N73-28338

Paper I 17

TERRAIN TYPE RECOGNITION USING ERTS-1 MSS IMAGES

Nicholas Gramenopoulos, *Earth Resources Data Processing, Optical Systems Division, Itek Corporation, Lexington, Massachusetts*

ABSTRACT

For the automatic recognition of earth resources from ERTS-1 digital tapes, both multispectral and spatial pattern recognition techniques are important. Recognition of terrain types is based on spatial signatures that become evident by processing small portions of an image through selected algorithms.

This paper describes an investigation of spatial signatures that are applicable to ERTS-1 MSS images. Artifacts in the spatial signatures seem to be related to the multispectral scanner. A method for suppressing such artifacts is presented. Finally, results of terrain type recognition for one ERTS-1 image are presented.

1. INTRODUCTION

The information conveyed to a human observer by a black and white MSS image is spatial. The multispectral information is contained in the brightness variations between the four spectral MSS images. It has been observed that combining the multispectral and spatial pattern recognition techniques enables more resources to be recognized at a greater accuracy.

The objects that can be recognized depend on the ground resolved distance and scale of the imagery. In the ERTS-1 images, various types of terrain can be recognized: cultivated land, urban areas, desert, mountains, bodies of water and cloud-covered terrain.

The recognition operation involves computer processing of small parts of an image to determine the presence of signatures that can be uniquely associated with terrain types. The spatial signatures are strongly dependent on image characteristics, such as scale and ground resolved distance and must be developed by analysis of the ERTS-1 MSS data.

This paper describes the terrain type recognition results obtained by processing a portion of the ERTS-1 MSS image no. 1049-17324-5. This image was acquired on 10 September 1972 over Arizona. The portion processed covers approximately 2,140 square nautical miles surrounding Phoenix, Arizona (see Figure 1).

Section 2 describes the preprocessing operations required to retrieve a black and white digital image suitable for spatial pattern recognition from the bulk processed computer compatible tapes delivered by the NASA Data Processing Facility.

Section 3 describes the development of spatial signatures for the various terrain types using optical diffraction patterns and digital processing algorithms.

Section 4 describes the results of the terrain classification for the ERTS-1 image discussed above, and in Section 5, conclusions are drawn.

2. PREPROCESSING OF MSS DATA

Each computer compatible tape delivered by NDPF contains one-quarter of an ERTS image. The four spectral bands (for an MSS image) are interleaved. In addition, the sampling interval (in meters) along a scan line is smaller than the sampling interval between scan lines. In other words, there are more picture elements along a kilometer on the surface of the earth parallel to a scan line (approximately East-West direction) than a kilometer normal to a scan line (approximately North-South direction). Furthermore, successive lines are slightly shifted to each other owing to the earth's rotation in relation to the satellite velocity.

The decoding and reformating program first retrieves the red band image (.6 - .7 microns) and separates it from the other spectral bands. It also selects data from the CCT's and combines them into one image covering a contiguous area of the test site. This image is then interpolated and resampled so that the sampling interval in both directions is equal and the skewness due to the earth's rotation is removed. Figure 1 shows an example of a reformated image obtained from two CCT's containing MSS data for ERTS-1 image 1049-17324. This image has 1,000 by 1,170 pixels and was formed by taking 1,000 lines from each of two adjacent CCT's. Each line in a CCT has 810 pixels. Corresponding lines in the CCT's were combined to form lines twice as long, containing 1,620 pixels each. After interpolation and resampling, the lines have only 1,170 pixels each. Skewness due to the earth's rotation has not been corrected in this image.

The red band image was selected because it carries more spatial information than the images of the other bands.

The resampling of an image to equalize the sample spacing in the two orthogonal directions is necessary to remove image distortion. If not corrected, the image distortion causes artificial variations in the spatial signatures of the terrain types. The distortion consists primarily of elongation of object dimensions in the scanning direction. Thus, a square farm would appear as a rectangle or a skewed parallelogram depending on its orientation to the scanning direction.

3. SPATIAL SIGNATURE DEVELOPMENT

Terrain types can be digitally recognized if they can be associated with spatial signatures which can be defined as unique patterns in a set of measurements involving a small area of an image. The area size that has been employed in this investigation is 32 x 32 picture elements which corresponds to about 2.5 x 2.5 kilometers on the surface of the earth.

