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MULTISENSOR DATA ANALYSIS AND ITS APPLICATION TO MONITORING OF CROPLAND, FOREST, STRIP MINES AND CULTURAL TARGETS

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I. ABSTRACT

Seasat L-band and aircraft X-band dual polarized synthetic aperture radar (SAR) data of the Western Kentucky Coal Region were examined, preprocessed and combined with the Landsat Multispectral Scanner (MSS) data to form a seven-band multisensor data set. Multisensor data analysis includes separate evaluation of the three-band SAR data, the four-band MSS data and the combined three-band SAR and Landsat MSS bands 5 and 7 data. Techniques for information extraction consist of visual image interpretation, grey scale count value comparison and spectral pattern recognition classification known as the maximum likelihood Bayesian classifier for the SAR and MSS data.

Analysis of classified data sets show that the three-band SAR data contain moderate discrimination accuracy for the strip mine class but low accuracy for the residential class. The four-band MSS data contain low classification accuracy for the strip mine and residential classes. The integrated five-band SAR/MSS data show that significant improvement in classification accuracy is obtained for both strip mine and residential classes. The results for this data set have shown that remotely sensed data from sensors with different electromagnetic spectral regions result in a mutual enhancement of spectral discrimination capability. The results suggest the usefulness of multisensor data in monitoring land cover types for which a single sensor data fail to accomplish.

II. INTRODUCTION

Many applications of satellite remote sensing techniques using Landsat multispectral scanner (MSS) data as an information source for resource assessment and management have already been made. However, some perceive the timely cloud free data acquisition, the resolution, accuracy of classification, etc. as limitations to increased utilization.

With the continual improvement and interest of sensors that obtain data in the microwave region (i.e. SAR systems), additional data sources with unique advantages over the MSS systems are becoming available. These advantages include day or night acquisition, cloud penetrating capabilities, signal returns that are related to surface roughness, geometry, dielectric constant, and physignomic properties of the cover types. The side look angle of SAR systems also provides unique characteristics of the data which are not found in other remote sensor systems. Nevertheless, SAR sensor systems also have limitations, and these limitations have been demonstrated in the "SAR only" data applications for land cover classification and mapping using the automated, spectral signature development techniques.[1,2,3,4]

This paper was formulated to seek answers to the limitations of the SAR data by combining SAR data with Landsat MSS data. The utility of MSS data in the multisensor data set produces different spectral signatures than that of SAR data for some land cover types. This increase in spectral dimension provides improved differentiation of various land cover types when the automated spectral pattern recognition technique is applied. The objectives were oriented towards the construction of a multisensor data set, information extraction of this data set, and the analysis of results to determine the advantages and limitations of each sensor data and the utility of the multisensor data for identifying and mapping surface features.

III. STUDY AREA AND DATA SETS

A. STUDY AREA

The study area is located in the Western Kentucky Coal Field of the Pond River

Watershed (Hopkins and Muhlenberg Counties) of the Green River Watershed as shown in Figure 1. The aircraft SAR data acquired over the study area encompassed an area of approximately 18km east-west by 30km north-south with the Pond River on the eastern boundary and the city of Madisonville and several other small towns on the western boundary (Figures 2 and 3). Several highways and railroads are located in the study area. The region is characterized by broad alluvial bottoms of major rivers, scattered out-croppings of sandstone, and hilly uplands with lakes and ponds. There are six major producing coal seams in the watershed. Muhlenberg County produced 17 million tons of coal in 1977, with 75% produced by strip mining. Other than coal production, major cash crops of the region are tobacco, corn, and soybeans. Croplands make up less than thirty percent of the land area. Livestock production varies greatly from year to year, depending on market conditions. Acreages of hayland and pasture land have been developed to support this industry. Forest land makes up the majority of the watershed area. The major forest type within the Green River Basin is Oak-hickory.

B. DATA SETS

The Landsat MSS data acquired on September 12, 1979, was used for merging with SAR data for land cover classification evaluation.

