Land Use Mapping and Change Detection Study in Athens Using Very High Spatial Resolution Satellite Imagery (IRS-1C, KVR-1000)

Kontoes C.C. Aifadopoulou D., Kanellopoulos I

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LAND USE LABELLING AND CHANGE DETECTION STUDY IN ATHENS USING VERY HIGH SPATIAL RESOLUTION SATELLITE IMAGERY (IRS-1C, KVR-1000)

C.C. Kontoes
Institute of Ionospheric and Space Research, National Observatory of Athens,
Lofos Nimfon, 11810, Thission, Athens

D. Aifadopoulou
GEOAPIKONISIS Ltd, 90 Themistokleous str
10681, Athens

I. Kanellopoulos
European Commission, Joint Research Centre, Space Applications Institute, EMAP Unit,
I-21020, Ispra (VA), Italy

Abstract

Two image analysis techniques, which integrate texture and spatial context properties for urban land use classification are presented in this paper. Very high resolution imagery of IRS-1C satellite system and KVR-1000, covering the city of Athens, have been processed to produce land use maps according to the EUROSTAT's CLUSTER nomenclature scheme. The classification approaches devised are the Kernel based Artificial Neural Network and the Kernel Reclassification Algorithm.
The satellite pre-processing steps and the level of performance of the above mentioned classification techniques, as well as the relevant comparison of their cost with more common approaches based on aerial acquisition campaigns are presented in this paper. The study shows that the use of kernel based approaches, return rather satisfactory results in terms of classification accuracy and land use class discrimination, while the cost of the works is kept at much lower level. A change detection study using the same satellite data is also reported in the paper.

Introduction

Satellite remote sensing data can provide regular and up to date information on urban areas. Although the relevant technology has changed significantly, there are still open questions concerning the development and implementation of a robust methodology for exploiting fruitfully the satellite imagery in urban areas.

The level of information that can be extracted from remotely sensed data is related to the spatial and temporal resolution of the acquired images. The interpretation of the aerial photography typically provides the needed information for urban studies. However, this approach is costly and difficult to apply with sufficient frequency. In contrary, satellite remote sensing can provide a method for acquiring regular and up to date information about urban areas, which may be particularly useful for monitoring the environment within and on the fringes of urban development (Foster B.C. 1985). Moreover, the continuous advancement of satellite technology and the acquisition of higher quality images, is strongly required for change detection studies in urban areas.

The first attempts to use satellite imagery in urban studies were not encouraging in terms of land use class specificity and map accuracy (Toll. D.L., 1985, Barnsley M.J. et al., 1989, Sadler G.J. et al. 1990). This was initially attributed to the coarse spatial resolution of the satellite sensors (Landsat TM, SPOT XS and P). Typical examples may be found in Haac B. et al. 1987, Khorram S. et al. 1987, Martin L.R.G. et al. 1989, Harrison A.R. et al. 1988.

However, satellite technology has changed and new sensors with higher spatial resolution and stereopair capabilities are offered for wider use (IRS, Radarsat, Ikonos, SPOT 5, KVR, KFA, etc). But the technology advancement introduced a new problem, that is to identify a robust, transferable and easily repeatable methodology in exploiting fruitfully the satellite imagery in urban areas and many research topics are still open and under investigation. This is attributed, by its turn, in the problem of "scene noise" (Martin L.R.G. et al. 1988, Cushnie J.L. et al. 1987), as the spectral responses of urban areas are much more varied, as being composed of the spectral responses of individual scene elements. This makes land use class description and identification problematic, especially when classification is treated on a per-pixel fashion.

