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THE USE OF AIRBORNE REMOTE SENSING IMAGERY IN THE CLASSIFICATION OF LAND COVER TYPES
An Andalusian Case-Study

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RESUMEN

Métodos convencionales de clasificación de imágenes basados en reflejos espectrales pueden resultar en una confusión entre los distintos usos de suelo. En este estudio se consideran dos métodos generales para mejorar la precisión de estas clasificaciones: (a) la selección de una combinación óptima de bandas espectrales, y (b) la incorporación de información topográfica dentro del análisis. El área de estudio es la Sierra de Humilladero cerca de Antequera en Andalucía y las imágenes usadas son obtenidas del Daedalus AADS-1286 Airborne Mapper. Para la selección de la combinación óptima de bandas fueron comparados los métodos de divergencia promedio y la mayor mínima divergencia. Cuando el método de la máxima semejanza fue aplicado con un 90% nivel de probabilidad, se encontró que el método de divergencia promedio era más adecuado para la imagen total y que el método de la mínima divergencia era más adecuado para distinguir cultivos específicos.

Cuando se usa la combinación de bandas sugerida por este análisis de divergencia con una imagen de elevación obtenida de un Modelo de Elevación Digital (Digital Elevation Model o DEM), se obtuvo una clasificación con una precisión de 94.6%. La adición de imágenes de aspecto y pendiente del DEM no llevó a ninguna mejora de esta precisión.

ABSTRACT

Conventional methods of image classification based on spectral reflectance may result in confusion between land-cover types. In this study two general approaches to the improvement of classification accuracy are considered: (a) the selection of an optimum combination of spectral bands, and (b) the incorporation of topographic information into the analysis. The study site is the Sierra de Humilladero area of Southern Spain, using imagery obtained from the Daedalus AADS-1286 AirborneThematic Mapper. For the selection of the optimum combination of bands the average divergence and the highest minimum divergence methods are compared. Applying the maximum likelihood classification method with a 90% probability level it was found that the average divergence method performed better for the whole image whereas the minimum divergence method was more suitable for discriminating a particular crop. Using the band combination suggested by this divergence analysis together with an elevation image obtained from a Digital Elevation Model (DEM) a classification accuracy of 94.6% was obtained. The addition of the slope and aspect images from the DEM did not lead to any improvement in accuracy.

1. INTRODUCTION

The objective of the first part of this study is to select the optimal subset of spectral bands selected from the 11 bands of the ATM data set that yields the most accurate parametric (Gaussian Maximum Likelihood) classification for land cover/land use mapping. Several measures of separability are available to predict optimum band combinations for classification (Section 3.0). They are based on measurements of the statistical distance between spectral classes of interest. Divergence is a commonly used form of separability measure designed to select optimum channel combinations. The average divergence method and highest minimum divergence method are used here in the selection of the optimal subset of spectral bands.

2. DATA AND TEST AREA

Airborne Thematic Mapper data were acquired over an area near the town of Antequera (37°05'N 4°40'W), 45 Km north of Malaga in Andalusia, southern Spain. The data were collected by a Daedalus AADS-1268 ATM sensor mounted on an aircraft operated by the NERC. Aerial photographs of the area at approximate scale of 1:20,000 were acquired simultaneously on 16th May, 1989. Topographic maps (1:10,000), a geological map (1:50,000), land use map (1:50,000) and some field information were also available for analysis.

A sub-image of 586 lines and 716 pixels per line was extracted for the purposes of this study. The sub-image covers the area centred upon the Sierra de Humilladero, a prominent east-west ridge with a marked south-east/north-east kink at its eastern end. It is formed by limestones and dolomites, surrounded by a flatter area of clay with some sandstones. The flatter area is intensively cultivated, with a predominance of olives, sunflowers, vineyards and cereals whereas on the ridge a mixture of pines and scrubland is predominant. Along the top of the ridge there is an outcrop of bare rock. These different land-cover types often fo m clearly defined layers or zones (see Image 1).