To facilitate ground truth verification, color infrared (CIR) aerial photography was acquired over the study area on March 15, 1980.

The aircraft SAR data were acquired with a AN/APQ-102A (X-band 9.6 GHz, 3.12 cm wavelength) SAR system, flown in a NASA Lyndon B. Johnson Space Center (JSC) WB-57 aircraft, on April 22, 1980. This AN/APQ-102A SAR system provides ground element resolutions of approximately 16 meters. The radar can transmit with either horizontal or vertical polarization and it receives both horizontal and vertical polarization of the same swath simultaneously on two recording channels. The SAR can be operated in either of two modes. Mode one views from 14.2° to 51.7° to the right of the aircraft and will provide a 18.5km image swath from about 4.63km to 23.16km from nadir when flying at an altitude of 18.3km. Mode two views from 45.5° to 63.7° to the right of the aircraft and will provide a 18.5km image swath from about 18.5 km to 37.1km from nadir when flying at an altitude of 18.3km. In this study, the SAR data were acquired with Mode two and horizontal transmit configuration. Since the SAR system receives both horizontal and vertical polarization of the same swath simultaneously on two recording channels, two data sets, one HH and the other HV polarization, were obtained from the mission.

The Seasat SAR system generated continuous radar imagery with a 100km ground range swath with 25 meter ground range resolution from an orbital altitude of 800km. The L-band (1.2782 GHz, 23.5 cm wavelength) SAR system transmits and receives only with horizontal polarization. The antenna is centered at 20 degrees off nadir with 6 degrees beamwidth. At 800 km altitude this gives a ground-range swath between 240 km and 340 km from nadir. Due to earth surface curvature, actual incidence angle at ground range varies from 20° to 26°. The SAR system can acquire data either in ascending pass or descending pass modes. In this study Seasat SAR had acquired data over the study area on August 5, 1978 with an ascending pass orbit. A digital data set was acquired from the Jet Propulsion Laboratory (JPL) and was used in building the seven channel data set.

IV. CONSTRUCTION OF MULTISENSOR DATA SET

A. SAR DATA PREPROCESSING

In order to reduce the characteristic "speckled" effect in the Seasat SAR data set, it was spatially filtered. An investigation concerning the need, approach, and results of using this technique have been reported elsewhere.[2] No across track radiometric correction was applied. The preprocessed image of the Seasat SAR data is shown in Figure 4.

Since the aircraft SAR data were optically correlated, the image product obtained from JSC was a roll of positive transparent film. Photographic prints or data images as shown in Figures 2 and 3 were produced from the film. It can be used to validate data quality and visually discriminate surface features using tone and texture differences. This kind of visual evaluation which is similar to photo interpretation were used in the SAR imagery study reported elsewhere.[5,8] For the digital analysis of SAR film images, the films must be scanned through a microdensitometer. The digital microdensitometer converts the image grey tone into discrete count value data (digital data) and automatically writes this digitized data to a computer compatible tape (CCT). The digitization of SAR film image was performed by NASA Wallops Flight Center using their digital microdensitometer.[6] The aperture size of the microdensitometer determines the digitization spot size. The aircraft SAR system produced an image film of 5 cm in width that represents approximately 18.5 km ground range swath. For this data set, a 50 micron aperture size (50 micron spot size) was selected and the films were digitized into 1000 elements across track with approximately 18.5m by 18.5m resolution. After digitization, the SAR data were further processed to reduce the striping or banding effect[6] and the radiometrically corrected data were used to form the seven-band data set.

B. REGISTRATION OF SAR AND MSS DATA

The digitized aircraft SAR data contain a ground range resolution of approximately 18.5m by 18.5m. The Seasat L-band SAR data contain a ground range resolution of 25m by 25m while the Landsat MSS data contain a resolution of 57m by 79m. To construct a multisensor data set using SAR and MSS data, a common resolution cell size is needed. Because the study area contains a variety of land cover types, particularly the strip mines which are extremely heterogeneous, a resolution of 20m by 20m was selected for the multisensor data set.

