are combined as follows:

$$\sum_c = \frac{N_c' - 1}{N_c - 1} \sum_c' + \frac{N_c'}{N_c - 1} (\mu_c' - \mu_c)(\mu_c' - \mu_c)^T +$$

$$\frac{N_c'' - 1}{N_c - 1} \sum_c'' + \frac{N_c''}{N_c - 1} (\mu_c'' - \mu_c)(\mu_c'' - \mu_c)^T$$

where $N_c = N_c' + N_c''$

μ_c is the combined mean vector.

A measure of the similarity of two classes is provided through the Bhattacharyya distance calculation. The more similar the two classes are to each other, the closer the distance measure is to 1, the more dissimilar, the closer the measure is to Ø.

The calculation of Bhattacharyya distance (Ref. No. 2) is as follows:

$$P = \frac{\left|\sum_i\right|^{1/4} \left|\sum_j\right|^{1/4}}{\left|\frac{1}{2}\sum_i + \frac{1}{2}\sum_j\right|^{\frac{1}{2}}} e^{-1/8\ \delta^T \left[\frac{1}{2}\sum_i + \frac{1}{2}\sum_j\right]^{-1} \delta}$$

where P is the Bhattacharyya distance

Σ_i is the covariance matrix for signature i

Σ_j is the covariance matrix for signature j

$\delta = \overline{x_i} - \overline{x_j}$

δ^T is the transpose of δ

$\overline{x_i}$ is the mean vector for signature i

$\overline{x_j}$ is the mean vector for signature j

$|\Sigma_i|$ is the determinant of the covariance matrix i

$|\Sigma_j|$ is the determinant of the covariance matrix j

Besides providing the capability to gather signature class statistics, combine class statistics, and calculate the Bhattacharyya distance, CLASTAT also provides the capability to:

1. Delete class record(s)

2. Print class data (name, size, means, covariance matrix, correlation matrix, and source field names) of selected classes on the line printer.

3.3.3 CLASTAT PDL

```
CLASTAT:BGNSEGMENT(MAIN)
CALL TITLE TO DISPLAY CLASTAT TITLE MENU
```

```
CALL FETEKFC TO SELECT FIELD/CLASS FILE
DO UNTIL NO FURTHER OPTION TO BE SELECTED
     CALL FETEKSO TO SELECT 1 OF 6 MAIN OPTIONS
     CASENTRY (FIELD STATS, COMBINE, DELETE CLASS,
               BHATTACHARYYA DISTANCE, PRINT FILE, END)
     CASE 1 (FIELD STATS)
          CALL FETEKSC TO SELECT COMPOSITE FILE
          CALL FETEKDF TO SELECT FIELD(S) FOR CLASS STATISTICS
          IF ONE OR MORE FIELDS CHOSEN
          THEN
               DO FROM 1 TO NUMBER OF FIELDS
                    CALL FEUTLFC TO RETRIEVE FIELD
                    CALL FEUTLLA TO DETERMINE MIN AND MAX LINES IN FIELD
                    COPY FIELD NAME INTO CLASS RECORD
                    DO FROM FIRST FIELD LINE TO LAST FIELD LINE
                         CALL FEUTLLA TO OBTAIN LINE SEGMENTS IN FIELD
                         DO FROM 1 TO NUMBER OF SEGMENTS
                            CALL FECLSUM TO ADD INTERMEDIATE SUMS
                         ENDDO
                    ENDDO
               ENDDO
               CALCULATE MEANS FOR EACH CHANNEL
               CALCULATE COVARIANCE MATRIX (UPPER HALF)
               CALCULATE CORRELATION MATRIX (LOWER HALF)
               ENTER CLASS NAME
               ENTER CLASS DESCRIPTION
          ENDIF
     CASE 2 (COMBINE)
          CALL FETEKDF TO SELECT CLASSES TO COMBINE INTO ONE
          IF ONE OR MORE CLASSES CHOSEN
          THEN CALL FEUTLFC TO RETRIEVE FIRST CLASS RECORD
               DO WHILE MORE RECORDS TO COMBINE AND NUM OF CHANNELS
                  ARE EQUAL
                    CALL FEUTLFC TO RETRIEVE NEXT CLASS RECORD
```

```
                IF NUMBER OF CHANNELS EQUAL
                THEN
                    COMBINE MEANS
                    COMBINE COVARIANCE MATRIX
                    ADD NUMBER OF PIXELS
                    COPY FIELD NAME(S) HISTORY
                ELSE
                    SET NUM OF CHAN EQ SW TO NO
                    CALL FETEKEM TO DISPLAY ERROR MESSAGE
                ENDIF
            ENDDO
            IF NUMBER OF CHANNELS EQUAL
            THEN
                CALCULATE RESULTANT CORRELATION MATRIX(LOWER HALF)
                ENTER NEW CLASS NAME
                ENTER NEW CLASS DESCRIPTION
            ENDIF
        ENDIF
    CASE 3 (DELETE CLASS)
        CALL FETEKFC TO SELECT CLASS(ES) TO DELETE
        CALL FEUTLFC TO DELETE
    CASE 4 (BHATTACHARYYA DISTANCE)
        CALL FETEKDF TO SELECT 2 CLASSES
        IF NUMBER OF CLASSES EQUAL 2
        THEN
            CALL FEUTLFC TO RETRIEVE 1ST CLASS
            CALL FEUTLFC TO RETRIEVE 2ND CLASS
            IF NUMBER OF CHANNELS EQUAL
            THEN CALCULATE BHATTACHARYYA DISTANCE
            ELSE CALL FETEKEM TO DISPLAY ERROR MESSAGE
            ENDTF
        ENDIF
```

```
     CASE 5 (PRINT FILE)
          CALL FETEKFC TO SELECT CLASSES TO PRINT
          IF ONE OR MORE CLASSES CHOSEN
          THEN
               DO FROM 1 TO NUMBER OF CLASSES
                    CALL FEUTLFC TO RETRIEVE CLASS RECORD
                    PRINT NAME,MEANS,COV/COR MATRIX,AND FIELD HISTORY
               ENDDO
               CALL Q9DISPO TO PASS PRINT FILE TO SYSTEM
          ENDIF
     CASE 6 (END)
          SET NO FURTHER OPTIONS SW
     ENDCASE
ENDDO
ENDSEGMENT
```

3.3.4 Subroutine Description

3.3.4.1 Subroutine FETEKCL

For a description, see section 3.2.4.4.

3.3.4.2 Subroutine FETEKDF

For a description, see section 3.2.4.5.

3.3.4.3 Subroutine FETEKEM

For a description, see section 3.2.4.6.

3.3.4.4 Subroutine FETEKFC

For a description, see section 3.2.4.7.

3.3.4.5 Subroutine FETEKSC

For a description, see section 3.2.4.8.

3.3.4.6 Subroutine FETEKSO

For a description, see section 3.2.4.11.

3.3.4.7 Subroutine FEUTLFC

For a description, see section 3.2.4.12.

3.3.4.8 Subroutine FEUTLLA

For a description, see section 3.2.4.13.

3.3.4.9 Subroutine SYMIN

For a description, see section 3.2.4.14.

3.4 CLUSTER PROCESSING MODULE

CLUSTER embodies an iterative unsupervised classification (clustering) process based on Ball and Hall's ISODATA (Iterative Self-Organizing Data Analysis Techniques A) algorithm (Ref. 1). The algorithm makes multiple passes through the data, assigning data to clusters, and splitting or combining the clusters so formed in a sequence determined by the user.

3.4.1 User Information

The user is first requested to specify a composite image containing at least two channels, and then to select fields within this image. CLUSTER forms the rectangular hull of the set of fields and it is the data in this area which is grouped into clusters. If the user has specified one or more COMTAL displays in the LOGON procedure, he may then elect to display the image to be clustered. In any event, the output (clustered) image to be created must be named. The name can also be annotated or described with up to 40 characters.

The user is then presented with an option menu from which the subsequent computational path is selected. The PM automatically returns to this menu at the appropriate points in the computation. In general, the "Cluster" option cannot be exercised until starting vectors have been specified, and the "Cluster Map" option cannot be exercised until clustering has taken place.

The "Modify Parameters" option enables the user to review the values of the eleven parameters which are used at various points in the computation and to specify the sequence of cluster splitting and cluster combining iterations. The eleven parameters are initialized to default

values when the PM is called, and the split/combine sequence is empty, that is if this sequence is not changed by the user, data would be assigned to clusters and the clustering process would terminate pending further instructions from the user. Each of the parameters has a maximum allowable value and if the user attempts to enter a value greater than the maximum, the message requesting the parameter value is repeated. Clustering is by its nature an interactive process and a certain amount of experimentation with the parameters is necessary to obtain optimal results.

The "Starting Vectors" option enables the user to specify cluster centers for the initial assignment of data to clusters. There are three possibilities: "Zero" or self-generated, which selects a single starting vector consisting of zeros in all channels; "New," which allows the user to select up to 50 previously defined classes as starting vectors; and "Old" which defines the starting vectors as the clusters determined during the immediately preceding cluster run of the present DIAL session. The "Old" option cannot be exercised until the "Cluster" option has been exercised at least once.

The "Cluster" option instructs the PM to perform the clustering computation. In the first pass through the data points are assigned to the nearest cluster according to one of two distance measures; unweighted Euclidean if IDISF = 1, and L_1 (sum of absolute values) if IDISF = 2. The subsequent computation depends on the split/combine sequence and the value of P. If P > 0, the program will perform the iteration cycle of splitting clusters and reassigning the data points to clusters until P x 100 percent of the clusters are stable, or PN iterations have taken place, at which time control is passed to the split/combine sequence. If P = 0, the initial cluster splitting is bypassed and control is passed to the split/combine sequence after the initial assignment of pixels to clusters. In either case, if the split/combine sequence is

empty, no further clustering computation takes place. After each iteration, the resulting cluster centers and channel variances are available for display. After the last iteration of a given sequence, cluster populations before and after thresholding and the distances between cluster centers and cluster means are displayed. At several points in the computation, the process pauses to allow the user to make a hard copy of the Tektronix display. Computation resumes when the user enters (CR).

Once an output (clustered) image has been created in the "Cluster" option, the "Results/Cluster Map" option enables the user to display a pseudo-color cluster map on one of the COMTAL displays, to display a portion of the clustered image on the Tektronix display in which each cluster is represented by a character chosen by the user, and to list the numerical clustering results (percent of the data points in each cluster, etc.).

Finally, the "Exit" option terminates the PM . If the Cluster PM is called again during the same terminal session (that is, without an intervening LOGOFF), the clustering parameters are set to their default values and no cluster means are available for the "Old" suboption of the "Selec Starting Vectors" option, but the names of any output images are saved, so that new names must be chosen for subsequent output images.

The Tektronix displays created in a representative session are shown in Figures 3.4-1 through 3.4-13. Figure 3.4-1 shows the first two menus the user encounters. Composite-scene-file ERIMSYN and associated field-class file FCERIM were selected. Figure 3.4-2 is the display after fields 1, 2 and 3 were selected and the "Drop Fields" option exercised. The asterisks indicate that the corresponding fields have been selected; in this run no fields were dropped subsequent to selection. Figure 3.4-3 displays the values of the clustering parameters after T1, T2 and R2 were changed from their default values to

```
CLUSTER      12/05/75  10.03.12.
UNSUPERVISED CLASSIFICATION BY A VERSION OF HALL AND BALL'S ISODATA ALGORITHM

     TO SELECT A COMPOSITE-SCENE-FILE TO BE USED IN CLUSTERING
      -ENTER COMPOSITE-SCENE-FILE NAME
      -OR (CR) TO DISPLAY COMPOSITE-SCENE-FILE LSIT
    @ ERIMSYN


          TO SELECT FIELD/CLASS-DATA-FILE TO BE USED-

           -ENTER FIELD/CLASS-DATA-FILE NAME
           -OR (CR) TO DISPLAY FIELD/CLASS-DATA-FILE LIST
           @ FCERIM
```

Figure 3.4-1 CLUSTER Composite Scene and Field/Class-Data-File Selection Menu

```
                                    DROP FIELD(S)

SELECTED  LINE NO.  ----------FIELD NAME----------  ----------DESCRIPTION----------  AREAL LINEAR  NUMBER OF PIXELS  LINE NO.
                    LINE -L1-- -L2-- -L3-- -L4-- -L5-- -L6-- -L7-- -L8-- -L9-- -L10- -L11- -L12- -L13-
                    PIXEL-P1-- -P2-- -P3-- -P4-- -P5-- -P6-- -P7-- -P8-- -P9-- -P10- -P11- -P12- -P13-

    *     1. WOODS2                          WOODS 2                                  AREAL          7816    1.
                      740   899   886   806   760
                      107   117   187   167   133

    *     2. WOODS1                          WOODS 1                                  AREAL         28212    2.
                      698   643   604   735   876   885   831
                      213   260   366   335   372   275   256

    *     3. VEGETATION1                     VEGETION 1                               AREAL          8398    3.
                      830   829   634   630   812   818
                       34    12    14    54    57    46

ENTER LINE NUMBER(S) TO  DROP  AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM   1 TO   3 OR (CR)--
```

Figure 3.4-2 Display of Selected Fields Data

```
THE CURRENT VALUES OF THE INITIAL CLUSTERING PARAMETERS ARE
        1. T1       = 10.0
        2. T2       =  5.0
        3. NMIN     =  30
        4. NUMMAX   =  60
        5. SEP      =  1.0
        6. ISODAT   =   1
        7. IDISF    =   2
        8. P        =  0.0
        9. R2       =  100.
       10. PMAX     =  10
       11. PN       =   1
       12. SPLIT/COMBINE SEQUENCE = SSSCS

-FOR THE DESCRIPTION OF A PARAMETER, OR TO CHANGE ITS VALUE,
 ENTER ITS NUMBER OR (CR) IF NO VALUES TO CHANGE
```

Figure 3.4-3 CLUSTER Initial Parameters Menu

the values indicated, and a split/combine sequence of SSSCS was specified. The "Zero" starting vector option was chosen, as Figure 3.4-4 indicates, and the clustering computation proper initiated. Figures 3.4-5 through 3.4-10 show the evolution of the clusters through the course of the specified split/combine sequence. Figure 3.4-11 gives a summary of the cluster populations before and after clusters having fewer than the minimum number of pixels are eliminated (in the present case none was eliminated). Finally, Figures 3.4-12 and -13 illustrate summary reports available in the "Reports/Cluster Map" option. (Of course, the actual cluster map which is displayed on one of the COMTALs is not available.) Not included in the group of figures are displays which report the percent of the image classified at 10% intervals, which keeps the user informed about the progress of the computation; displays which give the cluster number and channel of clusters which have been split, and the cluster number of clusters which have been merged; and a summary of the L_1 distances between cluster means and centers and minimum distance statistics.

