COMBINING ANCILLARY AND SPECTRAL DATA FOR URBAN APPLICATIONS

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ABSTRACT

The heterogeneity of urban and associated surfaces poses difficulties for cluster based pattern recognition procedures that rely solely on multi-spectral data. This is most apparent when the resolution of the sensor system is low as in the case of Landsat MSS data. These problems have encouraged many researchers to examine the potential of incorporating ancilliary data sources into the classification procedure. This paper examines some of the techniques that have been developed and applied for incorporating non-spectral based data, and investigates those sources of data of particular interest to urban studies under the headings of system, image neighbourhood, physical, administrative, cultural and logical sources.

INTRODUCTION

Serious limitations to the classification of urban areas using satellite based remotely sensed data, have been the inability of typical cluster based recognition techniques to cope with the heterogeneity of urban and associated surfaces or the continuum of cover classes found in urban areas. Relative to pixel resolution, considerable inter-pixel and intra-pixel change can occur, (Forster, 1981, 1984, Erb, 1974). Implicit in the process of classification is the assumption that each surface or object of interest has a unique set of attributes, resulting in spectral signatures sufficiently different to allow consistent recognition using statistical procedures. Typically urban multispectral response will not be amenable to these procedures because either clusters will have considerable overlap or be extended linear clusters, making it difficult to determine the probability of an unknown response value being part of one or other class. Improvements in satellite spatial resolution or utilising an increased number of spectral bands would seem an obvious approach to the solution of these problems, but it is not always the case that more usuable information will be added or classification accuracy improved (Ready et al, 1971, Townshend, 1981).

Certain system limitations also contribute to classification difficulties in urban areas, particularly the effect of the sensor point spread function, which will cause a smearing or spreading of the signal. The recorded response will be the integrated response from an observed or target pixel and its surrounding pixels. Over homogeneous agricultural areas this will not cause a problem, except at the interface of two separate cover classes, however it can significantly affect the response from a single cover class if the surrounding cover is dissimilar, which can occur quite frequently in urban areas

The incorporation of ancillary data into the classification procedure can overcome some of these limitations. This can be achieved in a number of ways, for example, by the inclusion of ancillary data as additional feature sets in the spectrally based classification procedure or by relaxing an existing classification procedure to allow probabilistic data from other sources to influence the classification decision. Possible sources of ancillary data are considered to include system induced spatial correlations and variation in image neighbourhood texture, various physical, cultural and administrative sources such as local government boundaries or terrain data, and logical sources, for example, the probability of one class changing to another, some having the possibility of bidirectional change and others only unidirectional change. The nature of urban areas ensues that a wealth of ancillary data is available for inclusion in classification procedures. This paper provides an introduction to ancillary data incorporation procedures, and describes a research project which aims to develop and operationalize, effective urban classification procedures using satellite image data in combination with physical and cultural urban data.

PROCEDURES FOR DATA INCORPORATION

Ancillary data can be incorporated into the classification procedure before, during or after a spectrally based classification has taken place. Hutchinson (1982) sees this incorporation as acting through stratification, classifier operations or post classification sorting.

Stratification takes into account the population under consideration by dividing the study area into sub-populations of known size and increased homogeneity. In a sense stratification is acting as a preclassifier by dividing the area into broad classes based on some prior knowledge. It is considered that within stratum spectral variation is reduced, and by processing each separately, that surfaces or objects of similar spectral properties between stratum are not confused. Criteria selected for stratification should be significant in describing the variation of the surfaces of interest (Hutchinson, 1982), for example by stratifying an area by elevation for forest studies. In the urban context elevation or more particularly, slope stratification, can also have benefit because of the association of various land use classes with specific slopes. Slope and aspect can also modify the amount of radiance incident on a surface producing a different sensed response from similar features; stratification for this purpose can also be effective. In a similar way, different features that appear spectrally similar can be manually separated prior to classification, thus avoiding confusion, as for example in the separation of some urban and rural land use classes (Gaydos and Newland, 1978). It is not always necessary that the basis of stratification comes from ancillary data in the strictest sense, it may be ancillary to the spectral classification but derive from the scene itself. For example textural variation, due to changed response between adjoining pixels, can be a basis for stratification using neighbourhood standard deviation.

The difficulties associated with stratification in classification improvement are well stated by Hutchinson (1982), in that differences between strata are absolute and abrupt, not allowing for subtle distinction. However, in urban areas many variations occur across man made features, such as roads or railways, and so abrupt change is a reality.