Georeferencing of Landsat MSS data was first performed with the data set resampled to 20m by 20m using bilinear-bilinear (BL BL) fit in both northing and easting directions. After this registration, the Landsat MSS data can be related to UTM coordinates. The same ground control points used in georeferencing of Landsat MSS data were then used to overlay the X-band SAR data and the Landsat MSS data. This scene-to-scene registration of X-band SAR data with the resampled and georeferenced Landsat MSS data set was performed without difficulty, because the SAR data, flown north-south with 18.5m by 18.5m resolution, were almost the same as the georeferenced MSS data in orientation and pixel size. The last step was to overlay the Seasat SAR data to the georeferenced MSS data. Detailed description of the scene-to-map and scene-to-scene computer programs can be found elsewhere.[7]

V. APPROACH AND RESULTS

A. VISUAL INTERPRETATION OF SAR IMAGE

Since the electromagnetic spectrum expressed in the wavelength of the X and L band SAR is about 100,000 times longer than that of MSS, the spectral characteristics of MSS and SAR data will be different. To gain a basic understanding of each spectral region, the data from the microwave sensors were first visually interpreted using the SAR images (Figures 2, 3 and 4), color infrared photography, and ground truth data.

In the microwave regions, orphan mines with a high wall and bench can be visually detected due to their heterogeneous terrestrial features and the fine resolution of SAR data. Cropland and forest boundaries, transportation networks such as highways and railroads, and even street patterns of the city of Madisonville can be clearly identified. The north-south bound aligned confluent railway which are parallel to the SAR data acquisition flight path contain the highest return from all three bands of SAR data. Spectrally confused classes in the microwave region consist of deciduous forest and residential/urban/cultural targets. These two surface classes contain high radar backscatter due to the volume scattering[9] of trees which present a similar spectral signature to that of high rise city buildings. This microwave attribute had been observed previously in the SAR data study in the city of New Orleans.[10]

B. SAR AND MSS DATA COMPARISON

Count value comparison of the SAR and MSS data after the formation of the seven-band data set was accomplished through digital data processing techniques by which the histogram of the data set was plotted and the mean count values of 23 selected sites were tabulated and plotted. The histogram, which is a distribution of count values displaced against the frequency of occurrence of the three band SAR data is shown in Figure 5. In Figure 5, the count values vary approximately from 10 to 70, from 30 to 170, and 40 to 160 for L-band, X-band HH pol, and X-band HV pol data, respectively. The highest frequency of occurrence occurs at count values 32, 118, and 105 for L-band, X-band HH pol and X-band pol SAR data, respectively. There are significant count value distribution difference between the L and X band data, but a minor difference between the X-band HH and HV polarization data. The histogram of the four-band MSS data is shown in Figure 6. For MSS four-band data as shown in Figure 6, there are close similarities and a high correlation between bands 4 and 5; and bands 6 and 7, with band 4 containing the narrowest count value variation and band 7 the widest. Since band 4 and 5 and bands 6 and 7 are highly correlated, band 5 and 7 data were used in the combined SAR/MSS data classification described in the following section.

Based on aerial color infrared (CIR) photography and some field verification plots 23 sites were selected to identify which spectral signature count values represent which land cover type (See Table 1). The first column of the table describes the site, and the second column give the size by showing the number of pixels used to get the average count values given in columns three through nine. Note that the first three columns are the SAR data with count values ranging from 0 to 255.

In the MSS spectral band region (See Table 1, columns 6 thru 9) mean count values of 19-23 and 42-45 for bands 5 and 7 respectively represents spectrally confused classes of strip mine and residential area. On the other hand, mean count values of 11 and 54 for bands 5 and 7 respectively, clearly separate the deciduous forest class from the residential class. A similar result can be obtained by examining SAR data using columns 3 to 5 of Table 1.

