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A Hybrid Image Classification Instructional Package

Image processing programs are used in conjunction with mainframe statistical and mapping library programs to teach an introductory course in digital remote sensing.

Abstract: *An introductory undergraduate course in digital remote sensing has been successfully conducted using a combination of Landsat image processing programs and mainframe statistical and mapping library routines. This hybrid approach allows for considerable flexibility and makes maximum use of the software and hardware commonly supported by an academic computer center. Students work through the entire classification process starting with Landsat image subsets extracted from a Computer Compatible Tape (CCT) and finishing with a colored hard copy map of the final classification. Emphasis is placed on students understanding the various classification procedures at the expense of image processing efficiency. A number of different computer graphic algorithms are used to facilitate the students' comprehension of both the spatial and statistical content of the image data. Students appreciate the "hands on" approach and the experience of working through the complete image classification process.*

Introduction

Instruction designed to introduce students to the fundamentals of digital remote sensing has to overcome a substantial number of mechanical and pedagogical obstacles in order to be successful. In particular, the design and implementation of the image processing algorithms need careful consideration if the purpose of the programs is to educate rather than facilitate the processing of Landsat data. The processing system (HICIP—Hybrid Image Classification Instructional Package) described in this article has been used to teach a first course in digital image classification to fourth year undergraduates and has the following attributes:

- The image processing algorithms (written in Fortran) are implemented on a university mainframe computer (IBM 3081) in batch mode using an interactive editing and filing system.
- Output is designed for those peripherals (line-printers, pen plotters, electrostatic plotters) usually supported by university computer centers.
- The processing system consists of easy-to-identify steps that require student information and decision-making inputs.
- Extensive computer graphics are used throughout so that the student can acquire a complete understanding of the data in both a spatial and statistical context.
- In order to increase flexibility, maximum use is made of statistical and mapping packages commonly maintained by a university computer center.
- Landsat image subsets, selected by the instructor, are used to circumvent storage problems and to reduce the run-time of the image processing programs.
- The student is introduced to the complete classification process starting with the raw Landsat data and finishing with a colored hard copy map of the final classification.
- Advanced students can modify the programs to suit their particular needs.

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- The entire package of programs and data sets can be taken by the student to a new job where he or she can easily demonstrate Landsat processing on the company computer system.

IMAGE DATA SETS

The image subsets used by the students consist of scenes that have been extracted from Landsat Computer Compatible Tapes (CCT's), deskewed, and stored as band sequential (BSQ) disk files. The principal reason for using disk storage and a small number of image data sets is the 40-student class size. Although tapes may circumvent the problem of storing 40 individually selected subimages, the sheer number of tape mount requests and the serial nature of the storage medium precludes this approach. The image data sets are kept small to reduce run-time and to keep the size of the line-printer maps at a manageable scale. The matrix size of each image or image subset is indicated in rows and columns following the data set name in the descriptions given below.

HARRISBURG, PENNSYLVANIA (2340 BY 3264)

Containing the entire Landsat image of central Pennsylvania (12 September 1976), this CCT is accessed by students as part of the initial exercise in unpacking image subsets. The scene contains a large number of features familiar to the student (ridge and valley structure, extensive strip mining areas, rivers, reservoirs, and a number of urban centers including the State College—Pennsylvania State University area) and provides a good first look at Landsat data.

ATIKOKAN, ONTARIO (200 BY 480)

This 9 May 1975 image data set is centered on the western flank of the Canadian Shield and contains the entrance to the Quetico wilderness canoeing area north of Ely, Minnesota. Elements in the scene are two large open pit iron mines, timbering clearcuts, areas of burned over forest, highways, lumbering roads, pipelines and hydroelectric transmission lines, and the town of Atikokan (population 6,000). The lakes in the scene have just broken up during spring thaw, and a residual ice cover shows up in the center of several of the larger lakes.

GEORGETOWN, SOUTH CAROLINA (288 BY 360)

Covering a portion of the Carolina coast, this image subset (5 January 1979) includes the industrial community of Georgetown (population 12,000), and the marine environments of Winyah Bay and the spartina tidal marsh at North Inlet. Visible in the scene are a newly formed spit at the entrance to North Inlet, the sand beaches lining the coast, an airport south of Georgetown, and reservoirs off of the Sampit River. Channelization within Winyah Bay, relic beach ridges, and the extensive southern pine forest cover can be clearly seen.