Incorporation of data during the classification procedure is based on two distinctly different approaches. The first simple adds further channels of data to the existing spectral data, the so called logical channel approach (Strahler et al, 1978). A layered variation has been the broad classification by spectral data and then a further subdivision of each class on the basis of ancillary data (Fleming and Hoffer, 1979). This approach raises a number of theoretical considerations particularly when classifying using a Gaussian maximum likelihood algorithm (Richards et al, 1982). These relate to the normality of the ancillary data, the relative scaling of the spectral and ancillary data components, the need for more training data to give reliable covariance estimates, increased classification cost and the requirement that ancillary data be available at the time of classification. The second approach biases the maximum likelihood classification procedure by introducing sets of prior probabilities derived from ancillary data (Strahler et al, 1978, Strahler, 1980). The prior probabilities can be developed on the basis of the estimated proportions of the cover classes or an observed or known association between the cover classes and the ancillary data. Both the logical channel and modified prior approach offer improvements in accuracy but the level of added sampling that is required is substantially more than for spectral classification alone (Hutchinson, 1982).

Post classification sorting modifies the spectrally derived classes by examining the existing class assignment of each pixel and reassigning it where necessary on the basis of ancillary data. This reassignment might be based on decision rules developed for the study area or be statistically based using a modified form of probalistic label relaxation (Richards et al, 1982). The decision rule approach derives from overlay procedures developed for grid based geographic systems while the latter is more akin to the modified priors approach except that the "prior" probabilities are derived from the spectral based classification and then modified on the basis of the ancillary data. One reported example of the decision rule approach uses slope and aspect data to separate confused classes derived from surfaces of similar spectral signatures,but different geomorphological origins (Hutchinson, 1982).

The relaxation approach has been used in particular to incorporate contextual information into the classification (Rosenfeld et al, 1976, Richards et at, 1981). The term relaxation refers to the mechanism by which the initial classification is relaxed on the basis of new information. A set of probabilities are derived from the spectral classification and represent the relative likelihoods of pixel membership of the available classes. These probabilities are updated recursively having regard to the influence of near neighbour class membership, which can be expressed in terms of the current probabilities, the conditional probabilities of likely and acceptable joint membership between neighbouring pixels and a set of weights expressing the spatial interrelationships between pixels. A supervised probabilistic relaxation procedure has been suggested by Richards et al (1981), which allows the information contained in the initial class membership labels to exert an influence on the direction of relaxation throughout the process while ultimately obtaining contextual consistency. The procedure is readily generalized to allow ancillary data to influence the process. A further extension of the method is based on the use of a logical combination of opinions, the so called "committee approach", to effect final membership rather than an algebraic combination of probabilities.

SOURCES OF ANCILLARY DATA

The wealth of information available in urban areas and within the image itself necessitates the division of ancillary data sources into six basic classes. These are considered to be

i) System sources
ii) Image neighbourhood sources
iii) Physical sources
iv) Administrative sources
v) Cultural sources
vi) Logical sources

The major system source is the effect of the sensor point spread function (p.s.f.) which for Landsat is determined by the blur circle and detector size in the across-scan direction, and the effect of a bandpass filter is added in the along scan direction (Dye, 1975). The two dimensional p.s.f.'s have as their product the joint two dimensional p.s.f. of the Landsat multispectral scanner. The scene recorded by the satellite system will be the result of a convolution of the p.s.f. with the individual incoming radiometric values. Thus the p.s.f. will integrate the response from the observed and surrounding pixels, so that while the recorded response derives predominantly from the observed pixel it will also partially derive from the surrounding pixels. A system related correlation will therefore be impressed upon the data. The weights to be given to each neighbouring pixel's true response as their contribution to the target pixel's recorded response can be determined for a 3 x 3 neighbourhood (Forster, 1982) and are as follows:

0.03	0.07	0.02	
0.18	0.45	0.13	Scan → Direction
0.03	0.07	0.02	

It is considered that by normalising the neighbourhood pixels to one, that these values may offer a theoretically derived basis for the determination of the weighting constants in the relaxation procedure. The weighting constant allows different pixels to have more or less influence on the labelling of the central pixel. These derived weights are therefore as follows for Landsat MSS data:

0.05	0.13	0.14
0.32	Target Pixel	0.24
0.05	0.13	0.04

Scan → Direction

The spatial frequency of spectral measurements inherent in remotely sensed imagery comprises the source of neighbourhood ancillary data, more generally referred to as image texture. Texture can be crudely related to the number of changes in spectral value per unit distance within a contiguous group of pixels. Homogeneous areas will have little variation, whereas heterogeneous urban areas (and sub-classes of that area) will exhibit more rapid change. Various texture measures can be used to aid the differentiation of urban classes and these include first order statistical measures such as means, variances and standard deviations. Todd and Baumgardner (1973), for example, found that the standard deviation over a neighbourhood (in the infrared bands) aided separation of residential areas. Improved residential cover prediction was also found by Forster (1981) when measures of standard deviation were used. Haralick et al (1973) have proposed a higher-order set of measures based on grey-tone spatial dependency matrices. One of these, the angular second moment has been used by Jensen and Toll (1982) as an aid in the detection of residential land use development at the urban fringe.

