USE OF COMPUTER-AIDED ANALYSIS TECHNIQUES FOR COVER TYPE MAPPING IN AREAS OF MOUNTAINOUS TERRAIN[1]

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BIOGRAPHICAL SKETCHES

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Michael D. Fleming received a B.S. in Forestry in Northern Arizona University, where his major emphasis was on multiple resource forest management and air photo interprètation. At present, he is a research associate in the Department of Forestry and Conservation and at the Laboratory for Applications of Remote Sensing, Purdue University. His work has centered around the interpretation of satellite multispectral scanner data and photography in the San Juan Mountains, Rocky Mountain National Park, and other test site areas in Colorado. The emphasis of his research work has been on the development and evaluation of procedures to be utilized in using computer-aided analysis techniques and multispectral scanner data for forest cover type mapping.

Paula V. Krebs is a Research Associate with the Institute of Arctic and Alpine Research (INSTAAR) and is an Assistant Professor Attendant in the Department of Biology at the University of Colorado. She received her B.A and Ph.D. degrees from the University of Colorado in dendro-ecology. Dr. Krebs is currently involved with the San Juan Ecology Project of the Bureau of Reclamation and is Principal Investigator of an ERTS "Follow-on" Investigation. Previous remote sensing activities on ERTS-1, Skylab, and NASA Office of University Affairs projects have committed her to working with user agencies interested in applications of remote sensing technology.

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ABSTRACT

Research during the past decade has proven the value of computer-aided analysis techniques (CAAT) for analysis of multispectral scanner data. However, most previous work has been limited to areas having little topographic relief. This paper describes the analysis of ERTS-1 multispectral scanner data obtained over the San Juan Mountains of southwestern Colorado. After geometrically correcting the data to produce 1:24,000 scale line printer maps, the data were analyzed using the LARSYS (1) computer software system and a newly-developed procedure for defining training samples. Results indicated that deciduous and coniferous forest and other basic cover types could be accurately mapped using CAAT, even in these areas of rugged topography. Only marginal accuracy was achieved when attempting to map individual forest types (species groupings) because of spectral variability due to slope, aspect, elevation, and variations in stand density. When two bands of ERTS data were utilized, rather than all four wavelength bands, the accuracy of the results achieved did not substantially decrease for basic cover type mapping.

INTRODUCTION

Previous work with multispectral scanner (MSS) data and computer-aided analysis techniques (CAAT) has proven the value of this combination of data and analysis techniques, but little work has been done in regions where the topographic relief would have much influence on the spectral characteristics of the data (2,3,4,5,6). Variations in aspect and slope were believed to have significant impacts on the spectral response measured by the ERTS-1 scanner system. If computer-aided analysis techniques are to provide an operational capability for use with MSS satellite data, the circumstances and conditions under which these techniques can be effectively utilized must be known as well as the reliability and amount of detail that can be obtained with these techniques.

The San Juan Mountains of southwestern Colorado were selected because of the importance of the forest, water, and geological resources of this area. The study was conducted jointly by the Laboratory for Applications of Remote Sensing (LARS), Purdue University, and the Institute of Arctic and Alpine Research (INSTAAR), the University of Colorado. The computer analysis of the ERTS data was carried out by LARS personnel, while INSTAAR provided the support data set used to define training sample areas and to evaluate the classification results. The support data set consisted primarily of cover type maps developed through photo-interpretation of NASA-obtained WB-57F color infrared photography and supplemental field checking.

Objectives

The purpose of the work reported herein was to test the applicability of computer-aided analysis techniques to identify, classify, and map forest cover types in the Colorado Rocky Mountains using multispectral scanner data from ERTS-1.

Three phases of this work will be described:

- Geometric correction of the ERTS-1 data tapes;
- Forest cover mapping results, involving computer classification of the data for both a Level 1 (basic cover types) and a Level 2 (forest types or species groupings) degree of detail; and
- Wavelength band comparison.

