Generation of objective urban land use maps of the Johannesburg area by semisupervised spectral and special choropleth classifications of SPOT and Landsat TM data.

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ABSTRACT

Land use patterns of the Johannesburg and Sandton areas are being mapped with the aid of SPOT multispectral and panchromatic as well as Landsat TM data. A semisupervised classification technique is initialy used were spectral domination of classes which are over-represented in the scene is avoided and "desired" classes are automatically identified in the "natural" grouping of the clusters. ISODATA of Ball and Hall was adapted to define the spectral signatures of the relevant cover types from a selected subsample of a full scene. Through an iterative process the subsample is reselected until a spectral classification well representative of all land cover classes in the study area is obtained.

A map of spectral cover classes does not necessarily result in a useful map of urban land use classes. Features in urban space have a relatively high spectral separability, but also a high textural complexity. The spectral cover classes therefore are grouped into urban land use classes by means of a special supervised choropleth classification where the spatial distributions of spectral classes are used as features rather than radiances. A relationship of spectral distributions is establised between a training window within an urban land use class and a window scanned over the whole scene. Areas with high levels of correspondance with one or more training windows is delimited and compiled into an objective map of urban land uses.

INTRODUCTION

Satellite remote sensing systems with better resolution than the 80 m of Landsat MSS has stimulated the interest of urban planners. Particularly the 10m and 20m resolution of respectively the panchromatic and multispectral SPOT products have become attractive potential sources of information in the urban environment.

The purpose of this study is to evaluate the usefulness of SPOT data in identifying urban and peri urban land use classes and thus also the potential of SPOT for monitoring urban change over time. In addition a comparison is being undertaken to compare the value of improved spatial resolution of SPOT with the value of increased amount of spectral information of Landsat TM in the urban environment. Furthermore it is attempted to generate products which combine the best attributes of these two sensing systems for urban planning.

STUDY AREA

Two test sites of the Witwatersrand metropolis, each about 15 x 15 km in size were selected from existing SPOT (April 1986) and TM (February 1986) data, for intensive study. The first covers a typical relatively stable though complex aggregate of urban land use classes in central to northwestern Johannesburg consisting of low and high density residential, recreational, CBD, commercial and industrial as well as active and abandoned gold mining activities. The second test site, situated in the north of Sandton (on the urban perifery), is less complex but in a very active state of transition. The major land use classes are agricultural, low density housing, recreation and to a lesser extent light industry and commercial.

SPECTRAL CLASSIFICATION

The multispectral SPOT and TM data is subjected to a semi-supervised method of classification. This consists of assembling subscenes of typical urban land cover classes into a composite subscene which is then subjected to an unsupervised classification for the determination of the spectral signatures of relevant cover classes, followed by a minimum euclidean distance classification of the full scene. The advantages of this appoach are that the necessity of selecting subscenes with "pure" spectral signatures of "typical" land cover classes is avoided and that the separability of spectral classes in the multidimensional feature space is automatically ensured.

SELECTION OF SUBSCENE

The selection of the subscenes of typical cover classes is a critical step in order to ensure that the various classes are given appropriate statistical weights in the unsupervised classification irrespective of their frequency of occurrence in the full scene.

A two dimensional scatterplot (of the least correlated channels) of the composite subscene give an indication of its scatter and potential clustering.

Particularly in central Johannesburg, the selection of such subscenes is not obvious. Experience has shown that certain well separable cover classes can be overlooked initially. These can be discovered by inspecting the distance map of the classification of the full scene and areas containing these should be added to the composite subscene for a further iteration. This process is represented graphically in Fig. 1.

