MULTISTAGE PATTERN RECOGNITION FOR DIGITAL LANDSCAPE MODELLING

Alfred Mehlbreuer* & Inigo Molina**

* International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands
** Gesellschaft fuer Angewandte Fernerkundung (GAF), Munich, Germany

ISPRS, Commission VII

ABSTRACT:

On the way to a politically unified Europe inventories have to be made of the territory of the member countries following standardized procedures and specifications. An initiative of the European Organization for Experimental Photogrammetric Research (OEEPE) aims at developing criteria and carrying out practical investigations for a large GIS called "Digital Landscape Model of Europe". It shall consist of topographic features, land utilization data and relief data in a uniform projection geometry.

The objective of the OEEPE initiative is to develop and apply fully digital methods and computer-assisted analogue methods to evaluate data recorded by sensors on board of satellites. This aim allows for both, evaluation of well known procedures in image classification which shall lead to scientifically sound, manageable and standardized processing steps as well as methodical developments required to improve pattern recognition techniques by incorporating texture or context measures, ancillary data and the like.

The paper reports on first results of systematical investigations carried out at the International Institute for Aerospace Survey and Earth Sciences (ITC) in which a strategy of multistage pattern recognition was applied. LANDSAT-TM, SPOT-XS and SPOT panchromatic data from a test area in the Netherlands have been used to extract topographic features and landcover data for setting up a small digital landscape model. The investigations will be continued.

KEY WORDS: Classification, Feature Extraction, Pattern Recognition, GIS, Standards

1. INTRODUCTION

One of the major advantages of remote sensing techniques is uniformity of data acquisition. This is obvious when compared to terrestrial survey methods. Recording phenomena and features by remote sensing techniques leads to data sets of uniform quality and resolution while results of terrestrial surveys are of varying quality since they are influenced by the knowledge, experience and conscientiousness of individuals involved in data collection.

On its way to a politically unified Europe, the European Community (EC) is asked to make an inventory of the territory of its member countries. This inventory has to follow common principles and criteria for data collection, classification and evaluation. No longer national or individual criteria shall be applied but overall uniform standards.

In this context, the European Community (EC) finances presently two projects with substantial support:

- The first project deals with the compilation, coordination and harmonization of data on the European environment and natural resources. This inventory programme is called CORINE (Coordinated Information on the European Environment).
- The second project is aiming at predicting crop production for agricultural statistics which will be used to decide on subsidies for European farmers.

The CORINE programme was launched in 1985 and aims at the establishment of a reference data set for a multi-purpose environmental data base relevant to European policy-making (Wiggins et al., 1987). Satellite remote sensing images and aerial photographs as well as topographic and thematic maps are used to determine areas of homogeneous land use in units of 25 ha (500m x 500m). The approach applied for extraction of features is conventional visual interpretation. The results of interpretation are digitized and incorporated in a large GIS for the entire EC.

Although these programmes are important steps in harmonizing criteria for data collection and the contents of Europe wide environmental and agricultural data bases, they have some serious deficiencies. Some of them are:

- The coarse resolution of 25 ha applied in the CORINE programme does not correspond with the small size of parcels in some European countries.
- Both projects exclude simultaneous evaluation of multitemporal and multisensoral recordings. The crop prediction programme intends to use LANDSAT-TM or SPOT multispectral data supported by extensive terrain inspections.
- A detailed classification nomenclature applied in the CORINE programme is in contrast to the coarse area unit of sampling and mapping.
- The content of data bases does not include height information which is relevant for both land use evaluation and crop growing. Also other elements which do characterize a landscape are missing.

These disadvantages led, as a consequence, to an initiative of the European Organization for Experimental Photogrammetric Research (OEEPE) which aims at developing criteria and carrying out practical investigations for establishing an improved GIS, called "Digital Landscape Model of Europe" (DLME). The objective is to develop and make consequent use of digital methods and computer-assisted analogue methods to evaluate data recorded by sensors on board of satellites. The evaluation shall include classification of linear and areal features and the determination of plan coordinates as well as a Digital Terrain Model (Schulz, 1991). Experience gained from the CORINE project should be integrated into investigations.

