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USE OF AN APPLE COMPUTER TO IDENTIFY VEGETATION AND ASSESS THE COVERAGE WITHIN SINGLE LANDSAT PIXELS

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I. ABSTRACT

Conventional image analyzing techniques are inaccurate when applied to Landsat data obtained from highly heterogeneous regions. In much of Florida, plant communities occupy small areas with erratic boundaries, meaning that most Landsat pixels represent a mixture of several different plant formations. This is especially true when studying an alien tree such as Melaleuca which is expanding its range by infiltrating a variety of plant communities. This paper describes development of a technique for using a personal computer to identify and quantify the major communities (plus sand and water) within a single pixel, and applies it to attempts to inventory the spread of Melaleuca.

High resolution photographs were used to prepare a vegetation map of all pure plant communities and dense Melaleuca stands in a 14km^2 study site. Landsat data was manipulated with the Image 100 until the spectral limits of dense Melaleuca stands, Flatwoods, Cypress, Swale, Sand and Water produced a coverage map that agreed with the ground truth map. Using the entire Landsat scene, each spectral band of all pixels identified as being one of the pure community forms was averaged to produce six sets of four point spectra (library spectra).

Pixel data from the study site was hand entered on an Apple II computer where a Pascal program determined what proportions of the six library spectra provided the best least squares fit of the unknown pixel's spectrum. Since some spectra could yield several different solutions, the program forced a number of solutions, each accompanied by three measurements of the solution's error. The program evaluated the error terms of all solutions, printing that solution with the least error; if all solutions exceeded acceptable limits, the pixel was labeled unsolvable.

Comparison of the computer's assessment of sixty pixels with that observed in aerial photos of an equivalent area was encouraging. Melaleuca was found to have an average coverage of 54.7% with the Apple as opposed to 55.6% as estimated from aerial photos. In addition, communities which were minor components of many pixels were fairly accurately measured (Sand, 13.2% by Apple vs. 14.9% by photo; Flatwood, 11.4% vs 16.8%; Swale, 7.1% vs 5.7%; Water, 4.4% vs. 3.2%; and Cypress, 1.6% vs 4.2%). Three of sixty pixels were unsolvable.

II. INTRODUCTION

The presence of two different objects within a reflectance spectrometer's field of view will yield a spectrum intermediate between that of the two components. Whether described by hundreds of data points or by only four values as in Landsat data, the composite spectrum is not comparable to either pure spectrum.

Because the instantaneous field of view of ERTS' multispectral scanner (MMS) is 72 M^2 (1.6 acres), when the satellite views an area that is highly heterogeneous or contains numerous minor components, the resulting spectra is difficult to correctly classify because it represents a mixture.[1] For example, Melaleuca is an imported tree species that is creating environmental problems due to its spread throughout southern Florida. The plant is difficult to detect during its early invading stages because either individual trees or small islands of trees are scattered among a natural community. Although more easily eradicated at this stage, the tree would not be detectable with analytical tools such as the Image 100 since many of the pixels containing Melaleuca would have spectra that are intermediate between that of Melaleuca and the dominant plant community. If not located and eradicated, the tree will become firmly established, replacing extensive acreage of the natural community.

Several different approaches have been employed to permit analyzing the four data points of picture elements (pixels) which contain mixtures. Most often, such a pixel is labeled as the vegetational form contributing most to the pixel's spectrum. Although such procedures provide an accurate portrait of an area in that the errors average out, the interpretation of single pixels is probably incorrect; the small scattered Melaleuca would be overlooked and classed as the dominant form. As pointed out by Richardson,[2] by suppressing the contradictory nature of the data, such techniques often find order where there was none.

One of the first approaches for resolving mixtures used quadratic equations to solve non-homogeneous pixels according to the average signature of each pure component.[3] Successful results were reported [4,5] for solving pixels containing a mixture of vegetation and water, presumably due to the opposite nature of the spectra of these two elements. Likewise, rice fields were differentiated from bare soil using this proportion estimation technique.[6] Further improvement was achieved by using information contained in the eight surrounding pixels to assist in the estimation of proportions.[3]

A different approach involved mathematically generating a series of artificial mixtures of two library spectra believed to be present in the mixture;[7] these synthetic spectra were then used as training values for standard pixel identification programs. Although the technique permits use of existing pixel recognition techniques without development of new algorithms, it is limited to solving mixtures within those ranges initially selected and presumes enough prior knowledge of the area to synthesize the proper mixtures.