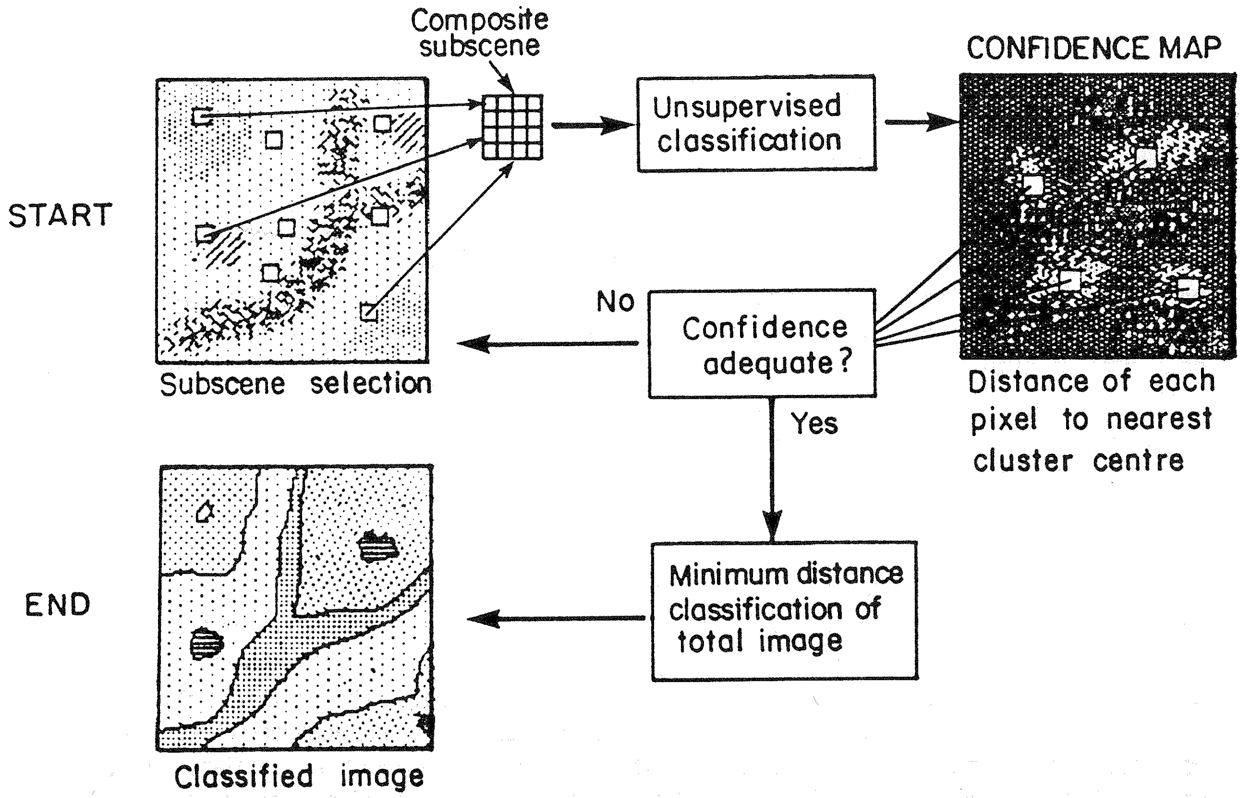

Fig. 1. Sequence of steps in semi-supervised classification.

CLASSIFIER

The composite subscene is normaly small in size (typically 80 x 80 pixels) and a highly iterative unsupervised classifier does not require unrealistically long computing times. An unsupervised classifier was developed from the original ISODATA of Ball and Hall (1965). The following are the major differences:

1) The multidimensional median of each cluster is taken as the centre instead of the mean. This places the centre closer to the densest part of the cluster when outliers are present. This ensures that the optimum grouping will be reached with less iterations than normal. An efficient algorithm of Kuhn, Kuenne and Cooper is used for this purpose.

2) The criterion for splitting or combining clusters in the middle phase is not based on prespecified parameters but on above or below mean variances. This makes the classifier more independent from the user and objective.

3) Groups are split perpendicularly equidistant between the mean and median, in order to split the class in the direction rather than dimension of largest variance. This should bring about a faster optimum grouping.