The Fourier transform of an image is a convenient means to isolate and extract spatial signatures. Terrain signatures in the ERTS image can be efficiently analyzed using the Fourier transforming properties of lenses. Section 3.1 describes the analysis of optical diffraction patterns for the development of terrain signatures. Section 3.2 describes the signatures that were developed digitally.
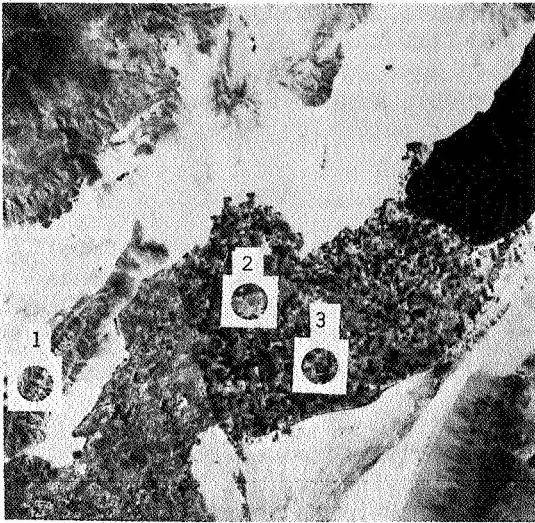
3.1 Optical Diffraction Patterns

To obtain diffraction patterns of small portions of ERTS-1 images, a special optical bench is employed. To obtain good size diffraction patterns, a long focal length lens (48 inches long) is being used. The 9½-inch transparencies supplied by NDPF were reduced to a scale of 1:3,000,000 and developed to a gamma of two. The image area whose diffraction was obtained was limited by a circular aperture 2mm in diameter.

The diffraction patterns have some artifacts not related to the terrain images.

To eliminate or suppress artifacts in the diffraction patterns, a mask is employed when photographing the diffraction patterns. The mask is itself the photograph of the diffraction pattern of an image area (from ERTS images) with no detail such as areas of water from lakes or the ocean. The masks have been used with very good results. They have suppressed artifacts and eliminated overexposure of low spatial frequency components by the central order.
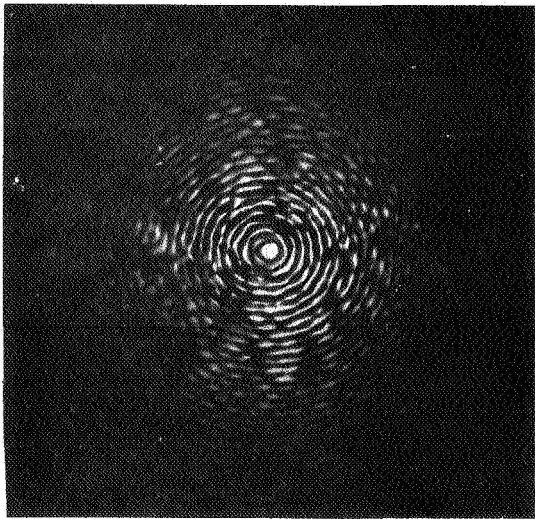
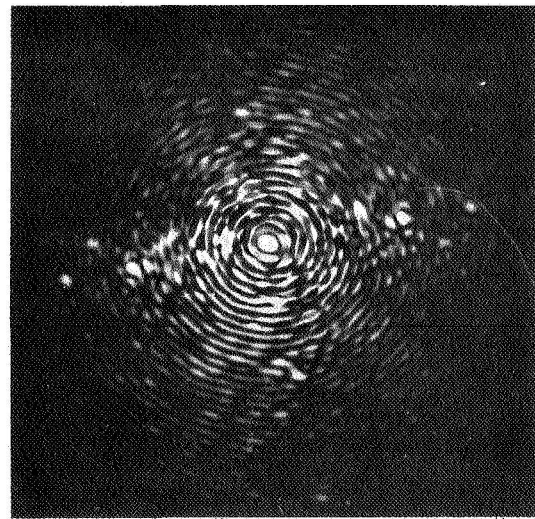FIGURE 1. ERTS-1 Image No. 1049-17324-5
Recorded from Digital Data