Several different methods are available to permit solving (stripping) complex spectra when there is a library of standard spectra. Solution of simultaneous equations, linear programming and least squares techniques have all been successfully used,[8] although each has certain disadvantages. For example, the appearance of negative quantities in least squares solutions is meaningless when solving vegetation spectra; fortunately, they can be prevented by a procedure developed by Trombka.[9]

Perhaps the most severe limitation to the use of spectral solution with vegetation data is the extreme similarity of spectra derived from plant communities with similar physiognomic characteristics; this means many different solutions are possible, although only one is correct. The order that the library spectra are presented to the algorithm can effect different results, presenting the problem of deciding which is correct. The least squares technique developed by Trombka and Schmadebeck[9] for solving pulse height spectra (RIDAS) offered several advantages in that three mathematical indicators of the solution's quality were presented with the result. Thus, RIDAS was converted from FORTRAN to Pascal and installed on an Apple II computer; in the process, it was extensively revised to eliminate nonessential routines, to permit accessing pixel data from floppy disk, to force a variety of different solutions and then to select that answer which has the highest probability of being correct. This paper describes the rationale of the method and presents some test results obtained with Melaleuca.

III. MATERIALS AND METHODS

At the time this work was begun, Apple had not introduced FORTRAN for their computer, necessitating the use of BASIC or Pascal. Very preliminary attempts at converting RIDAS to BASIC indicated that the task would offer unreasonable challenges; thus Pascal was selected. The program has several major components. First, a data entry and file maintenance program was developed to store and average spectra from individual pixels. The main program, SPECSOLVE, reads the library and pixel values from the disk, then uses the least squares technique of RIDAS to solve the mixture and derive error terms; this latter program is a separate unit which is incorporated into the System's library due to memory limitations. A series of at least twelve solutions are produced by resolving after rotating the library; SPECSOLVE then selects the solution which best meets a set of criteria.

A. DATA STORAGE PROGRAM

This program is based on a random access program supplied with Apple's Pascal system. The program permits spectra of various lengths to be manually entered and stored in a random access file on a floppy disk. A large portion of the program is designed to check for errors and to permit easy revision of incorrect entries. In addition, the program also permits selecting individual spectra so they can be averaged and stored in a separate disk file; such average records are usable as library spectra.

B. SPECTRAL SOLVING PROGRAM

Upon executing SPECSOLVE, the program reads a file of library elements from the disk and permits the operator to select which spectra should be used and then specify their order. The operator can either name the datafile to be used and the number of pixels to be solved, or enter data singly. Once entered into the computer's memory, the data is processed by RIDAS; while a brief description of the rational is in order, for a detailed description, see Reference #[9].

Suppose a pixel (X) has reflectance intensities of 5.72, 6.84, 8.73 and 7.12 in bands 1 to 4 respectively. Ground truth indicates surface features E1, E2, and E3 with the following reflectance values could contribute from 0 to 100% of the reflectance seen in X;

	Element 1	2	3
band 1	10	4	2
band 2	12	5	9
band 3	10	6	15
band 4	8	7	7

Our objective is to derive the factor (f) which, when multiplied by each of the four bands of a given element, will describe the element's contribution to X's reflectance. Thus:

$$\begin{array}{lcccccccc} & \text{Element } 1 & & \text{Element } 2 & & \text{Element } 3 & & \text{Pixel } X \\ \text{band 1} & 10 * f_1 & + & 4 * f_2 & + & 8 * f_3 & = & 5.72 \\ \text{band 2} & 12 * f_1 & + & 5 * f_2 & + & 9 * f_3 & = & 6.84 \\ \text{band 3} & 10 * f_1 & + & 6 * f_2 & + & 15 * f_3 & = & 8.73 \\ \text{band 4} & 8 * f_1 & + & 7 * f_2 & + & 7 * f_3 & = & 7.12 \end{array}$$