The classification in urban land use classes is more than the identification of the exact label of classified objects on the image plane. Urban areas are not characterised by typical signatures, but mainly by texture, which is caused by the road network, residential areas of varying density and buildings of different kinds and height. This mixture of roads, buildings and also vegetation, produces a certain pattern which appears on satellite data as a mixture of very high and low pixel values. In other words the fundamental problem in producing accurate lands use maps is that urban areas present a complex spatial arrangement of land cover types. Thus, the necessity for integrating techniques which account for the spatial arrangement of pixel values or alternatively land cover labels within a neighbourhood has been considered indispensable by a number of researchers (Haralick R.M. et al.1973, Jensen J. 1979, Haralick R.M., 1979, Conners R.W. et al. 1980, Nagao M. et al. 1980, Peddle D.R. et al. 1991, Galloway M.M. 1992, Vilnrotter F.M. et al. 1986, Ryherd S. et al. 1996, Gahegan M. et al 1996, Paola D.J. et al. 1997).

The present study examines the results of two methods, developed especially for the purposes of the study, which integrate texture and spatial context information to infer land use classes, either during classification or post-classification level of process.

Scope of the study

The study has been realised in the frame of a pilot project launched by the European Communities/CEO program with the purpose to identify the extend by which the requirements of EUROSTAT for statistical information over urban areas, can be met using very high resolution satellite imagery. Between the main objectives of the study is to define adequate image analysis techniques, to extract reliable signatures for urban land use classes from very high resolution satellite imagery, by studying image texture and spatial context properties. Moreover, the identification of the level of performance of the texture/contextual techniques in comparison to a common per-pixel maximum likelihood classification approach, in terms of classification accuracy and specificity, is between the scopes of this study.

Study area

The study area has been chosen to be the city of Athens and its surroundings covering an area of $40x40km^2$. Athens represents a typical example of a large European urban agglomeration with big human and economic importance. The dynamic change especially of the surroundings requires continuous monitoring and change detection.

Input satellite data

Multi-temporal and multi-spectral IRS-1C LISIII data with the spatial resolution of 25 m covering the city of Athens and its surroundings have been used for the purposes of the study. In addition, panchromatic satellite scenes of the IRS 1C-P and KVR-1000 sensors with a spatial resolution of 5m and 2m respectively have been exploited in the frame of the study.

Satellite data pre-processing

The need to proceed with multi-temporal classification required the application of radiometric and atmospheric corrections of the two multi spectral scenes. The assumptions made on the atmospheric model, aerosol and visibility index, were driven by real atmospheric data which have been collected the same dates and time as the available LISS III scenes as well as on existing reference spectra for specific targets found on the image plane.

The geometric registration of the two multi-spectral scenes, was based on the use of control points collected appropriately throughout the satellite scenes and an accurate Digital Elevation Model of the study area. The registration of the panchromatic scenes IRS-1C P and KVR-1000 was done with the accuracy of the sub-pixel. This experiment showed that these images could be used, in terms of geometric accuracy, for mapping purposes at the scales of 1:20000 and 1:10000 respectively.

The study required the integration of the multi-spectral IRS-1C LISS III scenes with the panchromatic data in order to combine in one product the spectral information with the pronounced texture and structure information provided by the panchromatic layers. The standard Principal Components Analysis technique (Welch R et al. 1987, Crippen R.E., 1989) has been used for the data fusion.

Kernel based classification approaches for the interpretation of IRS satellite imagery

On the basis of the above mentioned studies, it becomes clear that the extraction of reliable signatures for urban land use classes, requires algorithms which measure the spatial distribution of the spectral and texture properties found in the pixel context and produce significant features to introduce into the classification procedure. Therefore two Kernel Based Classification Approaches have been considered, for the purposes of the study. A combination of a supervised and unsupervised Artificial Neural Network (ANN) approach, as well as the Kernel Reclassification Algorithm.