EUDORA, KANSAS (116 BY 130)

This image data set incorporates registered scenes for three different dates (20 May 1976, 26 June 1976, 19 August 1976). The scene is located on the flood plain associated with the Kansas River near the town of Eudora (population 2,000). The extensive agriculture on the flood plain consists of three dominant crops: winter wheat, corn, and soybeans. The soybeans are planted shortly after harvest of the winter wheat, sometime in early July. A segment of the flood plain has been extensively field checked (Eyton *et al.*, 1979) and a map identifying the crop type for about four hundred of the fields is used in the analysis of this image data set.

CLASSIFICATION ALGORITHMS

The programs used to process the image data sets are summarized in Table 1. The first group of programs contains the basic classification sequence and consists of two types of algorithms: programs written specifically to handle Landsat data (IREAD, IHIST, IGREY, ITRAIN, ISPACE, ICOR, ITERY, and ICLASS) and procedures obtained from the Statistical Analysis System (PRINCOMP, FASTCLUS and DISCRIM) commonly supported by many academic computing facilities (SAS Institute, Inc., 1979). The combination of both types of algorithms provides a flexible, stepped approach to image processing and classification. This approach *does not* represent an efficient method for handling Landsat data, but instead presents a series of operations with each step made obvious to the user in order to increase understanding of the classification procedures.

The programs operating directly with the original Landsat data sets can extract data from an entire image data set or from any rectangular subset of the image data set. The mapping programs (IGREY and ICLASS) automatically configure the output into 120-column map segments and allow for four-character overprinting and the maximizing of grey levels for maps with fewer than eight classes. Class intervals need not be continuous, and unclassified sections of the map are printed as blanks. If only one class is selected for level slicing or theme extraction, the class is printed with the darkest overprint combination. The training field selection program (ITRAIN) will extract either rectangular or irregular shaped training fields for a maximum of 12 bands of image data. The classification program (ICLASS) will accommodate 12 bands of image data as well.

The SAS procedures were used in lieu of writing specific statistical processing algorithms because of their flexibility, ease of implementation,

TABLE 1. HYBRID IMAGE CLASSIFICATION INSTRUCTIONAL PACKAGE

Classification Algorithms	
IREAD	— extracts and displays raw data values from image data
IHIST	— produces histograms from raw or transformed image data sets
IGREY	— creates a brightness map
ITRAIN	— extracts raw data from user defined image polygons
ISPACE	— produces a scattergram of training field data
ICOR	— calculates correlation and covariance matrices for image data sets
PRINCOMP	— SAS principal component analysis procedure
FASTCLUS	— SAS cluster analysis procedure
DISCRIM	— SAS discriminant analysis procedure
ITERY	— produces territorial plots of discriminant analysis classifier
ICLASS	— creates a classified map using discriminant analysis classification functions
Graphic Algorithms	
SYMVUI	— SYMVU subroutine to plot perspective diagram of image data sets
VGREY	— grey-scale plotting routine to produce brightness maps from raw or transformed image data sets
SYMVUF	— SYMVU subroutine to plot perspective diagrams of training field frequency data
BVSTD	— plots bivariate standard deviation ellipses of training field data
VCOLOR	— produces individual class maps and color separations from classified image data set
Utility Algorithms	
UNPACK	— extracts and deskews image subset from Landsat CCT's
TRANSM	— transforms cartesian coordinates to image coordinates for training field selection from air photos

and their widespread adoption and support by academic computing centers. All of the procedures are well documented in manuals which are universally available to users, and therefore a common approach to the analysis of the data is maintained. Perhaps the principal reason for using SAS procedures is the extensive file handling capabilities of SAS, which include the tools for editing, subsetting, concatenating, merging, and updating data sets. Once sample data have been extracted from the Landsat image subscene using ITRAIN, the SAS procedure can be used with this sample data in a variety of image processing and classification approaches. Two common approaches to image classification using the SAS procedures are described below.

