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ELAS'S SEARCH ALGORITHM WITH A LINEAR WINDOW

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ABSTRACT

ELAS (Earth Resources Laboratory Applications Software) is a popular geobased information system designed for analyzing and processing digital imagery data. The system was developed by NASA's Earth Resources Laboratory and evolved from the Laboratory's work in studying remotely sensed data. A key component of ELAS is the SEARCH algorithm, devised to generate spectral classes used in the classification process of multispectral data. As an unsupervised procedure for producing spectral classes, SEARCH possesses several different input parameters, each conceived to examine the statistical characteristics of the data. However, only the 3 row by 3 column window which moves across the data set searching out statistically homogeneous areas within an image deals with the spatial nature of the data. This window is designed to detect surface features which are more areal in shape in comparison to linear and point features. Land surface features in general relate to one of three shapes or spatial patterns: areal, linear or point. This study examines the use of a linear window (1x9) with the SEARCH algorithm and compares the results of this shaped window to the areal window, especially with respect to detecting linear features. The test site for this study is the Syracuse, New York metropolitan area and the data set is a TM image taken on October 24, 1982.

SEARCH ALGORITHM

The SEARCH algorithm is based on moving in a prescribed manner a square or areal shaped window through the data set seeking out spectrally homogeneous surfaces. Certain statistical values are calculated from the multispectral data within a window and compared to three parameters to determine spectral homogeneity. Defined by the investigator these input parameters are: 1) the standard deviation limits for each spectral channel, 2) a coefficient of variation, and 3) a separability measure called scaled distance. Upper and lower standard deviation limits or bounds are established for each spectral channel. SEARCH initially allowed only one set of limits which was used for each channel but the algorithm version used in this study permits the establishment of individual limits for each channel. Windows that meet these standard deviation limits are used as training fields, the building blocks for creating spectral classes. A standard deviation value is calculated for each spectral channel from the respective spectral values within the window area. Each channel's standard deviation value must fall in between its designated deviation limits for the window to become a training field. The more channels used in a study or the smaller the deviation ranges are, the harder it becomes for a window to qualify as a training field. A set of window data values associated with the upper end of a channel's dynamic data range might demonstrate more absolute variation than a set of values found at the lower end of the range but both sets of data might possess the same relative variation with respect to homogeneity. Even though the relative variation might be the same for both sets, the standard deviation calculated for the data set in the upper portion of the data range will be greater, and thus, less likely to fall within the established limits than the standard deviation for the data set at the lower end of the data range. To handle this situation a second upper limit is established for each channel which is determined by the coefficient of variation times the channel's mean for the window. The largest of the two upper limits, the one established by the investigator as an upper standard deviation level or the one calculated based on the coefficient of variation, is used as the upper bound test for a particular channel within a window. The coefficient of variation is also an input parameter established by the investigator. Note Figure 1.