The paper reports on some tests carried out at the International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands, in which a strategy of combined multisensoral and multistage pattern recognition was applied for creating a small digital topographic data base. LANDSAT-TM, SPOT-XS and SPOT panchromatic data from an area in the Netherlands have been used to extract selected topographic features. The investigations are seen as a first contribution of ITC to the methodical developments aiming at finding criteria for a comprehensive "Digital Landscape Model of Europe". The work will be continued.

2. BASIC CONSIDERATIONS

2.1 What is a landscape?

A landscape can be seen under quite varying aspects. A painter, while creating an artistic view of a certain landscape, will most probably see other landscape elements than an architect who is planning to build a landscape for recreation purposes. The artistic image always reflects an individual feeling or emotion caused by light, colour, season, etc. Also the landscape architect sees the landscape as an image but this in a more strict and specific way compared to the artist. He may take into account landscape properties and correlate them with expected human activities for designing the landscape as a recreational phenomenon. Other interpretations of landscape could be easily added.

The scientific view of landscape is significantly different from this. Instead of rating only particular properties of a region, "landscape" is here seen as a complex territorial system or correlation structure of various geo-spheres (Carol, 1963; Isachenko, 1973). Cosmosphere, atmosphere, biosphere, hydrosphere, lithosphere, pedosphere and anthroposphere belonging to it. As a consequence, the ideal realization of a Digital Landscape Model would be a comprehensive data base which allows to study, synthesize, analyse and query for spatial and non spatial analysis and modelling in an integrated approach. The "landscape model" might be a large central data base which must allow for access by a variety of user groups.

This ideal concept may however be too idealistic. We have to realize that not only one comprehensive but several geo-scientific disciplines are involved in landscape surveying. Geological surveys, geomorphological surveys, vegetation surveys, soil surveys and topographic surveys are existing often independently from each other, carrying out their own data recordings and building and administrating their own data bases. Taking this already established distribution of tasks into account, a landscape model may also exist as a number of coordinated but decentralized data bases. In order to supply and share common landscape data between geo-scientists and different organizations, a data exchange standard or network solution has to be established in this case. These aspects, although of major practical importance, will however not be discussed in this paper.

2.2 Contents and scale of a DLM

The major question in any landscape survey is: Which landscape attributes have to be mapped for a given area of interest? The answer depends mainly on the following factors:

- The nature or characteristics of the lands to be surveyed.
- The purpose of the survey.
- The scale (resolution) of the survey.

Each landscape, as the main mapping unit, is characterized by its own differentiating characteristics. The differentiating elements to be mapped for distinguishing the land units may therefor be different for each landscape area. They may, for example, be smaller than a standard unit of sampling or resolution as already mentioned with the CORINE project. Instead of setting coarse uniform standards for such an inhomogeneous physiographic area like Europe, an adapted standard, open for modifications and applicable to particular regions is definitely the better solution. However, in any case a profound knowledge of landscape characteristics must be available before starting to build a landscape model.

The purpose of the CORINE project and the crop prediction project is quite clear: to provide European policy decision makers with multi-purpose environmental data and agricultural statistics. The purpose of the OEEPE initiative for developing a "Digital Landscape Model of Europe" aims at setting the basis for a second generation, essentially improved, Europe wide CORINE data base. The "Digital Landscape Model of Europe" shall consist of topographic features, land utilization data and relief data in a given projection geometry (Schulz, 1991). As the project is still in its first phase, the definition of topographic objects and land uses to be considered has still to be fixed.