Geometric Correction

The usual procedure for handling ERTS data at LARS involves a reformatting process in which the original four data tapes that contain a single frame of ERTS-1 data are combined onto a single 1600 bpi data tape. No changes are made in the radiometric quality of the data. Each line and column of data is defined by an X-Y coordinate system so that the analyst can define any particular location of interest in the data. Preliminary work with the ERTS-1 data indicated a great deal of difficulty in accurately locating particular ground features in the data. For example, even though a particular stand of aspen or Douglas-fir could be located accurately on the aerial photos, the degree of reliability with which one could locate the same stand of trees on the computer line-printer display of ERTS-1 data was somewhat questionable. A major difficulty involved the geometric distortion present in the ERTS-1 data.

To overcome this problem, a program was developed to geometrically correct and scale the ERTS-1 MSS data (7). The program involves a five-step correction in which the data is rotated, de-skewed, and rescaled to the user's specifications. Use of the system-corrected data tapes from NASA allows this geometric correction and rescaling to be carried out without loss in radiometric quality of the data. However, in the rescaling process, approximately three percent of the data points are deleted. The only input required for this program, other than the reformatted data tape, is the latitude of the center point of the data frame involved. The standard output is a data tape which produces a geometrically correct 1:24,000 scale printout, oriented with north at the top. Use of this scale allows the analyst to overlay the printout directly on 7 1/2 minute U. S. Geological Survey topographic maps or other 1:24,000 scale maps and imagery.

Figure 1 shows a portion of an uncorrected computer printout in which the Vallecito Study Area has been outlined. The U.S.G.S. topographic maps of this 1 1/2 quadrangle study area were overlaid with an acetate sheet, and a few of the features which could be easily delineated on the map and could also be seen on the computer printout of