UNSUPERVISED CLASSIFICATION

IHIST and IGREY are used to produce a grey-scale map which provides the reference for choosing characteristic samples of the image data. The row and column coordinates of the points outlining the sample areas become the input to ITRAN, which extracts all the grey-level values for the pixels contained within the borders of the sample polygons. The output from ITRAIN consists of a table of pixel values for each band, along with the sample observation numbers, all in a format suitable for processing by the SAS FASTCLUS procedure. FASTCLUS produces a table of grouped data (requiring some screen editing) which is then used directly by the DISCRIM procedure. DISCRIM produces the classification function coefficients used by ICLASS to produce a classified map of the entire image data set.

SUPERVISED CLASSIFICATION

The same basic steps (with the exclusion of the FASTCLUS procedure) are followed in completing a supervised classification. Training field data are extracted from homogeneous regions within the image data set and are treated as data representing single, unique features. The processing sequence is IHIST, IGREY, ITRAIN, DISCRIM, and ICLASS.

Programs IREAD and ISPACE are not necessary to the classification process, but aid in the selection and identification of supervised training fields or in the examination of the structure of groups produced by FASTCLUS. IREAD can be used to display raw digital values extracted from a rectangular window defined for any of the Landsat data sets, and limits for specific features can then be determined by inspection. ISPACE produces a bivariate scattergram of the training field or cluster data, with each observation plotted as a character indicating either training field type or group membership.

GRAPHIC ALGORITHMS

The second group of programs listed in Table 1 was written in order to provide students with the means to visualize both the raw data and the statistical form of the data at various stages in the classification process. These programs are used in conjunction with the basic classification programs previously discussed and rely on the plotting facilities of an academic computer center. Programs VCOLOR and VGREY require electrostatic plotting

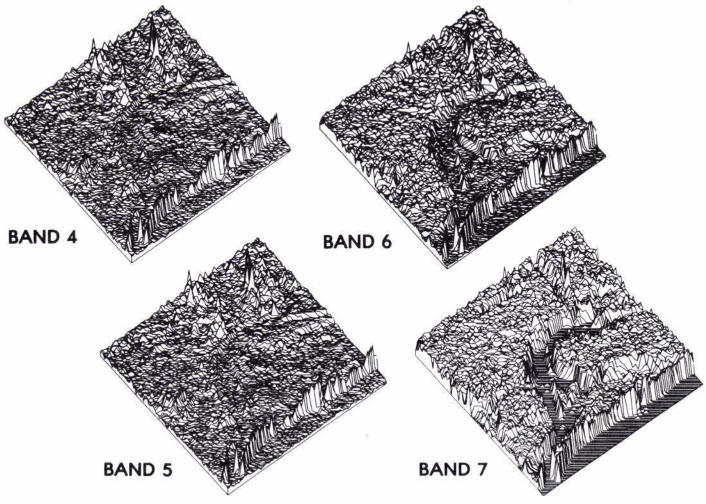

FIG. 1. Landsat MSS 4, 5, 6, and 7 perspective plots of Georgetown, South Carolina with zero smoothings.

equipment, and the remainder of the graphic programs can be used in conjunction with either electrostatic, drum, or flatbed blotter equipment. Although these graphic packages are not necessary to the classification procedures, the ability to produce a variety of displays allows the student to gain considerable insight into the analytical and statistical procedures involved in the analysis of the image data.

Subroutine SYMVUI prepares the Landsat data for the Harvard SYMVU (Laboratory for Computer Graphics and Spatial Analysis, 1977) program which creates a perspective view of the image data. Besides providing a simple and effective means of displaying the data, the perspective view presents a completely different graphic form of the data in which intensity of the reflected radiation is represented by variation in plot height. This type of view allows for the rapid assessment of the relative range and variation of the data, and comparisons between different spectral bands (Figure 1) are easily made. Smoothing options and close-up windows can provide clearer views of the spatial characteristics of the image data (Figure 2).