To help visualize the mean count values of various surface features in the microwave regions, the count values were plotted against typical land cover types represented by the 23 sites in Figure 7. In Figure 7, the spectral signature variation can be approximately divided into four groups of spectrally confused classes. The first group consists of aligned railway (RR), Residential/urban area (RS), deciduous forest (DF) and the high wall (HW) of strip mines. These surface features contain high count values in all three bands of the SAR data with X-band HH and HV polarization data exceeding 100 and L-band data from a low 40 to a high of 80. The second group consist of the bench (BC) of strip mines, active mines (AM) and area mines with large area of waste coal, rock pyrites or other unmerchantable materials of relatively large size which are separated from coal in the cleaning process. Area mines with these features are called gob (GM). These strip mine features contain moderate count value ranging from 50 to 90 for the X-band HH and HV polarization data, and from 20 to 35 for L-band data. The third group consists of pasture (PS) and cropland, and the cropland is further divided into cornfield (CF) and soybean field (SF). These surface features contain moderate to high count values (80 to 120) for the X-band HH and HV polarization data, but relatively wide count value variation (from 20 to 40) for L-band data. The last group consists of open water (OW) and water impoundment (WI). These surface features have the lowest count values in all three bands of SAR data.

C. SPECTRAL CLASSIFICATION

After count value comparison of SAR and MSS data, the analysis proceeded to the step of using the automated spectral signature development program and spectral pattern recognition technique to investigate the contribution of SAR, MSS and combined SAR/MSS spectral regions for improving land cover classification. An evaluation of the classified results will substantiate the findings described in the previous section.

Since surface features of the test area, particularly strip mines, are very heterogeneous, and since unsupervised signature development program will do better on heterogeneous surface features, in this paper, unsupervised classification is used to evaluate the SAR only, MSS only, and the combined SAR/MSS data.

The maximum likelihood classifier uses the developed statistics and a priori probability and threshold to set the classification boundary. If no threshold is set, all pixels within the data will be classified into a specific spectral class but if a threshold is set, some pixels will be left unclassified. For the purpose of evaluation no threshold was set in this investigation.

D. CLASSIFIED RESULTS

The classifications resulting from the use of the unsupervised signature development and maximum likelihood classifier computer programs were related to the general land cover condition of the study area by using the ground truth and color infrared photography. The surface feature classes or the land cover types were grouped into seven classes: Pasture, Forest, Residential, Soybean Field, Corn Field, Water, and Strip mine. The residential class contains the cities of Madisonville, Earlington and Morton Gap and a few small suburban residential areas as well as the transportation network, particularly highways and railroads which are not included in the other land cover types. The pasture class contains pasture for cattle and some other minor surface features and it is a rather loosely defined class. The remaining five classes are well defined and easy to identify using color infrared photography, SAR image and MSS data. The grey scale land cover classification of the combined SAR 3 band and MSS bands 5 and 7 data are shown in Figure 8. The results obtained from the use of field verified plots and the classification accuracy evaluation computer program[7] are tabulated as follows with the verification values expressed as a percentage of correctly classified pixels:

Land Cover Types	SAR 3 Band	MSS 4 Band	SAR/MSS 5 Band
Pasture	46.9	81.3	96.7
Forest	92.3	88.0	92.5
Residential	10.0	59.4	79.0
Soybean Field	89.5	59.4	90.9
Corn Field	88.3	32.5	99.0
Water	99.9	97.4	99.9
Strip Mine	64.9	47.7	77.4
Overall	48.2	64.2	81.1

The classified results indicate that "SAR only" data with 48.2 percent overall classification accuracy is not suitable for general land cover mapping when spectral information alone was applied. Poor results were obtained for the residential and pasture classes. But for strip mine detection "SAR only" data do better than "MSS only" data. The combine SAR/MSS data improved classification accuracy for all seven land cover types.