The application of an unsupervised neural network based on a topological network (Kohonen map, Kohonen T., 1987, 1988) was done in order to decide about the optimal kernel size and input image information content, similarly to the works of Paola J.D. et al. 1995 and Wilkinson et al. 1995. The best class differentiation was given when using a 7x7 window on the basis of the multi-temporal and enhanced (merged) data set. The output of this investigation, was used to feed appropriately the back-propagation neural network, consisted of one input layer, two hidden layers and an output layer. The number of hidden layers and their dimension depends on the complexity of the given separation problem. The dimension of the network has been defined in an iterative approach in order to avoid over-learning of the network. The following network definition was used for the purposes of the study:

Layers = 4 (number of all layers)
Layer#1 = 7 * 7 * 6, 0, 0, 0
Layer#2 = 14 * 9 * 6, 0, 0, 0
Layer#3 = 26 * 2 * 1, 0, 0, 0
Layer#4 = 8* 1 * 1, 0, 0, 0

For layer #1, the notation "7*7" is the applied window size and „6" defines the number of input layer. For layer #4, „8" defines the number of output classes and „1" the number of output layer. The network dimension is defined in layers #2 and 3 whereas the number of zeros indicates, that all layers are completely linked with each other layer. The classification has been achieved in three steps: the training phase, the pre-reclassification phase to verify the success of the learning phase and the classification phase.

The Kernel Based Reclassification Algorithm attempts to derive information on urban land use based on the frequency and the spatial arrangement of the land cover labels within a square kernel. The assumption underlying this approach is that individual categories of land use have characteristic spatial mixtures of spectrally distinct land cover types that enable their recognition in high spatial resolution images (Wharton 1982, Barnsley et al. 1992). The algorithm operates in two stages: The first involves labelling of the image pixels into single land cover classes by the application of a supervised or unsupervised clustering. In a second stage, the pixel labels are grouped into discrete land use categories on the basis of their frequency and spatial arrangement within a square kernel.

The algorithm operates by examining pairs of adjacent labels within a square kernel, which scans the image. For each new position of the square kernel, a so-called adjacency-event matrix M is calculated.

$$M = \begin{bmatrix} f_{11} & f_{12} & & f_{1n} \\ f_{21} & f_{22} & & f_{2n} \\ & & f_{ij} & \\ f_{n-1\,1} & f_{n-1\,2} & & f_{n-1\,n} \\ f_{n1} & f_{n2} & & f_{nn} \end{bmatrix}$$

The matrix dimension equals to the nxn, where n = number of land cover classes. The matrix elements "fij" denote the frequency with which pixels belonging to class "i" are adjacent to those belonging to class "j", within the square kernel. As the spatial reclassification kernel is passed over the image, the current adjacency-event matrix is compared with template matrices (produced during the stage of classifier training) using a statistical similarity criterion given by:

$$\Delta_k = 1 - \sqrt{0.5\, N^{-2} \sum_{i=1}^{n} \sum_{j=1}^{n} \left(M_{ij} - \mathrm{T}_{kij}\right)^2}$$

$$0 <= \Delta_K <= 1$$

where Mij is an element of the current adjacency-event matrix, Tkij is the corresponding element of the template matrix for land use category "k" and, N is the total number of adjacency events in the kernel. By the term Δ_K is expressed the degree of match between the current adjacency even matrix and the template matrix for land use category "k". Values of Δ_K close to 1 indicates a perfect match while a value very close to 0 indicates no match. A detailed presentation of this method is given in Barnsley M. et al. 1996.

Compared with a pure statistical approach like the maximum likelihood classifier, neural networks or reclassification approaches can offer some advantages. This is especially the case, when insensitivity against noise and redundant information, as well as independence from normal distribution and introduction of texture information is required. Moreover, the employment of neural network and reclassification techniques, allows the integration of any type of sources of data classes in order to derive information (land use) classes, indifferently if the assumption of normal distribution of density functions is fulfilled or not.