A second subroutine (SYMVUF) is used with the SYMVU program to examine the bivariate spectral feature space as defined by the supervised training field data or cluster data. Program ISPACE displays these same data as a scattergram of labeled observations without including any indication of the frequency of the observations. The traditional means for displaying this frequency content is in the form of bivariate standard deviation ellipses (Figure 3) in which the ellipses represent 95 percent confidence limits of the data distribution for two bands. SYMVUF determines the frequency of grey-level observation pairs and displays the result as a bivariate frequency perspective plot. Figure 4 shows the frequency of pixel pairs for band 5 versus band 7 for the entire image subset and for the training field data also shown in the lower graph of Figure 3. Figure 5 presents feature space graphs for supervised training field data obtained

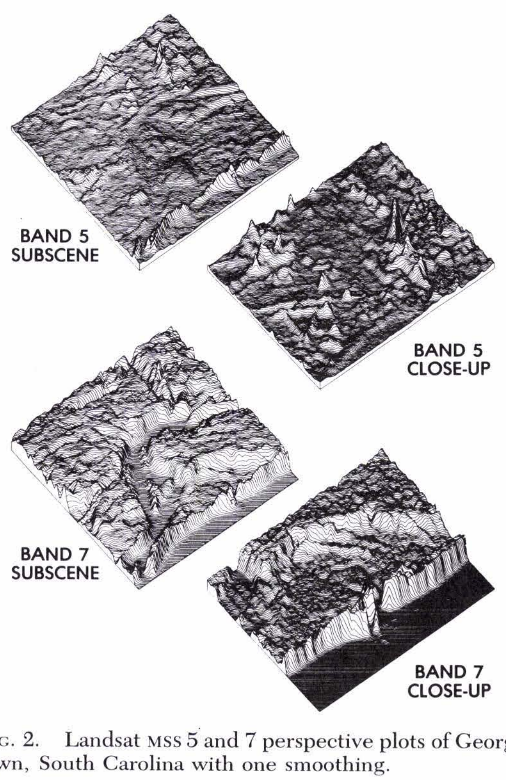

FIG. 2. Landsat MSS 5 and 7 perspective plots of Georgetown, South Carolina with one smoothing.

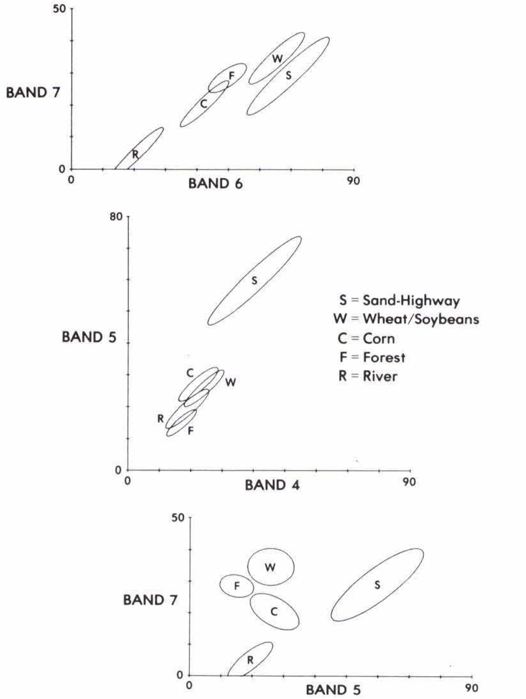

FIG. 3. Bivariate standard deviation ellipses (95 percent confidence level) of supervised training field data from Eudora, Kansas, image data set.

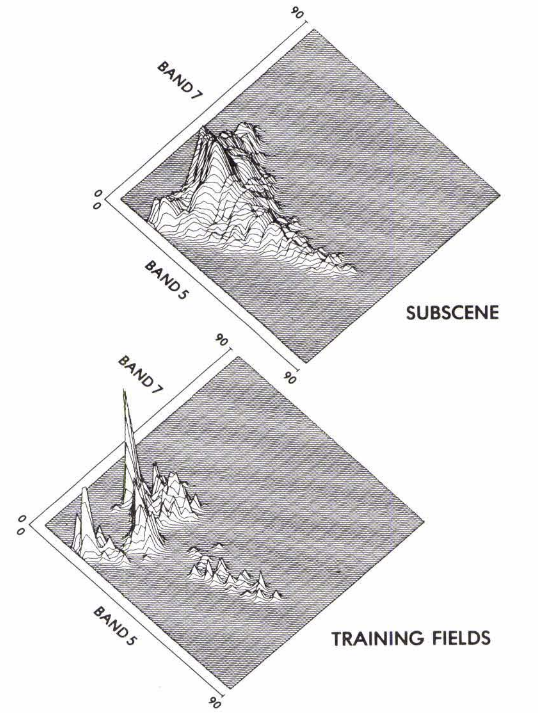

FIG. 4. Band 5 versus band 7 frequency perspective plots of image subscene and supervised training field data from Eudora, Kansas, image data set.

over two time periods. The raw data for each date were transformed (and rescaled) into a greenness or vegetation index (McDaniel and Hass, 1982) in order to display the multitemporal feature spaces. Such plots help the student to gain a better understanding of the separability of features using either raw or transformed data.