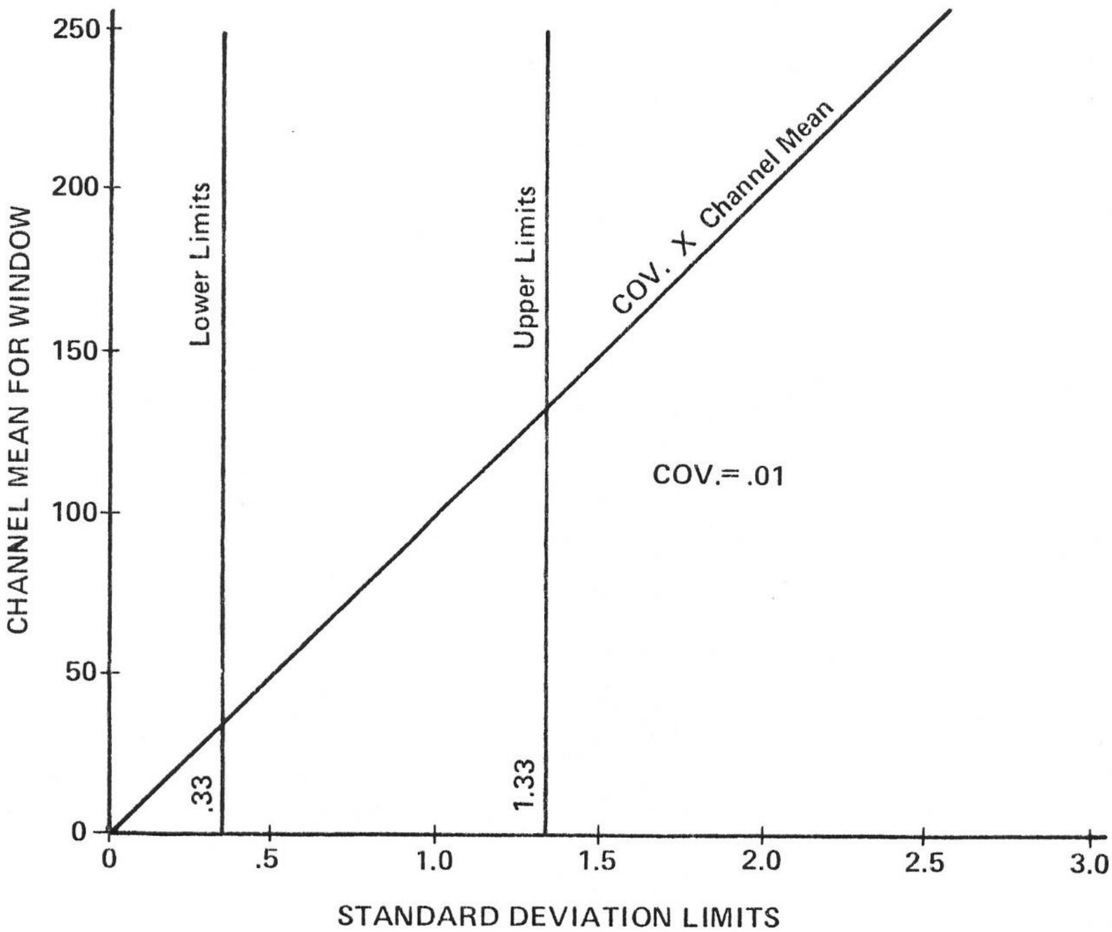


Figure 1: Channel 2's Lower And Upper Or COV Limits In Comparison To Different Channel Means For A Window

The means and covariance matrix for each training field are maintained by the SEARCH program until an upper storage level is reached. The SEARCH program used in this study permits 100 training fields to be stored. To allow the search for training fields to continue through the remainder of the data set once the upper storage level is realized, it becomes necessary to merge training fields. The scaled distance between each training field is calculated to ascertain separability and the pair of training fields with the smallest pairwise scaled distance is merged. Some versions of SEARCH provide slightly different procedures for reducing the number of training fields such as eventually eliminating fields with too few data points. The version used in this study keeps all areas identified as training fields and merges similar ones together to provide extra storage.

This merging process opens a storage area for another training field. This alternating field selection and merging continues over the entire data set. If at any time the smallest pairwise distance is greater than the desired maximum scaled distance, the third parameter established by the investigator, the desired maximum scaled distance is incremented automatically by .25. After moving the window through the complete data set, the training fields with pairwise distances which are less than the desired maximum scaled distance or the incremented distance, whichever is greater, are merged. This process consolidates those final training fields which are statistically similar. The remaining training fields are now referred to as spectral classes. The means and covariance matrixes from these spectral classes are used with a classifier to assign each pixel within the data set to a particular spectral class.

The modified algorithm used in this study possesses all of the features described above but it also has a 1x9 linear window which can be orientated to move through the data set in one of four directions, namely vertically, horizontally, forward 45 degrees diagonally, and backward 45 degrees diagonally. More than one window orientation can be used in a single run through a data set. The 3x3 squared window cannot be rotated to various angles without changing the overall size of the window.

STUDY AREA AND PARAMETER SELECTION

Urban areas possess a variety of linear surface features particularly transportation routes; thus, to test SEARCH with a linear window an urban study area was selected, namely Syracuse, N.Y. The Syracuse metropolitan area holds approximately 650,000 people and covers over 26 square miles. The city's commercial core is situated at the southeast end of Onondaga Lake and the city spreads out on hilly terrain overlooking the lake. Syracuse was selected as the study area due to the availability of excellent low altitude color photography which could be used to verify features and a cloud free TM data set with high quality ratings in all seven channels. Taken on October 24, 1982, this mid-fall scene captured much of the vegetation changing colors and trees dropping leaves which should have made direct surface features more visible to the TM scanner. A 480 line by 670 element subset of this scene was used as the actual data set for this study.