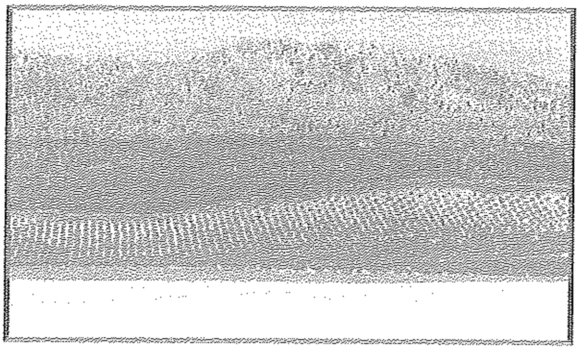

Image 1.- Southern slope of the Sierra de Humilladero showing vegetation zones.

3. DIVERGENCE

It is generally the case that the data forming the several spectral bands of an image set area correlated to a greater or lesser extent. Principal components analysis of a similar 11-band data set by Townshend (1984) showed that the dimensionality of the data, that is, the number of uncorrelated linear combinations that can be formed from 11 bands, is substancially less than 11. Hence, there is redundancy in the data and, since the computations involved in image classification are heavy, it could be expected that levels of classification accuracy would not be reduced significantly if a subset of the 11 bands were used in the analysis. Each band does, however, contain some unique information as Townshend's (1984) analysis showed, so that the use of a subset of bands will inevitably result in a loss of classification accuracy. In many instances, including the present case, broad land cover classes are used and in such instances the loss of classification accuracy will be small.

Elimination of redundant information in a data set can be achieved through the use of principal components analysis. The principal components, wich are linear combinations of the original spectral bands, are often difficult to interpret and racionalisation of a classification based upon principal components might be problematical. An alternative approach is to consider the statistical separability of the classes on the basis of combinations of the spectral bands. At some point the additional contribution to statistical separability resulting from adding another band will be subjectively considered to be insignificant, and subsequent analysis will be bassed only on the set of select bands. The measurement of separability is not straightforward, and a number of alternatives is available. The most commonly-used method is based upon the divergence measure, which is described by Mather (1987). A forward selection strategy is used, involving the selection at each iteration of that spectral band wich is associated with the greatest increase in separability. Usually separability is measured in terms of the average divergence measured for all mutually- exclusive pairwise combinations of classes, though in this study we consider an alternative, wich involves selecting that spectral band subset for wich the minimum interclass divergence over all pairwise combinations is the greatest. Thus a band subset may have the largest average divergence, but the average may be the result of summation of one very high value and a number of very small values, indicating that one pair of classes is well-separated on this band subset but other pairs of classes are not. If the largest minimum divergence is used it should result in those bands that are best at separating the most difficult pair of classes being selected. Further details of the calculation of divergence are given by Sing (1984).

4. METHODOLOGY

4.1. Data Preprocessing.

Details of the ATM specification are given by Williams (1984). In this experiment the aircraft was flying at a ground clearance of 3.300 m. The effects of variable viewing of the scanner result in a variable ground resolution, which is at a minimum at nadir, increasing towards the edges of the scan by a factor of about two. Sun-objetc-viewer geometry and the changing proportions of atmospheric path radiance and attenuation with scan angle result in severe radiometric distortion in the across-track direction. The combined effects of these distortions were modelled using a least-squares quadratic polynominal relating mean column pixel intensity values at nadir to mean intensities of other columns (Barnsley et al., 1989; Royer et al., 1985). A separate correction was determined for each band. Band 1 was excluded due to noise occurrence and the remaining eleven bands were corrected.

4.2. Developing Ground Reference Data.

Photo-interpretation based on the aerial photographs acquired at the same time as the imagery was used to determine training areas for the selected land cover classes. The photo-interpretation was supported by a land use map (1:50,000) and some limited field information in the form of photographs and slides taken at various points in the study area, plus annotated ortophoto mosaics at 1:25,000 scale.