A consideration of homogeneity in terms of *both* the pixel size and the size of the elements being viewed, affords an interesting application of texture data. Variance over a pixel neighbourhood (say 3 x 3) will increase as the pixel size approaches the size of the elements and will then reduce as the size of the pixel continues to decrease. This suggests that the resolution of the higher resolution satellite systems Landsat TM and SPOT is approaching the optimum for maximum textural discrimination of surface features. It follows then for a constant pixel size, that as housing density varies from low to high, variance will pass through a maximum, as shown schematically in Figure 1. Because housing density is a major predictor of residential sub-classes, the use of neighbourhood variance can act as independent source of probabilistic data, for input into relaxation procedures, or as an initial basis for stratification.

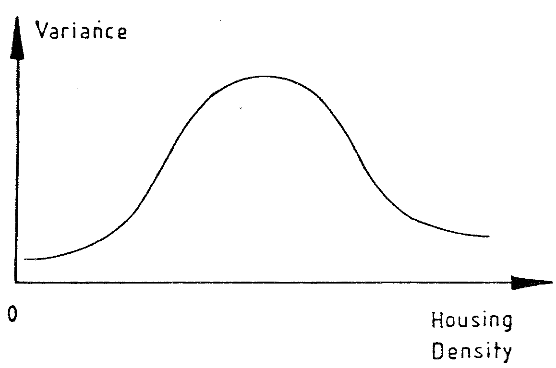

Figure 1: Schematic relationship between response variance over a 3 x 3 pixel neighbourhood and increasing housing density.

Physical data potentially comprises one of the largest sources of ancillary data. In urban areas the distribution of different classes and sub-classes of land use are strongly related to spatial location and terrain variability. Those ancillary data sets of particular interest in urban areas include elevation, slope, aspect and terrain variability, distance to the central business district (and other sub-nodes) and distance to waterways, and the relative amounts of vegetative cover compared to built cover within a particular area. The latter can be derived from remotely sensed data and provides information on the likely character of the urban space and the probability of it being a particular land use class.

The slope of a site will determine to a large extent the possible classes of land use that can be located upon it. Many urban authorities have developed urban land capability classification schemes that rely on slope characteristics and use them as a primary basis for land use zoning. In general, the intensity of urbanization a site is capable of absorbing, is inversely proportional to the slope, so that large scale industrial, commerical and institutional development are restricted to slopes of 5% or less, whereas for slopes greater than 30%, any disturbance for urban development is not recommended. Historically, natural site selection has followed a similar pattern, except in isolated cases. Using the proportion of area covered by each land use class over a city and their planned or natural distribution according to slope, the relative likelihood of particular land use classes occurring as a function of slope, can be determined. Typical values might be as shown in Table 1, for four simple classes, where for each slope category the sum of the probability of occurrence of each land use class is 100%. The proportion of each land use class within an urban areas was taken to be 0.10 (industrial), 0.05 (commercial), 0.70 (residential) and 0.15 (open space). These probabilities can be used as prior probabilities during classification or to influence the relaxation procedures following classification. Alternatively slope can be the basis of an initial stratification.

Table 1: Relative likelihood of land use classes as a function of slope. (Estimated values)

	Slope Categories (%)						
Land Use Classes	0-5	5-10	10-15	15-20	20-25	25-30	30
Industrial	23	8	0	0	0	0	0
Commercial	7	5	6	0	0	0	0
Residential	67	84	88	67	33	20	0
Open Space	3	3	6	33	67	80	100

Administrative ancillary data sources are epitomized by zoning policies, which reflect the "public's" concern to regulate the amount, juxtaposition and density of land use classes. The land use indicated by zoning will not necessarily equate with the actual land use, but depending upon the nature of the zoning and the length of time the zoning has been in force, it can indicate the probability of occurrence of a particular land use class. Equally important is that current zoning policies can be used to estimate the likelihood of occurence of adjoining land use classes. Differences in policy can also occur across local political boundaries.

The location of transportation routes can be considered as either physical or administrative ancillary data. It is here considered as administrative data because the transition between zoning policies invariably occurs along such routes. The road pattern in particular will determine the framework in which urban land use change takes place. The road elements will make up cells considerably larger than the individual parcels, and within each cell there will be a high probability of a common land use.