A first orientation for this task is provided by the CORINE classification nomenclature which is a three level structure. Level 1 distinguishes between artificial surfaces, agricultural areas, forest- and semi-natural areas, wetlands and water bodies. In level 2, looking for example only at agricultural areas, separations are made between arable land, permanent crops, pastures and heterogeneous agricultural areas. The latter is finally separated in level 3 into annual crops associated with permanent crops, complex cultivation patterns, land principally occupied by agriculture with significant areas of natural vegetation and, last but not least, agroforestry areas. In total a number of 44 land cover classes are distinguished. This within CORINE applied principle of a multistage classification scheme will be in its structure also used for the practical tests described in this paper. The classes will however be different.

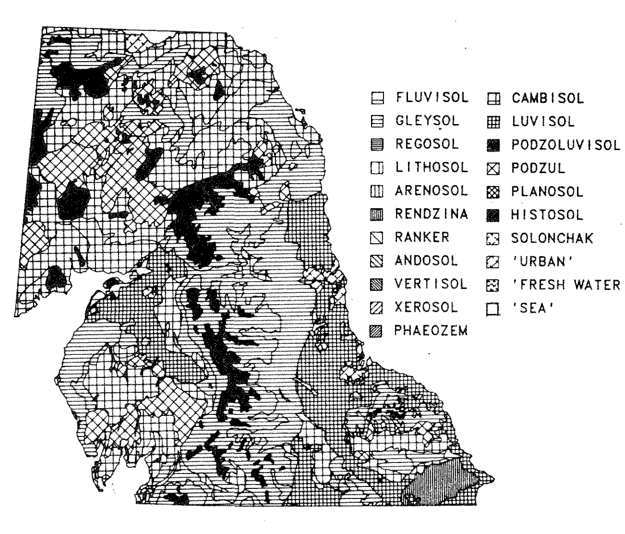

Fig. 1: CORINE Soil Map of an Area in Scotland (original scale 1:1,000,000)
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The scale used for the presentation of results is an indicator for the resolution by which a landscape is surveyed. For example, the 250 ha applied as sampling unit in the CORINE programme do result in an area size of 5 mm x 5mm at scale 1:100,000. This is quite coarse. In contrast, the minimum recognizable size of an area feature can be assumed as 0.6 mm x 0.6 mm independently from map scale. This would basically allow to present CORINE data at map scale 1:1,000,000 (see figure 1). High resolution satellite remote sensing data have, however, a higher potential. The 30 m spatial resolution of LANDSAT-TM, for example, corresponds nicely to the minimum size of 0.6 mm x 0.6 mm at scale 1:50,000. SPOT-XS and SPOT panchromatic data are even finer.
As a consequence, the authors are in favour of a resolution for the "Digital Landscape Model of Europe" which corresponds to a map scale 1:50,000. This resolution would by far better fit to European conditions than the resolution applied within the CORINE programme. The resolution would also be fine enough to be used for regional planning purposes in a future Europe composed of regions instead of nations. Moreover, national topographic map series at scale 1:50,00 are available all over Europe in a reasonable quality. Some topographic features could be digitized from the map sheets and directly incorporated into the data base or be used as ancillary data in the classification of digital remote sensing data.

3. STRATEGY

The availability of high resolution imaging systems results in growing demands for the reliability, accuracy and completeness of extracted features as well as accuracy of geometrical processing. These demands may no longer be fulfilled by using standard image processing algorithms. Therefore, investigations are required to improve classification, or more generall: pattern recognition (Swain and Davis, 1978), by including additional elements like ancillary data, texture or context measures, a priori knowledge and integrated terrain information. The geometric accuracy may be improved by using control blocks instead of control points as input data for image registration.

On the other hand, it has to be evaluated which combinations of well known procedures will lead to scientifically sound, manageable and standardized processing steps. This is especially of importance for comprehensive projects like CORINE or DLME since many organizations will be involved in data processing each of them probably following different approaches and applying different procedures. For the European crop prediction programme this was already taken into account since the individual working steps and the evaluation method to be applied are firmly fixed by ISPRA. As an example, the method of evaluation within this programme is based on the discrimination of classes according to the criterion of highest probability (maximum likelihood method). Developing standards for processing will also for the "Digital Landscape Model of Europe" be one of the goals.