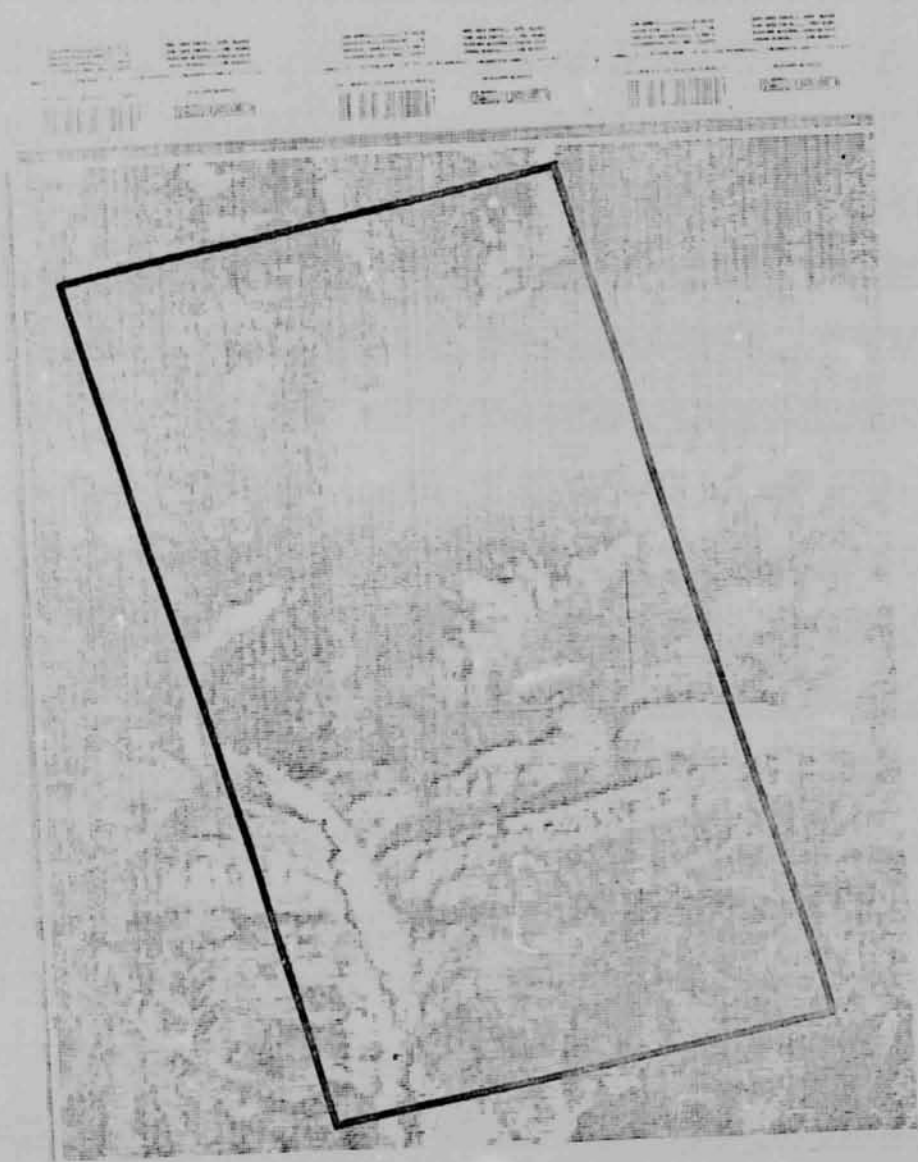

FIGURE 1.

Uncorrected computer printout of reflectance values in 0.70-0.80μm wavelength band. The study area shown in Fig. 2 is outlined.

FIGURE 2.

Topographic map with acetate overlay on which a few easily defined features have been delineated.

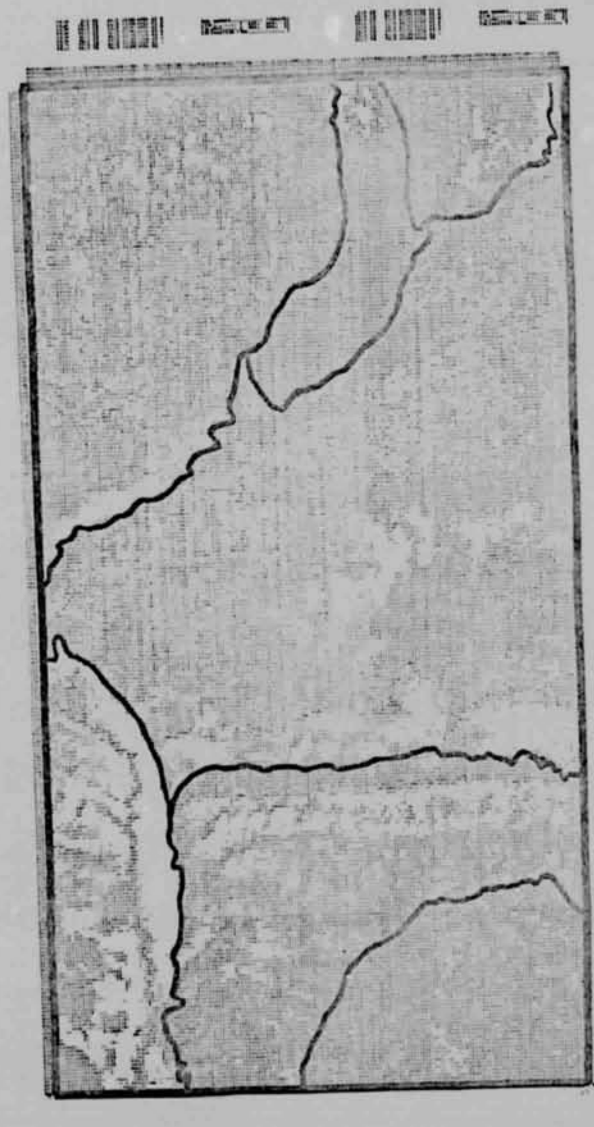

FIGURE 3.

Geometrically corrected, 1:24,000 computer printout of reflectance values. The same acetate overlay used for Figure 2 has been overlaid on the printout as an indication of the accuracy of the geometric correction and scaling procedure.

ERTS imagery were defined (Figure 2). After the data had been geometrically corrected and rescaled, a 1:24,000 printout was obtained and the acetate overlay previously obtained from the topographic map was then overlaid on the computer printout. Figure 3 shows the resultant printout with the acetate overlay, and indicates the accuracy of the geometric correction and scaling procedure.