Seven land-cover classes were defined as follows:

1. bare rock (Br) 2. pines (Pe)
3. olives (Ol) 4. sunflower (Sf)
5. cereal (Ce) 6. vineyard (Vi)
7. roads (Rd)

Sample mean vectors and sample variance-covariance matrices were derived for each of training class corresponding to the seven land-cover classes listed above. These sample esti-

Table 1

Summary of band combinations using forward selection and average transformed divergence.

No. of variables	Av.Tr. Diverg.	Band numbers									
1	23.14	6									
2	89.71	6	7								
3	97.12	6	7	2							
4	99.31	6	7	2	4						
5	99.74	6	7	2	4	11					
6	99.88	6	7	2	4	11	8				
7	99.92	6	7	2	4	11	8	9			
8	99.98	6	7	2	4	11	8	9	10		
9	99.98	6	7	2	4	11	8	9	10	5	
10	99.99	6	7	2	4	11	8	9	10	5	3

Table 2

Summary of band combinations using forward selection and highest minimum transformed divergence.

Number of variables	Mx.Tr.Divergence	Band numbers									
1	0.10	2									
2	56.89	2	6								
3	80.51	2	6	9							
4	93.09	2	6	9	7						
5	96.90	2	6	9	7	10					
6	99.08	2	6	9	7	10	11				
7	99.61	2	6	9	7	10	11	4			
8	99.79	2	6	9	7	10	11	4	8		
9	99.85	2	6	9	7	10	11	4	8	3	
10	99.87	2	6	9	7	10	11	4	8	3	5

mates were used in the divergence analyses.

5. RESULTS AND DISCUSSION

5.1. Three-band combination.

Bands 3,5 and 7 of the ATM, wich are similar to the Landsat TM channels 2, 3 and 4 (green, red and near-infrared spectral bands), were initially selected to form a false-colour composite image. These bands were selected empirically in order to provide a basis for testing the statistically-selected band combinations.

5.2. Separability analysis of band combinations.

The ten-channel data set (excluding the thermal band) would yield 210 possible four-channel combinatios. The average transformed divergence and the highest minimum divergence were computed for the best subsets of size 1, 2,...10 using a forward selections strategy. Table 1 shows the summary of the band selection based on average transformed divergence. There is an increase in the average transformed divergence value from 23.14 for a single band to 89.71 for the two band combinations, 97.12 for the three band combination and 99.31 for the four band combination. The addition of further bands results in a very slight increase in the average transformed divergence value. The best band average combination of four bands was bands 6, 7, 2 and 4. Table 2 shows the separability of class pairs based on highest minimum pairwise transformed divergence for combinations of bands. The best band combination is bands 2,6,9 and 7.

Tables 3, 4 and 5 show the confusion matrices for classifications based on the three sets of band combinations. Table 3 shows that the four empirically selected bands had an overall accuracy of 81.44% whereas the combination of bands

Table 3

Confusion matrix for band combination 3, 5, and 7.

	Br	Pi	Ol	Sf	Ce	Vi	Rd	Total	Omission errors(%)
Br	117	5	2	-	1	-	-	125	6.4
Pi	79	447	20	-	-	29	-	575	22.2
Ol	8	8	358	-	10	16	-	400	10.5
Sf	-	-	-	104	-	46	-	150	30.7
Ce	-	-	16	-	55	29	-	100	45.0
Vi	-	1	-	13	-	136	-	150	9.4
Rd	-	-	2	-	-	-	34	36	5.6
Total	204	461	398	117	66	256	34	1536	
Commission errors(%)	42.6	3.0	10.1	11.1	16.7	46.9	0		

Overall percentage correctly classified 81.44%

Table 4

Confusion matrix for average transformed divergence band combination.