VI. CONCLUDING REMARKS

The SAR image interpretation, the SAR and MSS count value comparison and an evaluation of the unsupervised classifications of "SAR only," MSS only" and the combined MSS and SAR data sets result in the following findings:

1. All three-band SAR data can readily delineate man-made targets with contiguous row structures, such as aligned confluent railways, when row structures are parallel to microwave sensor flight path. This microwave attribute had been observed previously in the SAR study in the city of New Orleans.

2. All three-band SAR data contain relatively high return from the foliated deciduous forest class. This implies deciduous forest is insensitive to wavelength, look angle, and polarization changes in the microwave region. This response characteristic can be interpreted as being related to a phenomena in which the canopy of the biomass layer is thick and rough enough to sustain a volume scattering for both X and L band.

3. For strip mine detection SAR data is significantly better than Landsat MSS data. Orphan mines with high walls and benches can be readily detected due to their heterogeneous terrestrial features and the fine resolution of SAR data as shown in Figures 2,3. Quantitative analysis of the classification results show that strip mine percent correct values are 47.7, 64.9 and 77.4 for MSS, SAR, and SAR/MSS data, respectively.

4. Since Landsat MSS data is readily available over all parts of the United States, and since it can be resampled and registered to SAR data it is advantageous to combine MSS and SAR data to improve the separation of residential and forest classes. It also improves delineation of strip mines with highwalls and benches. This is because MSS data can better delineate strip mines with highwalls and benches from forest, but for SAR data spectrally confused signatures occur between forest and highwalls and make them difficult to separate. The improvement of the strip mine class is about 12.5 percent, namely the verification values change from 64.9 to 77.4 when MSS data are combined with SAR data.

5. Close examinations of SAR data reveal that textural features are significantly different among residential, strip mines with highwalls and benches, and deciduous forest classes. The texture component may serve to improve delineation of these spectrally confused classes without the use of MSS data. This approach remains to be explored in the future study.

6. Significant corn field and soybean field signature differences were presented in the SAR data, but due to the likelihood of significant changes in cropland features, between the acquisition of SAR and MSS data, the result is inconclusive. In case of crop cover type delineation concurrent data acquisition data for both MSS and SAR sensors is essential. As for relatively more stable land cover types such as residential, forest, pasture, water and strip mines, the concurrent time factor is not that critical.

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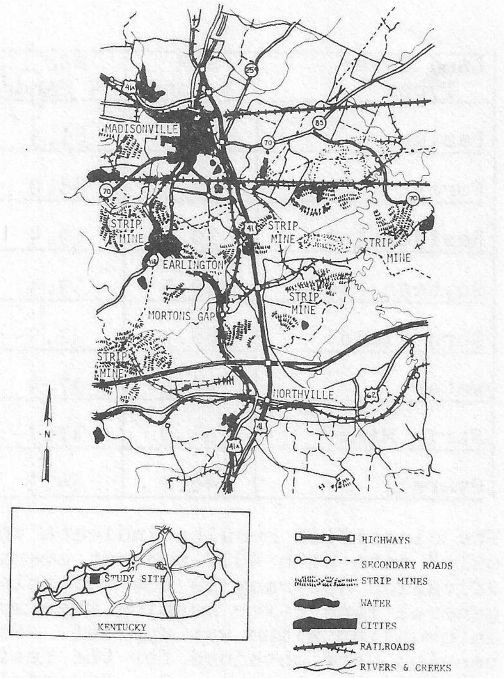

Figure 1. Western Kentucky Coal Region Study Area.