3.4.2 Engineering Description

As mentioned in Section 3.4.1, the CLUSTER PM embodies a version of Ball and Hall's ISODATA algorithm, a method of unsupervised pattern classification. The method is iterative, making a series of passes through the data to assign the data points (pixels) to clusters on the basis of one of two possible distance measures, and a sequence of splitting or combining of clusters so formed, the cycle of computations being dependent on parameters chosen by the user. The region to be clustered in the present version of CLUSTER is the rectangular hull of the fields within the composite image designated by the user. The composite image must contain at least two channels, that is each data point considered as a vector must have at least two dimensions. All

STARTING VECTORS (CLUSTER CENTERS)

CHANNEL	CLUSTER 1
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00

TO SEE NEXT GROUP OF STARTING VECTORS ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-4 CLUSTER Starting Vectors Display

INTERIM CLUSTER STATISTICS

CLUSTER 1

CHANNEL	MEAN	ST.DEV
1	101.47	11.65
2	62.56	18.39
3	52.04	17.22
4	101.43	15.98
5	94.84	18.16
6	68.25	15.88

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-5 CLUSTER Interim Statistics Display, First Pass

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV
1	110.99	11.16	94.27	4.87
2	79.65	14.21	49.62	7.20
3	65.25	18.21	42.07	6.25
4	107.88	16.23	96.56	13.94
5	109.55	15.48	83.72	10.52
6	78.67	18.67	60.38	5.97

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-6 CLUSTER Interim Statistics Display, Second Pass

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2		CLUSTER 3		CLUSTER 4	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV
1	116.98	13.40	94.73	4.98	108.92	5.91	94.55	5.11
2	88.38	17.08	51.47	8.47	75.44	7.60	50.51	8.46
3	78.72	20.71	42.82	6.25	58.05	7.63	42.61	6.59
4	100.99	14.08	106.50	7.22	115.90	14.51	84.19	9.77
5	119.86	13.89	85.42	10.01	106.21	10.85	82.33	10.32
6	97.76	14.56	60.47	5.51	66.82	6.33	60.61	5.90

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-7 CLUSTER Interim Statistics, Third Pass

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2		CLUSTER 3		CLUSTER 4		CLUSTER 5		CLUSTER 6	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV
1	127.67	13.10	96.54	4.50	108.97	5.84	95.40	4.73	111.81	6.86	106.88	5.66
2	100.42	18.39	53.90	7.26	76.92	6.54	52.88	7.30	83.40	7.72	78.10	6.88
3	96.87	19.77	43.83	5.50	55.82	5.81	43.91	5.97	68.06	5.97	59.23	6.29
4	96.77	12.12	108.66	7.30	128.61	7.53	85.44	8.54	103.52	13.52	102.47	9.06
5	126.99	13.92	92.74	6.04	111.29	7.56	89.60	5.48	119.55	8.02	100.31	10.52
6	107.25	14.77	61.82	5.62	66.91	8.38	61.94	5.98	92.37	10.83	71.18	8.73

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-8a CLUSTER Interim Statistics, Fourth Pass

INTERIM CLUSTER STATISTICS

	CLUSTER 7		CLUSTER 8	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV
1	93.08	4.92	93.28	4.65
2	46.78	7.91	47.99	7.79
3	40.50	6.46	40.62	6.06
4	81.13	10.36	106.86	7.31
5	73.36	7.15	77.29	6.74
6	58.74	5.40	58.64	4.86

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-8b CLUSTER Interim Statistics, Fourth Pass (continued)

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2		CLUSTER 3		CLUSTER 4		CLUSTER 5	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV
1	127.07	12.98	96.60	4.88	109.17	5.46	100.31	6.12	88.38	4.36
2	99.80	18.03	55.44	6.90	77.06	6.99	76.92	8.36	45.71	7.80
3	96.07	20.28	45.30	5.66	55.76	6.02	62.86	7.32	30.36	5.73
4	96.88	11.88	99.30	12.22	127.80	8.17	108.62	11.11	93.45	14.60
5	127.81	12.85	90.68	6.45	111.64	8.21	106.24	12.61	76.95	7.75
6	107.89	13.78	62.41	5.33	66.93	8.99	78.53	12.11	57.90	4.50

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-9 CLUSTER Interim Statistics, Fifth Pass

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2		CLUSTER 3		CLUSTER 4		CLUSTER 5		CLUSTER 6	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV
1	131.29	7.32	97.03	4.86	109.24	5.94	108.87	6.39	91.97	3.98	121.10	6.89
2	104.24	9.82	56.62	6.80	77.06	6.20	79.92	8.52	45.19	6.43	92.11	8.20
3	105.43	9.15	45.79	5.35	55.65	6.64	64.95	7.88	30.64	5.21	83.68	7.11
4	95.44	11.09	109.17	6.82	127.82	8.66	104.52	11.27	104.78	7.22	97.88	11.66
5	129.52	11.16	91.54	7.34	111.57	6.11	117.36	6.39	78.12	8.46	125.20	9.41
6	111.91	14.06	62.60	5.44	66.32	7.86	84.05	10.26	57.61	4.20	106.54	12.95

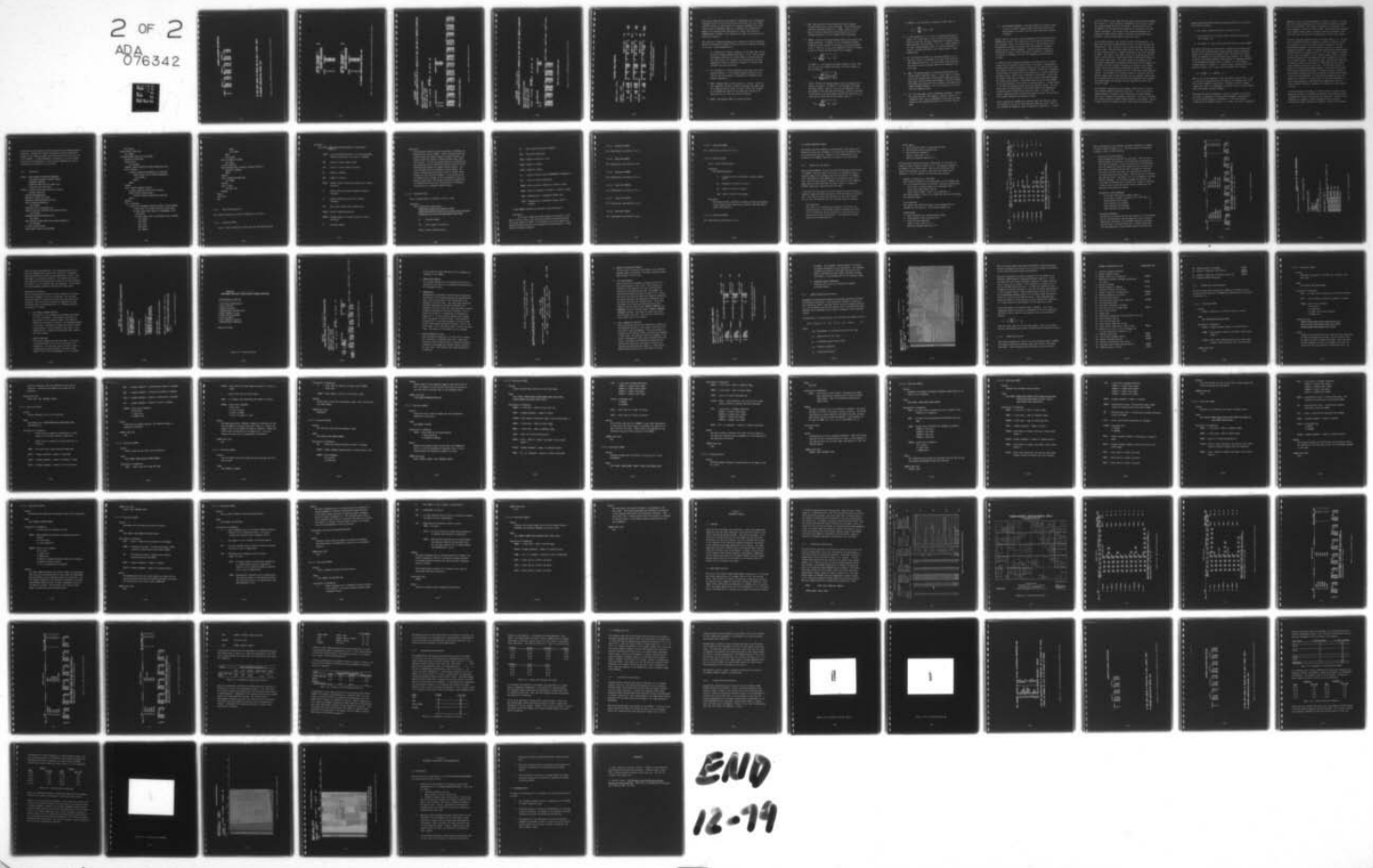
TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-10a CLUSTER Interim Statistics, Sixth Pass

AD-A076 342 IBM FEDERAL SYSTEMS DIV GAITHERSBURG MD F/G 5/8
INTERACTIVE DIGITAL IMAGE PROCESSING INVESTIGATION.(U)
DEC 78 W C RICE , J S SHIPMAN , R J SPIELER DAAK70-77-C-0166
UNCLASSIFIED ETL-0172 NL

2 OF 2
ADA 076342



END
12-79

INTERIM CLUSTER STATISTICS

	CLUSTER 7		CLUSTER 8		CLUSTER 9	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV
1	92.84	4.27	107.96	5.30	96.83	4.71
2	45.28	6.78	72.38	6.54	55.71	6.53
3	39.28	5.60	60.84	6.39	45.86	5.50
4	79.23	9.67	102.08	10.17	89.51	8.55
5	75.43	8.44	95.36	8.17	89.24	7.27
6	58.08	4.43	72.29	9.82	62.84	5.64

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-10b CLUSTER Interim Statistics, Sixth Pass (continued)

MINPOP (PN+NCHAN) = 7
NO. OF CLUSTERS = 9

CLUSTER POPULATIONS

CLUSTER	POPULATION
1	2458
2	17364
3	11811
4	9568
5	18060
6	5767
7	12361
8	9798
9	18899

MINPOP (PN+NCHAN) = 7
NO. OF CLUSTERS = 9

CLUSTER POPULATIONS

CLUSTER	POPULATION
1	2458
2	17354
3	11811
4	9568
5	18060
6	5767
7	12361
8	9798
9	18899

TO RESUME COMPUTATION ENTER (CR)

Figure 3.4-11 CLUSTER Population Statistics Before and Eliminating Small Clusters

CLUSTER 12/06/73 10.26.23.

UNSUPERVISED CLASSIFICATION BY A VERSION OF HALL AND BALL'S ISODATA ALGORITHM

OVERALL CLUSTER RESULTS FOR SUBIMAGE

COMPOSITE NAME------ERIMSYN

RESULTS IMAGE NAME--CLTEST

SUBIMAGE

PIX MIN 12 PIX MAX 372 LINE MIN 604 LINE MAX 899

	CLASS	CLUSTER NAME	CHARACTER POPULATION
1	1		2458
2	2		17354
3	3		11811
4	4		9568
5	5		18060
6	6		5767

1		2		3		4		5		6	
MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS
131.2897	7.3191	97.0871	4.8614	109.2423	5.0369	108.8693	6.3906	91.9884	3.9787	121.1046	6.8853
104.2404	9.8228	58.6158	6.7984	77.0577	6.1994	79.9230	8.5836	45.1911	6.4291	98.1150	8.2876
105.4300	9.1504	45.7915	5.3455	55.5464	5.6411	64.9458	7.2759	38.6415	5.2051	83.6778	7.1149
96.4406	11.0923	109.1707	6.6238	127.8173	8.6471	104.5244	11.2719	104.7213	7.2217	97.8807	11.6549
129.5203	11.1564	91.5417	7.3431	111.5719	6.1145	117.3580	6.3924	78.1186	8.4627	125.1959	9.4078
111.9129	14.0594	62.5963	5.4376	66.3172	7.8551	84.0472	10.2599	57.6077	4.2037	106.6372	12.9526

ENTER (CR) TO GET NEXT PAGE OF RESULTS

Figure 3.4-12a CLUSTER Summary Statistics

CLUSTER 12/05/78 10.26.38.

UNSUPERVISED CLASSIFICATION BY A VERSION OF HALL AND BALL'S ISODATA ALGORITHM

OVERALL CLUSTER RESULTS FOR SUBIMAGE

COMPOSITE NAME------ERIMSYN

RESULTS IMAGE NAME--CLTEST

SUBIMAGE

PIX MIN 12 PIX MAX 372 LINE MIN 604 LINE MAX 899

	CLASS	CLUSTER NAME	CHARACTER	POPULATION
1	7			12361
2	8			9798
3	9			18899

1		2		3		4		5		6	
MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS
92.2441	4.2878	107.9693	5.2989	96.8336	4.7050						
45.2774	6.7821	72.3805	6.5379	55.7079	6.5262						
39.2809	5.6986	60.8425	6.3850	45.8605	5.5040						
79.2296	9.5724	102.0811	10.1651	89.6109	8.5505						
75.4340	8.4422	95.3581	8.1664	89.2368	7.2721						
58.0792	4.4344	72.2860	9.8220	62.8376	5.6389						

ENTER (CR) TO DISPLAY RESULTS MENU

Figure 3.4-12b CLUSTER Summary Statistics (continued)

CLUSTER FIELD RESULTS

COMPOSITE IMAGE-----EPIMSYN

THRESHOLD = 0.0000

FIELD NAME----------WOODS2 NUMBER OF PIXELS 7816

CULSTER/NUMBER			NUMBER IN CLASS		AND PERCENT OF FIELD			
1	6	.0768	2	3044	38.9468	3	38	.4862
4	74	.9468	5	2224	28.4545	6	5	.0640
7	796	10.1842	8	32	.4094	9	1595	20.4069
10	2	.0256						

FIELD NAME----------WOODS1 NUMBER OF PIXELS 28212

CULSTER/NUMBER			NUMBER IN CLASS		AND PERCENT OF FIELD			
1	0	0.0000	2	4957	17.5706	3	20	.0709
4	3	.0106	5	10280	36.4384	6	0	0.0000
7	6416	22.7421	8	47	.1666	9	6489	23.0009
10	0	0.0000						

FIELD NAME----------VEGETATION1 NUMBER OF PIXELS 8398

CULSTER/NUMBER			NUMBER IN CLASS		AND PERCENT OF FIELD			
1	11	.1310	2	32	.3810	3	7388	87.9733
4	169	2.0124	5	0	0.0000	6	13	.1548
7	0	0.0000	8	777	9.2522	9	0	0.0000
10	8	.0953						

TO ADVANCE TO NEXT PAGE OF FIELD RESUTLS ENTER (CR)

OR, TO TERMINATE FIELD RESULTS ENTER X

Figure 3.4-13 CLUSTER Field Statistics

such vectors must have the same number of components, and corresponding components of all of the vectors must be of the same type (e.g. sensor intensity values in a given band), but different components of a given vector may be of different types (e.g. components one through four might be the respective MSS intensities of a pixel (data point) in LANDSAT bands 4 through 7, and component five might be the elevation of the pixel in meters).

The course of a clustering computation is governed by twelve parameters which are initialized to default values, but whose values may be changed by the user. These parameters are:

1. T1 - Threshold for cluster splitting, in the same units as the respective channel standard deviations. If for a given cluster the standard deviation of a given channel is greater than T1, then that cluster is a candidate for splitting (in the split computation) along the channel in question, if certain other conditions are met (see below).

2. T2 - Threshold for cluster combining in the same units as the distance measure. If the distance between clusters is less than T2, the two clusters are candidates for merging in the combine computation.

3. NMIN - Minimum number of data points in a cluster. After the last requested iteration, clusters with fewer than NMIN points are eliminated and the points in those clusters are assigned to the remaining clusters if the respective distances are less than R2, or to the null cluster otherwise.

4. NVMAX - The maximum number of clusters allowed.

5. SEP - The scale factor which multiplies the ith channel standard deviation in cluster splitting. The resulting clusters have respective means of $\mu_i \pm SEP*\sigma_i$, where μ_i is the mean of the ith channel before splitting, and σ_i is the standard deviation of the ith channel before splitting.

6. ISODAT - Selects the distance measure used in the cluster combining algorithm. If ISODAT = 0, the unweighted euclidean distance is used to define the distance Δ_{ij} between clusters i and j. That is, if μ_{ik} is the component of the k-th channel of the ith cluster and each cluster has n channels,

$$\Delta_{ij} = \sqrt{\sum_{k=1}^{n} (\mu_{ik} - \mu_{jk})^2}$$

If ISODAT = 1, the weighted euclidean distance is used. That is, if σ_{ik} is the standard deviation of the kth channel of the ith cluster,

$$\Delta_{ij} = \sqrt{\sum_{k=1}^{n} \left[\frac{\mu_{ik} - \mu_{jk}}{\sigma_{ik} * \sigma_{jk}} \right]^2}$$

7. IDISF - Selects the distance measure used in assigning data points to clusters. If IDISF = 1, the unweighted euclidean distance is used. That is, if x_{ik} is the component of the kth channel of the ith data point and m_{jk} is the kth component of the vector of the jth cluster centers, the distance D_{ij} between the ith point and the jth cluster center is

$$D_{ij} = \sqrt{\sum_{k=1}^{n} (x_{ik} - m_{jk})^2}$$

If IDISF = 2, the so-called L_1 distance is used, that is

$$P_{ij} = \sum_{k=1}^{n} |(x_{ik} - m_{jk})|$$

8. P - The proportion (0. < P < 1.0) of clusters which must be stable (i.e. do not split) in the "Initial Split Iteration" option in order for the split computation to terminate before PMAX iterations (see 10 below). If P = 0., control passes to the split combine sequence after the initial assignment of pixels to clusters and there is no initial series of split computations.

9. R2 - The distance threshold to determine whether or not a data point (pixel) is assigned to the null class after the last requested iteration. All data points whose distance to the nearest cluster is greater than R2 are assigned to the null class.