To calculate the multiplication factors (f_1, f_2 and f_3) we set the problem in a matrix format as follows:

$$\begin{array}{ccccccc} & E & & & f & & X \\ 10 & 4 & 8 & & & & 5.72 \\ 12 & 5 & 9 & & f_1 & & 6.84 \\ 10 & 6 & 15 & * & f_2 & = & 8.73 \\ 8 & 7 & 7 & & f_3 & & 7.12 \end{array}$$

Reducing this to an algebraic equation,

$$E * f = X$$

Then solving for f

$$f = \frac{X}{E} \text{ or } f = \frac{1}{E} * X \text{ or } f = E^{-1} * X$$

This, if the element Matrix is inverted (divided into one), then multiplied by the pixel solution, the multiplication factors are derived:

$$f_1 = .12 \qquad f_2 = .63 \qquad f_3 = .25$$

This means that the pixel's reflectance could result from a surface composition of 12% coverage by surface feature E1, 63% coverage by E2 and 25% by E3.

Since negative solutions are possible with the least squares technique, a non-negativity constraint is imposed to eliminate any library elements which are oscillating towards a negative solution before the matrix is inverted. This method makes it possible to use more than three library elements in any given solution because the final inversion is less than four elements.

The completed solution is evaluated by comparing the original spectrum to the sum of each library element times the multiplication factor. The difference between the observed spectrum and the computed spectrum is described by a Chi squared value.

An error term is then derived for each element that had a multiplication factor greater than zero. This error term is based on the standard deviation of the computed multiplication factor and is expressed as the "percent error". The "total intensity" is determined by summing the intensities of each element. A third parameter, "fit" is calculated by summing the errors for each element, subtracting it from the total, then converting it to a percent of the total intensity.

The program derives one set of multiplication factors or coverage values, although subsequent runs with the same library but in a rearranged order could produce different solutions. This occurs when several library elements have similar spectra and one spectrum can substitute for another without substantially lowering the quality of the solution. The program is designed to force numerous solutions for each pixel so that each may be evaluated. To accomplish this, the order of the library elements is rotated so each element is presented first, then the pixel is solved again; the internal sequence is then rearranged and the rotation repeated. With six library elements, a total of eighteen solutions is derived for each pixel, each using a unique arrangement of library elements.

Although the same pixel is solved many times, the solutions are not necessarily different since identical solutions may have been computed from all rearrangements. Alternatively, many different solutions may result with few duplicates. To facilitate selection of the results, the solutions are arranged according to ascending Chi square value and all duplicates are eliminated.

The remainder of the program is responsible for selecting the best solution from those provided. Selection is based on the three summary values presented with each solution; Chi square indicates how closely the computed solution agreed with the actual pixel's data, with perfect agreement yielding a value of 0.0000. The total intensity represents the sum of the various components appearing in the computed solution, and is closest to the truth as it approaches 100%. Likewise, the fit is better as it approaches 100% since it means the standard deviation of all the various elements is extremely low. Thus, a perfect solution would have a Chi square of 0, a total of 100% and a fit of 100%. However, the problem was to determine which solution was best when none approached perfection. This was accomplished by subjectively developing criteria that provided the highest proportion of correct values.

Selection begins by checking the lowest Chi squared value to determine if it is less than 0.0005. If so, then several other solutions probably have the same Chi square, but with different totals. Such solutions usually have a perfect Chi square value and 100% fit, so the unique solutions are averaged and the result tested for its suitability. If the solution does not meet the criteria, and another set of solutions with low Chi squares exist, then the procedure is repeated.

If the solution with the lowest Chi square has a total that is not within 10 points of 100%, then the solution is discarded and the next unique set is tested. If acceptable, its fit is checked and, if it is greater than 87, the solution is printed. However, if the fit is too low, subsequent solutions are evaluated until a maximum of 3 solutions are tested. If all solutions are unacceptable, the limits for total are reset to ±20, all solutions rechecked and the first answer within the criteria is printed. If all three solutions have acceptable totals but low fits, the one closest to 100% fit is printed. However, if no totals were within the limit, the statement "no solution met criteria" is printed.

C. DATA ACQUISITION

The first critical step in solving pixels is to determine the values to be used for each library element. This was accomplished by using the Image 100 at Kennedy Space Center to analyze portions of a scene taken on January 11, 1978 (Scene #8210851447).