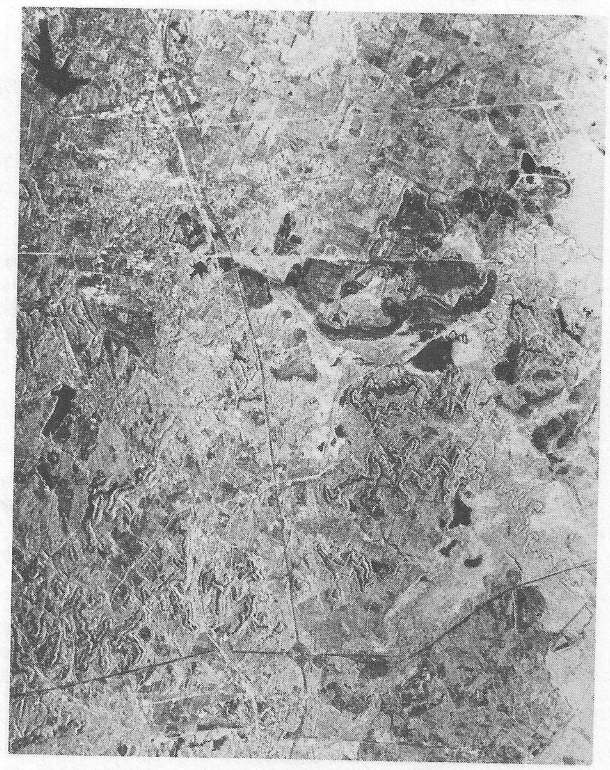

Figure 2. Aircraft X-band SAR image, HH pol.

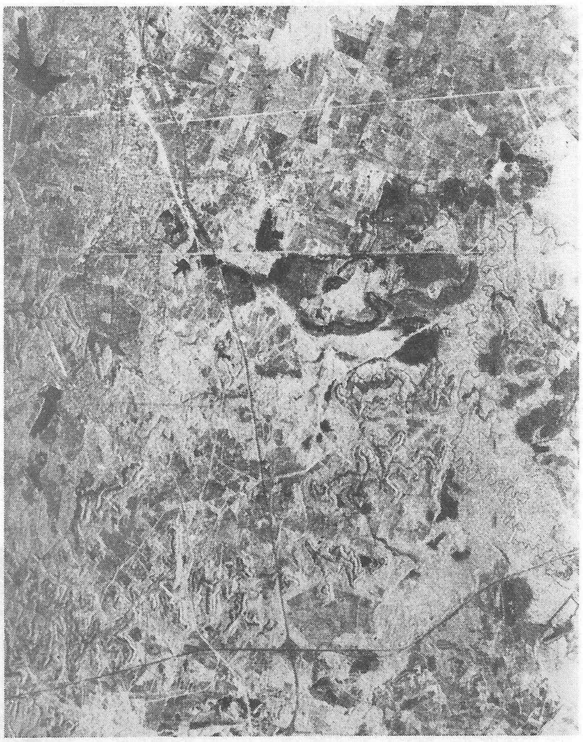

Figure 3. Aircraft X-band SAR image, HV pol.

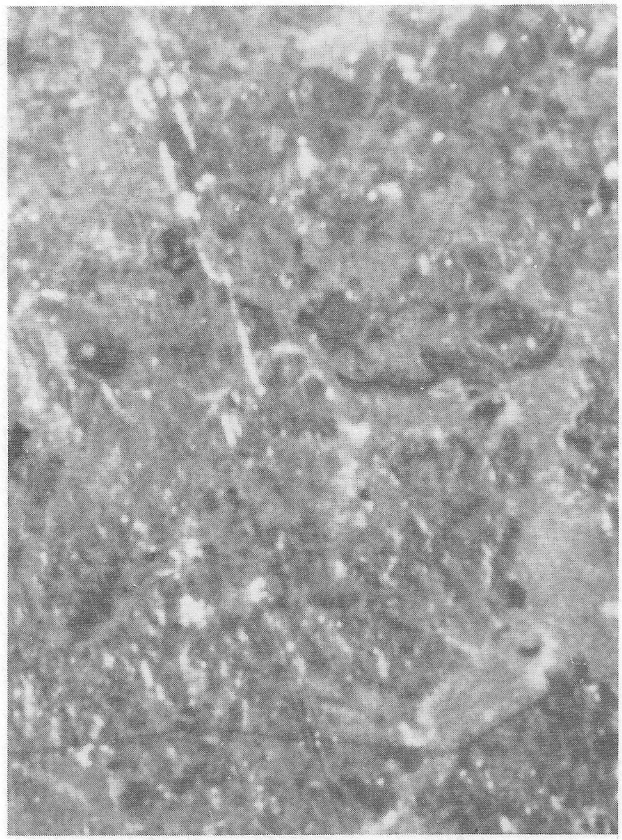

Figure 4. Seasat L-band SAR image, HH pol.