10. PMAX - The maximum number of iterations allowed under the "Initial Split Iteration" option. If more than P x 100 percent of the clusters split, another split computation takes place after the data points are assigned to the new clusters. After PMAX such iterations control passes to the input split/combine sequence whether or not P x 100 percent of the clusters have remained stable.

11. PN - Last pass small cluster elimination threshold. Clusters with fewer than PN + (the number of channels) points are eliminated, and a final reassignment of the points in those clusters to the remaining clusters or to the null class is made.

12. SPLIT/COMBINE SEQUENCE - Determines whether an attempt is made to split or combine (merge) clusters after data points have been assigned to clusters and the cluster means and variances recomputed.

Default values of the first eleven parameters are initialized when the CLUSTER PM is called. The values of T1, T2, and R2 are particularly data dependent, and it is to be expected that a certain amount of experimentation with data of interest will be necessary to determine optimal values of these parameters. The split/combine sequence is initialized as "empty," which means that no splitting or combining of clusters is attempted, but only the assignment of data points to clusters.

In addition to the clustering parameters, starting vectors or cluster centers must be specified; three options are provided. SeIf-generated starting vectors may be requested in which case one cluster center with zero values in all of the channels is selected. On the first assignment of data points to clusters all of the points are, of course, assigned to the same cluster. But if split iterations are specified, in most cases the single cluster will be split, and after several iterations meaningful clusters will develop. It has been found in practice that ISODATA is not very sensitive to the choice of starting vectors. A second option is to select as starting vectors previously defined classes. The third option uses the final values of the cluster means in the immediately preceding cluster computation as starting vectors. In effect, the present computation picks up where the previous one left off and allows split/combine sequences of indefinite length.

Before entering the CLUSTER PM a composite image (one having at least two channels) to be used in clustering must have been built. This is done through the INTERL PM, which is described in Section 3.1. Further,

a file of fields in that image must have been created using the FIELDEF PM, Section 3.2. Upon entering the CLUSTER PM, the user must specify the composite image and select the fields. The data points in the rectangular hull of the selected fields will be clustered in the subsequent computation. The values of the clustering parameters are changed from their default values, if desired, and starting vectors specified. These two steps may be done in any order.

In the normal procedure, the "cluster" option is selected next. As many lines (records) of image data as will fit are read from disk and stored in ECS. Then a line at a time is read from ECS, unpacked, and stored in core. For each pixel (data point) in the line, the distance to each existing cluster is computed according to the metric specified by IDISF. The index of the cluster closest to the pixel and the distances to that pixel are recorded and stored in interleaved fashion on disk as the output image. The output image may be thought of as a two channel image which corresponds pixel by pixel with the image to be clustered, the first channel containing the distance to the nearest cluster and the second channel containing the number of the nearest cluster. The process continues until all of the lines in ECS have been treated. If the image to be clustered cannot fit into ECS, the next group of image lines is read into ECS up to its capacity, and the process continued until all of the pixels of the image have been assigned. The channel means and variances are then computed for each of the clusters formed.

The subsequent computational path depends on the value of P and the split/combine sequence specified by the user. If P = 0, the split/combine sequence is tested on each iteration to determine whether a split (S) or combine (C) iteration is specified. In a split iteration, the cluster having the largest channel variance is determined. Two new cluster centers are formed from this cluster center by respectively

adding and subtracting SEP (channel standard deviation) to the mean of that channel, provided:

- The channel standard deviation is greater than T1;
- The population of the cluster under consideration is greater than 2*(NMIN + 1);
- The number of clusters after splitting would not exceed NVMMAX.

The cluster which has just been split is removed from consideration, and the cluster having the next largest channel variance determined, tested, and if the tests are passed, split. The process continues until all candidates for splitting have been examined. In a combine iteration, the distance between cluster centers is computed according to the unweighted euclidean metric if ISODAT = 0 or the weighted euclidean metric if ISODAT = 1. Clusters closer together than T2 are merged by forming a new cluster center according to the formula

$$m_j = \frac{n'}{n' + n''} \mu_j' + \frac{n''}{n' + n''} \mu_j'' \quad .$$

where m_j is the jth component of the new cluster center vector, μ_j' and μ_j'' are the jth channel means of the cluster to be merged, and n' and n" are their respective populations. Following a split or combine computation, pixels are reassigned to clusters, and new cluster channel means and channel variances computed.

Following the initial assignment of pixels to clusters, the cycle of splitting or combining of clusters and reassignment continues until the split/combine sequence is exhausted. If the split/combine sequences has the default values, i.e. is empty, the cycle is completed

immediately after the first assignment of pixels to clusters. At this point the cluster populations are tested and each cluster whose population is less than PN + (the number of channels) is eliminated, and a final assigment of pixels to clusters made. Those pixels whose distance to the nearest cluster center is greater than R2 are assigned to the null class, that is they are not considered to belong to any cluster.

The other principal computation path is followed where P > 0. In that case, following the initial assignment of pixels to clusters, a cycle of iterations is carried out before control is passed to the input split/combine sequence. In each iteration, the ratio of clusters having more than PN + (number of channels) pixels whose maximum channel standard deviation is greater than T1, to the total number of clusters in that class, is computed. If the ratio is greater than P, a cluster splitting computation is performed and pixels reassigned to the new set of cluster centers. The iteration cycle continues until the ratio of unstable clusters is less than P, or PMAX iterations have taken place, whichever condition occurs first. At this point control is passed to the input split/combine sequence. The initial split iteration option is particularly useful in dealing with data for which a split/combine sequence which can be expected to produce useful results has not yet been developed. In such cases the algorithm allows the formation of clusters to continue until the situation stabilizes, at which time examination of the results may suggest what course of action (further splitting, combining, or termination of the process) to follow.

To assist the user in deciding on further courses of action, cluster means and variances are available for display on the Tektronix (and consequently for hard copying) after each iteration. After the final iteration of a sequence, cluster populations before and after elimination of small clusters are available, as well as the distance

between the cluster means and cluster centers and the minimum distance statistics. Through the "Cluster Map Reports" option a pseudocolor display of the clustered image (the cluster map) can be put up on one of the COMTALS. A fixed assignment of pseudocolor to cluster number is built into the subroutine. Cluster report summaries can also be displayed on the Tektronix in this option.

3.4.3 CLUSTER PDL

```
INPUTS  - USER SELECTED CLUSTERING PARAMETERS
          AND STARTING VECTORS (ENTERED THROUGH
          TEKTRONIX TERMINAL)
        - COMPOSITE IMAGE DATA SET (FROM DISK)
        - FIELD DATA SET (FROM DISK)
OUTPUTS - CLUSTER OUTPUT IMAGE DATA SET (TO DISK)
        - CLUSTER STATISTICS
     CLUSTER:BGNSEGMENT(MAIN)
     TEKDISPLAY CLUSTER TITLE MENU
     TEKDISPLAY COMPOSITE-SCENE-FILE LIST
     SELECT COMPOSITE-SCENE-FILE
          CALL FETEKFO
     TEKDISPLAY FIELD -FILE-NAME LIST
     SELECT FIELDS FOR CLUSTERING AND POSSIBLE DISPLAY
          CALL FETEKDF
     DETERMINE MINIMUM RECTANGULAR HULL
          CALL RECFLD
     READ COMPOSITE IMAGE LABEL AND VALIDATE SUBIMAGE TO
          BE CLUSTERED
     IF IMAGE DISPLAY OPTION
     THEN DISPLAY IMAGE TO BE CLUSTERED
```

```
     CALL DSPCLA
CREATE OUTPUT IMAGE FILE
     CALL KREARI
DO WHILE ANOTHER OPTION TO BE SELECTED
     TEKDISPLAY OPTION MENU
     SELECT OPTION
          CALL FETEKSO
     CASENTRY (MODIFY,STARTING VECTORS,CLUSTER,MAP,EXIT)
     CASE 1 (MODIFY)
          DO WHILE CLUSTERING PARAMETERS TO BE MODIFIED
               SELECT OPTION (ONE OF TWELVE PARAMETERS)
                 CALL FETEKSO
               MODIFY
          ENDDO
     ENDCASE
     CASE 2 (SELECT STARTING VECTORS)
          DO WHILE STARTING VECTORS TO BE SELECTED
          SELECT OPTION (ZERO,OLD,NEW)
               STARTING VECTORS SELECTED AND DISPLAYED
          ENDDO
     ENDCASE
     CASE 3 (CLUSTER)
          DO WHILE SPLIT/COMBINE ITERATIONS REMAIN TO BE PERFORMED
               ASSIGN PIXELS TO CLUSTERS AND BUILD OUTPUT IMAGE
               DO WHILE IMAGE LINES REMAIN TO TRANSFERRED TO ECS
                 CALL FTLECS
                 DO WHILE IMAGE LINES IN ECS REMAIN TO BE CLUSTERED
                    CALL READEC
                    CALL UNPKF
                    CALL CLUS2
                    CALL PACKF
                    CALL WRITEC
```

```
                    ENDDO
                    CALL EMTECS
               ENDDO
               CALL DCLOSE
          SPLIT OR COMBINE CLUSTERS
               CALL CESCA
          IF LAST ITERATION
          THEN ELIMINATE SMALL CLUSTERS, REASSIGN PIXELS TO
               REMAINING CLUSTERS
               ENDDO
          ENDCASE
          CASE 4 (REPORTS,CLUSTER MAP)
               CALL RMENU
          ENDCASE
          CASE 5 (EXIT)
               SET EXIT FLAG
          ENDCASE
     ENDDO
     CALL FINIS
     END
```

3.4.4 Subroutine Description

The principal subroutines called by CLUSTER are as follows:

3.4.4.1 Subroutine CESCA

Title - Cluster elimination, splitting, and combining algorithm.

Parameters

CALL CESCA (ECHAR,VMP,VAR,ND,NVM,NMIN,T1,T2,SEP,ISODAT,
NVMMAX,IT)

ICHAR - Left justified Hollerith S or C which determines whether clusters are to be split or combined

VMP - Array of cluster channel means

VAR - Array of cluster channel variances

ND - Number of channels

NVM - Number of clusters

NVMIN - Minimum cluster population parameter for cluster splitting

T1 - Cluster splitting channel standard deviation threshold

T2 - Cluster combining intercluster distance threshold

SEP - New cluster channel mean scaling factor

ISODAT - Selects combining algorithm

NVMMAX - Maximum number of clusters allowed in cluster splitting

IT - Iteration number

Description

This subroutine performs cluster splitting or combining, depending on the value of ICHAR. Cluster splitting finds the cluster having the largest channel variance and splits the cluster along that channel, providing certain other conditions are met. The two new cluster centers are removed from the competition and the algorithm finds the cluster from the remaining group having the largest channel variance. The cycle continues until no candidate clusters remain. The cluster combining algorithm finds a pair of clusters whose distance is less than the threshold. A new cluster center is formed from the average of the two weighted by their respective populations. The merged clusters are removed from the competition and the cycle repeated with the remaining clusters until no candidate clusters remain.

3.4.4.2 Subroutine CLUS2

Title - Assigns pixels to clusters a line at a time

Parameters

```
CALL CLUS2(IT,ITL,IDISF,R2,NVLL)
     COMMON/RESIMG/NAMER,NBITR,NWPSR,NLV,NPIXC
     COMMON/PROCPIEM/KOPTP,NCHAN,NCLUS,NSLC,NELC,NSPC,LEPC,NWECS
     COMMON/STATS/VM,VMP,VAR,NVG,RMINM,RMINV,VSUM1,VSUM2
```

IT - Iteration number

ITL - Total number of iterations

IDISF - Selects distance metric

R2 - Last iteration distance threshold

NULL - Null class population

NPIXC - Number of pixels in a line

NCHAN - Number of channels

NCLUS - Number of clusters

VM - Array of cluster centers (NCHAN*NCLUS components)

NVG - Array of cluster populations

RMINM - Array of means of distance to nearest cluster

RMINV - Array of variances of distance to nearest cluster

VSUM1 - Working array to accumulate channel sums

VSUM2 - Working array to accumulate channel sums of squares.

(Other COMMON variables not required in this subroutine.)

Description

For a line of image data CLUS2 computes the distance of each pixel in turn to each of the clusters and enters the minimum distance and cluster number for which it is attained in the output image array. Minimum distance statistics are accumulated and running sums of channel means and variances computed.

3.4.4.3 Subroutine DSPCLA

For a description, see Section 3.5.4.3.

3.4.4.4 Subroutine EMTECS

For a description, see Section 3.5.4.5.

3.4.4.5 Subroutine FETEKDF

For a description, see Section 3.2.4.5.

3.4.4.6 Subroutine FETEKFC

For a description, see Section 3.2.4.7.

3.4.4.7 Subroutine FEUTLFC

For a description, see Section 3.2.4.12.

3.4.4.8 Subroutine FILECS

For a description, see Section 3.5.4.6.

3.4.4.9 Subroutine KREARI

For a description, see Section 3.5.4.7.

3.4.4.10 Subroutine PACK

Title - Array packing routine.

Parameters

CALL PACK(V,ND,NV,IND)

V - On input, array to be packed; on output, packed array.

ND - Dimension of vectors in array V.

NV - Number of vectors in array V.

IND - Index of vector to be removed.

Description

PACK forms an array of ND*(NV-1) elements in which all elements of the original array whose index is greater than IND* ND are moved up ND positions.

3.4.4.11 Subroutine RECFLD

For a description, see Section 3.5.4.11.

3.5 MAXLIK PROCESSING MODULE

The maximum likelihood (MAXLIK) processing module (PM) assigns each observation vector in a subimage to the class with the smallest value of the likelihood function. Results of the classification can be displayed on the COMTAL, Tektronix or printed on the line printer.

3.5.1 MAXLIK User Information

Before entering MAXLIK, the user must have defined fields (see Section 3.2 FIELDEF), defined classes (see Section 3.3 CLASTAT) and have a composite image on the assigned disk pack (see Section 3.1 INTERL). After completing the above MAXLIK can be initialized in one of two ways. First by just typing in "MAXLIK" and second, if the composite image name and field/class data set name is known, by typing in "MAXLIK, Image Name, Field/Class Data Set Name."

If the first way were used the PM would request the user to select a composite image and field/class data set from the library on the disk pack. Once MAXLIK has been initiated and the data sets attached, the user will be presented with the following requests and menus.

Field Selection

The fields to be classified are selected at this time, all pixels interior to the minimum rectangle enclosing the fields will be classified, and the population of each class will be calculated for each field selected. The selection procedure begins with the menu given below.

Select Option

1. Select Field(s) Fields to classified--25 Max--
2. Drop Field(s) From the selected list
3. Field Selection completed

(Enter a value from 1 to 3) 1

Where the response should be a "1."

The second menu presented contains a description of the fields, an example of which is given in Figure 3.5.1. The required response is the numbers of the fields wanted. When all the fields have been selected and reviewed, the select option menu will appear and a response of "3" will terminate the field selection process.

Display of Subimage to be Classified

This request determines if one band/channel of the subimage that is to be classified should be displayed. The menu is given below.

Do you want to display image to be classified (Y/N)? Y

Enter input image display name B1

Enter channel number 1 thru 3 to be displayed 3

The channel number n refers to nth image that was used in building the composite image.

Class Selection

The classes into which every pixel in the subimage will be assigned are now selected. The procedure begins with

SELECT OPTION

1. Select Class(es) for classification--10 Max--
2. Drop Class(es) from the selected list
3. Class selection completed

(Enter a value from 1 to 3) 1

Where the response should be a "1."

SELECT FIELD(S)

SELECTED LINE NO.	FIELD NAME	DESCRIPTION	AREAL LINEAR	NUMBER OF PIXELS	LINE NO.
	LINE -L1- -L2- -L3- -L4- -L5- -L6- -L7- -L8- -L9- -L10- -L11- -L12- -L13-				
	PIXEL-P1- -P2- -P3- -P4- -P5- -P6- -P7- -P8- -P9- -P10- -P11- -P12- -P13-				
1.	TREESKY	TREE SKY	AREAL	972	1.
	297 296 349				
	289 324 307				
2.	TREEROAD	TREE ROAD	AREAL	1107	2.
	426 479 473				
	288 308 266				
3.	TREEGRASS	TREE GRASS	AREAL	1048	3.
	418 470 462 416				
	271 221 200 263				
4.	TREEWHOLE	WHOLE TREE FIELD	AREAL	142320	4.
	29 31 444 422				
	80 438 428 82				
5.	DOT BLUE		AREAL	23	5.
	430 431 436 436 433				
	440 442 441 438 439				
6.	TREETRUNK	TREE TRUNK LINE	LINEAR	132	6.
	179 205 226 259 295				
	186 189 188 183 177				
7.	TREEBRANCH	TREE BRANCHES	AREAL	790	7.
	120 172 169 162 128 149 126				
	167 183 202 187 202 186 186				

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 1 TO 7 OR (CR)--

Figure 3.5-1 Field Description

Next a description of the available classes is presented, an example of which is given in Figure 3.5.2. The class selection termination proceeds as that of field selection.