Experiences have shown that valuable improvements of digital image classification and extraction of features have been obtained by the combined use of multisensor data (e.g. Cliche et al., 1985; Chavez, 1986; Green, 1986). This approach requires precisely referenced data sets to be in the position to relate the multisensoral spectral values properly to each other. Only then can statistical and structural pattern recognition techniques make fully use of the potential of multisensor data.

The investigations carried out at the International Institute for Aerospace Survey and Earth Sciences used LANDSAT-TM data in combination with SPOT-XS and SPOT panchromatic data. High resolution photographic images like those of the Russian KFA-1000 are foreseen to be included in DLME investigations but hadn't been available yet for the chosen test area.

The final classifications for deriving a DLME will most probably subset the area of interest into smaller portions in order to increase classification accuracy. Each subset will then cover a physiographic region or landscape unit where the terrain and vegetation relationships are relatively consistent. Accurate classification will strongly depend on the identification of appropriate regions in Europe. This "stratification" called procedure (Hutchinson, 1982) reduces the variance associated with a given spectral signature, thus providing a more precise definiton of landcover classes. The test areas to be chosen will have to take this into account.

Furthermore, it can be expected that for deriving a comprehensive DLME no special data acquisition programme will take place. For this task, already existing data will most probably be used even if they own deficiencies. Investigations for developing standard classification procedures must pay attention to this.

4. CLASSIFICATION

4.1 Resources

The study area chosen is about 12 km x 10 km wide and can roughly be separated into 1/3 urban area and 2/3 rural area features. The rural area is mainly made up of grassland and forest (deciduous and mixed). It is a quite typical physiographic area for The Netherlands characterized by homogeneous landuse, nearly no height differences, a number of water bodies and growing urbanization; it is the city of Utrecht and its northern vicinity (see also figure 2).

The satellite image data used for this project had been already available at ITC. The LANDSAT-TM data are recorded in June 1986, the SPOT-XS data in October 1986 and the SPOT panchromatic data in February 1987. Due to malfunctions during recording, only LANDSAT-TM bands 1, 2, 3 and 4 had been available. This means, an easily achievable improvement of vegetation classification by utilizing LANDSAT-TM bands 5 and 7 can consequently not be expected. SPOT data, all of them of level 1B, were expected to be useful for identifying the detailed features common to urban areas. Moreover, topographic maps at scale 1:25,000 have been available for identifying control points and obtaining information on the topography and landuse. Aerial photographs or other sources of information like thematic maps have not been used for these tests.

Investigations were carried out by using ILWIS, the "Integrated Land and Watershed Management Information System", a PC-based second generation GIS developed by ITC (Meijerink et al., 1988; Valenzuela, 1988). ILWIS is a comprehensive GIS containing some 200 functions grouped into several modules. The image processing module, for example, enables processing of remote sensing data, such as geometric corrections, classification, filtering etc. In contrast to many other GIS', ILWIS does not merely incorporate map overlaying capabilities in vector mode; it includes capabilities that enable the user to perform analysis in raster and vector format. A module which contains mathematical, conditional, relational and

Boolean operators enables the user to apply his own algorithms. The system runs on an industry standard platform and is compatible with many other data sources (such as Arc/Info, Erdas, Intergraph, etc.). Recently, ILWIS version 1.3 is available.

4.2 Preprocessing

Prior to classification the original image data have to undergo some basic preprocessing steps such as haze correction, contrast enhancement, destriping and geometric registration. For achieving a georeferenced data set, the SPOT panchromatic data was first registered to the map geometry laid by the 1:25,000 map sheets. SPOT-XS and LANDSAT-TM data were then in turn being registered to the geo-referenced SPOT panchromatic image while resampled to 10m pixel size. The standard deviations of transformation were in all cases less than σ = +/- 0.5 pixel of the original spatial resolution.