Evaluation of the use of the two kernel based algorithms for IRS data classification

The application of the kernel based classification algorithms on high resolution IRS satellite data over Athens, provided useful information concerning the classification abilities of texture based classifiers in respect to the EUROSTAT's CLUSTERS nomenclature scheme. It should be noted that the CLUSTERS nomenclature scheme presents four hierarchical levels of detail in land use/land cover classes for urban, agricultural and forested areas. The experiments showed that some urban land use classes at Level VI and Level III could be derived with relatively good accuracy by applying kernel based classifiers. The Neural Network and Kernel Reclassification algorithms produced more accurate maps at the fourth Level of the CLUSTERS nomenclature scheme and four residential classes which differ one another in terms of housing density, were returned. These classes are "Continuous dense residential", "Continuous residential with moderate density", "Discontinuous residential with moderate density", "Isolated building areas". However these classes, are making a subset of the CLUSTERS classes, as many of the remaining classes in the nomenclature are functional classes, which can be derived solely from ancillary data and analog photo-interpretation. Although many experiments have been conducted by using various kernel sizes and image layer combinations, including multi-spectral and multi-temporal sets of enhanced (fused) data, it was not possible to separate class "Industrial or commercial activities". This most likely happens because there is no a typical texture pattern for this class on the image plane.

Best classification results show an accuracy of the order of 72% to 75% for the classified urban classes. In general, the texture based classification approaches proved to be useful for the classification of high spatial resolution data. In contrast, pixel-based approaches like e.g. the Maximum Likelihood Classifier, classify most of these classes as a mixture of single classes, like vegetation, roads and houses of different kinds resulting in confused classifications with a lot of noise. The results show, that the classification accuracy is directly linked to the applied size of the kernel used, since heterogeneous classes need large window sizes to be correctly represented, whereas small objects demand the contrary. Therefore, a combination of both results is necessary in case homogeneous classes are needed, but without accepting a loss of all small structures. It is for further research to study a set of pre-defined kernel sizes for data classification depending on the class or set of classes which are subject of classification. In all the experiments the texture properties of the land use classes have been introduced by the use of enhanced satellite data, which is the result of the fusion of the multi-spectral images of LISS III sensor with the high spatial resolution panchromatic image of IRS1C-P sensor. Figure 1 illustrates an

Fig. 1. Final classification after refinement of the back-propagation neural network output.

Classification nomenclature: A111='continuous dense residential', **A112**='continuou residential of moderate density', **A113**='discontinuous residential of moderate density' **A12**='public services', **A321**='roads', **A322**='rail networks', **A20**='industrial o commercial', **A502**='sport facilities', **A503**='green/leisure areas", **A421**='building sites' **D102**='bushes', **C13**='conifers', **F201**='inland water courses' extract of the final classification map provided by the application of the neural network algorithm and refined by the use of ancillary land use information. The application of the Kernel Reclassification Algorithm returned a very comparable classification map in terms of thematic and statistical accuracy.

Change detection in urban zones

Change detection has been based on the comparison of a very high resolution satellite imagery captured by KVR-1000 sensor (2m spatial resolution) in July 1992, with an ortho-photo map produced by the use of high altitude aerial photography (scale: 1:45000) acquired 5 years earlier. The area of interest is located at the north-north western part of the city of Athens covering the suburbs of Menidi, Thrakomakedones, Melissia, Nea Penteli, Kifissia, Erithrea and Ekali. Twelve stereo-pairs of aerial photographs have been processed appropriately on a digital photogrammetric station to produce an ortho-photo map of the study area. The production of the ortho-photo map has been based on an accurate aerotriangulation solution with mean RMS errors of the order of σx=1.396m, σy=1.359m and σz=0.916m in the three directions, fulfilling thus the requirements for mapping in the scale of 1:10000. A set of appropriately collected GCP points, as well as a very accurate DTM, were used for the geometric correction and ortho-rectification of the KVR-1000 image covering the study area, in order that it conforms with the accuracy requirements in the scale of 1:10000.