ERTS-1 image 1070-17445-5
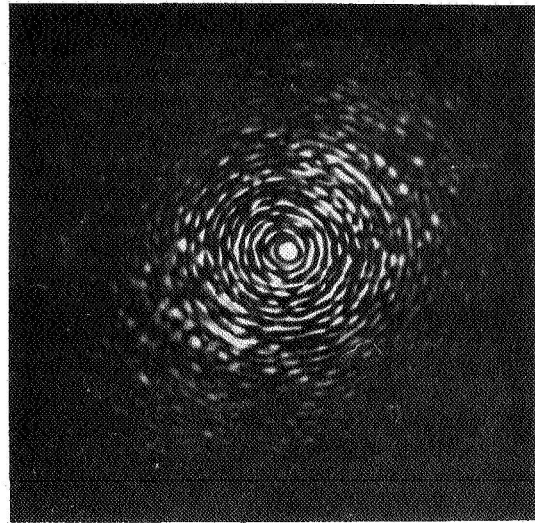
030-1 Mountaninous

030-2 Urban

030-3 Cultivated

FIGURE 2. ERTS-1 Image and Diffraction Patterns

1233

Diffraction patterns of terrain types from eight ERTS-1 images have been obtained and analyzed.[1] Signatures have been isolated for cultivated land in the red band image, and some urban areas in the IR2 (.8 - 1.1 microns) band. The signatures consist of orthogonal rows of frequency spots. Mountains and rivers have structured diffraction patterns. Simple spatial signatures such as rows of frequency spots have not been isolated for these terrain types. Figure 2 shows an ERTS-1 image and diffraction patterns from the encircled areas.

3.2 Digital Signatures

The digital recognition of terrain types is partially dependent on developing spatial signatures from the Fourier transforms of small areas of an image. Each area, otherwise known as a cell, consists of 32 x 32 picture elements. Thus, the entire image is divided into a matrix of 36 x 31 non-overlapping cells. Each cell is subjected to processing that assigns it to one terrain type.

The processing operations are divided into feature selection and classification. Feature selection preceeds classification. This is a data reduction operation. While each cell is initially characterized by 1,024 numbers, after feature selection, each cell is characterized by 8 numbers. Thus, in the feature space, each cell is described by a vector of greatly reduced number of dimensions. The selection of the features must be accomplished by analysis of the data, and there is no guarantee that the features selected convey most of the information available in the original data. The features that have been employed during this investigation are: the mean value of a cell, the histogram, a number representing a count of high derivative values within the cell, and the energies contained in specific non-overlapping sectors of the Fourier transform of a cell.

Figure 3 shows the amplitude of the Fourier transforms of four cells. The horizontal direction coincides with the scanning direction of the multispectral scanner. The frequencies represented by the squares vary from 0.39 to 5.9 cycles per kilometer. Due to the ground resolved distance of the MSS data, the street pattern of Phoenix is not resolved in the red band image. Also, the boundaries between adjacent farm plots are not resolved (see Figure 1). The farm pattern within a cell seems to be established by crops of equal brightness. If such crops exist in adjacent plots, they have the appearance of larger farms of irregular shape. Also, the farm pattern is affected by clouds and highways.
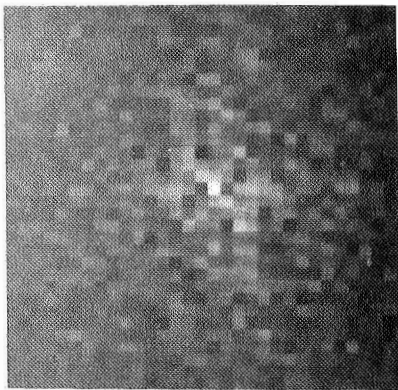
---