In order to incorporate textural and context measures into classification two additional bands have been derived from SPOT panchromatic data. One is obtained by a variance filter computed within ILWIS leading to a textural edgeness image. The other band is derived by an image enhancement procedure in which noise is suppressed without loosing the essential information and features are enhanced without "sharpening" the noise (Michaelis, 1988). Homogeneous areas in this enhancement procedure are smoothed according to the context of the pixel.

In order to reduce the redundance of SPOT multi-spectral data, a principal component transformation was carried out to obtain a reduced data set. From the three transformations, two bands are kept. The first principal component is the weighted sum of the original bands containing mainly differences in albedo. The second principal component contains mainly spectral differences while albedo and illumination differences are eliminated.
Moreover, an overall principal component transformation was applied to all original bands readily available for classification, i.e. the SPOT panchromatic band, the three SPOT multispectral bands and the four available LANDSAT-TM bands. As here some quite inconsitent spectral bands are combined, all principal component transformations are kept for the time being.

As result of this preprocessing step, seventeen images are now available to be used in classification. Not all of them have been tested in all of their possible combinations. The decision on the best combinations was taken after correlation matrices had been computed, indicating the less correlated bands. Finally, twentythree combinations have been selected with a maximum of four bands per combination.

4.3 Classification

In an attempt to derive manageable and standardized processing steps for the creation of a future Digital Landscape Model of Europe, also well known procedures have to be systematically tested and evaluated. As one of the consequences, the maximum likelihood method for the discrimination of classes was chosen as the only classifier to be applied. This is in accordance to the settings fixed by ISPRA for the European crop prediction programme. A systematical test had for us also higher priority than to examine very detailed training sites. The classes chosen have been identified from topographic maps only; no field data are captured. According to the landscape characteristics, a final set of fourteen landuse classes was chosen as follows:

Natural grassland	Urban area (very dense)
Marsh and reed	Urban area (dense)
Forest (deciduous)	Urban area (scattered)
Forest (mixed)	Roads and railways
Orchard	Asc. land (e.g. parking)
	Industrial area (very dense)
Water bodies	Industrial area (dense)
	Industrial area (scattered)

The classification of the twentythree combinations has been carried out using the appropriate modules of ILWIS. The results have been assessed visually and by randomly distributed test blocks. Due to the lack of ground data, the topographic maps have been used to locate the pixels for the respective classes. From these investigations it turned out that four band combinations gave superior results over others although varying in the degree of classification accuracy for the same class.

- The two principal components of SPOT multispectral data in combination with the context band derived from SPOT panchromatic data gave good results for the transportation network. Also the progressive transition from scattered to very dense urban areas is very well identified when compared to the topographic map.
- The LANDSAT-TM bands three and four in combination with the context band from SPOT panchromatic data show good results for the urban area and also for water bodies. In contrast, forest and vegetation is classified not so well.
- The SPOT panchromatic image combined with LANDSAT-TM bands two and four give similar results than described before. However, there is a better separation of vegetation classes within the urban area.
- The classification of the first two principal component images from the overall transformation gives the best results for the vegetation classes and for details of water bodies. This band combination turned out to be very efficient in differentiating between vegetation classes and artificial surfaces.

However, it also turned out that none of the band combinations tested led to a satisfactory overall classification result. Some classes had been classified better in one of the combinations while another class gave better results in a different combination. Not according to expectations is that the textural band is not represented in the superior classification results. For further investigations planned to be carried out at ITC, special attention will be paid to evaluate the directed use of statistical and structural texture bands for DLME classifications.

4.4 Post classification processing

Post processing aims at creating a final result image which is used to derive a vector data set as the final product of the process. The steps involved in this procedure are:
- composition of only one image out of four.
- incorporation of ancillary data.
- raster to vector conversion.