A number of geometrically corrected printouts have been used by personnel from U. S. Forest Service, U. S. Geological Survey, as well as many people from LARS. These efforts have shown that the geometrically corrected data is accurate to within ±1 resolution element.[1]

Work with the ERTS-1 data indicated that accurate training of the classifier would have been nearly impossible in areas of diverse cover types without the ability to accurately locate ground features in the ERTS data, and that evaluation of the classification results would have been extremely difficult without the geometrically corrected data. Therefore, the geometric correction procedure has proven to be a particularly significant data handling capability that was developed during the course of these ERTS-1 investigations.

Forest Cover Mapping Results

Preliminary work with the ERTS-1 data indicated that a normal "supervised" procedure for classification would not be suitable for this work because of the complexity of the area involved (8). Attempts to use the "non-supervised" or clustering approach indicated that there were frequently more than twenty spectral classes present in even relatively small geographic areas. Because of the difficulty of relating the spectral classes to the cover types of interest, the non-supervised approach was not suitable either. A modified clustering approach was developed and proved to be quite effective. In this approach, a number of small areas are defined in the data which are clustered to develop a set of training statistics. The training statistics are then utilized in a normal classification procedure and the results are evaluated.

The LARSYS programs are designed in such a way that two major types of output from a classification can be obtained. The first is a map showing the spectral classes or cover types of interest, as specified by the analyst. The second type of output is a table indicating the performance of the classification for selected test areas. The test areas must be defined by the analyst. These tables provide a great deal of insight into the reliability of the classification of the various cover types throughout the area classified by the computer.

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[1]One resolution element of ERTS-1 data represents the integrated reflectance from an effective area on the ground of approximately 56 x 78 meters, or 184 x 256 feet.

To ensure statistical validity of such test area results, two factors should be considered. It is important that (1) the test areas should be selected as randomly as possible, and (2) the ratio of test field data points per class to total number of test field data points should be approximately the same as the percent of total area in that cover type class. For example, if approximately 50% of the test area is coniferous forest cover and 10% of the test area is water, then approximately 50% of the total data points involved in the test results should have come from areas occupied by coniferous forest cover and 10% of the test data points from areas occupied by water. In this way the test results should provide some indication of the actual classification performance for the entire area involved.

In this study, the test area involved an area in the southern part of the San Juan Mountains, northeast of Durango, Colorado. Approximately 23,068 hectares (57,000 acres) were included in this test site, which involved a heterogeneous mixture of deciduous and coniferous forest cover, some agricultural land (predominantly hayfields in the valley bottoms), a major reservoir, and rock outcrops (9). Table 1 shows the two levels of detail of cover type maps which were defined. Computer classifications were attempted for both the Level I (basic cover types) and Level II (forest type) degrees of detail.

TABLE 1. COVER TYPE BREAKDOWN

Level I	Level II
Conifer	Pinyon-Juniper
	Ponderosa Pine
	Doug & White Fir
	Spruce-Fir
	Krummholz
	Col. Blue Spruce
Deciduous-Conifer	DWF,P.Pine, & Aspen
Deciduous	Cottonwood-willow
	Alpine Shrub
	Oak-Shrub
	Oak
	Aspen
Grassland & Crops	
	Cultivated Crops
	Cultivated Pasture
	Pasture
	Meadow
	Tundra
	Wet Meadow
Barren	Exposed Rock
	Exposed Soil
Shadow	Ridge shadow
	Cloud shadow

TABLE 1 (continued)

Water	Clear Turbid
Snow	Snow only Snow-Forest Mix
Cloud	
Urban	

The Level I classification indicated that these basic cover types could be identified with a reasonably high degree of accuracy (85-95%), even in these areas of mountainous terrain. Figure 4 shows the test areas used in this analysis while Table 2 shows the test area results for the Level I classification.