Rather than use all seven TM channels, only four were employed in the study. As the number of channels used in the SEARCH algorithm increases the number of tests for homogeneity also expands making it generally harder to obtain spectrally homogeneous training fields. The four channels selected were band 2 with a spectral range of .52 to .60 microns, band 4 (.76 to .90 microns), band 5 (1.55 to 1.76 microns) and band 7 (2.08 to 2.35 microns). Channel 6 was not used since its 120 meter resolution size in comparison to the 30 meter resolution for the other channels would not have contributed much in differentiating surface features. Also, the SEARCH algorithm cannot handle a training field which has a channel possessing perfect spectral homogeneity. Most 3x3 windows would encounter such homogeneity with channel 6 since a data value associated with one of its 120 meter pixels would cover sixteen 30 meter pixels related to the other channels. Channels 1 and 3 were not selected since they are highly correlated with channel 2 as shown in Table 1; thus, little additional information would be obtained by including these channels. Channel 2 demonstrated better spatial clarity than channels 1 and 3 especially in the residential areas of the city.

TABLE 1: Correlation Matrix

Channel Numbers	1	2	3	4	5	6	7
1	1.000	.969	.927	.426	.305	.383	.445
2	.969	1.000	.959	.505	.363	.341	.472
3	.927	.959	1.000	.586	.533	.426	.623
4	.426	.505	.586	1.000	.743	.487	.590
5	.305	.363	.533	.743	1.000	.505	.895
6	.383	.341	.426	.487	.505	1.000	.537
7	.445	.472	.623	.590	.895	.537	1.000

Specific lower and upper standard deviation limits were established for each channel, and in order to maintain continuity and reduce bias between the various computer test runs, these limits remained the same throughout the entire study. The lower limit on all four channels was the same, .33. This value was selected since it is the lowest standard deviation possible to generate in a 9 pixel window without encountering perfect homogeneity or zero standard deviation. As stated before SEARCH cannot handle zero standard deviations due to certain statistical restraints. The established upper limits were: Ch. 2 - 1.33, Ch. 4 - 2.20, Ch 5 - 3.63, and Ch. 7 - 2.02. A frequency count was taken for these four channels over the entire study area and channel 2 had the smallest dynamic data range. An arbitrary range of one was selected for this channel making the lower and upper limits .33 and 1.33. The upper limits for the other channels were determined by taking their respective dynamic data ranges as a proportion of the channel 2 range. This procedure attempts to establish lower and upper limits which possess the same homogeneity level for each channel, even though each channel has different dynamic data ranges. The coefficient of variation (0.01) and the maximum desired scaled distance separability (1.0) were also kept constant throughout the study.

SPECTRAL CLASSES

Six sets of spectral classes were generated using the SEARCH program with the parameter values and data set discussed above. One set was based on the 3x3 areal window, four on the four different individual 1x9 linear windows, and one on a combination of two linear windows. Table 2 shows the total number of individual training fields found under each of the six approaches, the number of spectral classes formed from the training fields, and the final scaled distance levels.

As previously stated the initial scaled distance established for each program run was 1.0. If during the merging process the smallest pairwise distance between the two closest training fields is greater than the scaled distance, the scaled distance is incremented by .25 until the pairwise distance is less than the scaled distance. The new scaled distance value is used for the remainder of the program run unless it is necessary to increment it again. At the end of the program run the pairwise distances for all 100 training fields are compared one final time and those fields with distances below the scaled distance are merged with the remaining fields which become the spectral classes. As shown in Table 2, the scaled distances for four of the program runs were not incremented which indicates that all pairwise distances checked for merging were below 1.0. Thus, the spectral classes generated from these four program runs are likely to be relatively close to each other in four dimensional (4 channels) space which might make it difficult to detect and separate various land surface conditions. Of the four program runs, the one associated with the areal window appears to have produced the best spectral classes. It has the greatest number of spectral classes which should allow an investigator more opportunity to associate correctly classes with land cover conditions. Also, only twenty of its final 100 training fields were merged during the final merging stage leaving 80 spectral classes with pairwise distances greater than 1.0. The other three program runs, all associated with linear windows, demonstrated much poorer results by creating fewer spectral classes, and thereby, reducing the opportunity for the investigator to group classes into reasonably accurate land covers.