[1] Gramenopoulos, N. and Corbett, F., "Diffraction Pattern Analysis of ERTS-1 Images," Technical Report of ERTS-1 investigation.
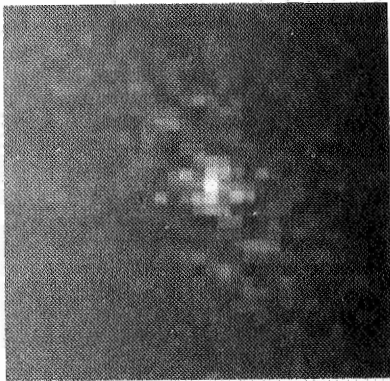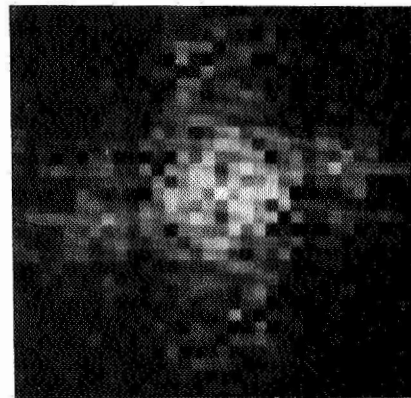
Mountain
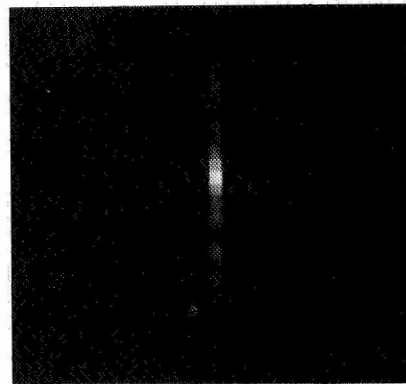
Desert

City

Farms

FIGURE 3. Digital Fourier Transforms of Cells

Extensive analysis of the Fourier transforms has produced the following results:

1. It appears that frequencies larger than 3.5 cycles/km contain the information needed to discriminate between the terrain types. Frequencies less than 3.5 cycles/km carry significantly less information.

2. Regardless of terrain type, there is significant energy along the vertical frequency column $(f_x = 0, f_y)$ where x is the horizontal direction and y the vertical. In addition, this column has local peaks at the frequencies $f_y = 2.1$, 4.2 and 6.3 cycles/km. These appear to be multiples of 1/6 the scanning rate (12.6 lines/km) of the Multispectral Scanner. Since the scanner has six detectors per spectral band, it is conceivable that these frequencies are artifacts due possibly to small errors in detector response remaining after calibration. The calibration errors may not be large enough to produce line structure in an MSS image. In any case, the frequency column mentioned and the two columns adjacent to it contain frequency components of the same order of magnitude as the components which have been related to farms. The discrimination results between the various terrain types were improved when these three columns were replaced by zeros.

Measurements of Fourier transform energy are made as follows:

a. All frequencies less than 3.5 cycles/km and larger than 5.9 cycles/km are eliminated.

b. In the remaining Fourier transform, the largest peak (or maximum) is determined.

c. The energy in a sector which is $\pi/8$ radians wide and centered on the largest peak is determined. The energy within this sector (S_1) is one of the features.

d. The energies in similar size sectors which are displaced from the first one by $\pi/4$, $\pi/2$ and $3\pi/4$ radians in a clockwise direction are also determined and constitute the features S_2, S_3 and S_4, respectively.

1236

Upon completion of the feature selection operation, the classification operation can then be carried out using only the feature vectors. The classification involves assignment of the cells to the terrain types by partitioning the feature space. For this investigation, the division of the feature space was done manually, in order to analyze the usefulness of the features that were selected. The classification algorithm consists of logic statements containing many thresholds.

4. TERRAIN CLASSIFICATION RESULTS

In order to determine the accuracy of the classification algorithms, two assignment matrices of cells were developed by photointerpretation. One matrix represents assignments using only the ERTS-1 red band image 1049-17324-5. The other matrix represents assignments using all available information (maps, aerial photography, and a land use map*). Comparing these two matrices, one finds that the first one has about 2.5% errors, which indicates the error rate of a photointerpreter if he were to use only the red band ERTS-1 image. Most of the errors are due to isolated urban areas near cultivated land, mountains or desert.

The computer classification matrix was compared to the most accurate photointerpreter matrix. The results are tabulated in Table 1.

Many cells contain two terrain types and the computer assignment of a cell is deemed correct if one of the terrain types is correctly recognized. Clouds and cloud shadows can confuse the classification of underlying terrain. Therefore, cells that contain even a small cloud or a cloud shadow are not assigned to a terrain type. The underlying terrain can be classified from different ERTS-1 images when it is cloud free.