Selection of Class Parameters

Three parameters are selected for each class. They are color, apriori weight and character: color selection is required and the others are optional. Color is obtained by first presenting a set of pseudocolor tables and asking the user to select one. This table is displayed and the user is requested to position the cursor over the color that is to represent the class and to press the selection done button. This is done for all classes plus the null class. See Figure 3.5.3 for an example of the menu and the responses. For the apriori weight and character the class name is displayed with a request for a weight or character. A typical case is given below where apriori weights were not wanted but characters were wanted.

```
SELECTION OF CLASS PARAMETERS
     Do you want class apriori weights (Y/N)?  N
     Do you want to assign a character to a class (Y/N)?  Y
     Enter character for-treesky                          S
     Enter character for-treeroad                         R
     Enter character for-treegrass                        G
     Enter character for-null class                       N
```

Processing Parameters

The next set of requests are for how the data is to be processed and for describing the class map image that will be created. Classically, the kernel of the maximum likelihood classifier uses the class covariance matrix, but to reduce computation time approximations to the covariance matrix have been used.

SELECT CLASS(ES)

SELECTED	LINE NO.	CLASS NAME	DESCRIPTION	NUM. OF CHANNELS	/NUMBER /OF PIXELS	/LINE /NO.
	1.	TREESKY	TREE SKY	3	972	1.
	2.	TREEROAD	TREE ROAD	3	1107	2.
	3.	TREEGRASS	TREE GRASS	3	1048	3.
	4.	TREEROADGRASS	TREE-ROAD GRASS	3	2155	4.
	5.	TREESKYROAD	TREE-SKY ROAD	3	2079	5.
	6.	TREESKYGRASS	TREE-SKY GRASS	3	2020	6.

	LINE NO. 1		LINE NO. 2		LINE NO. 3		LINE NO. 4		LINE NO. 5		LINE NO. 6	
CH	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV
1	180.08	5.82	161.38	10.23	68.63	32.78	116.28	52.21	170.13	12.59	122.26	60.63
2	173.43	5.88	116.76	7.88	32.96	17.13	76.00	43.93	143.25	29.14	100.55	71.39
3	183.93	5.99	143.83	9.47	70.20	30.86	108.02	43.17	162.58	21.56	124.93	61.17

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 1 TO 6 OR (CR)--1,2,3

Figure 3.5-2 Class Prescription

```
                                SELECTION OF CLASS PARAMETERS
ENTER INPUT IMAGE DISPLAY NAME B1


                        SELECTION OF PSEUDOCOLOR TABLE


AVAILABLE PSEUDOCOLOR TABLES
--------- ----------- ------

 1 RAY A
 2 HOTEARTH2
 3 RAY C
 4 LINEAR A
 5 LINEAR B
 6 COLOR CONTOUR
ENTER TABLE NUMBER 3

DO YOU WANT TO VIEW ANOTHER TABLE (Y/N)! N


-------------------------------
SELECTED TABLE IS   RAY C

                    SELECTION OF COLOR FROM TABLE TO REPRESENT CLASS
POSITION CURSOR OVER DESIRED COLOR
FOR CLASS--TREESKY
PRESS SELECT OR DONE BUTTON
POSITION CURSOR OVER DESIRED COLOR
FOR CLASS--TREEROAD
PRESS SELECT OR DONE BUTTON
POSITION CURSOR OVER DESIRED COLOR
FOR CLASS--TREEGRASS
PRESS SELECT OR DONE BUTTON
POSITION CURSOR OVER DESIRED COLOR
FOR CLASS--NULL CLASS
PRESS SELECT OR DONE BUTTON
```

Figure 3.5-3 Class Pseudocolor

There are three approximations to the covariance matrix incorporated in MAXLIK, any of which can be selected. Processing modes describe where and when the processing will be done. Only mode number 1 is currently available. The name for the output class map and the A/N specification conform to the DIAL standards. See Figure 3.5-4 for a typical menu and responses. At this point the actual maximum likelihood classification takes place.

Presentation of Results

When the classification process has been completed, the results menu given in Figure 3.5-5 will be displayed. The user then enters the number of the option he wants and those results are presented. After the option selected has completed its task, the results menu is redisplayed until a 9, "Terminate Results Processing," is entered.

1. LIST OVERALL SUBIMAGE RESULTS

   MLC results for the subimage are displayed (see Figure 3.5-6 for an example). The subimage coordinates are with respect to the composite image. The population numbers are the number of pixels in the subimage assigned to the class. The means and sigmas are means and standard deviations of all the pixels in that class. This example was for a composite image having three channels and three classes.

2. DISPLAY CLASS MAP

   This option displays the class map image. Each pixel is displayed in the color of the class that it was assigned to. This can also include the null class if thresholding has been performed. The user is also asked if the color/class assignment is to be reviewed.

```
MAXLIK          12 01 78  08.49.57.
PERFORMS MAXIMUM LIKELIHOOD CLASSIFICATION


PROCESSING OPTIONS FOR MLC KERNEL
---------
 1 USE COVARIANCE MATRIX
 2 USE DIAGONAL ELEMENTS
 3 USE EXPECTED VALUE OF TRACE
 4 USE IDENTITY MATRIX


ENTER OPTION NUMBER 1


PROCESSING MODES FOR MAXLIK
---------
 1 USE INTERACTIVE 6400
 2 PERFORM MLC VIA BATCH JOB ON 6400
 3 PERFORM MLC ON STARAN INTERACTIVELY
 4 PERFORM MLC ON STARAN VIA BATCH JOB


 ENTER MODE NUMBER 1

ENTER IMAGE NAME FOR OUTPUT CLASS MAPTESTMLC1


ENTER A/N SPEC FOR IMAGE (1 TO 40 CHAR), OR HIT (CR)

    CHARACTER          1         2         3         4
    COUNT....*1234567890123456789012345678901234567890

   A/N SPEC *
```

Figure 3.5-4 Processing Parameters

```
MAXLIK          12 01·7C  08.53.3C.
PERFORMS MAXIMUM LIKELIHOOD CLASSIFICATION

AVAILABLE RESULTS OPTIONS ARE
-----------------------------
1 LIST OVERALL SUBIMAGE RESULTS
2 DISPLAY CLASS MAP
3 ANNOTATE RUN RESULTS
4 THRESHOLD RESULT DISTANCE METRICS
5 ASSIGN CHARACTER TO CLASS
6 DISPLAY COMPOSITE SUBIMAGE
7 LIST FIELD RESULTS
8 LIST A SUBAREA OF CLASS MAP
9 TERMINATE RESULTS PROCESSING


ENTER OPTION NUMBER
```

Figure 3.5-5 Results Options

MAXLIK 12 01 78 08.51.59.

PERFORMS MAXIMUM LIKELIHOOD CLASSIFICATION

OVERALL-MLC RESULTS FOR SUBIMAGE

COMPOSITE NAME------BILL999

RESULTS IMAGE NAME--TESTMLC1

SUBIMAGE
PIX MIN 80 PIX MAX 438 LINE MIN 29 LINE MAX 479

		CLASS CLUSTER NAME	CHARACTER	POPULATION
CLASS	1	TREESKY	S	92186
CLASS	2	TREEROAD	R	17309
CLASS	3	TREEGRASS	G	52414

	CLASS 1		CLASS 2		CLASS 3		4		5		6	
	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS	MEANS	SIGMAS
CHANNEL 1	168.7701	18.3430	151.3416	23.5811	69.8246	45.1510						
CHANNEL 2	172.7533	16.8291	113.3965	18.9121	59.2981	48.6321						
CHANNEL 3	176.3019	18.3943	137.7579	22.6625	73.7334	46.7034						

ENTER (CR) TO DISPLAY RESULTS MENU

Figure 3.5-6 MLC Subimage Results

If yes, then the class name and the color assigned are displayed on the COMTAL.

3. ANNOTATE RUN RESULTS

Up to eighty characters of run annotation data can be entered and this data will be displayed and printed with all subsequent results.

4. THRESHOLDING

Thresholding is performed by calculating the cumulative distribution of the distance metrics and requesting the user to enter the percent of the distribution to be assigned to the null class. All pixels that exceed the threshold determined by the above information are assigned to the null class and a new class map is created having the same name as the prior class map. The requests and results of a computation are presented in Figure 3.5-7. In this case the request was to assign 51% of the pixels to the null class. This resulted in having 50.93% of the pixels assigned to the null class and the other pixels assigned as follows: 23.3% to the first class, 7.2% to the second class, 18.6% to the third class. The percent is with respect to the subimage.

5. ASSIGN CHARACTER TO CLASS

The class name is presented to the user with a request for a character to represent that class. Each class requires a unique character and if a duplicate character is entered, the program will request another character for that class. The characters are used when Option 8 is selected.

```
THIS ROUTINE THRESHOLDS THE DISTANCE METRIC IN THE RESULTS IMAGE
AND CREATES A NEW RESULTS IMAGE

THE THRESHOLD IS BASED UPON THE PERCENT OF PIXELS TO BE ASSIGNED TO THE NULL CLASS
ENTER 1 F.P. VALUE IN THE RANGE 0. ,100. EG( 6.5) 51.

                    THRESHOLD =  51.0000
 82460  PIXELS IN NULL CLASS      50.9298  PERCENT OF SUBIMAGE
          CLASS/CLUSTER NUMBER, POPULATION AND PERCENT OF SUBIMAGE
     1    37703   23.2865     2    11619    7.1763     3    30127   18.6074     4    82460   50.9298
                ENTER (CR) TO RETURN TO RESULTS MENU
```

Figure 3.5-7 Thresholding

6. DISPLAY OF COMPOSITE SUBIMAGE

If this option is selected, one channel of the composite subimage image is displayed. The same procedure as given under Section 3.5.1B is used.

7. LIST FIELD RESULTS

Field results are the number of pixels and percent of the field assigned to each class. These results are displayed on the Tektronix for every field selected during the field selection process. An example of a field results display is given in Figure 3.5-8. After the title, the first line gives the composite image name, the second line gives run annotation information, and the third line gives the threshold value. After this individual field results are displayed and in this example there are three fields, TREESKY, TREEROAD, and TREEGRASS, and four classes; namely, TREESKY, TREEROAD, TREEGRASS and NULL. The names of classes and fields are selected by the user. Also the user can have the field results sent to the printer.

8. LIST A SUBAREA OF CLASS MAP

This option gives the user the capability to display on the Tektronix and send to the printer a 100 pixel by 40 line area of class assignments. This option works in conjunction with Option 5 where a character was assigned to each class. The character which was assigned to the class is displayed for every pixel classified into that class. The subarea is determined by having the user position the cursor over the center of the area of interest and depressing the "select" or "done" button which defines the center of a 100 pixel by 40 line

MAXLIK INDIVIDUAL FIELD RESULTS

COMPOSITE IMAGE-----BILL399

MLC TEST TOTAL COVARIANCE MATRIX LARGE IMAGE

THRESHOLD = 0.0000

FIELD NAME----------TREESKY NUMBER OF PIXELS 972

	CLASS NAME,	NUMBER IN CLASS	AND PERCENT OF FIELD
1	TREESKY	971	99.8971
2	TREEROAD	1	.1029
3	TREEGRASS	0	0.0000
4	NULL CLASS	0	0.0000

FIELD NAME----------TREEROAD NUMBER OF PIXELS 1107

	CLASS NAME,	NUMBER IN CLASS	AND PERCENT OF FIELD
1	TREESKY	0	0.0000
2	TREEROAD	1107	100.0000
3	TREEGRASS	0	0.0000
4	NULL CLASS	0	0.0000

FIELD NAME----------TREEGRASS NUMBER OF PIXELS 1048

	CLASS NAME,	NUMBER IN CLASS	AND PERCENT OF FIELD
1	TREESKY	0	0.0000
2	TREEROAD	1	.0954
3	TREEGRASS	1047	99.9046
4	NULL CLASS	0	0.0000

TO ADVANCE TO NEXT PAGE OF FIELD RESUTLS ENTER (CR)

OR, TO TERMINATE FIELD RESULTS ENTER X

Figure 3.5-8 Field Results

rectangle. As an example, consider Figure 3.5-9 where the header information is self explanatory. The subimage coordinates are given in the header data and the line numbers (350-389) and pixel numbers (168-258) are given with respect to the subimage and not the composite image.

9. TERMINATE RESULTS PROCESSING
   Selecting this option will terminate the MAXLIK processing module.

3.5.2 MAXLIK Engineering Description

The MAXLIK processing module embodies the maximum likelihood and Bayes classification algorithms. These supervised, parametric classification techniques require class mean vectors (μ_k) and covariance matrices (Σ_k), and in addition the user may specify a set of probabilities which represent prior knowledge of the relative frequencies of the different classes.

An observation x is classified into the class with the smallest value of

$$L_k(x) = \log |\Sigma_k| + (x - \mu_k)^T \Sigma_k^{-1} (x - \mu_k) - 2 \log p_k \qquad (1)$$

where

$|\Sigma_k|$ = determinant of covariance matrix for kth class

μ_k = mean vector for kth class

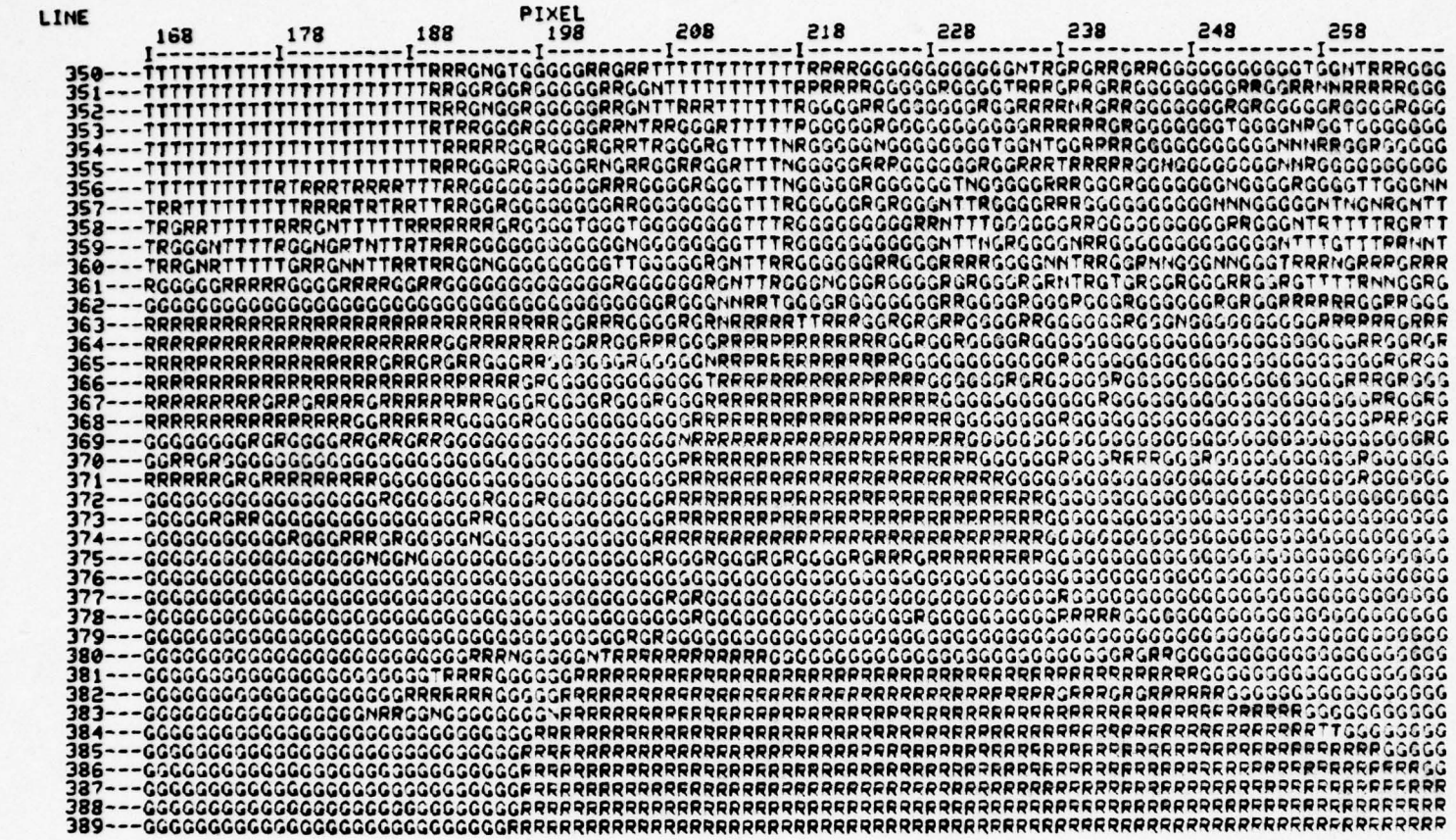
Σ_k = covariance matrix for kth class

p_k = apriori probability

L_k = likelihood function

CLAS: CLUSTER MAP RESULTS

COMPOSITE IMAGE-----BILL999
RESULT: IMAGE NAME TESTMLC3
TEST OF MLC
PIX MIN 80 PIX MAX 438 LINE MIN 29 LINE MAX 479
THRESHOLD = 20.0000



TO LIST ANOTHER MAP AREA ENTER (CR)

OR TO RETURN TO RESULTS MENU ENTER X

Figure 3.5-9 Subarea Map Results

This is the most widely used supervised parametric algorithm, mainly because it maximizes the proportion of correctly assigned observations of data from multivariate normal distributions.