	Br	Pi	Ol	Sf	Ce	Vi	Rd	Total	Omission errors(%)
Br	122	3	-	-	-	-	-	125	2.4
Pi	55	484	6	-	-	30	-	575	15.8
Ol	2	1	367	-	9	21	-	400	8.4
Sf	-	-	-	148	-	2	-	150	1.3
Ce	-	-	4	10	67	19	-	100	33.0
Vi	-	-	-	25	-	125	-	150	16.7
Rd	-	-	2	-	-	-	34	36	5.6
Total	179	488	379	183	76	197	34	1536	
Commission errors (%)	31.8	0.8	3.2	19.1	11.8	36.5	0		

Overall percentage correctly classified 87.69%

6, 7, 2 and 4 had an overall accuracy of 86.19%. Clearly the empirically-selected bands provided a less accurate classification of cover classes than the band combinations based on the two divergence measures.

Comparison between the two statisttically-selected band combinations (Tables 4 and 5) shows that the average transformed divergence gives the higher overall classification accuracy. A closer examination of the class omission errors shows that the values for bare rock, sunflower and road are the same for both band combinations. There is an increase in the accuracy of classification of the pine, olives and vine classes with the average transformed divergence measure whereas with the highest minimum transformed divergence measure there is an increase in the classification accuracy of the cereal class.

Visual analysis of the classified images corresponding to the three different band combinations revealed important differences in classification, particularly for a number of fields on the southern side of the Sierra de Humilladero. These fields are classified predominantly as vineyards on image 1 (based on the empirically selected combination), but as sunflowers, olives and pines on images 2 and 3 (based on the two divergence measures). The lack of information about

Table 5

Confusion matrix for highest minimum transformed divergence band combination.

	Br	Pi	Ol	Sf	Co	Vi	Rd	Total	Omission errors(%)
Br	122	3	-	-	-	-	-	125	2.4
Pi	60	465	3	-	-	47	-	575	19.1
Ol	-	2	347	-	48	3	-	400	13.3
Sf	-	-	-	148	-	2	-	150	1.3
Co	-	-	-	1	84	15	-	100	16.0
Vi	-	-	-	26	-	124	-	150	17.3
Rd	-	-	2	-	-	-	34	36	5.6
Total	182	470	352	175	132	191	34	1536	
Commission errors(%)	32.9	1.1	1.4	15.4	36.4	35.1	0		

Overall percentage correctly classified 86.19%

the actual crops in these fields and their exclusion from the training areas probably accounts for these differences in classification. For the rest of the study area there was a number of minor differences in the land-use categories as classfied by the three images. For example a clear improvement was observed in the classification of cereals from image 1 (3 bands) to image 3 (maximum). Similarly an improvement in the classification of pines was evident, particularly along the southern side of the Sierra de Humilladero, with the best result being derived from the classification based upon the four bands selected using average divergence (image 2). The classification of "road" is slightly better on images 2 and 3, but on the other hand, a significant number of pixels are misclassified as roads (commission errors) on both these two images.

6. DISCUSSION

The separability measures showed excellent and similar results for predicting the best band combination for classification of the seven land cover features studied. The empirical choice of band combination gives lower overall accuracy and shorter CPU time. Vineyards gave a higher accuracy in the empirical choice of bands but the percentage of pixels incorrectly classified as vineyard (commission errors) is very high wich shows some bias towards this class. The omission errors for road remains constant for the three classifications. The class "road" has a high separability over all the three band combinations.

Comparing the separability measure of classifications, as expressed by the confusion matrices, the average divergence shows an overall slightly better result than the highest minimum divergence. However, for all land cover classes, except cereal, the average divergence gives equal or better results. Therefore, for the whole scene this band combination is better, whereas if the objective is to discriminate cereals, the highest minimum divergence is more appropriate.