Image differencing (Macleod R.D., 1998) was applied by subtracting the pixel values of the two panchromatic layers, that is the ortho-photo map and the KVR-1000 image for the area of interest. A series of threshold values based on standard deviations from the mean were used on the difference image to determine the changed from unchanged pixels. Threshold values were chosen using 0.5, 1, 1.5 and 2 standard deviations from the mean. An accuracy assessment on the no-change / change pixels was performed by applying visual photo-interpretation of the two panchromatic scenes. This helped to identify the threshold value, which returns better discrimination between changed and unchanged pixels. This experiment showed that a threshold value close to one standard deviation returns better result. Photo-interpretation of the difference image in combination with the two panchromatic layers and the corresponding enhanced multi-spectral images, resulted in the identification of the following changes within the study area:

From **discontinuous residential** to **continuous residential of moderate density**.
From **isolated residential areas** to **discontinuous residential of moderate density**.
From **open land/green areas** to **discontinuous residential of moderate density**.
From **open land/green areas** to **isolated residential areas**.
From **open and agricultural land** to **industrial activities**.
From **open and agricultural land** to **commercial activities**.
New **road construction**.

Figure 2 illustrates a subset of the final change image map. The dashed polygons represent areas of change.

The advantage of using high spatial resolution satellite imagery for urban mapping

The use of very high spatial resolution satellite imagery for land use mapping in urban areas is recommended especially when extended areas have to be covered and map update is often required. This pilot project demonstrated that the satellite imagery may be useful to produce appropriate cartographic products on which land use delineation and identification may be realised. The integration of the multi-spectral and panchromatic layers returns a very detailed map with useful spectral content and pronounced texture and structure components very similar to the ones found on high altitude aerial photography (aerial photography scale: 1:40000 to 1:50000). The classification of the satellite data with the advanced processing algorithms based on texture, results in accurate map products which may be easily refined and completed by the integration of ancillary land use information, especially when functional classes have to be mapped. Therefore the need for in site visits to report or confirm already reported land use classes is minimised significantly. The possibility for continuous image acquisition in lower cost comparing to the one for the organisation and realisation of an aerial survey campaign is best suited for the monitoring of the urban and peri-urban areas towards the identification of changed (legally or illegally) land use classes. The differencing method presented in this paper shows rather easily areas which present high probability that changes have been happened. The delineation of changed/unchanged areas is done by photo-interpretation of the multi-spectral enhanced satellite data and the reported changes are labelled mainly on the screen and few of them in-site if it is required.

The cost analysis realised in the frame of the study showed that the use of satellite imagery reduces the cost for map production by a factor of 2 compared to the one needed when aerial survey campaign is required. In addition, the cost for regular update of the map is even lower since it is partially released from the cost of the ancillary data acquisition, DTM production and classification algorithm testing. The cost analysis showed that it is very important to have available ancillary data for the study area, since they are very useful to perform accurate classifications and refine final map products. In case that ancillary data do no exist the mapping cost per km^2 becomes the double, since the number of in-site visits increases significantly.

Conclusions

The use of very high resolution satellite imagery (IRS-1C, KVR-1000) for urban land use classification, requires the employment of kernel based classification approaches in order to discriminate between land use classes with representative texture patterns. The two kernel based classification approaches tested, that is the back-propagation neural network and the Kernel Reclassification algorithm, returned satisfactory classification results for classes differing in terms of housing density. The rest of the artificial land use classes, as they are required by the CLUSTERS nomenclature (e.g. public services/local authorities, commercial activities, cultural sites, sport facilities) may not be provided by any of the automatic approaches tested in the frame of the study. Their identification is subject of classification refinement, in which rule based techniques and ancillary maps are integrated in the labelling process. The employment of image analysis techniques which account for the geometric and structural properties of the objects, as well as the use of specific knowledge to recognise and label them, in respect to their use (e.g airports, extractive industries, wasteland, tips, sport facilities, etc), is considered indispensable, especially nowadays that the spatial resolution of the satellite data is getting increased.