When prior knowledge of relative frequencies of the classes is not available, MAXLIK employs a maximum likelihood classifier. It has the same form as the Bayes classifier, equation (1), except that the term $-2 \log p_k$ is not present. This classifier is optimal if all of the prior probabilities are equal. To reduce the computation time necessary to evaluate equation (1), the user can select approximations to the covariance matrix. These approximations replace (Σ_k) by (1) the corresponding diagonal matrix, (2) a constant times the identity matrix $\sigma^2 I$, and (3) by the identity matrix. These approximations reduce the number of operations per class per pixel from a quadrutic to a linear function of the dimension of the observation vector.

A class map image is the primary output of MAXLIK. It is a two dimensional image, each pixel is represented by two 8 bit quantities. The first 8 bits is used for the quadratic term in the likelihood function

$$(\chi - \mu_k)^T \sum_k^{-1} (\chi - \mu_k)$$

while the other eight are for the class number. This is the vehicle used for calculating field results, thresholding and displaying results.

3.5.3 MAXLIK Control Flow

This section presents the control flow and processing steps of MAXLIK. The steps are described in general forms and the major subroutines identified. These subroutines are described in the next section.

	CONTROL FLOW/PROCESSING STEP	SUBROUTINES USED
1.	Initialize MAXLIK processing	
2.	Request composite image	
3.	Request fields to be classified	FETEKDF
4.	Determine rectangular subimage encompassing all fields	RECFLD
5.	Validate subimage	
6.	Display channel of subimage	DSPCLA
7.	Calculate distance scale factor	
8.	Request classes for classification	FETEKDF
9.	Request parameters for classes	CLASDA
10.	List processing options	
11.	Calculate and reformat class signatures	SIGPREP
12.	List processing modes	
13.	Start MLC processing of subimage	
14.	Fill ECS with set of image lines	FILECS
15.	Get a line from ECS	
16.	Unpack line	
17.	Perform MLC computation for each pixel in the line	
18.	Scale distance results	
19.	Pack results image line	
20.	Write results image line to ECS	
21.	Write results image lines in ECS to disk	EMTECS
22.	Return to 14 if all lines in subimage have not been processed or continue at 23.	
23.	Display results menu	RMENU
24.	List overall subimage results	RESSUB
25.	Display classification map	DSPMAP
26.	Annotate classification run results	
27.	Threshold result image distance metrics	THRESD
28.	Assign character to class	ASSCHR

29.	Display channel of subimage	DSPCLA
30.	Display on Tektronix field results	FLDRES FEUTLLA
31.	Display on Tektronix a subarea of class map	LSTMAP
32.	Terminate MAXLIK processing	

3.5.4 MAXLIK Subroutine Description

All of the subroutines developed for MAXLIK are described in this section with the exception of FETEKDF and FEUTLLA which are described in Section 3.2.4.

3.5.4.1 Subroutine ASSCHR

Purpose

Assign a character to a particular class or cluster

Usage

```
CALL ASSCHR(NCLASS,CNAME,CLASCH)
```

Description of Parameters

NCLASS - Integer parameter number of classes/clusters

CNAME - Array names of classes, each name 4 words stored modulo 4

CLASCH - Array class characters one word for each class/cluster stored in display code, left justified.

Common Areas Used

None

3.5.4.2 Subroutine CLASDA

Purpose

Associates a pseudocolor, a weight and a character with each class.

Usage

```
CALL CLASDA (IREC,NCLS,IERROR)
```

Description of Parameters

IREC - An input array containing the class record numbers

NCLS - Input variable containing the number of classes

IERROR - Output error parameter
=0 no errors
=1 label error
=2 cannot find record requested
=3 DREAD error

Subroutines Used

CURSDEF,CURSXY,DREAD,DSPLAY,DSPNME,GALPHA,GSET, IMGECS,IMGLINE,LBLRD,LNTYPE,PACKF,PACKI,PSEUDO, SETCORE,TEKMSG,TEKRD,TEKWRIT,TITLE,WRITEC

Method

Pseudocolors are associated with classes by first generating an image containing all 64 values, one per PC table entry. PC tables are used to display this image. When a PC table has been selected, the user is requested to position the cursor over the color wanted for a particular class. As

colors are selected, they are displayed in the order of selection. Characters and weights are entered via the Tektronix.

Common Areas Used

CLASS, ECS, LINE, PROGRRM, RESIMG

3.5.4.3 Subroutine DSPCLA

Purpose

Display subimage that is to be classified

Usage

CALL DSPCLA (A,B, IERROR,NAMEC,NBITC,NCHAN,NWDSC,NSPC, NSLC,NPIXC,NLO)

Description of Parameters

A - Buffer used for temporary storage must be large enough to hold packed composite image line

B - Buffer used for temporary storage (same size as buffer A)

NAMEC - Four word array having composite image name

NBITC - Integer parameter - number of bits/pixel

NCHAN - Integer parameter - number of channels in image

NWDSC - Integer parameter - number of 60 bit wds/record

NSPC - Integer parameter - starting pixel number of subimage

NSLC - Integer parameter - starting line number of subimage

NPIXC - Integer parameter - number of pixels/line in subimage

NLO - Integer parameter - number of lines in subimage

IERROR - Output error parameter
=0 No errors
=1 Find error
=2 DREAD error

Method

Based upon the channel selected, the composite image is sampled and displayed

COMMON Areas Used

ECS

3.5.4.4 Subroutine DSPMAP

Purpose

Display class map and class color association

Usage

CALL DSPMAP (NAME,NACLAS,A,NUMCL,IERROR)

Description of Parameters

NAME - Input array with image map name

NACLAS - Input array with class names each name is 4 words in length

A - Input array used for label buffer

NUMCL - An integer value specifying the number of classes

IERROR - Output error parameter
=0 No errors
=1 error in label
=2 error in DREAD
=3 error in number of lines

Method

The image generated by CLUSTER or MAXLIK is displayed with the function memory on and the pseudocolor memory on. Before the image is sent to the COMTAL the image is sampled to remove the chi**2 value and adjusted for the image size. Also upon request the class color correspondence is displayed.

COMMON Areas Used

ECS

3.5.4.5 Subroutine EMTECS

Purpose

Take the packed chi**2 and class map lines from ECS and write them to disk

Usage

CALL EMTECS (A,LINECS)

Description of Parameters

A - Array used for temporary storage, must be NWDSQ words long

LINECS - Input number of lines to be written to disk.

Remarks

Packed lines in ECS have interspersed values: first chi**2 then the class number.

COMMON Areas Used

RESIMG,ECS

3.5.4.6 Subroutine FILECS

Purpose

Fill ECS with lines from the composite image

Usage

CALL FILECS (LBC,LINECS,IERROR)

Description of Parameters

LBC - Input line being classified relative to subimage

LINECS - Output parameter giving number of lines stored in ECS

IERROR - error parameter
=0 no errors
=3 FIND error

Remarks

Packed lines from the composite image on disk are stored in ECS. The number of words from the first word of one line to the first word of the next line is the parameter IECSS.

COMMON Areas Used

ECS,COMIMG,PROCPRM,RESIMG,LINE.

3.5.4.7 Subroutine KREARI

Purpose

Create the output class map image and store appropriate parameters in the label

Usage

```
CALL KREARI (IFLAGC)
```

Description of Parameters

IFLAGC - Flag having the following meaning

=1 MLC processing

=2 CLUSTER processing

Method

Generate the standard label and move data from COMMON and store it in the photogrammetric parameter record. Also a function memory and pseudocolor memory are stored.

COMMON Areas Used

CLASS, COMIMG, FIELDS, LINE, PROCPRM, RESIMG

3.5.4.8 Subroutine FLDRES

Purpose

Present Cluster/Class results on a per field bases

Usage

```
CALL FLDRES (NAMEFC,NFLDS,FLDNAM,NAMER,NAMEC,IANNO,CNAME,
NCLASS,DTHRES,IDOR,IFLAGC,IBUF1,IBUF2)
```

Description of Parameters

NAMEFC - 4 word array - name of field/class file

NFLDS - Integer parameter - number of fields

FLDNAM - Array names of fields each name 4 words stored modulo 4

NAMER - 4 word array - name of results image

NAMEC - 4 word array - name of composite image

IANNO - Array of 10 words describing run

CNAME - Array - names of classes, each name 4 words stored modulo 4

NCLASS - Integer parameter - number of classes/clusters

DTHES - Flt. pt. parameter - percent of pixels thresholded

ICOR - 4 word array subimage definition
ICORR(1) = lowest pixel number
ICORR(2) = highest pixel number
ICORR(3) = lowest line number
ICORR(4) = highest line number

IFLAGC - Processing flag
=1 MAXLIK
=2 CLUSTER

IBUF1 - Array used as a buffer (5K words)

IBUF2 - Array used as a buffer (1K words)

Method

This routine reads the file (NAMEFC) to get field description. It then reads the results image to determine the population of each class for the field. These results are displayed on the Tektroniz along with field outlines on the COMTAL.

COMMON Areas Used

ECS

3.5.4.9 Subroutine LSTMAP

Purpose

Displays on Tektronix a 100 pixel by 40 line area of class assignments

Usage

CALL LSTMAP (NAMEC,NAMER, IANNO, CLASCH,ICOR,OTHRES,IBUF1)

Description of Parameters

NAMEC - 4 word array - name of composite image

NAMER - 4 word array - name of results image

IANNO - Array of 10 words describing run

CLASCH - Array - class characters, one word for each class/ cluster, stored in display code left justified.

ICOR - 4 word array - subimage definition
ICORR(1) = lowest pixel number
ICORR(2) = highest pixel number
ICORR(3) = lowest line number
ICORR(4) = highest line number

DTHES - Flt. pt. parameter - percent of pixels thresholded

Method

The user is asked to position the cursor over the center of the area where detailed pixel assignment is to be displayed on the Tektronix and printed.

COMMON Areas Used

None

3.5.4.10 Subroutine MLC2

Purpose

Performs maximum likelihood classification on one image a line at a time

Usage

CALL MLC2

Description of Parameters

ALINE - Input array of pixel values, floating point format. Upon exiting array contains chi**2 value and chosen class number. They are interwoven starting with chi**2 value.

Remarks

The upper triangular part of the matrix is assumed to be stored row-wise in N* (N+1)/2 successive storage locations. The second class matrix is stored similarly starting in the next location. Mean vectors are also stored successively. The procedure can be used for NCHAN .GT. 2 but .LT. 25. and NCLASS .LE. 10.

Subroutines Used

None

Method

Classification is done by maximum likelihood. Based upon option selected the full covariance matrix is used, or the diagonal, or the expected value of the trace times the identity, or just the identity matrix

COMMON Areas Used

RESIMG, LINE, PROCPRM, STATS

3.5.4.11 Subroutine RECFLD

Purpose

Determine the minimum rectangular subimage encompassing all the fields to be classified

Usage

```
CALL RECFLD (IRECS,NAME,ICORR,IERROR)
```

Description of Parameters

IRECS - An input array containing the record number of the fields to be classified

NAME - An input array containing the Field/Class data set name

ICORR - Output array containing the subimage coordinates
- ICORR(1) = min line
- ICORR(2) = min pixel
- ICORR(3) = max line
- ICORR(4) = max pixel

IERROR - Output error parameter
- =0 no errors
- =1 label error
- =2 DREAD error

Method

All requested field records are retrieved from the data set and the minimum and maximum vertices are selected

COMMON Areas Used

FIELDS, LINE

3.5.4.12 Subroutine RMENU

Purpose

Displays the available results options

Usage

```
CALL RMENU (NAMER,NAMEC,NAMEFC,NFLOS,FLONAM,NCLASS,CNAME,
            CLASCH,ICOR,NCHAN,FMEAN,FSD,IPOP, IFLAGC,
            NBITC,NPIXT,IBUF1,IBJF2,IBUF2)
```

Description of Parameters

NAMER - 4 word array - name of results image

NAMEC - 4 word array - name of composite image

NAMEFC - 4 word array - name of field/class file

NFLDS - Integer parameter - number of fields

FLDNAM - Array names of fields, each name 4 words stored modulo 4

NCLASS - Integer parameter - number of classes/clusters

CNAME - Array names of classes, each name 4 words stored modulo 4

CLASCH - Array class characters, one word for each Class/ Cluster, stored in display code left justified

ICOR - 4 word array subimage definition
ICORR(1) = lowest pixel number
ICORR(2) = highest pixel number
ICORR(3) = lowest line number
ICORR(4) = highest line number

NCHAN - Integer parameter - number of channels

FMEAN - Floating point array - Cluster/Class means, NCHAN values per Cluster/Class stored modulo NCHAN

FSD - Floating point array - Cluster/Class standard deviations, stored like FMEAN.

IPOP - Array: Class/Cluster population per subimage

IFLAGC - Processing flag
=1 MAXLIK
=2 CLUSTER

NBITC - Integer parameter number of bits/pixel in composite image

NPIXT - Integer parameter number of pixels per line of composite image

IBUF1 - Array used as a buffer (5K words)

IBUF2 - Array used as a buffer (1K words)

IBUF3 - Array used as a buffer (1K words)

Remarks

This routine asks the user for the type of output wanted and calls the appropriate subroutines

COMMON Areas Used

None

3.5.4.13 Subroutine RESSUB

Purpose

Displays on the Tektronix the overall subimage results

Usage

```
CALL RESSUB (NAMEC,NAMER,IANNO,CLASCH,CNAME,ICOR,FMEAN,FSD,
             IPOP,NCHAN,IFLAGC,NCLASS)
```

Description of Parameters

NAMEC - 4 word array - name of composite image

NAMER - 4 word array - name of results image

IANNO - Array of 10 words describing run

CLASCH - Array of class characters, one word for each Class/Cluster, stored in display code left justified

CNAME - Array - names of classes, each name 4 words stored modulo 4

ICOR - 4 word array - subimage definition
ICORR(1) = lowest pixel number
ICORR(2) = highest pixel number
ICORR(3) = lowest line number
ICORR(4) = highest line number

FMEAN - Floating point array - cluster/class means, chan values per cluster/class, stored modulo NCHAN

FSD - Floating point array - cluster/class standard deviations stored like FMEAN

IPOP - Array - class/cluster population per subimage

NCHAN - Integer parameter - number of channels

IFLAGC - Processing flag
=1 MAXLIK
=2 CLUSTER

NCLASS - Integer parameter - number of classes/clusters

Remarks

This routine displays on the Tektronix class population values and statistics of all the pixel vectors in the subimage assigned to the class.