Based on the evaluation of classification results which is available in form of confusion matrices, decision rules can be derived for creating a final image out of four intermediate results. The basic idea is to use only those features which are classified the best from each of the four intermediate results to compose a new overall result image. This approach takes advantage from the fact that particular features are better to be separated

in specific band combinations than in others.
The procedure of merging was easy to implement in ILWIS using the "map calculation" module. This part of the GIS-software is used for the execution of spatial analysis functions and modelling operations. One possibility is the manipulation of one or more raster maps by performing arithmetical, logical or conditional operations. The result achieved is shown in figure 2.

The accuracy of this multistage classification result ranges from 60% for orchards, which are always difficult to separate, to 99% for natural grassland, which forms the major landuse of the test area. The overall accuracy achieved is 84%. However, it should be noted that these accuracy measures are related to randomly distributed test pixels which are taken from maps only. No field verification was carried out.

In an attempt to incorporate ancillary information into the procedure, some main landcover classes were digitized from the topographic maps and transformed into a raster image. The now available two raster images are combined by a function implemented in ILWIS. The module "crossing" calculates a cross table and an output raster image combining pixel values of two input images. Each combination in the cross table is assigned a unique value that corresponds to the pixel values in the output image. The program also performs different types of aggregation functions on the pixel values such as calculating the correlation coefficient between the pixel values of the two input images or calculating the average of pixel values. The approach was successfully tested for more static features like water bodies and roads which are not subject to rapid changes. The accuracy achieved turned out to be in the 90% range.

However, the success of this approach relates completely to the actuality and completeness of available map data. Maps which are out of date have to be treated with care when foreseen to be used as ancillary data. In our case the map data had been luckily from the same year as the satellite image data. Special concern requires also the completeness of map data. The classification of features applied in topographic mapping varies from country to country and may not in all cases fit to the overall intensions of a DLM of Europe. It cannot be expected that maps are always valuable sources for a supranational Digital Landscape Model of Europe.

Once the raster land cover data is complete, it can be converted to a data format suitable for vector-based GIS'. As all the classes obtained are allocated to defined attributes, also polygon maps can be created. It might be advisable to remove before vectorization scatterd individual pixels ("salt and

Fig. 2: Result Image (combination of four intermediate results, scale approxim. 1:70,000, b/w reproduction of an originally multicoloured representation), Utrecht and vicinity

pepper") by performing a majority filter. Thus the raster data become more homogeneous. However, precaution has to be taken not to remove valuable information. Vector data may then be smoothed by generalizing and splining all segments according to the requirements. The result of vectorization performed by ILWIS for a subset of the data is shown in figure 3.

Fig. 3: Vectorized Data Set of a Subset of Figure 2 (scale approximately 1:30,000)

5. CONCLUSION

The initiative of the European Organization for Experimental Photogrammetric Research (OEEPE) can be an impulse for scientists and organizations to develop and test refined methods of feature extraction for a future "Digital Landscape Model of Europe" (DLME). Developing criteria and elaborating scientifically sound but manageable solutions for this large second generation GIS is indeed a challenge. On one hand tailor made specifications and procedures are required which fit to the characteristics of European landscapes. In contrast to this more generalizing requirements are to be expected from the political administration which has to apply uniform standards for entire Europe.

The Department of Geoinformatics of the International Institute for Aerospace Survey and Earth Sciences (ITC) has accepted the challenge and contributes to discussions by analysing systematically the use of pattern recognition techniques for DLME purposes. The first results of a combined multisensoral and multistage classification approach are presented in this paper. Emphasis was laid on the evaluation of already known algorithms applied to a test area in the Netherlands.
It turned out that good results for this particular landscape could be achieved by merging the intermediate results of four separate classifications into one final image. Incorporation of data digitized from existing maps at scale 1:25,000 into post processing again improved accuracy.

However, the tests described in this paper relate completely to reference data taken from available topographic maps; also field verification was not applied. This will not stay since maps usually cannot fulfill demands in terms of actuality and completeness of landscape features. Therefore, future investigations will have to utilize field measurements. Also the test area will change to a hilly region, this, to evaluate the influence of relief data on multisensoral feature extraction. Finally, special attention will be paid to the directed use of statistical and structural texture measures in pattern recognition.

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