However, before the Image 100 could be used, it was first essential to map and be thoroughly familiar with a region in the scene being analyzed. The area selected was a natural region near Ft. Myers, Florida. The study site was approximately 2 X 7 km large and had been thoroughly documented by twenty high resolution (1:2400 and 1:7200 scale) aerial IR transparencies on February 14, 1978. In addition to these photos, the area was investigated on foot several times and was photographed.

Using microscopic enlargement of the IR photos, the boundaries of all regions which contained pure communities were mapped. The particular communities recorded were: dense tree canopy (thick Melaleuca stands), dead grass (swales), open tree canopy with grass below (flatwoods), shallow water with deciduous trees (cypress), standing water and pure sand.

With a detailed map of the study site, the Image 100 computer system was used for processing Landsat data and broadly classifying pixels. The pixel limits in the study area were repeatedly adjusted until only pixels located approximately within boundaries of a pure land form or community were marked. In this manner, those pixels which were pure for a given community type could be located. Then the computer was used to identify all pixels within the entire scene which fell within the same limits.

The spectral values for all selected pixels were averaged to derive the mean reflectance for a given pure community type. This process was repeated for each of the community types selected.

The Image 100 was also used to transcribe some of the actual pixel values within the scene. Although for development purposes the data was printed, transfer of data from tapes to microprocessor will eventually be direct. Each library spectrum was hand entered and stored on disk as were the raw data values for each pixel.

Ground truth estimations of the Ft. Myers study area were made by superimposing a grid, ruled to enclose 79 X 56.6 meter areas, over the area believed to correspond with the region where the pixel data was taken. Since the Landsat radiometer overlaps approximately 37% of an adjacent pixel, a given pixel is actually 79 M^2. To compensate for this overscan, estimations of the approximate percentage of each community were made through a second grid calibrated at 79 M^2.

IV. RESULTS

The complexity of this study site was enormous, with only 13% of the pixels being pure for a given element, 48% containing two elements, 18% with three, and 20% with four or more. Due to the uncertainty involved with positioning the study grid on the precise area sampled by Landsat, the actual area sampled may be shifted by as much as one pixel in any direction.

When all sixty pixels were averaged and compared with the average of the ground truth assessments, one sees fairly good agreement (Table 1). The class "unknown" represents three pixels which were not solvable within the bounds of the selection criteria. Even minor components in the scene are observed and are computed to have concentrations close to those observed on the ground.

Table 1. The average of sixty pixels in the Ft. Myers Study grid. The computed composition is compared to the actual estimates based on infrared photographs.

	Computer Assessment	Estimated from IR Photo
Sand	13.18	14.91
Swale	7.13	5.68
Flatwood	11.37	16.79
Melaleuca	54.72	55.57
Cypress	1.62	4.18
Water	4.38	3.20
Unknown	5.00	---
	97.40	100.33

A more challenging test of the method's accuracy was initiated by averaging the solution for each pixel with its eight neighbors and then

Table 2. The observed composition of a pixel which is averaged with the results in its eight adjoining neighbors.

sand	1.7	19.4	42.7	44.8	27.1	3.6	0.3	0.3
swale	2.6	2.2	2.8	1.3	1.5	1.6	1.1	2.2
flatwood	20.6	25.6	19.4	9.4	1.7			
Melaleuca	74.2	52.8	33.3	41.9	55.8	93.6	97.8	96.7
water	0.7		1.8	2.5	2.8	1.3	0.8	0.8
cypress	0.3							
sand	0.6	10.6	38.6	46.3	36.3	8.6	0.3	0.3
swale	7.8	7.8	2.2	0.7	1.0	1.9	1.4	1.4
flatwood	43.3	51.7	38.9	19.4	2.2	1.7	2.8	6.7
Melaleuca	47.3	30.0	19.1	31.0	57.7	85.8	93.9	90.0
water	0.3		1.2	2.5	2.8	2.1	1.6	1.6
cypress	0.3							
sand	3.9	7.3	37.8	47.8	41.1	10.6		
swale	10.6	19.4	13.9	9.5	0.9	2.3	2.0	2.8
flatwood	51.9	58.9	45.0	19.4	2.2	2.5	13.1	17.8
Melaleuca	28.1	10.6	2.4	20.8	51.9	81.1	82.2	77.8
water			0.9	2.2	2.4	2.1	1.6	1.6
cypress	7.8	3.3		0.3	1.4	1.4	1.1	
sand	5.6	7.8	35.3	46.4	41.4	12.2		
swale	8.9	21.1	15.6	13.4	3.4	6.8	7.3	7.0
flatwood	34.2	36.1	31.7	7.2	10.6	13.1	23.1	26.7
Melaleuca	26.9	16.7	9.7	18.6	35.8	57.2	58.3	56.7
water	1.7		0.6	2.4	6.8	7.6	9.1	8.6
cypress	24.4	18.3	7.2	0.9	2.0	3.1	2.2	1.1