COMMON Areas Used

None

3.5.4.14 Subroutine SIGPREP

Purpose

Retrieves class signatures and prepares them for MLC computation

Usage

```
CALL SIGPREP (IPRINT,IERROR)
```

Description of Parameters

A - An array used for temporary storage

IPRINI - Input parameter indicating if signatures should be printed
=0 do not print
=1 print signatures

IERROR - Output error parameter
=0 no errors
=1 label error
=2 DREAD error
=3 number of channels between classes not consistent
=4 matrix inversion problem
=5 not all signatures are available

Remarks

The class signatures which are stored on disk in a name parameter data set are retrieved and for each class the determinant and the inverse of the covariance matrix are calculated. The off diagonal elements of the inverse are modified to increase computational speed and only the upper triangular portion of the matrix is stored. How the results are stored in main memory is based upon the processing option.

COMMON Areas Used

CLASS, LINE, PROCPRM, STATS

3.5.4.15 Subroutine STDCAL

Purpose

Calculates the class mean and standard deviation

Usage

```
CALL STDCAL (IPOP,FMEAN,FSD,NCHAN,NCLASS)
```

Description of Parameters

IPOP - Array - class/cluster population per subimage

FMEAN - Floating point array - cluster/class means, NCHAN values per cluster/class stored modulo NCHAN

FSD - Floating point array - cluster/class standard deviations stored like FMEAN.

NCHAN - Integer parameter - number of channels

NCLASS - Integer parameter - number of classes/clusters

Method

The unnormalized first and second moments are input and the routine calculates the mean and standard deviation and stores the results back in the input arrays (FMEAN,FSD).

COMMON Areas Used

None

3.5.4.16 Subroutine SYMFAC

Purpose

Factor a given symmetric positive definite matrix

Usage

```
CALL SYMFAC (A,N,EPS,IER)
```

Description of Parameters

A - Upper triangular part of the given symmetric positive definite N by N coefficient matrix. On return A contains the resultant upper traingular matrix

N - The number of rows (columns) in the given matrix.

EPS - An input constant which is used as relative tolerance for test of loss of significance

IER - Resulting error parameter coded as follows

IER=0 - No error

IER=1 - No result because of wrong input parameter N or because some radicand is nonpositive (matrix A is not positive definite, possibly due to loss of significance)

IER=K - Warning which indicates loss of significance. The radicand formed at factorization step K+1 was still positive but no longer greater than ABS (EPS=A(K+1, K+1)).

Remarks

The upper triangular part of the given matrix is assumed to be stored columnwise in N*(N+1)/2 successive storage locations. In the same storage locations the resulting upper triangular matrix is stored columnwise too. The procedure gives results if N is greater than 0 and all calculated radicands are positive. The product of returned diagonal terms is equal to the square root of the determinant of the given matrix.

Subroutines and Function Subprograms Required

None

Method

Solution is done using the square root method of Cholesky. The given matrix is represented as product of two triangular matrices.

COMMON Areas Used

None

3.5.4.17 Subroutine SYMINV

Purpose

Invert a symmetric positive definite matrix

Usage

CALL SYMINV (A,N,EPS,DET,IER)

Description of Parameters

A - Upper triangular part of symmetric positive definite N by N matrix. On return contains resultant upper triangular matrix.

N - The number of rows (columns) in given matrix.

DET - Determinant of matrix.

EPS - An input constant which is used as a relative tolerance for test of loss of significance

IER - Resulting error parameter coded as follows

IER=0 - No error

IER=-1 - No result because of wrong input parameter N or because some radicand is nonpositive

IER=K - Warning which indicates loss of significance. The radicand formed by factorization step K+1 was still positive but no longer greater than ABS(EPS*A(K+1, K+1)).

Remarks

The upper triangular part of the given matrix is assumed to be stored columnwise in N*(N+1)/2 successive storage locations. In the same storage locations the resulting upper triangular matrix is stored.

The procedure gives results if N is greater than 0 and all calculated radicands are positive.

Subroutines Used

SYMFAC

Method

Solution is done by upper triangular factorization

COMMON Areas Used

None

3.5.4.18 Subroutine THRESD

Purpose

Creates a new results image with all pixel distance metrics exceeding the threshold assigned to the null class

Usage

CALL THRESD (NAMER,NCLASS,DTHRESS,IBUF1,IBUF2,IBUF3)

Description of Parameters

NAMER - 4 word array - name of results image

NCLASS - Integer parameter - number of classes/clusters

DTHES - Flt. pt. parameter - percent of pixels thresholded

IBUF1 - Array used as a buffer (5K words)

IBUF2 - Array used as a buffer (1K words)

IBUF3 - Array used as a buffer (1K words)

Method

The user enters the percent of pixels to be assigned to the null class. The program determines the cumulative distribution of the distances and selects the appropriate threshold. Then each pixel with a distance greater than the threshold is assigned to the null class. A new results image is generated with the new assignments.

COMMON Areas Used

ECS

Section 4
EXPERIMENT RESULTS

4.1 OVERVIEW

Classification experiments were performed on three multi-dimensional image data sets and these experiments constituted the testing of the feature extraction software package. They had two purposes: (1) to verify that the PMs which make up the package and the constituent functions of the PMs work properly, and (2) to validate the accuracy of the versions of the supervised (maximum likelihood) and unsupervised clustering algorithms implemented in the package. The three image data sets were a LANDSAT scene containing the LACIE intensive study site in Hand County, South Dakota, a synthetic data set used in the thematic mapper design parameters investigation (LANDSAT-D), and an Indiana scene taken with the ERIM 6-channel aircraft scanner. Because ground truth was not available for the Indiana scene the results are not included in the report.

4.2 HAND COUNTY DATA SET

This set is four-channel Landsat MSS imagery containing a 5 x 6 nautical mile LACIE intensive site in a LANDSAT scene of 100 x 100 nautical miles. Each of the four bands in the scene was transferred to disk as an image file and a composite image built through the INTERL PM. This image, 2340 x 3240 pixels, was displayed on a COMTAL, and by successive use of the image expansion facility of the FIELDEF PM, a 512 x 512 pixel region containing the 5 x 6 nautical mile ground truth area was defined.

It should be appreciated that locating such a small area in a large image is a nontrivial matter, since the area does not have any particularly distinctive features, and since large scale (1:24,000) maps of the region of interest were not available at the time classification was carried out. A standard road map in which the Landsat scene could be outlined and which had county boundaries was available, which, it turned out, was all that was needed in conjunction with image expansion. A 512 x 512 pixel region containing the ground truth area in its interior was defined, and a four-channel composite image called HANDCO was built using INTERL for subsequent field definition, signature computation, maximum likelihood classification, and clustering.

4.2.1 Supervised Classification

The ground truth area with the exception of about 2% of the area consists of spring wheat, oats, corn, and pasture, the proportions of each being known from the ground inventory. Using this inventory, a sample page of which is shown in Figure 4.2-1, fields in the four classes were selected and then located in the ground truth overlay, Figure 4.2-2. With the aid of the overlay, some seventeen fields were defined in the SELECT FIELDS option of FIELDEF including the area to be classified (named GRTRUTH) which contains 17,394 pixels, four wheat fields, four oat fields, three corn fields, and three pasture/grass fields. These are shown in Figure 4.2-3. The same fields except for GRTRUTH were then designated as classes (Figure 4.2-4), signatures computed (channel means and covariance matrices) and five classes defined for classification purposes as follows

WHEAT	W204, W270, WHEAT210, WHEAT49
SPRING WHEAT	SW236, SW263

5' 1986

TEST SITE # 35 (HYRUM), S.D.)
INVENTORY OBSERVATION

GROUND TRUTH INVENTORY FORM

DATA RECORDED BETWEEN = 6/ 2 5/75
AND = 6/ 2 6/75

p. 9

LAND USE CROP CODES

SPRING WHEAT (GEN)	211 PARSHALL	306 KESSEY	410 MARSHALL	423 CAPELIN	606 BLONDO FLAX
SEE LIST ATTACHED	212 HUNTER	307 HARMON	411 MCCALL	424 EAGLE SCOUT	607 CORN
WINTER WHEAT (GEN)	213 CONQUEST	308 MISSION	412 ARAPAHOE	425 TRAPPER	610 BUCKWHEAT
BARLEY	214 WISCONSIN	400 WINTER WHEAT (GEN)	413 CHEYENNE	426 CHEYENNE	611 SUNFLOWERS
OATS	215 HECTOR	401 PARK HARD NORTHERN	414 NUGAINES	427 MINERVA	612 DRY BEANS
RYE	216 MYRNA	402 SCOUT	415 DAKOTAH	428 ARAPAHOE	613 LENTILS
FLAX	217 MARQUIS	403 PARKER	416 MOHA	500 GRASS/PASTURE ETC.	614 DRY PEAS
MIXED	300 CULTIVATED	404 CHEYENNE	417 NOVA	600 OTHER CROPS (GEN)	615 SUGAR BEETS
POTATOES	301 RUSSELL	405 APACHE	418 SUNRISE	601 SAFFLOWER	616 GRAIN SORGHUM
SUGAR BEETS	302 LASSER	406 TRAPPER	419 AMIDON	602 RYE	617 SOYBEANS
BEANS	303 KESSEY	407 SERANTA	420 TASCOSA	603 MUSTARD	618 COTTON
220 STEPTOE	304 ROLFEY	408 CENTURK	421 STUDY	604 FLAX (GEN)	700 SUMMER FALLOW
221 PEARLS	305 LUDI	409 BISON	422 CONCHO	605 WILLISTON FLAX	800 NON-AGRICULTURE
					900 UNKNOWN CROPS

MAP REFERENCE # OF FIELD	ACREAGE	LAND USE CROP CODE	IRRIGATED	FERTILIZED	PLANTING DATE MONTH DAY YEAR	COMMENTS
225	32.6	607	Y (O)	Y (A)	5 12 21 75	E-W, 35"
226	73.0	300	Y (O)	Y (B)	5 1 8 1 75	E-W, 7", 22" 28 oat/cultivated fence line
227	17.6	501	Y (O)	Y (C)	— 1 — 1 —	
228	34.4	607	Y (O)	Y (D)	5 1 16 1 75	E-W, 28"
229	20.8	501	Y (O)	Y (E)	— 1 — 1 —	
230	44.1	505	Y (O)	Y (F)	Before 1 70	
231	46.5	505	Y (O)	Y (G)	5 1 1 73	
232	16.3	300	Y (O)	Y (H)	4 1 30 75	N-S, 7", Cochrane
233	47.9	501	Y (O)	Y (I)	— 1 — 1 —	
234	42.4	505	Y (O)	Y (J)	Before 1 70	
235	92.2	501	Y (O)	Y (K)	— 1 — 1 —	
236	42.5	700	Y (O)	Y (L)	4 1 25 75	Cochrane 42.5, 7" Braskem
237	29.8	300	Y (O)	Y (M)	5 1 1 1 75	E-W 7" Cochrane
238	31.9	505	Y (O)	Y (N)	5 1 1 74	
239	30.3	607	Y (O)	Y (O)	5 1 14 1 75	E-W, 42"
240	22.9	700	Y (O)	Y (P)	4 1 23 1 75	E-W, 7" Cochrane
241	30.5	607	Y (O)	Y (Q)	5 1 15 1 75	E-W-42"
242	23.1	702	Y (O)	Y (R)	4 1 25 1 75	N-S, 6"
243	13.1	300	Y (O)	Y (S)	4 1 30 1 75	Broadcast spread Barley seed Oats
244	57.6	300	Y (O)	Y (T)	4 1 30 1 75	Brunette, Broadcast, some Barley seed Oats
245	42.8	702	Y (O)	Y (U)	4 1 26 1 —	N-S, 6"
246	71.2	505	Y (O)	Y (V)	5 1 — 1 73	
247	76.1	300	Y (O)	Y (W)	5 1 12 1 75	E-W, 7" Brunette
248	35.5	111	Y (O)	Y (X)	5 1 5 1 75	E-W, 7"
249	55.8	501	Y (O)	Y (Y)	— 1 — 1 —	
250	42.2	502	Y (O)	Y (Z)	Before 1 70	Contained with part 249
251	45.6	502	Y (O)	Y (N)	Before 1 70	Contained with 252
252	5.4	502	Y (O)	Y (N)	Before 1 70	Contained with 252

Figure 4.2-1 Sample Ground Truth Inventory Page

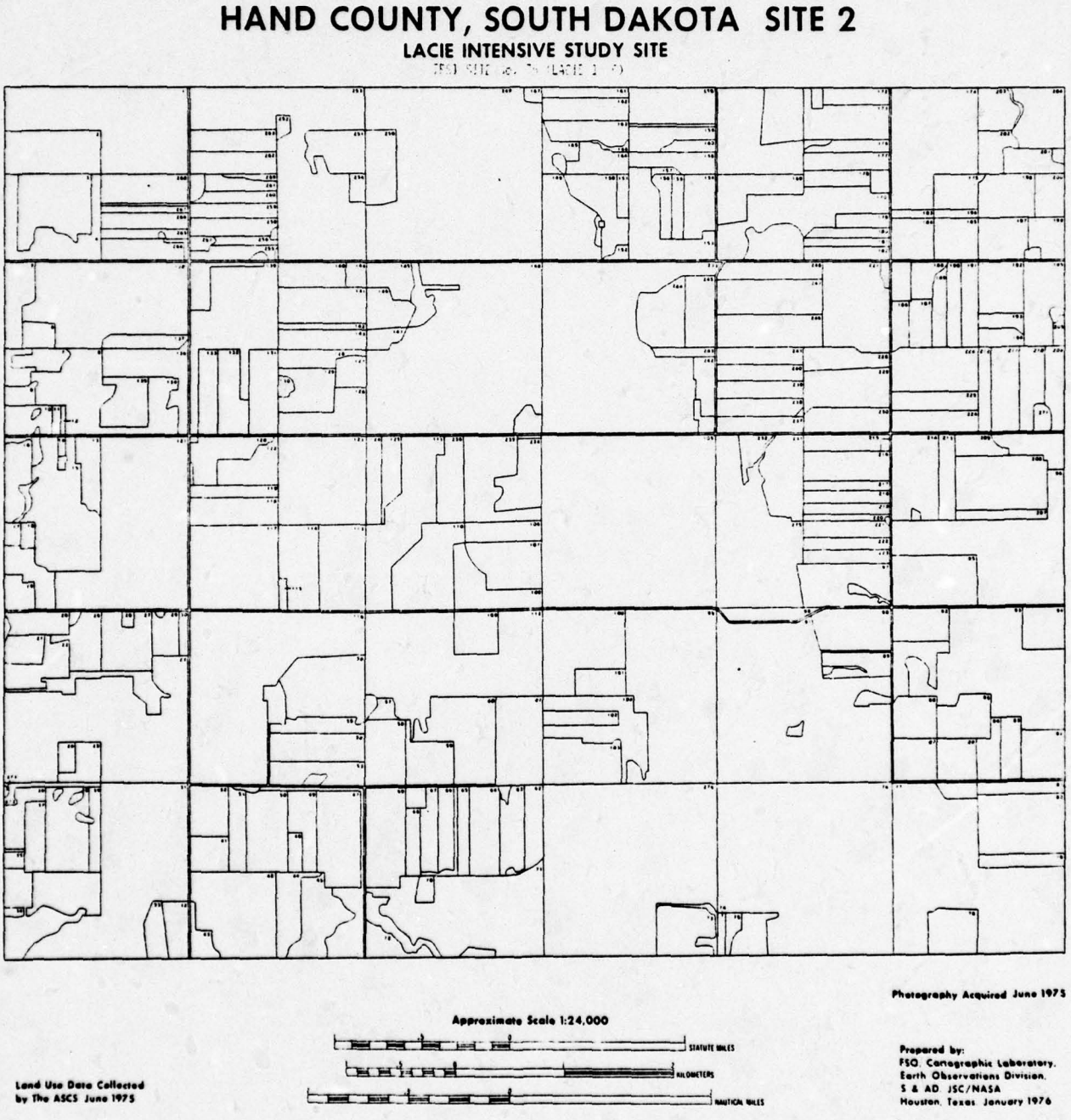


Figure 4.2-2 Ground Truth Overlay

SELECT FIELD(S)