As an alternative to line-printer graphics for creating brightness maps and classified maps, programs VGREY and VCOLOR use the Versatec electrostatic plotter (Versatec, Inc., 1978) to create grey-scale images and color separation plots. The Versatec has a plotting resolution of 0.005 inches and is supported by line screening software for

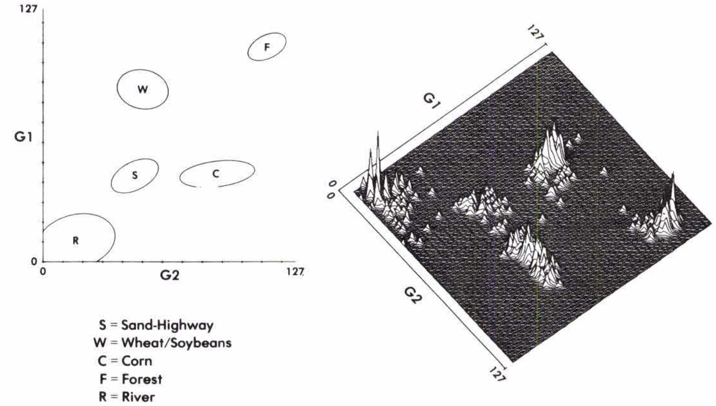

FIG. 5. Two date feature space graphs using greenness-vegetation index transformation of supervised training field data from Eudora, Kansas, image data set.

FIG. 6. Band 7 electrostatic plotter brightness map of Georgetown, South Carolina, image data set.

producing halftone images processed at an effective screen frequency of 200 dots per inch. VGREY produces brightness maps for each Landsat band (Figure 6) and, when used with IHIST, can produce maps of any user defined transformation such as ratios, greenness index, level slicing, and principal components. VCOLOR creates individual class maps (Figure 7) or color separations using the classification function coefficients obtained from DISCRIM. The individual class maps are useful for the interpretation of both supervised and unsupervised classifications, and the color separations can be used in conjunction with color proofing systems (Diazo, Color Key, Chromalin, Kwik Proof, etc.) for the production of a colored final classification map.

EXERCISES

The introductory course in digital remote sensing is currently taught in a ten-week term with two seventy-five minute lectures and one two-and-one-half-hour laboratory per week for the equivalent of three semester credits. Because of the demand on computer resources and subsequent poor turn-around at the end of the term, all computing is completed by the end of the eighth week. To accomplish this, students work through eight exercises (Table 2) without the interruption of a mid-term exam and are given the last two weeks of the term to complete a comprehensive take-home final exam and finish the color proofing of their final classification map.

Several problems continue to persist. The students use an interactive editing system and a personal file library to complete their work. Output from batch runs are returned to their work space and edited for subsequent runs. The output formats for the Landsat data handling programs are compatible from one run to the next, but the output from the SAS procedures require substantial screen editing before proceeding with the next step. SAS allows for the creation of user defined output files; consequently, modifications are currently being made to the SAS procedures to ensure format compatibility between all programs.

A second problem is universally associated with many academic computing systems—poor job turn-around times. This can severely limit the