High spatial resolution satellite imagery has been proved useful for land use change detection studies. The comparison of a KVR-1000 scene (resolution of 2m) acquired on July 1992, with a high altitude aerial photography acquired 5 years earlier showed 10 types of land use changes within the north / north western part of the city. These changes were mainly the result of the continuous housing construction activity and industrialisation of the city surroundings, especially along the axes of big roads (e.g national auto-route "Athens-Thessaloniki").

As a general conclusion the advent of the satellite technology, provides to the city planners base maps but also value added products which may be used for land use mapping and change detection studies. High spatial resolution satellite imagery provides low cost information in time, which respond to current requirements for studying the urban environment. A relevant study showed that the cost of using high altitude aerial photography for the same reason is the double of the one required when satellite imagery is used.

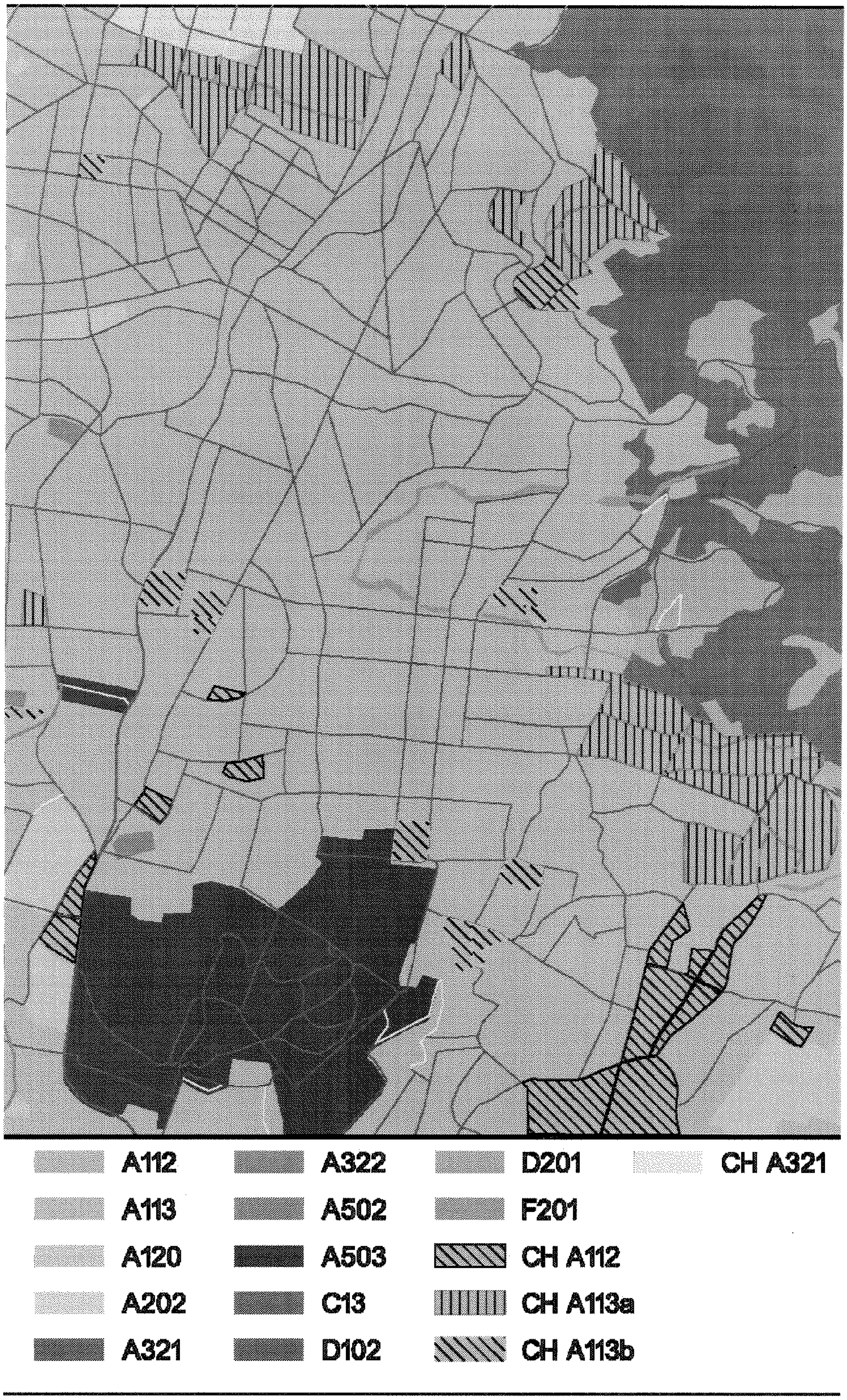

Figure 2. Extract of the change map. The class nomenclature has as follows:

A112= Cont/ous resid. modrate density, **A113**= Disc/ous resid. moderate density, **A120**= Public services and local authorities, **A202**= Manufacturing industrial, **A321**= Road transport, **A322**= Rail networks, **A502**= Sport facilities, **A503**= Green and leisure areas, **C13**= Conifers, **D102**= Bushes, **D201**= Grassland, **F201**= Inland waters courses, **CH A112** = From «A113» to «A112», **CH A113a** = From «A114-isolated residential areas» to «A113», **CH A113b** = From «Open land/green areas" to "A113", **CH A321** = New road construction.

References

BARNSLEY M.J., BARR S.L., 1996, Inferring Urban Land Use from Satellite Sensor Using Kernel-Based Spatial Reclassification, Photogrammetric Engineering Remote Sensing, Vol. 62, No 8, 949-958.