SELECTED	LINE NO.	FIELD NAME	DESCRIPTION	AREAL LINEAR	NUMBER OF PIXELS	LINE NO.
		LINE -L1- -L2- -L3- -L4- -L5- -L6- -L7- -L8- -L9- -L10- -L11- -L12- -L13-				
		PIXEL-P1- -P2- -P3- -P4- -P5- -P6- -P7- -P8- -P9- -P10- -P11- -P12- -P13-				
	1.	GRTRUTH	GROUND TRUTH AREA	AREAL	17394	1.
		263 234 333 361				
		110 273 313 148				
	2.	W204	WHEAT	AREAL	42	2.
		235 240 241 241 238 236				
		272 275 272 269 267 267				
	3.	OATS247	OATS	AREAL	50	3.
		263 266 268 265				
		244 244 230 229				
	4.	OATS192	OATS	AREAL	35	4.
		256 261 261 260 257				
		274 275 270 269 268				
	5.	OATS226	OATS	AREAL	41	5.
		267 270 272 269				
		271 272 260 260				
	6.	CORN211	CORN	AREAL	40	6.
		264 273 273 264				
		277 280 277 274				
	7.	W270	WHEAT	AREAL	42	7.
		245 248 250 249 247				
		217 219 209 207 207				
	8.	WHEAT210	WHEAT	AREAL	40	8.
		264 271 271 272 273 265				
		281 285 284 282 281 278				
	9.	CORN80	CORN	AREAL	58	9.
		316 321 322 318				
		306 308 297 295				
	10.	P76	PASTURE	AREAL	446	10.
		327 328 325 318 317 321 337 340 334 335				
		253 265 267 265 273 280 286 269 265 256				

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 1 TO 10 OR (CR)--

Figure 4.2-3a Hand County Training Fields

SELECT FIELD(S)

SELECTED	LINE NO.	FIELD NAME / DESCRIPTION										AREAL LINEAR	NUMBER OF PIXELS	LINE NO.
		LINE	-L1--	-L2--	-L3--	-L4--	-L5--	-L6--	-L7--	-L8--	-L9--	-L10-	-L11-	-L12-	-L13-
		PIXEL	-P1--	-P2--	-P3--	-P4--	-P5--	-P6--	-P7--	-P8--	-P9--	-P10-	-P11-	-P12-	-P13-
	11.	P274				PASTURE							AREAL	168	11.
			344	339	336	331	329	335	336	338	343	344			
			231	234	241	243	252	253	248	246	246	235			
	12.	P105				PASTURE							AREAL	180	12.
			284	292	297	288									
			234	237	219	216									
	13.	SU263				SPRING WHEAT							AREAL	30	13.
			261	263	266	264									
			153	153	141	141									
	14.	C0RN110				CORN							AREAL	66	14.
			302	302	303	310	311	307	304						
			194	199	198	200	193	191	194						
	15.	SU236				SPRING WHEAT							AREAL	27	15.
			292	299	300	295									
			195	197	194	193									
	16.	CORN54				CORN							AREAL	36	16.
			326	329	331	329									
			192	193	181	181									
	17.	OATS38				OATS							AREAL	45	17.
			341	342	343	344	345	348	349	344					
			148	150	151	153	155	157	151	148					

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 11 TO 17 OR (CR)--

Figure 4.2-3b Hand County Training Fields (continued)

SELECT CLASS(ES)

SELECTED	LINE NO.	CLASS NAME	DESCRIPTION	NUM. OF CHANNELS	/NUMBER /OF PIXELS	/LINE /NO.
	1.	U204	WHEAT	4	42	1.
	2.	OATS247	OATS	4	50	2.
	3.	OATS192	OATS	4	35	3.
	4.	OATS226	OATS	4	41	4.
	5.	CORN211	CORN	4	40	5.
	6.	U270	WHEAT	4	42	6.

CH	LINE NO. 1 MEAN	STD-DEV	LINE NO. 2 MEAN	STD-DEV	LINE NO. 3 MEAN	STD-DEV	LINE NO. 4 MEAN	STD-DEV	LINE NO. 5 MEAN	STD-DEV	LINE NO. 6 MEAN	STD-DEV
1	23.90	.96	24.78	.82	25.74	1.09	27.73	.81	18.60	1.01	23.12	1.02
2	31.19	2.39	33.04	1.40	34.03	2.11	37.56	1.16	20.23	1.39	30.69	1.83
3	38.36	1.85	39.24	1.39	41.51	1.98	43.20	.81	28.33	1.05	36.98	1.65
4	30.24	2.55	30.78	1.45	34.00	2.36	34.24	1.39	20.23	1.21	28.45	2.06

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 1 TO 6 OR (CR)--

Figure 4.2-4a Hand County Classes

SELECT CLASS(ES)

SELECTED	LINE NO.	CLASS NAME	DESCRIPTION	NUM. OF CHANNELS	/NUMBER OF PIXELS	/LINE NO.
	7.	WHEAT210	WHEAT	4	40	7.
	8.	CORN80	CORN	4	58	8.
	9.	P76	PASTURE	4	446	9.
	10.	P274	PASTURE	4	168	10.
	11.	P105	PASTURE	4	180	11.
	12.	SW263	SPRING WHEAT	4	30	12.

	LINE NO. 7		LINE NO. 8		LINE NO. 9		LINE NO. 10		LINE NO. 11		LINE NO. 12	
CH	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV	MEAN	STD-DEV
1	19.35	7.53	17.14	.83	20.26	.72	19.66	.73	20.27	.77	19.97	.93
2	24.48	9.77	17.88	.97	22.22	.94	21.48	.97	22.56	1.15	24.80	.81
3	29.90	11.66	27.34	.81	34.71	1.13	33.59	1.23	32.25	1.25	31.73	.78
4	22.13	8.75	19.81	.95	27.45	1.41	26.40	1.34	24.34	1.55	24.17	.79

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 7 TO 12 OR (CR)--7,8,9,10,11,12

Figure 4.2-4b Hand County Classes (continued)

SELECT CLASS(ES)

SELECTED	LINE NO.	CLASS NAME	DESCRIPTION	NUM. OF CHANNELS	NUMBER OF PIXELS	LINE NO.
	13.	CORN110	CORN	4	66	13.
	14.	SU236	SPRING WHEAT	4	27	14.
	15.	CORN54	CORN	4	36	15.
	16.	OATS38	OATS	4	45	16.
	17.	WHEAT49	WHEAT	4	29	17.

CH	LINE NO. 13 MEAN	LINE NO. 13 STD-DEV	LINE NO. 14 MEAN	LINE NO. 14 STD-DEV	LINE NO. 15 MEAN	LINE NO. 15 STD-DEV	LINE NO. 16 MEAN	LINE NO. 16 STD-DEV	LINE NO. 17 MEAN	LINE NO. 17 STD-DEV
1	16.86	.63	18.96	.94	16.89	.52	24.11	.83	21.72	1.16
2	16.94	.78	22.81	1.08	17.25	.81	31.84	1.30	27.62	1.24
3	26.68	1.15	30.93	1.14	28.67	.96	38.09	1.02	34.97	1.40
4	18.48	1.29	23.48	.94	21.64	1.40	29.40	1.05	26.28	1.51

ENTER LINE NUMBER(S) TO SELECT AND PAGE (E.G. 11,13,18,20)
-OR (CR) TO PAGE ONLY (AFTER LAST PAGE, RETURNS TO OPTION MENU)

ENTER VALUE(S)FROM 13 TO 17 OR (CR)--13,14,15,16,17

Figure 4.2-4c Hand County Classes (continued)

OATS	OATS247, OATS192, OATS226, OATS38
PASTURE	P76, P274, P105
CORN	CORN80, CORN100, CORN54

A preliminary classification was performed by the MAXLIK PM yielding the results shown in Table 4.2-1, where the percentages of the principal classes derived from the ground truth inventory are also shown for comparison.

IMAGE	AREAL PROPORTION ESTIMATES (%)				
	CORN	OATS	PASTURE	SPRING WHEAT	WHEAT
GROUND TRUTH MAP	8.06	6.47	81.23		4.24
HANDCO	11.04	3.27	59.98	15.26	10.46

Table 4.2-1 Preliminary Classification Results

While this preliminary classification demonstrated that the PMs are operating, it is not a very satisfactory result. It is clear that the two wheat classes are significantly overclassified, while pasture is underclassified. Examination of the results indicated that pasture pixels were being classified as wheat, and a further set of Bhattacharyya distances indicated that class W204 was very distinct from SW236, and that OATS226 was distinct from the remaining oat classes. Accordingly new classes were defined to reflect these observations as follows:

		% of CLASSES	
SPRING WHEAT	SW236, SW263	6	(4)
CORN	CORN80, CORN110, CORN211	18	(8)
OATS	OATS38, OATS274	10	(6)
PASTURE	P76, P274	66	(80)

(Ideally, these classes should be on the same proportion as in the total inventory (shown in parentheses), but it is not always possible to identify training fields of the appropriate type to be combined into classes of the desired proportion).

A second classification with MAXLIK yielded the results of Table 4.2-2. The results of another classification using the ERMAN-II system are given for comparison.

IMAGE	AREAL PROPORTION ESTIMATES (%)			
	CORN	OATS	PASTURE	SPRING WHEAT
GROUND TRUTH MAP	8.06	6.47	81.23	4.24
HANDCO	11.04	9.27	61.10	18.60
ERMAN-II CLASSIFICATION	9.35	8.70	80.52	1.42

Table 4.2-2 Results of Second Classification Run

An examination of the results shows that the training fields OATS247, CORN80, P76, CORN110, and OATS38 each is classified 100% in its own class, but that 5% of P274 is classified as spring wheat, and 11% of SW236 and 3% of SW263 is classified as pasture. What is happening is that a small percentage of pasture is being classified as spring wheat, and a small percentage of wheat is being classified as pasture. Since the ground truth area is 80% pasture, the number of pasture pixels classified as spring wheat is far greater than the number of spring wheat pixels as classified as pasture.

The important point is that these effects are inherent in the data, not in the algorithm or its implementation. The Hand County classification exercise confirms that the supervised classification portion of the feature extraction package is functioning properly.

4.2.2 Unsupervised Classification

The CLUSTER PM was exercised with the Hand County data in two modes. In the first, the four classes employed in the MAXLIK exercise were taken as starting vectors (cluster centers), while in the second, self-generated (zero) starting vectors were used. The results of the second mode will be described here since it is representative of the most common use of unsupervised classification, that is in situations where there is no prior information. A split/combine sequence of SSSCS was chosen, and T1 and T2 set to 2.0 and 4.0 respectively, the remaining clustering parameters being at their default values. The split/combine sequence chosen yielded seven clusters plus the null cluster (to which only 0.4% of the pixels were assigned). A convenient way of summarizing and evaluating the results is to determine the clusters into which pixels of each of the four classes were assigned. This is done in Table 4.2-3 (certain clusters with a small percentage of pixel assignment were

CLASS	CLUSTER	% OF CLASS
OATS	1	51
	8	48
CORN	3	6
	6	90
SPRING WHEAT	3	29
	4	71
PASTURE	2	9
	3	3
	4	65
	7	20

Table 4.2-3 Assignment of Classes to Clusters

ignored in this summary). To determine the reasonableness of this result, the channel means of Cluster 1 may be compared with a training field known to be oats, cluster 6 with corn, and cluster 4 with spring wheat and pasture. This done on Table 4.2-4. When it is recalled that

CLUSTER 1	OATS247	CLUSTER 6	CORN54
24.53	24.78	17.64	16.89
32.37	30.04	18.39	17.25
39.13	39.24	29.40	28.67
30.72	30.78	21.85	21.64

CLUSTER 4	SW263	P105
20.40	19.97	20.27
23.12	24.80	22.56
33.24	31.73	32.25
25.53	24.17	25.34

Table 4.2-4 Cluster and Training Field Means

the clusters, and therefore, their means, were generated by a process which is completely independent of the selection of training fields, the agreement between supervised and unsupervised classification must be considered quite good. Note that the confusion between spring wheat and pasture is corroborated.

In an actual application, further effort would be made to locate further spring wheat fields and perhaps pastures in order to improve the separation of the two classes. However, from the point of view of testing the feature extraction package, the results obtained confirm its satisfactory operation.

4.3 SYNTHETIC DATA SET

The synthetic data used in the second series of tests of the feature extraction package was derived from a set consisting of six bands each of 1,650 lines and 442 samples which provided field sizes of 2.5, 5, 10, and 20 acres, with form factors (width to length ratio) of 1 x 1, 1 x 2, and 1 x 4. Spectral signatures of six classes, namely trees, corn, pasture, winter wheat, soybeans, and soil were derived from covariance matrices obtained from aircraft data of an actual region comprising those classes. This set was resampled to simulate satellite multispectral imagery, yielding a data set of 154 lines and 54 pixels in bands 1 through 5 and 38 lines and 13 pixels in band 6 to simulate an infra-red sensor. Since band 6 has too few pixels for adequate field definition, only bands 1 through 5 were used. After transference to disk, these were combined in the INTERL PM to build a composite image called SYNDATA.

4.3.1 Supervised Classification

Although detailed "ground truth" data is available for the original synthetic data set, time limitations prevented its use in defining training fields, which would have involved long and tedious identification of pixel coordinates. Instead five training fields simply designated FIELD1 through FIELD5 were identified visually and designated as classes, along with a class corresponding to the wedge shaped borders along the left and right hand vertical edges of the image designated BACKGROUND.

Supervised classification was carried out with MAXLIK. Individual field results showed that 100% of the pixels in each of the six training fields were classified into their respective classes (all of the 56

pixels in field F1 were assigned to class FIELD1, all of the 54 pixels in field FIELD2 were assigned to class FIELD2, etc.) thus justifying the training field definition.

Thresholding was applied to the resulting class map at the 30% level, which resulted in the assignment of 29.94% of these pixels to the null class. The resulting class map shows very clearly that the null class is primarily the boundary line (simulating roads or bare soil) between the fields. Polaroid photographs of the COMTAL displays of the original data set and the threshold data set are shown in Figure 4.3-1. In spite of the small size of the image because the image expansion facility is not yet available for output images (class and cluster maps), the good quality of the classification is obvious.

The synthetic data set results confirm the satisfactory operation of the INTERL, FIELDEF, CLASTAT, and MAXLIK PMs.

4.3.2 Unsupervised Classification

Unsupervised classification was carried out on the composite image SYNDATA through the PM CLUSTER. Initial clustering parameters were chosen as shown in Figure 4.3-2, and the zero initial starting vector selected. While an iteration-by-iteration report of the development of clusters will not be given here, it is interesting to note that the cluster corresponding to the bright border pixels (corresponding to the class BACKGROUND in the supervised classification) begins to appear after the first split (as CLUSTER 1, Figure 4.3-3a), and is well-defined after the second split (as CLUSTER 1, 4.3-3b).