TABLE 2: Comparative Results From The Six SEARCH Runs

	Number of Training Fields	Number of Spectral Classes	Final Scaled Distances
Areal Window (3x3)	489	80	1.0
Linear Window (Horizontal 1x9)	428	91	3.5
Linear Window (Vertical 1x9)	546	53	1.0
Linear Window (Forward 45 degrees, 1x9)	536	24	1.0
Linear Window (Backward 45 degrees, 1x9)	557	21	1.0
Linear Window (Horizontal and Vertical 1x9)	974	96	4.5

During the other two program runs the scaled distances were increased with the final scaled distances (3.5 and 4.5) being well above the established distance of 1.0. To produce these results the training fields used during these two runs had to possess much greater pairwise distances or separability than the fields associated with the other four runs. Also, both program runs produced a large number of spectral classes (91 and 96) indicating that the classes are likely to be well separated in four dimensional space and more distinctive in being associated with surface features. The ninety-one classes developed during the one run must have pairwise distances above 3.5 and the ninety-six from the other run must have distances above 4.5. With such high final distance values one would expect that a great number of the 100 training fields would be consolidated during the final merge stage but this condition did not materialize with these two runs suggesting that the classes generated with these windows possessed a great degree of separability. Both of these program runs produced better results than the run using the areal window.

The one run was based on a horizontal linear window and the other on combining the horizontal and vertical windows. The question must be raised "What is it about the horizontal window that produced such better results than the other linear windows?" Is it the sensor's scanning swath, the difference between the scan line detectors, or the nature of the data set? This question and these possibilities need to be considered, but at another time. The combination window has a total number of training fields equal to the number of fields developed by the two individual vertical and horizontal windows added together.

Using the vertical window in the combination run may appear initially not to have added significantly to the number of spectral classes generated but the horizontal window had already accounted for 91 of the possible 100 spectral classes leaving only the possibility of adding 9 classes. The use of the vertical window did add 5 more spectral classes and moved the scaled distance up from 3.5 to 4.5. The higher distance moved the separability level of 96 spectral classes to a higher level and potentially more distinctive conditions with respect to different surface features.

CLASSIFICATION FINDINGS

Each of the six sets of spectral classes was used to classify the study area using the maximum likelihood classifier. Only two of these classifications will be discussed in this paper, namely the classifications based on the areal window and the combined horizontal and vertical linear windows. The classification findings for the combined linear windows and the horizontal linear window were basically the same. The other three linear windows produced, in general, poor classification results. To obtain a more detailed analysis of the two classifications to be discussed two subareas within the study area were examined. These two subareas were the Syracuse-Hancock International Airport and the Solvay-Westvale residential areas. Both areas demonstrated distinctive different linear features as well as certain areal features.

The overall findings suggest that the combined linear window classification produced much better results than the areal window classification. The areal window required seventeen spectral classes to identify water bodies, slightly more than 21 percent of the total of eighty spectral classes. These seventeen classes defined mainly Onondaga Lake, the Erie Canal, and some small ponds. No one class created a solid pattern of water in defining the water bodies but they all produced intermittent horizontal stripe patterns. For an areal window one would have expected that only a few spectral water classes would have been produced especially with such a large homogeneous surface as Onondaga Lake and that the classes generated would have been solid in appearance. The classification created by the combined linear windows had only four spectral water classes, two of which accounted for about 90 percent of the water surfaces. The areal classification assigned 15,638 pixels as water while the linear classification identified 15,331 pixels as water. The 307 pixel difference represent an area of about 76.75 acres. The difference appeared mainly around the edge of the Lake and other water bodies. It was not possible to identify the exact amount of water surface existing at the time that the image was recorded; thus, one cannot indicate which of the two classifications was more accurate.

The areal window classification had one spectral class which accounted for 70,380 pixels or 22.32 percent of the entire study area. This class could be best identified as residential land use. A second spectral class had 26,817 pixels or 8.5 percent of the study area. This class corresponded to high reflectance surfaces such as highways, airport runways, commercial and industrial areas, and open cultivated fields. With two spectral classes representing over 30 percent of the study area and seventeen classes associated with water surfaces, the remaining spectral classes did not provide much opportunity for the investigator to create a relatively accurate land cover product. The largest spectral class produced by the linear classification had only 19,446 pixels or 6.1 percent of the total number of pixels. With no single spectral class dominating the image and only four out of ninety-six classes being related to water, the linear classification provided a considerable amount of flexibility for the investigator in developing an accurate land cover classification.