7. TOPOGRAPHIC CORRECTIONS

Digital classification is commonly applied over flat terrain or areas on which terrain has a negligible effect on radiance recived at the sensor. Noticeable surface variations could introduce variability of radiance over homogeneous land-cover types which could affect the accuracy of digital classification. Confusion was noted above between cover types on the Sierra de Humilladero image where, for example, crops in lowland areas were classified with trees in highland areas. Inclusion of a terrain image amongst spectral bands might be expected to result in improved classification accuracy.

The first study involving the incorporation of topographic data as an additional channel in multichannel classification of Landsat imagery was carried out by Strahler et al. (1979). This particular work successfully increased the accuracy in classification of species-specific forest cover. Preliminary work presented in this paper attempts to demonstrate the use of a similar approach applied to multichannel ATM data with one additional band comprising a digital terrain image.

8. MATERIALS AND METHODS

The basic data used in this part of study included the ATM imagery for 16 May 1989 together with digital terrain data abstacted from the 1:10,000 scale Spanish local topographic map series (map 1023/3-3, 1023/3-2, 1023/2-2 and 1023/2-3).

8.1. Creation of digital terrain data.

Those parts of the four topographic map which covered the 5 x 5 Km study area were digitised. Features digitized include roads and farm houses, which were used for ground control identification together with spot heights and contour lines at 10 m intervals. These four digital maps were merged together to cover the study area on one sheet. The merged digital map was used to create terrain images with a 10 x 10 m grid size and registrered to a geometrically-corrected ATM sub-image 194 x 250 pixels in size. The geometric correction was based on a least-squares fit using the ground control points. The terrain images represented elevation, slope and aspect. An elevation images was produced to represent the height range of 409 m to 688 m. Slope was represented in 100 gradient steps. Twelve orientation categories were used in the aspect image.

8.2. Radiometric and geometric correction of ATM image.

Radiometric correction of the imagery was accomplished using the procedures described in section 4.1. Twelve ground control points were identified on the terrain and ATM images, and a second order least-squares polynomial was used to transform the radiometrically-corrected image for the selected bands (section 8.3) to fit the topographic maps. Only these selected bands as described in section 8.3 were geometrically corrected. The image was resampled to a 10 x 10 m pixel size from its original size of 6 x 6 m using the nearest neighbour method of resamplig. The standar errors obtained as a result of this geometric correction were 2.0 pixels for columns and 1.8 pixels for rows.

Table 6

Number of pixels used for Training and Test area.

Land cover class	Training pixels	Test pixels
Bare rock	189	155
Cereal	215	118
Pine	244	287
Sun Flower	90	138
Olives	240	261

Table 7

Average Transformed Divergence Values and Band Combinations.

A. Spectral bands		B. Mixture bands	
Div.value	Band combination	Div.value	Band combination
19.01926	5	32.45022	E
98.01080	5,2	99.01053	E,2
99.99870	5,2,4	99.99974	E,2,4
99.99961	5,2,4,7	99.99996	E,2,4,7
99.99975	5,2,4,7,6	99.99998	E,2,4,7,S
99.99983	5,2,4,7,6,3	99.99999	E,2,4,7,S,A
		100.0000	E,2,4,7,S,A,3
———	———	100.0000	E,2,4,7,S,A,3,5
———	———	100.0000	E,2,4,7,S,A,3,5,6
———	———		

E – Elevation image; S – Slope image; A – Aspect image.

8.3. Selection of bands and preparation of the training class statistic.

Firstly, the eleven spectral bands (bands 2 to 12) and the elevation, slope and aspect images were visually evaluated. From this examination based upon the clarity of the images it was decided to exclude bands 8 to 12. Accordingly, bands 2 to 7 were included in the geometric correction routine. After the sevenbands had been geometrically corrected and resampled to 10 x 10 m pixel size, the shape of the corrected image was distorted due to the geometric warping so that blank space (non-image area) occurred around the edge. For this reason a subimage of 194 x 250 pixels in size was extracted from each geometrically-corrected band so as to exclude non-image areas.