BARNSLEY M.J., BARR S.L., 1992, Developing kernel-based spatial reclassification techniques for improved land use monitoring, using high spatial resolution images, Proceedings XXIX Conference of the International Society for Photogrammetry and Remote Sensing (ISPRS '92) International Archives of Photogrammetry and Remote Sensing : Commission 7, Washington DC, 2-14 August 1992, 646-654.

BARNSLEY M.J., SADLER G.J, SHEPHERD 1989, Integrating Remotely Sensed Images and Digital Map Data in the Context of Urban Planning, Proceedings of the 15^{th} Annual Conference of the Remote Sensing Society, Bristol Uk, pp. 25-32.

CONNERS R. W., HARLOW C. A. 1980, A Theoretical Comparison of Texture Algorithms, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. PAMI-2, N^{O} 3.

CUSHNIE J.L. 1987, The Interactive Effect of Spatial Resolution and Degree of Internal Variability within Landcover Types on Classification Accuracies, International Journal of Remote Sensing, Vol.8, 15-29.

CRIPPEN R.E. 1989, A Simple Spatial Filtering Routine for the Cosmetic Removal of Scan Line Noise from Landsat TM P-Tape Imagery, Photogrammetric Engineering and Remote Sensing, Vol. 55, No 3, 327-331.

FOSTER B.C. 1985, An Examination of Some Problems and Solutions in Monitoring Urban Areas from Satellite Platforms, International Journal of Remote Sensing, Vol. 6, 139-151.

GALLOWAY M. M. 1992, Texture Analysis Using Grey Level Run Lengths, Computer Graphics and Image Processing, 4, 172 - 179.

GAHEGAN M., FLACK J. 1996, A model to Support the Integration of Image Understanding Techniques within a GIS, Photogrammetric Engineering and Remote Sensing, Vol. 62, No 5, 483-490.

HAAC B., BRYANT N., ADAMS S., 1987, An Assessment of Landsat MSS and TM Data for Urban and Near Urban Land Cover Digital Classification, Remote Sensing of Environment, Vol. 21, 201-213.

HARALICK R. M., SHANMUGAM K., DINSTEIN Its' HAK 1973, Textural Features for Image Classification, IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-3, N^{O} 6.

HARALICK R. M. 1979, Statistical and Structural Approaches to Texture, IEEE Proceedings, Vol. 67.