Syracuse-Hancock International Airport

The Syracuse-Hancock International Airport maintains two operational runways, one of which is 9003 feet long and the other 7501 feet. A third, non-operational runway exists which is intersected by the airport main entrance road causing the runway to appear as two sections. Each runway possesses paved shoulders which are shorter in length and different in surface material from the runways. The three runways are orientated in three different directions forming a triangular shaped appearance to the airport. These runways with their various support roads for taxiing planes and the other roads for ground transportation provide very distinctive features. In addition, the terminal building, the paved apron around the terminal, the parking lots, the other sizeable airport buildings, and the large open grass areas represent major homogeneous areal features. Thus, the airport forms an ideal test site for studying the results of the areal window classification versus the linear window.

The areal window classification assigned the three runways, the support roads, the parking lots, and the terminal with its large apron into basically one spectral class making it impossible to separate these features as individual items. The main entrance road plus some small sections of the apron were associated with a second spectral class. The large open grass areas throughout the airport related to several spectral classes. In comparison, the combined linear window classification displayed many of the different features under separate spectral classes. The runways, the runways' shoulders, the terminal, the apron, and the various support roads were identified as individual items under different spectral classes. Unlike the areal window classification, this classification made it possible to separate key airport features. The grass areas around the airport were also associated with several spectral classes indicating diverse grass conditions. Note the amount of gray tone variations in Figure 2b, the combined linear window classification, in comparison to Figure 2a, the areal window classification, with respect to the different airport features. These variations reflect how the linear window did a better job of detecting and separating major features than the areal window in this test site area.

Figure 2a:
Areal Window

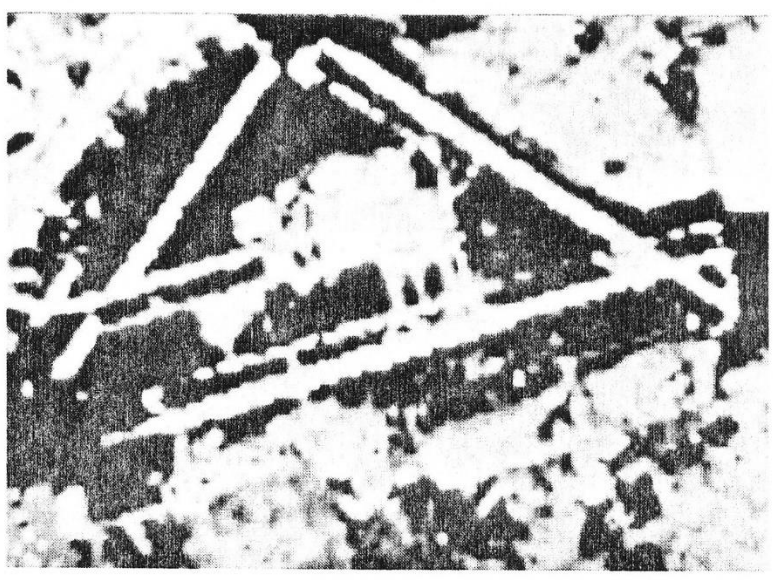
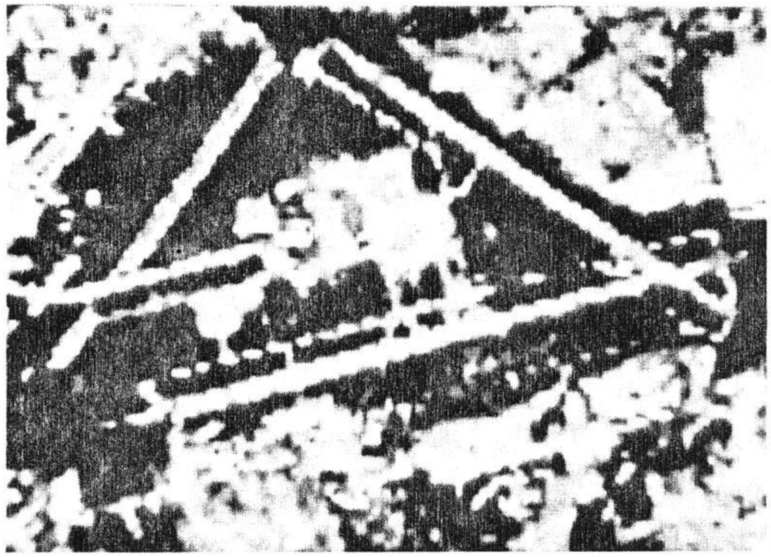