Cultural urban data can be viewed partly in the context of *urban ecology*, viz how people adapt to the urban environment ans their concern for the physical, spatial and material aspects of urban life, and partly in the context of *social structure* within the city, viz human values and behaviour and their interaction with families, church, government and business. The primary and broadest processes identified by urban sociologists is called aggregation with its localized sub-processes of dominance, gradient and segregation, centralization and decentralization, and invasion and succession (Timms, 1971). These processes have been incorporated into a number of urban models, such as the early 20th century Burgess concentric zone model and the Hoyt sector model, the former suggesting successive waves of land use invasion from the central city outwards, and the latter the tendency for like rental classes to follow a definite path in one or more sectors of the city. A more recent model proposed by Berry (1965) suggests that the basic organization of the urban residential pattern can be seen in terms of the axial variation of neighbourhoods according to family structure. A third factor influencing the urban pattern is ethnic status, which results in the formation of clusters, usually near the central business district. An illustration of this model is shown in Figure 2 (Murdie, 1969). This model has been supported more recently by social area analysis which essentially determines principal components from socio-economic statistics derived across a city (Timms, 1971). It should be noted that Berry's model has been derived from a study of expanding, western style, cities with a strong industrial base and may not be applicable in other circumstances. The model will also be distorted by the physical nature of the individual sites.

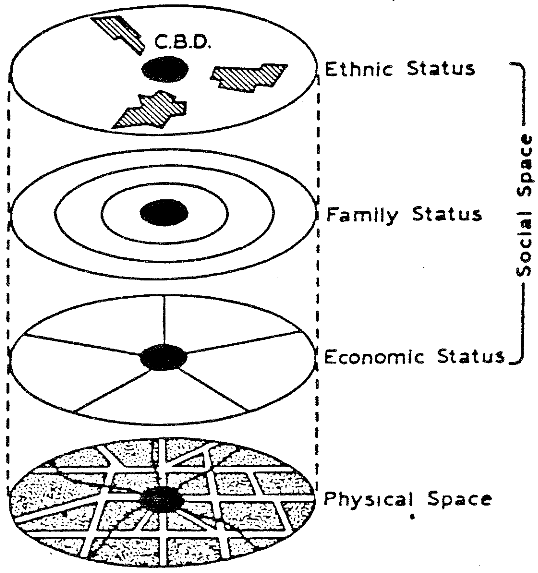

Figure 3: Idealized concept of urban space (after Murdie, 1969).

As socio-economic status is highly correlated with residential quality, and negatively correlated with proximity to non-residential development, the likelihood of different classes of residential use being located in certain areas of the city can be determined. In addition, as socio-economic status is relatively constant in a particular direction from the central business district, new residential growth on the edge of the city will tend to take on the character of the initial growth in that sector, to which a probability can be attached.

Finally, logical ancillary data can also be derived from urban areas. This type of data concerns the logical connections that may develop in time and space between different land uses, or over a transition period between land use classes. The residential development process is a good example of a logical transition. Here agricultural or forested land will undergo firstly a clearing phase, then a building phase, and finally a revegetation phase. Recognition of the stages of the transition over a temporal sequence of images, may allow the end class to be predicted. Some land use changes can also be considered as bidirectional, in that the change could be reversed at a later period, and others as unidirectional, the change being essentially irreversible. In an expanding city,changes will tend to be to a 'higher and better use', which basically indicates a greater intensity of development and a change to a more profitable land use. This can occur within classes, for example changing from single unit dwellings to multi-unit dwellings, or between classes, for example, residential class changing to a commercial class. As an illustration of this concept the relative likelihood of direction of land use change between six classes has been estimated for an urban area, and are shown as a matrix in Table 2. Changes are read *from* the vertical column *to* the horizontal column; for example, an existing single family residential area that has

Table 2: Relative Likelihood of Direction of Land Use Change (Example only)

	Ind	Com	M.Fm	S.Fm	O.Sp	N.Ur
Industrial	-	45	45	5	5	0
Commercial	20	-	45	30	5	0
Multiple Family	10	40	-	40	10	0
Single Family	5	15	75	-	4	1
Open Space	5	5	40	40	-	10
Non-Urban	23	7	17	50	3	-

undergone change has a 75% chance of that change being to multi-family residential, whilst the reverse process has only a 40% likelihood of occurrence. Given a knowledge of the land use classes at a previous time, any change that is monitored using remotely sensed data can have a value associated with it which represents the conditional probability of that change having taken place given the previous land use class.

SUMMARY OF THE PLANNED RESEARCH PHASES

Phase one of the study will examine the complex relationships that exist between mixtures of land cover classes, and response at the sensor, and the influence of building, vegetation and topographic shadowing, surface slope and aspect variations, and seasonal variations. For temporal monitoring it is essential that these effects be minimized so that real land use changes can be determined.

In the second phase of the study small blocks of Landsat data, containing only two or three well defined land use classes, will be used with point, line and area ancillary data, typical of urban areas, to modify the classification. While the characteristics of relaxation labelling algorithms are relatively well known this is primarily with reference to point source data (Richards et al, 1981). By using small scenes of limited class complexity the effects of ancillary data on the classification can be more readily examined. On the basis of experience gained, more complex sub-scenes will be examined.

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