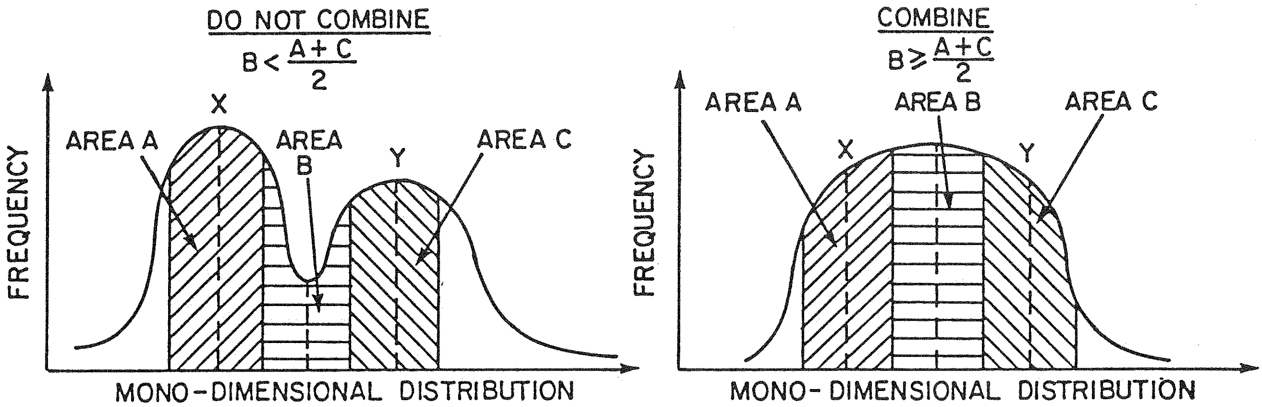

Fig. 2. Criterion for cluster combination.

4) The critereon for the final cluster recombination phase is based on the density between them in feature space (see fig. 2.). This has the advantage that a more "natural" grouping is ensured. Nearest neighbour groups with an inter distance larger than a maximum distance limit in feature space specified by the user, will be prohibited from combination. This means that large "natural" spectral classes may stay sub-devided in smaller meaningfull classes (a vegetation class may for instance consists of classes ranging from non-vigorous to vigorous classes)as needed by the user.

The various phases of the supervised classifier each consist of a number of splitting, testing and recombination subroutines which can be combined in various sequences and for a variable number of iterations. By monitoring the progress of the classifier through inspection of a two-dimensional scatterplot at intermediate stages, these sequences can be reorganized in order to obtain optimum convergence to stable classes. A minimum euclidean distance classifier utilizing all spectral bands is used for the classification of the full scene.

THE VISUAL RECOGNITION OF URBAN LAND USES

The classification of spectral data received from the satellite leaves the interpreter with an areal distribution of different types of ground cover, which is still a long way from urban land uses. A factor which complicates the association of a certain type of ground coverage with a specific land use type, is the mixture of differenyt types of ground coverage that is encountered within a small area. This is further complicated by the fact that a mixture of ground coverage is found within a single pixel unit, which transforms most of the pixels within a city into mixels.

In spite of these problems a visual interpretation of the areal distribution of the classified spectral data made it clear that distinctive areas could be delineated. This was possible because of a particular propotion of certain spectral classes which were found in different urban land use categories. By taking into acount these proportional differences a land use map of parts of Johannesburg and Sandton were created. This land use map were then compared with orthophoto maps and land use maps drawn up by field research. The results showed that broader urban land use categories could easily be recognized, i.e. residential areas, business areas, industrial areas and recreational areas. Thus, it was possible to delineate areas of higher income from lower income, and newly developed areas from older established areas.

The visual interpretation still leaves the researcher with a subjective result. Presently the research is being concentrated on eliminating this factor, by training the computer to distinguish between different proportions of spectral classes that is to be found in different areas and do the delineation of urban land usage objectively.

GEOGRAPHIC CLASSIFICATION

As concluded above, the classification of an urban scene into spectrally distinct cover classes very seldom results directly into a map of urban classes which is meaningful to the urban geographer. His main interest lies in subdividing the urban area into units such as CBD, commercial, light and heavy industrial, low and high density residential, etc. Each of these urban classes is composed of different aggregates of spectrally distinct cover classes such as vegetation, rooftops, tarred road, concrete, etc.

This situation differs from that in the agricultural environment where spectrally distinct cover classes, such as bare soil, ripened wheat, alfalfa, etc, are direcly meaningful to the agricultural planner.

The mapping problem for different cover types of interest to the different disciplines could be represented schematically as in Fig. 3.