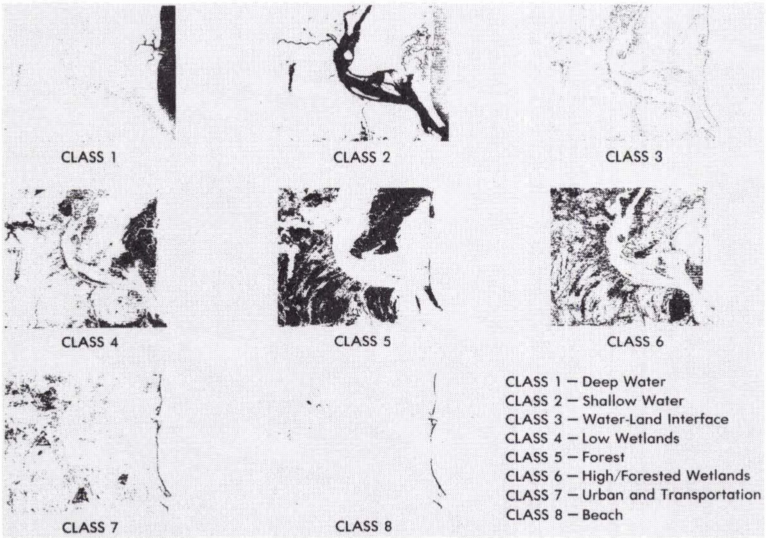

FIG. 7. Individual electrostatic plotter maps of supervised classification of Georgetown, South Carolina image, data set.

TABLE 2. LAB EXERCISES

Exercise #1:	Unpack a portion of the Computer Compatible Tape. In this example the Georgetown South Carolina data set will be used. Programs Used: UNPACK
Exercise #2:	Produce band 4, 5, 6, and 7 histograms for the Georgetown, South Carolina image data set; generate band 5 and 7 brightness maps. Extract raw data subsets containing highway, airport, or urban areas. Extract raw data subsets of a land-water interface. Create single class maps of highways (band 5); create single class map of water (band 7). Programs Used: IHIST, IGREY, IREAD
Exercise #3:	Create perspective plots (no smoothing and 1X smoothing) for all four bands of the Georgetown, South Carolina image data set. Produce Versatec (grey-scale) brightness maps for one of the visible bands and one of the near infrared bands using saturated and unsaturated contrast stretches. Programs Used: SYMVUI, VGREY, IREAD
Exercise #4:	Generate covariance matrix for all four bands of the Georgetown, South Carolina image data set. Run principal components analysis using covariance matrix. Create principal components brightness maps. Programs Used: ICOR, PRINCOMP, IHIST, VGREY
Exercise #5:	Construct color composite from raw data and/or principal components brightness maps using graphic arts camera and Color Key proofing system.
Exercise #6:	Select characteristic image samples and cluster the data. Select supervised training fields. Produce feature space graphs for both training field data sets. Programs Used: ITRAIN, FASTCLUS, ISPACE
Exercise #7:	Run discriminant analysis on both training field data sets. Clean data sets using a second or third discriminant analysis run. Produce "clean" feature space graphs for both training field data sets. Programs Used: DISCRIM, BVSTD, SYMVUF
Exercise #8:	Generate supervised and unsupervised classification maps. Create color separations for either the supervised or unsupervised classification. Construct a color composite from the color separations. Programs Used: ICLASS, VCOLOR

feedback and reinforcement derived from the exercises, which are somewhat hierarchical in nature. Structuring the course in order to complete all of the necessary computing in the first eight weeks of the term alleviates the problem to some extent. Students that fall behind usually cannot recover in time and do not have the necessary output material to undertake the final cartographic production exercise.

EVALUATION

Computing costs are not prohibitive for processing the image subsets. ITRAIN is the longest running non-graphics program requiring a total of 15 central processing unit (CPU) seconds in order to extract eight training fields of about 40 pixels each for four bands. The remaining non-graphics programs use less than 2 CPU seconds per run. The graphics programs (particularly the grey-scale routines using the Versatec plotter) need more time. VCOLOR uses 116 CPU seconds to produce three color separations for eight classes; the other graphics programs use only about 6 CPU seconds.

Most of the programs are quite transportable. Installations not supporting SAS (found only on IBM and plug-compatible computers) usually support SPSS (Statistical Package for the Social Sciences) or BMDP (Biomedical Computer Programs) which can be readily substituted for the SAS procedures. HICIP algorithms (excluding SAS) are available from the author for a nominal charge to cover the cost of tape reproduction, manual duplicating, and mailing.

Overall student response to the course has been positive. Students appreciate the "hands on" experience and feel that they have acquired a good understanding of the fundamentals of digital image analysis. Many of the students felt that the principal value of the image processing package is that is allowed them to "see," through the extensive use of graphics, all of the steps in the classification process from unpacking raw data to completing a professional quality final classification map.

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