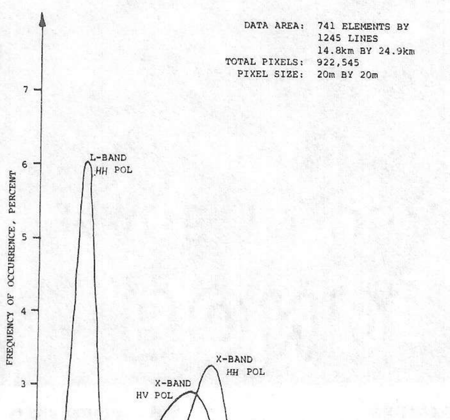

Figure 5. Histogram of SAR data.

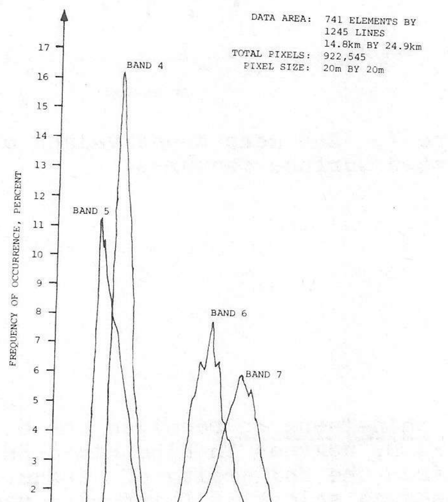

Figure 6. Histogram of MSS data.

Table 1. SAR and MSS mean count values of selected surface features.

Site Description		No. of Pixels Used	SAR DATA			LANDSAT MSS BANDS			
			X, HH	X, HV	L, HV	4	5	6	7
North-South railroad	1	122	147.3	154.2	79.6	22.4	22.9	33.5	32.5
North-South railroad	2	154	154	149.4	45.4	18.5	16.8	36.2	40.6
Madisonville		6951	126.8	104.7	35.7	24.5	23.5	39.9	42.1
Earlington		400	104.8	94.2	46.2	23.3	21.9	38.9	42.4
Mortons Gap		467	115.4	102.7	57.0	22.7	21.0	41.9	47.0
Deciduous Forest	1	2016	123.1	116.9	45.9	15.8	11.3	42.8	54.6
Deciduous Forest	2	766	129.0	120.0	41.6	17.1	13.4	38.1	45.1
Orphan mines high wall	1	116	142.3	118.5	36.6	17.1	14.3	36.6	43.9
Orphan mines high wall	2	114	134.9	124.7	36.8	18.1	16.2	43.4	52.4
Orphan mines bench	1	179	62.4	68.6	29.0	22.5	20.6	38.6	40.6
Orphan mines bench	2	106	66.2	77.0	36.1	17.6	13.6	36.9	43.3
Active mines	1	293	78.9	73.3	24.1	29.6	32.7	44.5	42.6
Active mines	2	119	90.1	77.6	23.7	20.5	19.0	38.3	43.5
Area mines GOB	1	150	56.3	49.3	25.5	21.1	19.8	20.6	16.6
Area mines GOB	2	277	76.8	55.2	31.4	25.3	24.4	24.8	18.5
Pasture	1	212	106.4	80.8	30.9	20.4	18.8	53.4	62.6
Pasture	2	139	116.4	94.9	31.5	20.7	18.2	52.5	61.4
Corn Field		360	108.3	97.0	19.0	19.1	15.4	64.5	78.7
Soybean Field	1	831	102.5	93.8	41.9	18.2	13.7	65.2	82.4
Soybean Field	2	515	110.6	90.0	40.0	20.6	18.4	49.8	59.3
Open Water, Lake	1	831	31.0	53.7	12.7	15.0	9.5	6.2	4.1
Open Water, Lake	2	332	31.3	52.6	11.9	14.0	9.9	7.4	4.3
Water Impoundment		295	26.7	52.4	19.5	16.2	13.4	15.4	9.6