TABLE 2. LEVEL I TEST, FIELD PERFORMANCE FOR THE VALLECITO INTENSIVE STUDY AREA

	TYPE	NO. OF SAMPLES	PERCENT CORRECT	CONIFEROUS	DECIDUOUS	GRASSLAND	WATER	BARREN
1	CONIFEROUS	1858	97.5	1812	22	3	1	20
2	DECIDUOUS	685	85.4	13	585	87	0	0
3	GRASSLAND	242	95.9	2	6	232	0	2
4	WATER	240	100.0	0	0	0	240	0
5	BARREN	98	93.9	0	0	6	0	92
	TOTAL	3123		1827	613	328	241	114

OVERALL PERFORMANCE (2961 / 3123) = 94.8

AVERAGE PERFORMANCE BY CLASS (472.7 / 5) = 94.5

Classifications of individual forest cover types resulted in a much lower classification accuracies as indicated in Table 3. Previous work at both Purdue and University of

TABLE 3. LEVEL II TEST FIELD PERFORMANCE FOR THE VALLECITO INTENSIVE STUDY AREA

	TYPE	NO. OF SAMPLES	PERCENT CORRECT	PINE	SF	OAK	ASPEN	PASTURE	BARE	WATER	CULTCROP
1	PONDEROSA PINE	1111	81.4	904	169	5	9	3	20	1	0
2	SPRUCE-FIR	747	64.9	254	485	2	6	0	0	0	0
3	GAMBEL OAK	481	61.7	8	0	297	95	80	0	0	1
4	ASPEN	204	78.4	5	0	33	160	6	0	0	0
5	PASTURE	188	94.1	2	0	4	0	177	1	0	4
6	BARREN	98	93.9	0	0	0	0	1	92	0	5
7	WATER	240	100.0	0	0	0	0	0	0	240	0
8	CULTIVATED CROP	54	61.1	0	0	2	0	18	1	0	33
	TOTAL	3123		1173	654	343	270	285	114	241	43

OVERALL PERFORMANCE (2388 / 3123) = 76.5

AVERAGE PERFORMANCE BY CLASS (635.5 / 8) = 79.4

FIGURE 4.

ERTS-1 MSS band 5 (0.60-0.70μm) gray-scale image of the Vallecito Study Area showing the location of the test fields used to evaluate the classification accuracy.

Michigan, using aircraft multispectral scanner data in areas without much topographic relief had given somewhat variable results, but there was promise for utilizing these techniques for mapping individual forest types and species (5,10). The difficulties in distinguishing the individual forest types in this research are thought to be due, in part, to the effects of topography on the data as well as the limited spectral range and the spatial characteristics of the ERTS-1 scanner system. Additional work with this ERTS-1 data indicated that there was a great deal of spectral variability due to differences in slope, aspect, elevation, as well as variations in density of the forest stands. Statistical analysis has revealed that all of these variables are of significance(8). For practical purposes, until topographic variability can be accounted for, a computer-aided analysis of individual cover types does not seem feasible. However, a Level I classification can be obtained with a reasonable degree of accuracy.

As another approach to evaluating the basic cover type classification results, the acreage estimates of the various cover types were examined. INSTAAR personnel obtained planimeter estimates of the acreage for each cover type within the test site, using type maps developed from color infrared aerial photos and standard photo interpretation techniques. Working independently with the results obtained by computer classification of ERTS-1 data, LARS personnel defined each quadrangle as a test site. The computer tabulated the number of data points that had been classified into each cover type. These numbers were easily converted to acreages using a conversion factor of 1.145 acres per resolution element (a factor based upon the 1:24,000 scale of the printout). Since the computer classification is basically a statistical approach, there are often both inclusive and exclusive errors present in the classification results, in which a data point is classified as something other than what it should have been classified. By simply tabulating the acreage of the various cover types on a large area, some of these inclusive and exclusive errors tend to offset each other. In this study, the acreages for the individual cover types of each of the quadrangles involved compared favorably to the acreage estimated by planimetering of the cover type maps. Note that the cover type maps were derived through a normal photo-interpretation process using color infrared photos. Table 4 shows the comparison between the acreage figures obtained through computer analysis of ERTS data and through planimetering of the type maps. The statistical analysis of these two sets of data showed a highly significant correlation coefficient (0.982) at the 0.95 confidence level.

This second approach to evaluating the computer classification results also indicates that the Level I classification of ERTS-1 data for basic forest cover type mapping can achieve a highly satisfactory result.