HARRISON A.R., RICHARDS T.R. 1988, Multispectral Classification of Urban Land Use Using SPOT HRV Data, Digest-International Geoscience and Rem. Sensing Symposium, Edinburg, UK, pp. 205-206.

JENSEN J. 1979, Spectral and Textural Features to Classify Exlusive Land Cover at the Urban Fringe, The Professional Geographer, Vol. 4, 400-409.

KHORRAM S., BROCHAUS J.A., CHESIRE H.M., 1987, Comparison of Landsat MSS and TM Data for Urban Land Use Classification, IEEE Transactions on Geoscience and Remote Sensing, GE-25(2), 238-243.

KOHONEN T., 1987, Self Organisation and associative Memory, 2nd edition, Berlin: Springer-Verlag.

KOHONEN T. 1988, An introduction to neural computing, Neural Networks, Vol.1, 3-16

MARTIN L.R.G., HOWARTH P.J., HOLDER G. 1988, Multispectral Classification of Land Use at the Rural-Urban Fringe Using SPOT Data, Canadian Journal of Remote Sensing, Vol. 14, 72-79.

MARTIN L.R.G., HOWARTH P.J., 1989, Change Detection Accuracy Assessment Using SPOT Multispectral Imagery of the Rural-Urban Fringe, Remote Sensing of Environment, Vol. 30, 55-66.

MACLEOD R.D., CONGALTON R.G. 1998, A Quantitative Comparison of Change-Detection Algorithms for Monitoring Eelgrass from Remotely Sensed Data", Photogrammetric Engineering and Remote Sensing, Vol. 64, N^{O} 3, 207-216.

NAGAO M., MATSUYAMA T. 1980, A Structural Analysis of Complex Aerial Photographs, Plenum Press, New York, ISBN 0-306-40571-7, pp. 190.

PAOLA J.D., SCHOWENGERDT R.A. 1995, A review and Analysis of back-propagation neural networks for classification of remotely sensed multi-spectral images, International Journal of Remote Sensing, Vol. 16, 3033-3058.

PAOLA J.D., SCHOWENGERDT R.A. 1997, The effect of Neural Network Structure on a Multispectral Land Use/Land Cover Classification, Photogrammetric Engineering and Remote Sensing, Vol. 63, No 5, 535-544.

PEDDLE D.R., FRANKLIN S.E. 1991, Image Texture Processing and Data Integration for Surface Pattern Discrimination, Photogrammetric Engineering and Remote Sensing, Vol. 57, N^{O} 4, 413-420.

RYHERD S., WOODCOCK C. 1996, Combining Spectral and Texture data in the segmentation of Remotely sensed Images, Photogrammetric Engineering and Remote Sensing, Vol. 62, No 2., 181-194.

SADLER G.J., BARNSLEY M.J., 1990, Use of Population Density Data to Improve Classification Accuracies in Remotely Sensed Images of Urban Areas, Proceedings of the 1st European Conference on GIS (EGIS 90), Amsterdam, EGIS foundation, Utrecht, 968-977.

TOLL D.L. 1985, Effect of Landsat Thematic Mapper Sensor Parameters on Land Cover Classification, Remote Sensing of Environment, Vol. 17, 129-140.

VILNROTTER F. M., NEVATIA R., PRICE K.E. 1986, Structural Analysis of Natural Textures, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol PAMI-8.

WELCH R, EHLERS W. 1987, Merging Multiresolution SPOT HRV and Landsat TM Data, Photogrammetric Engineering and Remote Sensing, Vol.53, No 3, 301-303.

WHARTON S.W. 1982, A contextual classification method for recognizing land use patterns in high resolution remotely-sensed data, Pattern Recognition, Vol. 15, 317-324.

WILKINSON G.G, FIERENS F., KANELLOPOULOS I. 1995, Integration of neural network and statistical approaches in spatial data classification, Geographical Systems, Vol. 2, No. 1, 1-20.