Figure 2b:
Linear Window



Solvay-Westvale Residential Areas

Solvay and Westvale are predominantly residential areas situated just west of downtown Syracuse. Solvay developed mainly before World War II with some housing being constructed immediately after the war. Westvale reached its peak growth during the late 1940s and throughout the 1950s. Solvay represents more of a low-middle to middle-middle income area; whereas, Westvale relates more as a middle-middle to high-middle income section of the city. The combination of these factors has resulted in a real mixture of residential landscapes within the two areas. Some sections are organized in the traditional grid street pattern with either a high density of houses packed close together with little vegetation coverage or a more median housing density with mature tree crowns extending over streets and houses. In other sections the streets conform to the topography by meandering across the landscape. These sections generally have larger yards with more tree coverage. Several major roads cross through the two areas with some parallelling commercial development. In general, the Solvay-Westvale areas provide a number of small linear and areal features that might be difficult to identify using the 30 meter TM pixel which makes this test site a difficult challenge for the different SEARCH windows.

The areal classification produced six residential spectral classes over the Solvay-Westvale area but one of these classes accounted for over half of the residential landscape and a large portion of the major roads and commercial development. Due to this one class saturating the man-made features associated with this test site, it was not possible to separate the different residential areas let alone the residential from the non-residential areas. The remaining five spectral classes either helped to define better some of the residential features related to this one dominating class or identify some of the larger vegetation found throughout the residential sections. Some separation between the vegetated and non-vegetated sections of the residential areas did occur causing some linear patterns. Two spectral classes in addition to the one dominating residential spectral class outlined the major roads and commercial activities with one of the two classes accounting for a major portion of these two land cover conditions. The combined linear window classification had nine residential spectral classes. With these classes it was possible to identify at least three different residential areas and possibly four. These areas were clearly recognizable on the supporting aerial photography and related well to the U.S. Bureau of the Census' census tracts. Some of these spectral classes corresponded to the actual buildings and street surfaces in a particular residential area while other classes dealt with defining residential vegetation within the same area. Each class demonstrated clear linearity with respect to the overall layout of a residential neighborhood. The linear window classification also had seven spectral classes related to the major streets and commercial activities but no strong separation occurred between these two land covers based on these classes. Figures 3a and 3b show as black and white images the areal window and linear window classifications respectively. The variation in grey-tone indicates the different spectral classes before they are grouped and assigned to particular land covers. Figure 3b illustrates greater grey-tone variation than Figure 3a supporting the finding that the linear window found more identifiable land cover conditions than the areal window.

Figure 3a:
Areal Window

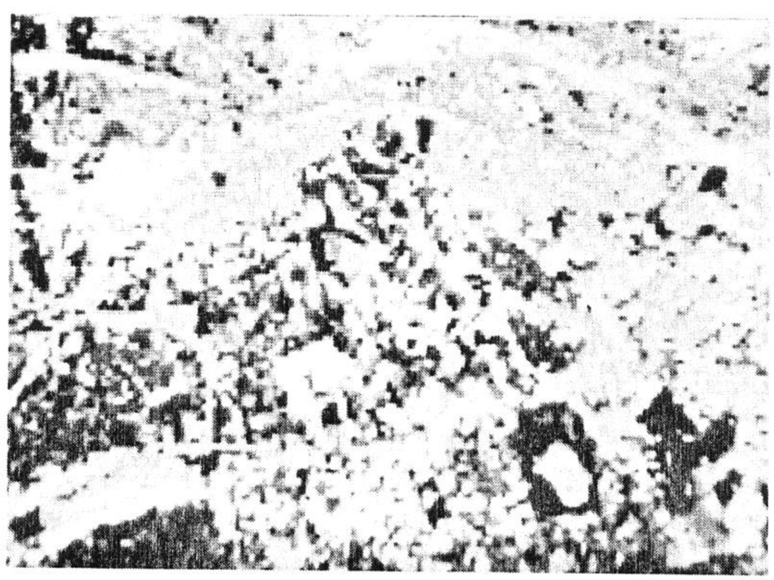


Figure 3b:
Linear Window

SUMMARY

Based on the number of spectral classes generated, the scaled distance separability of the classes, the flexibility of assigning classes to land cover features associated with not having one or two classes dominating a classification, and the noticeably better definition in identifying both linear and areal items, the combined horizontal-vertical linear window must be viewed as generating a better product than the areal window. Since the horizontal linear window in comparison to the other linear windows created a more superior classification, one must wonder if better homogeneity is found between pixels along a scan line rather than cutting across scan lines. Is this a product of the detectors associated with the individual scan lines?

REFERENCES

NASA/Earth Resources Laboratory. 1980, ELAS: Earth Resources Laboratory Applications Software, National Space Technology Laboratories, Mississippi.