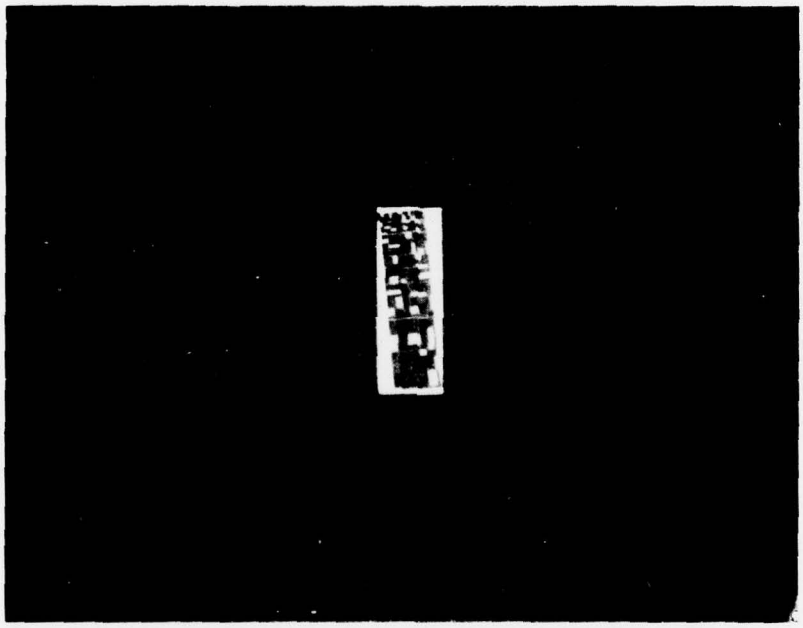


Figure 4.3-1a Synthetic Data Set, Band 3

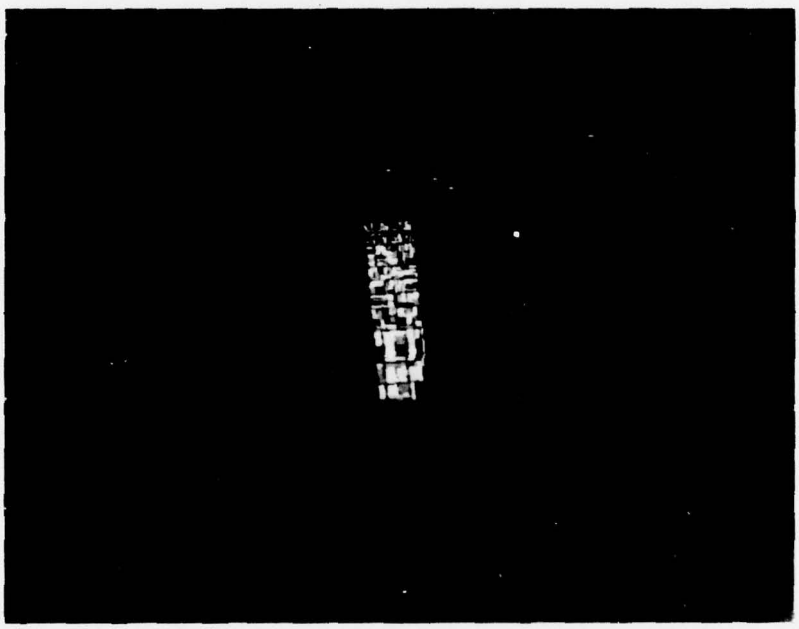


Figure 4.3-1b Thresholded Class Map

```
THE CURRENT VALUES OF THE INITIAL CLUSTERING PARAMETERS ARE
        1. T1        =  8.0
        2. T2        =  3.2
        3. NMIN      =  30
        4. NUMMAX    =  60
        5. SEP       =  1.0
        6. ISODAT    =   1
        7. IDISF     =   2
        8. P         =  0.0
        9. R2        =   24.
       10. PMAX      =  10
       11. PN        =   1
       12. SPLIT/COMBINE SEQUENCE = SSSSCS

-FOR THE DESCRIPTION OF A PARAMETER, OR TO CHANGE ITS VALUE,
 ENTER ITS NUMBER OR (CR) IF NO VALUES TO CHANGE
```

Figure 4.3-2 Initial Clustering Parameters for Synthetic Data Set

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV
1	232.72	43.86	93.76	24.30
2	231.58	48.15	88.58	16.95
3	227.58	55.74	53.59	19.25
4	233.22	47.79	125.28	43.47
5	229.47	48.53	41.76	16.77

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 4.3-3a Interim Statistics for Synthetic Data Set, Second Pass

INTERIM CLUSTER STATISTICS

	CLUSTER 1		CLUSTER 2		CLUSTER 3		CLUSTER 4	
CHANNEL	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV	MEAN	ST.DEV
1	252.74	4.69	87.14	11.51	199.93	21.47	101.05	30.12
2	253.46	4.39	90.51	11.59	197.81	21.99	88.86	21.36
3	253.20	4.75	49.10	13.45	185.42	26.84	59.66	23.82
4	253.66	4.35	164.66	23.40	206.94	29.16	95.09	28.42
5	252.39	5.26	45.94	18.12	181.80	27.49	44.04	24.74

TO SEE NEXT GROUP OF MEANS AND ST.DEV's ENTER 'NEXT'

TO RESUME COMPUTATION ENTER (CR)

Figure 4.3-3b Interim Statistics for Synthetic Data Set, Third Pass

Cluster field results show the assignment of training field pixels to clusters, summarized in Table 4.3-5. (as before certain small percentage pixel assignments are not included in the summary).

FIELD NAME	CLUSTER NUMBER	% PIXELS ASSIGNED
F1	6	100
FIELD2	3	76
	12	24
FIELD3	10	72
	5	23
	12	4
FIELD4	2	98
FIELD5	3	90
	12	10
BACKGROUND	1	100

Table 4.3-5 Assignment of Training Field Pixels

It is apparent that a direct identification can be made between F1 and CLUSTER 6, FIELD4, and CLUSTER 2, FIELD5 and CLUSTER 3, and BACKGROUND nad CLUSTER 1, but CLUSTERS 5 and 10 are confounded. Statistics of these clusters are given in Table 4.3-6 for comparison.

CLUSTER 5		CLUSTER 10	
MEAN	STD. DEV.	MEAN	STD. DEV.
148.09	3.06	147.83	3.06
120.44	1.62	120.19	1.33
95.66	1.58	95.09	1.79
46.55	2.89	46.12	2.44
66.14	4.56	58.75	2.33

Table 4.3-6 Cluster Statistics Comparison

Indeed these two clusters are quite close, and perhaps would have merged if another combine iteration had been specified. Since eleven clusters were generated, CLUSTER 12 is the null cluster which, it turns out,

corresponds to the field boundaries or "roads" between fields. The only surprising result is the apparent confusion between FIELD2 and FIELD5 which are mostly assigned to the same cluster, CLUSTER 3. Statistics for these fields are shown in Table 4.3-7 for comparison.

FIELD2		FIELD5	
MEAN	STD DEV.	MEAN	STD. DEV.
79.40	2.83	82.56	3.08
65.59	0.79	77.15	1.16
36.43	1.19	43.97	1.61
113.74	1.08	114.03	1.44
22.93	2.39	26.10	3.29

Table 4.3-7 Field Statistics Comparison

There is a considerable degree of similarity between the two training fields, and it would be interesting to pursue the matter further.

Figure 4.3-4 has a polaroid photograph of the cluster map, which is not as vivid as it might be because of the particular color selection used to denote clusters. However, the excellent agreement between cluster map and original image can be seen by comparing Figure 4.3-4 with Figure 4.3-1a. As a final comparison, pixel by pixel subimage listings are shown in Figure 4.3-5 for supervised and unsupervised classifications. It is concluded that the principal components of the feature extraction package are working properly, and that the package is ready for application to actual classification problems.

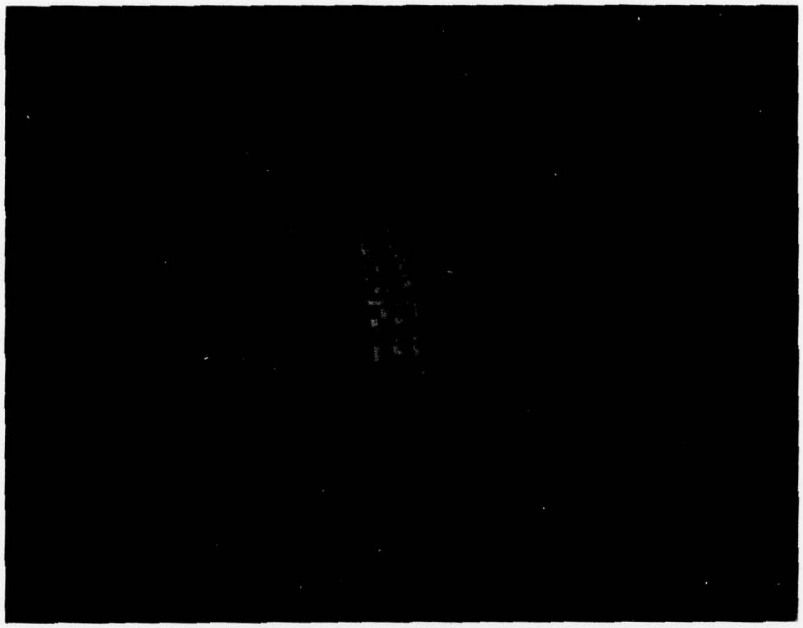


Figure 4.3-4. Cluster Map of SYNDATA

CLASS/CLUSTER MAP RESULTS

COMPOSITE IMAGE ------SYNDATA
RESULTS IMAGE NAME DEBUG 2

PIX MIN 8 PIX MAX 61 LINE MIN 6 LINE MAX 159
THRESHOLD = 0.0

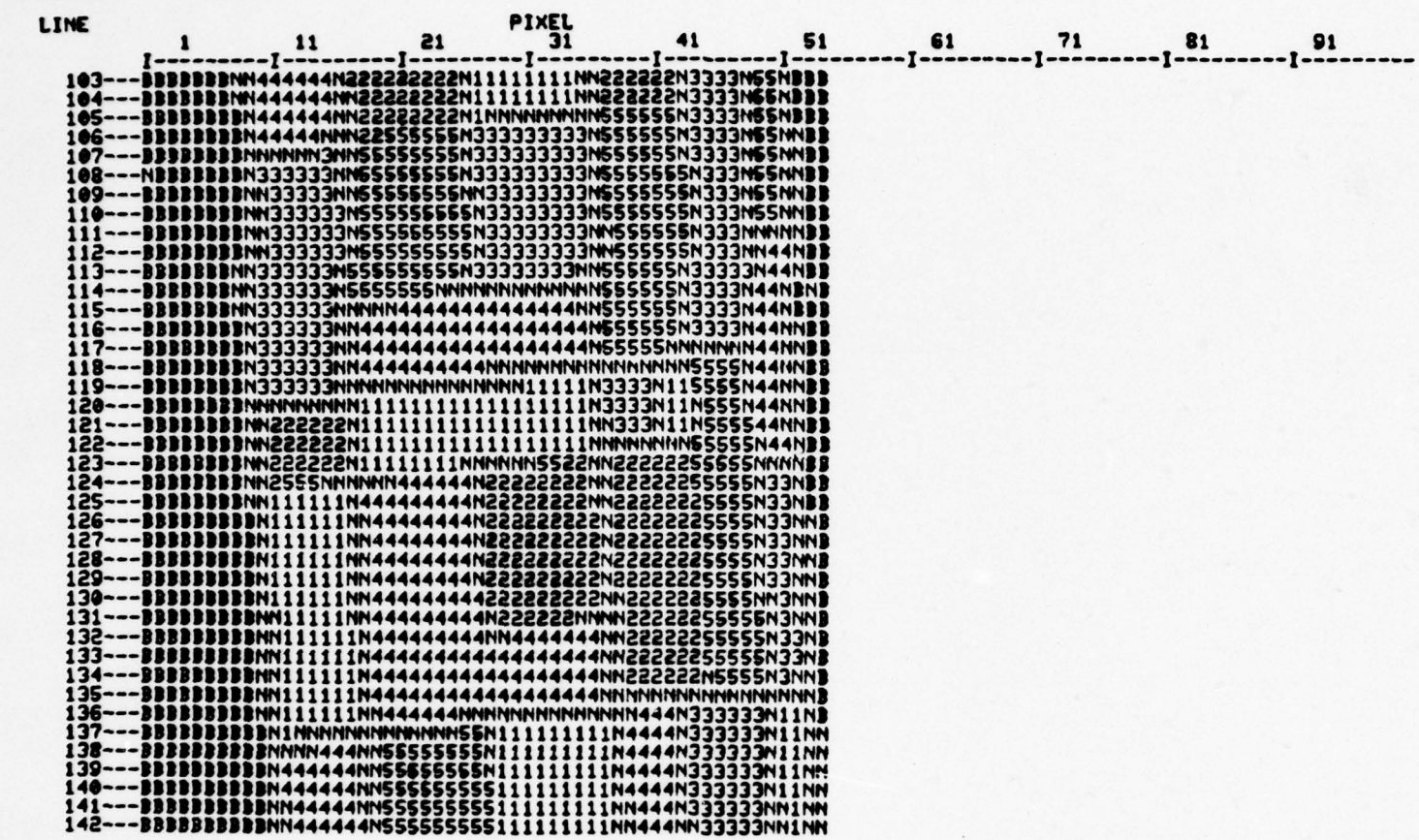
```
LINE                                  PIXEL
          1        11        21        31        41        51        61        71        81        91
     I---------I---------I---------I---------I---------I---------I---------I---------I---------I---------
 116---111111110AAAAA500222222222222222222033333305AAA0220111
 117---111111110AAA5AA00222222222222222220333000000000220011
 118---111111110AAAAA500222222222B000000000000040033302220011
 119---111111110 5AAAA5000000000000000006666055A576633330220011
 120---111111110000000000066666666666666606605AAA06603330B20011
 121---111111110033033306666666666666666666605A5A06603333B20011
 122---111111110030333006666666666666666666000000033333B22011
 123---111111110033330306666666666090003333003003333333370011
 124---111111110033330000BBBBB22220033300030003033333330AA011
 125---111111111066666602222222220333333030003330033333 0AA011
 126---1111111110666666 4B22222222003033333303333033333330A5011
 127---1111111110666666402222222203033330030033333333305A001
 128---1111111110666666402222222203303303330333333333330AA001
 129---1111111110666066002222222B333330333033303333333 0AA001
 130---1111111110666666002222222B333333033030333033333330AA001
 131---1111111110066666002222222B033030000003033333333 0AA001
 132---1111111110066666602222222200BBB22220033303033330055 1
 133---1111111110066666602222222222222222220030303333333305A01
 134---1111111110066666622222222222222222220003003333333005501
 135---1111111111066666602222222222222222220000020000000000301
 136---1111111111066666602222 2B000000444444 0B2205AAA5A76601
 137---1111111111060044 0000000000066666666 0022227AA05AA76601
 138---1111111111000BB22203333333306666666660222220AAA5AA06600
 139---1111111111102222220033333333066666666602222 0AAAAAA06600
 140---1111111111022222200333333330666666666 0B2220AAA5AA0S600
 141---1111111111002222220033333333066666666660 2220AAAA5A0S600
 142---1111111111002222 2B033333333396666666660 222 0A5AA5AA0600
 143---1111111111002222 2B033333333096666666660 2220A5AA55A0660
 144---1111111111002222220333033333966666666600 222B0AAAAAA0660
 145---1111111111002222220033333333000003333002 22B05AAAAA0660
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 148---1111111111102222220033033333333030333302 2220007700 BB0
 149---1111111111102222220033333333333330000902 2220666 B22220
 150---1111111111102222BB04000009066666666666600222B6666000000
 151---1111111111100000A5A5066666666666666660000000000000011111
 152---1111111111110 0AAA5A5C666000000000000001111111111111111111
 153---1111111111110000000000000011111111111111111111111111111111
 154---1111111111111111111111111111111111111111111111111111111111
```

Figure 4.3-5a Cluster Map Results, Synthetic Data

CLASS/CLUSTER MAP RESULTS

COMPOSITE IMAGE-----SYNDATA
RESULTS IMAGE NAME MLC

PIX MIN 8 PIX MAX 61 LINE MIN 6 LINE MAX 159
THRESHOLD = 30.0000



TO LIST ANOTHER MAP AREA ENTER (CR)

OR TO RETURN TO RESULTS MENU ENTER X

Figure 4.3-5b Classification Map Results, Synthetic Data

Section 5
EXPERIMENT CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

During the period of performance of the FEATURE EXTRACTION EXPERIMENT the following conclusions evolved.

a. Extensive testing validated the techniques and software implementation of the FEATURE EXTRACTION SYSTEM. Tests were run using
   - o 5-channel Synthetic Data Set
   - o ERIM 6-channel aircraft scanner data
   - o LANDSAT 4-channel scenes of Hand County, South Dakota

   and the results were analyzed and compared to ground truth when it was available. The results compared favorably to the ground truth. Further, supervised and unsupervised classification of the same data sets were in substantial agreement with each other.

b. Execution time of maximum likelihood classification on the CDC 6400 for a full LANDSAT scene of 3240 pixels x 2340 lines and 4 channels with 10 classes takes approximately 378 minutes. This is probably too long a period of time for an interactive system. However, smaller scenes take proportionally less time, the LACIE sets requiring less than a minute.

c. The developed system has a broad range of applications and is best used for the purpose of testing and evaluating

processing techniques and hypotheses about remotely sensed data.

d. More robust distance metrics are needed to help analyze the separation (probability of misclassification) between classes.

e. More feedback and correlation is needed between the supervised and unsupervised classification (MAXLIK and CLUSTER) processing modules.

5.2 RECOMMENDATIONS

To improve the performance of the package, the following steps should be taken.

a. Both CLUSTER and MAXLIK should be implemented on the STARAN to reduce computation time.

b. Processing modules to reduce the dimensionality of the data should be developed. An example is the principal components technique which uses the Hotelling transformation.

c. Implementation of the Probability of Error and Chernoff Distance is desirable in order to enable the user to better decide whether his selection of classes is adequate, and when to merge classes.

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2. Kailath, Thomas. The Divergence and Bhattacharyya Distance Measures in Signal Selection. IEEE Trans. on Communication Technology, 15-1, February 1967, pp. 52-60.