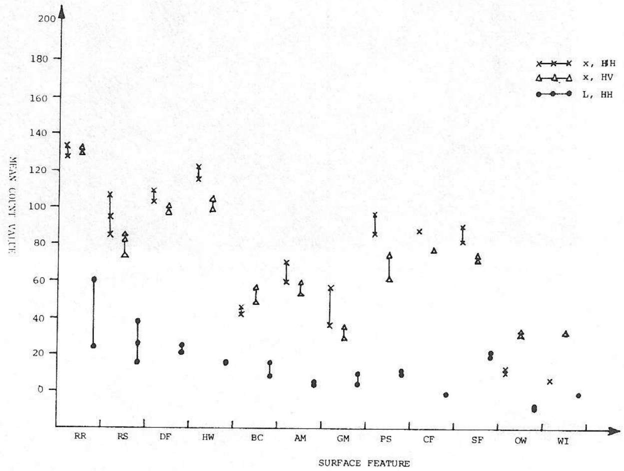

Figure 7. SAR mean count values of selected surface features.

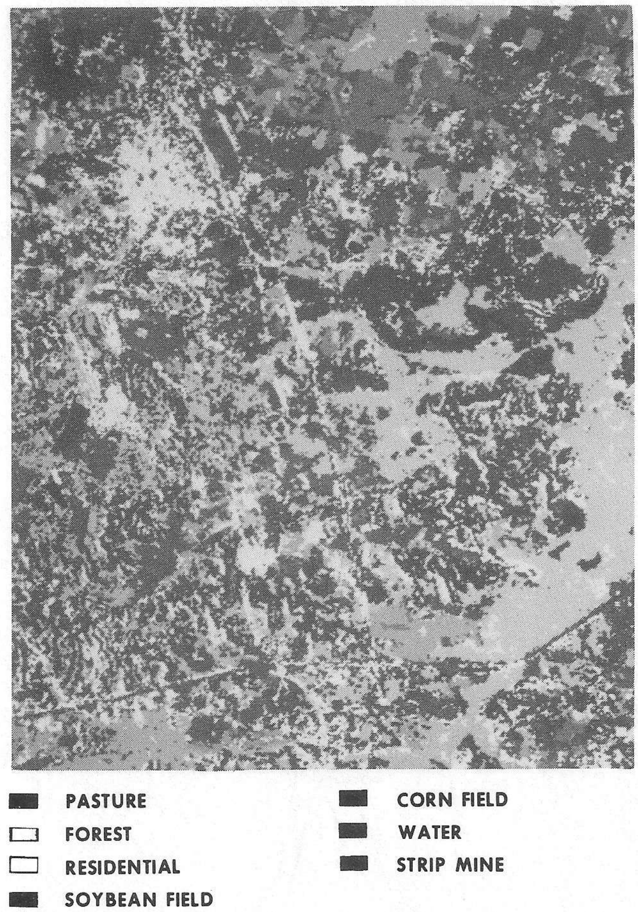

Figure 8. The grey scale land cover classification using SAR and MSS data.

Shih-Tseng Wu received the M.S. and the Ph.D. degrees in Electrical Engineering from the University of Kansas. He is a research scientist (microwave remote sensing) in the Technique Development Group of the Earth Resources Laboratory. Current research activities involve the development of techniques for the analysis, application, and integration of microwave data with other remotely sensed data. He is currently involved in the AgRISTARS Domestic Crop and Land Cover Project.