Whenever cells cannot be classified with reasonable confidence, they are assigned to an unidentified group. This can be justified by the fact that all the information available (the other three spectral images) is not being utilized yet and it is desirable to defer making decisions on questionable cells until the spectral information is introduced. Due to scale and resolution, only three types of natural terrain can be recognized: desert, mountains, and riverbeds or flood plains. However, in the land use map*, the following categories of terrain were classified: undissected flat land, slightly dissected flat land, rolling land, moderately dissected land, hills, mountains and flood plains. Our

---

* Poulton, C.E., Schrumpf, B.J., Johnson, J.R., "Ecological Resource Analysis from High-Flight Photography for Land Use Planning," Applied Remote Sensing of Earth Resources in Arizona, Proceedings 2nd ARETS Symposium, University of Arizona, November 2-4, 1971.

TABLE 1. COMPARISON OF CLASSIFICATION RESULTS
PHOTOINTERPRETER'S ASSIGNMENT

COMPUTER ASSIGNMENT	1	2	3	4	5	6	7	8	TOTAL
0	0	0	3	15	22	6	14	0	60
1	61	0	0	0	0	0	0	1	62
2	0	2	0	1	0	0	0	1	4
3	1	0	417	6	7	8	5	0	444
4	0	0	3	248	1	9	2	1	264
5	0	0	5	3	131	2	4	0	145
6	0	0	1	5	3	71	8	0	88
7	0	0	1	0	0	0	4	0	5
8	0	0	0	0	0	0	0	13	13
TOTAL	62	2	430	278	164	96	37	16	1085

CLASS IDENTIFICATION

0 = Unidentified   4 = Farms
1 = Clouds   5 = Mountains
2 = Water   6 = Urban
3 = Desert   7 = Riverbed
    8 = Cloud Shadows

category of desert includes: undissected, slightly dissected, rolling and moderately dissected deserts. Our mountainous category includes hills and mountains. Our urban category includes airports and military bases.

Due to the population density of the area and man's activities, the signatures of the various terrain types vary considerably, thus increasing the probability of error. The following examples have been noted:

1.   Highways and canals cutting through desert can be confused with flood plains.

2.   Urban development has extended into the hills north of Phoenix and new developments farther north into the desert have been initiated. These areas are now urban, but retain some of their former desert or mountainous characteristics, thus producing some classification errors.

3.   The urban areas are spreading into farmland near Glendale and farms have been noted surrounded by urban areas or in the process of being coverted to new developments. Such areas have produced classification errors or unidentified cells. Sun City, a circular urban development near Glendale, is quite different in appearance than downtown Phoenix.

4.   The Salt River bed runs through Phoenix. The waters of this river have been diverted for irrigation and the river bed is now dry. The river bed is used for urban or industrial purposes, but it is thinly populated in comparison to Phoenix. Classification errors and unidentified cells were found along the river bed.

It was also noted that farms are a dominant terrain type. Most cells containing two terrain types with farms being one of them, were assigned to the farm category.

The classification results are shown in the annotated photograph of Figure 4. The letters were superimposed on the image of Figure 1, and are centered within each cell. The interpretation of the symbols is:

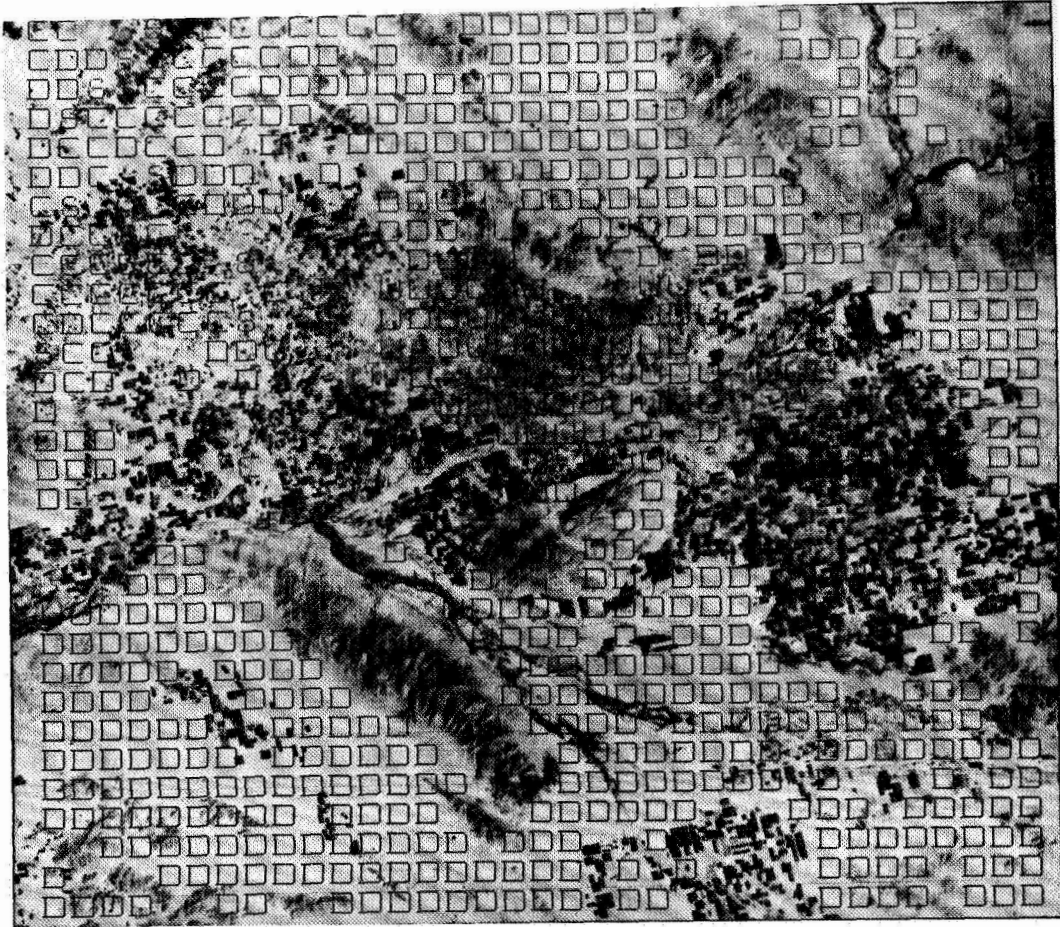|			
D	= Desert	R	= Riverbeds
U	= Urban	C	= Clouds
F	= Farms	S	= Cloud Shadows
M	= Mountains	Blank	= Unidentified

FIGURE 4. ERTS-1 Image and Terrain Classification Results

5. CONCLUSIONS

The recognition of terrain types is accurate for desert (97%), farms (89%) and mountains (80%). The accuracy for urban areas is lower (74%) and poor for riverbeds (11%). These results are indicative of what can be achieved using a single ERTS-1 image. Due to the resolution of the system, urban areas cannot be recognized with a very high degree of confidence until the information in the other spectral bands has been exploited. Most of the errors in the urban category seem to occur in thinly populated areas associated with recent urban expansion into desert, farms, riverbeds and hills.

One potential application of the technique described is in land use inventory and management. For this application, boundaries between terrain types are also required and one needs to demonstrate that the technique works accurately for other regions of the country with human adjustment of the classification algorithm kept to a minimum.

We are proceeding with the automatic boundary development which at the present time, has not been completed. The boundaries can be used to accurately define the terrain regions and, furthermore, cells containing boundaries can be eliminated, thus, further improving the accuracy of the classification.

An expansion of the classes recognized will be implemented by the introduction of the multispectral information (the other three spectral bands).

A very significant result of this investigation is that the features selected are sufficient for the purposes of classifying terrain types. The four most important features are derived from the Fourier transforms of the cells. That these features can be used to classify terrain from other test sites is strongly suggested by the similarities observed in the diffraction patterns from six test sites. On the other hand, the classification algorithm which employs the feature vectors is image-dependent. While a specific algorithm may be applicable to a small sequence of ERTS-1 images, it seems unlikely that a fixed algorithm could be used successfully on all ERTS-1 images. For this reason, the partitioning of the feature space will be done by "clustering" techniques similar to those employed by multispectral recognition algorithms. Feature space vectors will be grouped into classes that satisfy a selected criterion. By this approach, a fully automatic terrain recognition system can be evolved which consists of an image-independent selection of features followed by an image-dependent classification algorithm.