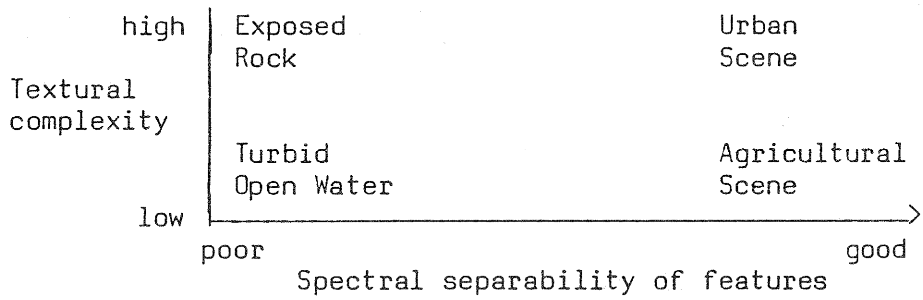

Fig. 3. Schematic representation of factors influencing the mapping of cover types

The agricultural environment in which spectral classification has traditionally been applied most successfully, represents the simplest case. The geological environment represents the other extreme, where features with ill-defined, gradually changing spectral signatures form spatial aggregates with complex textures. These usually cannot be satisfactorily analyzed by spectral classification.

(It is of course evident that the positions occupied by the different cover types in Fig 3 are dependent on the relation between their sizes and the sensor resolution.)

The remaining problem facing the urban geographer is thus a meaningful classification of aggregates of spectrally separable cover classes at the resolution of 20m to 30m.

COROPLETH CLASSIFICATION OF SPECTRAL CLASSES

Of the number of approaches considred, a multidimensional supervised classification of spectral classes into a map of urban land uses was decided to be the most promising. This approach will give a researcher maximum scope for experimentation in a new unknown environment and technique.

This procedure follows the traditional scheme of supervised classification but the features now are represented by the relative frequencies of classes within prespecified window limits instead of the spectral radiances.

The N spectral class frequencies thus define a N-dimensional feature space in which the coordinates of each training site (CBD, industrial, recreational, etc) are defined by the pixel frequency of spectral classes contained in a training window chosen from the main scene. The coordinates of each pixel to be classified are defined by the pixel frequency of spectral classes contained in a moving window of adjustable size surrounding it in geographic space. The relationship between the moving window and the training window is represented by the euclidean distance in N-dimensional space.

Each pixel is classified according to a minimum euclidean distance criterion and the minimum distance map which is generated this way is stored.

This technique is currently implimented on an AT IBM compatible personal computer wich might prove usefull for urban planning purposes later. For a 9 X 9 moving window classifying a 512 x 512 image accourding to one urban laduse, it takes ±27 minutes in Turbo Pascal 4.0. A mathematical coprocessor might help to improve on this time.

After some experimenting the following results were obtained:

1) This method is an objective way of deliniating desired urban land uses by training the classifier of the spectral classes through selection of a training site with the desired characteristics.

2) The desired sub devided detail of land uses obtained on the coropleth map can be obtained by adapting the size of the training site and moving window, (eg. a smaller window will result in more detail).

3) A distance limit in feature space beyond wich a pixel is not included in the particular class, can be selected in order to control the generalisation of the urban land use map. The more general the classification the longer the distance limit and visa versa.

4) By training the classifier to identify one landuse at a time, gives the best result because it is easier to consentrate on one landuse at a time. More than one training site can be used to classify only one landuse and naturaly improves the classifiers abbility to identify the desired landuse. When well chosen training sites for all desired landuses have individualy been identified as described, all can be classified in one scan over the image.

5) Problems are still present for example where two training sites could consist of similar pixel frequencies of spectral classes but differ in spatial arangement of the classes (for example a spectraly homogenious landuse vs a spectraly heterogenious landuse). Some solutions are being investigated, one of which is the employing a

nearest neighbor index of pixels in the same spectral class in stead of the pixel frequencies discussed.

COMBINATION OF SPOT, TM AND OTHER DATA

Coregistered SPOT panchromatic, SPOT multispectral and TM data were used as follows:

1) The spectrally classified SPOT multispectral and TM data, enlarged by pixel repetition to the same resolution as SPOT panchromatic, were combined with the latter by means of a colour space transformation, utilizing the SPOT panchromatic as brightness.

2) The same was also done for the geographically classified images of SPOT and TM in order to create a product with texture in the various coloured regions that represent urban land uses.

3) The same method can be applied to combine classified images with topo-maps.

4) Textural parameters such as mean deviation of the SPOT multispectral can also be combined with classified images.

Combination in such a final product of the finer spatial detail of SPOT panchromatic with the finer spectral discrimination ability of SPOT multispectral or TM data, results in an efficient way of visual presentation. This is also an excellent way to identify spatial texture within uniformly classified areas to assist the human interpreter's further visual analysis of the image, for example, to highlight problem areas.

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