Training class statistics were generated from selected training class areas. In this experimental work the training areas were divided into two groups, one to provide "training" input to the supervised classification and the other to provide test data for the accuracy assessment stage. In each group, the sample was taken randomly using window sizes from 2 x 2 to 4 x 4 pixels. The number of pixels selected for every class in ech group is listen in Table 6.

Selection of the best band combination was undertaken using the average transformed divergence method based on the training pixel data, as described above. For the purposes of examination and comparison of the results obtained using spectral bands only and mixture bands (a combination of spectral bands with terrain images), two divergence analysis were carried out. Results obtained from the divergende routine are ilustrated in Table 7.

8.4. Supervised classification.

Sets of mixture band combination (the best combinations of up to seven bands based on transformed divergence statistics which are listed in 7B) were used in the classification. A mixture set of 7 bands was selected as being the overall best set. These band combinations were used in a maximum-likelihood classification with equal prior probabilities for each class. A confusion matrix from each set was computed and the overall misclassification plotted on a graph as shown in Figure 2.

9. DISCUSSION OF RESULTS

From the average transformed divergence results, as displayed in Table 7 A and B, the divergence value of each band combination showed different stages of progression. A mixture combinations shows a better overall result in comparison with the purely spectral bands. When using the four band combination, for example, the divergence value on the mixture bands shows a better result than the same order of combination on the spectral bands. This means a better separability in using an elevation image with the other spectral bands 2, 4 and 7. At the maximum band combination as given by spectral bands, the divergence value has not reach the maximum value, 100. On the other hand, a combination of three terrain images with three spectral images shows 100% of the maximum divergence value.

Using the band combination as suggested by the divergence analysis, a maximum-likelihood classification was carried out and a confusion matrix computed. Inclusion of an elevation image on band 2 followed in turn by the addition of bands 4 and 7 led to marked improvement in overall accuracy as show in Figure 2, with the optimum accuracy achieved from the supervised classification being 94.68%. The further inclusion of slope and aspect in this particular study has not resulted in greater improvements, on the contrary, there was a reduction in accuracy as shown in Figure 1. It is suspected that is due to the inclusion of a wider range of density values in the training area. Adding more bands to the classification has not only reduced the efficiency of the classification but has also increased measurement complexity.

A visual assessment of the classified image obtained from incorporating the elevation image with the other three bands, such as band 2 (blue), 4 (mid green-red) and 7 (infrared) revealed improvements in classification as was shown by the disappearance of confusion between vegetation at the lower elevations and pine trees further up the hillside.

10. SUMMARY

This preliminary study into improvements in digital classification over rough terrain has demonstrated the advantage of using an elevation image together with spectral information. In this study a summary of the work is more appropriate at present rather than any definitive conclusions. The topographic effect on radiance as suggested by Justice et al. (1980) and Thomson and Jones (1990) and the effect of sensor view angle on radiance as reported by Barnsley and

Kay (1990), were not considered at this stage but further studies on such lines are planned. The results presented here show that the inclusion of elevation data, improved supervised classification results. From the empirical point of view a visual assessment revealed that confusion between cover types, for example sun flower with pine trees, was reduced.

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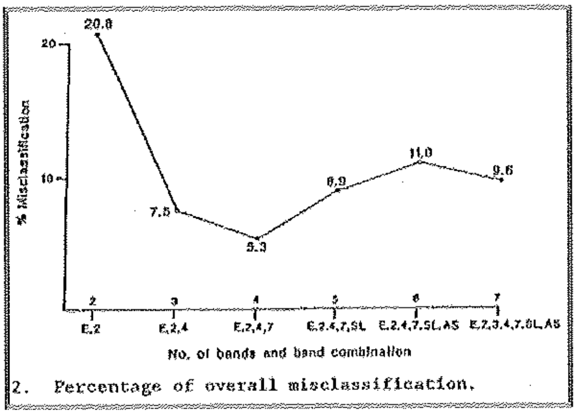

Figure 1.

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