Table 3. The computed composition of a pixel which is averaged with the results in its eight adjoining neighbors.

sand	2.6	16.9	45.2	45.6	30.8	1.4		
swale	2.3	2.3	7.2	19.1	19.1	14.2		
flatwood	12.8	10.8	10.8				2.0	2.0
Melaleuca	76.2	55.8	26.8	25.2	49.1	81.5	93.1	95.3
water	0.4	0.4						
cypress								
unknown		11.1	11.1	11.1				
sand	1.6	7.6	28.8	30.2	23.7	1.4		
swale	14.2	12.2	2.3	14.2	14.2	14.2		
flatwood	14.9	14.9	14.8			10.8	10.8	10.8
Melaleuca	59.5	51.4	33.0	24.9	36.7	58.0	81.4	85.0
water	6.1	4.0	2.2				1.4	1.4
cypress								
unknown		11.1	22.2	33.3	22.2	11.1		
sand	2.2	11.3	32.4	37.2	27.5	5.4	0.6	1.1
swale	17.2	15.2	0.7	13.6	13.6	13.6		
flatwood	31.7	22.2	16.8		8.9	21.7	21.7	12.8
Melaleuca	35.8	45.8	37.7	25.1	19.1	38.9	68.9	80.1
water	6.6	4.0	2.2	2.5	2.6	2.6	1.4	1.4
cypress	0.3	0.3	0.3					
unknown			11.1	22.2	22.2	11.1		
sand	0.7	8.0	28.9	37.7	30.3	9.5	0.8	1.3
swale	17.2	15.2	0.7	3.6	3.6	6.2	5.3	5.3
flatwood	30.3	11.4	6.0		8.9	21.8	21.9	21.8
Melaleuca	28.9	49.9	44.3	28.6	18.9	34.2	57.9	62.0
water	7.0	4.0	2.2	7.4	12.2	15.8	13.3	9.6
cypress	10.8	10.8	5.5					
unknown			11.1	22.2	22.2	11.1		

comparing the results to similarly averaged ground truth data. The nine pixel average was used to compare the data since a subtle disagreement between the presumed area surveyed and the actual position of the pixels could result in substantial shifts in the results. Thus, increasing the area by averaging blocks equivalent to about fifteen acres minimizes the effects of such errors.

From comparing the results in Tables 2 and 3, it is apparent that while many of the solutions are quite accurate, a substantial number of solutions miss the mark. Apparently, these errors cancel out when dealing with areas approaching 100 acres (Table 1). The errors could result from a variety of different causes; for example since the pixel boundaries used for swale and flatwood produced the poorest agreement between the Image 100 and the ground, perhaps their library elements are incorrect. Accuracy of the library is the most critical factor in the success of the method. A second possibility is that not enough solutions were produced; perhaps forcing additional solutions by introducing three library elements at a time may produce a better solution for these pixels. A third possibility is that there is an error in the selection criteria program, although a thorough review of the results indicates that the criteria are correct. It is also possible that the problems occur because the data has only four points per spectrum. If this is the case, the procedure may prove more successful with the new Landsat which has several additional data channels. Finally, the inaccuracies may mean the limits of the technique have been reached. Work is continuing to determine if the success ratio can be improved.

One final consideraton is that the technique is very slow when run on the Apple. Although a mainframe computer could execute the procedures in a fraction of the time, the convenience of having a computer dedicated to the technique offsets problems caused by the delay.

In summary, the technique may be of value when assessing small areas that are too complex to be accurately classified by conventional means.

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