TABLE 4. LEVEL I ACREAGE COMPARISON
FOR THE VALLECITO INTENSIVE STUDY AREA

TYPE	COMPUTER CLASSIFICATION OF ERTS-1 DATA	AIR PHOTO-INTERPRETATION AND PLANIMETERING OF TYPE MAP
CONIFEROUS	31,124	29,135
DECIDUOUS	17,044	20,749
GRASSLAND	5,256	6,072
WATER	1,730	1,777
BARREN	1,772	1,966
TOTAL	56,926	59,699

Wavelength Band Comparison

One of the advantages of computer analysis of [illegible]spectral scanner data is that work can be done with a [illegible] or as few wavelength bands as required. In most o[illegible] analysis with ERTS data, all four wavelength bands ar[illegible]lized in the classification procedures. However, visu[illegible] interpretation of the data tends to indicate that the two visible wavelength bands are very similar, and that the two infrared wavelength bands are also similar in appearance. Therefore, to test differences in classification performance when various combinations of wavelength bands are utilized, a series of classifications were performed on the test area, using combinations of two, three, and four wavelength bands. The results were assessed using the same test fields that had been previously defined.

The feature selection processor, incorporated in the LARSYS analysis procedures, aids in selecting the best subset of bands for classifying the defined cover types. Using this processor, the best combinations of two and then three channels were selected and the data were classified. As the results in Table 5 indicate, when all four wavelength bands were utilized, an overall Level I classification performance of 94.8% was achieved, but surprisingly when the "best" combination of three wavelength bands were used, the classification accuracy was 94.7%, and when the "best" combination of only two wavelength bands were utilized, the classification performance was still 94.2%. Thus, in this classification sequence, a combination of only one visible and one infrared wavelength band seemed to allow nearly as good classification performance at Level I as when all four wavelength bands were utilized. This is significant because in computer analysis of MSS data, increasing the number of wavelength bands utilized in the classification causes the computer time to increase exponentially. Therefore, if fewer wavelength bands can be utilized and reliable and reasonably accurate results can be achieved the procedure becomes more cost effective.

TABLE 5. WAVELENGTH BAND COMPARISON

NUMBER OF BANDS	ERTS-1 MSS BANDS UTILIZED*	TEST FIELD PERFORMANCE
4	4,5,6,7	94.8
3	4,5,7	94.7
2	5,7	94.2

*BAND 4= 0.50-60μm; BAND 5 = 0.60-0.70μm; BAND 6 = 0.70-0.80μm; BAND 7 = 0.80-1.10μm.

Summary and Conclusions

This work involved computer analysis of ERTS-1 data for an area of 57,000 acres in the San Juan Mountains of southwestern Colorado. Results of the analysis indicated that:

- Geometric correction and rescaling of the data to obtain a 1:24,000 printout was extremely important, if not essential, for satisfactory analysis of the data.

- Computer classification allowed basic cover type maps (i.e. deciduous forest, coniferous forest, agriculture, water, exposed rock and soil) to be obtained with a high degree of accuracy (94%), even in this complex mountainous terrain.

- More detailed (Level II) cover type maps, involving individual forest cover types (i.e. ponderosa pine, spruce-fir, Gambel oak, aspen) could not be obtained with a reasonable degree of accuracy due to spectral differences caused by variability in slope, aspect, elevation, and density.

- One wavelength band in the visible and one wavelength band in the near reflective infrared regions of the spectrum produced results that were nearly as accurate (94.2%) at Level I as when all four wavelength bands of ERTS-1 data were utilized (94.8%) in the basic cover-type classification. This supports previous work (both theoretical and empirical) that indicates that fewer wavelength bands are required for less complex cover type situations (i.e. Level I vs Level II classifications).

These results are of major significance, since this was the first time that computer-aided analysis techniques has been successfully applied to satellite MSS data for this type of test site, where topography has caused significant variability in spectral response. The results demonstrate a reasonable capability to map complex, mountainous areas, and indicate that computer-aided analysis of ERTS-1 data offeres a method whereby reasonably accurate regional inventories can be rapidly obtained. Such inventories can be rapidly obtained. Such inventories will fulfill a major need of many land managers as an aid in the making of sound management decision.

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