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Comparison of various approaches to the classification of urban areas with the use of high-resolution satellite images

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ABSTRACT: Digital classification of urban environment, due to its heterogeneity and fragmentation, is still a great challenge. In this paper several approaches to analysis of urban agglomeration were studied and evaluated. Data from three different satellite sensors: Landsat ETM+, Terra ASTER and QuickBird were used in the research works. The following methods of digital analysis and classification of satellite images were investigated in the course of the works:

- Spectral mixture analysis;
- Classification of urban areas with inclusion of texture measures;
- Object-oriented analysis with the use of multi-resolution segmentation, fuzzy logic and membership functions;
- Artificial neural networks.

As a result of the conducted works it was found, that hybrid method, combining elements of object-oriented analysis and artificial neural networks, is optimal for classifying urban areas with adequate accuracy. Application of multi-resolution segmentation enables to distinguish homogeneous objects within urban areas and to determine their several spectral and non-spectral parameters. Neural Networks analysis allows to find optimal solution concerning type of network for classification and importance of various parameters used in the classification process. The mean accuracy of classification with the use of this method, with division of urban areas into 3 levels of built-up land density, reaches 85%. The crucial for obtaining high accuracy, while classifying high-resolution satellite image, is to select properly parameters of segmentation and a set of features characterizing land cover classes, later used in neural network analysis.

1 INTRODUCTION

Detailed information on land cover and land use within urban areas is indispensable for proper management and physical planning. As urban environment is highly dynamic one, remote sensing images proved to be optimal for monitoring these areas. Due to great spatial and spectral diversification high-resolution images (Landsat type) and very high-resolution data (QuickBird type) tend to be the most appropriate for urban studies. First attempts to use these images were based on analog interpretation, but recently in some remote sensing centers the research works were started, in order to apply advanced digital classification methods (Gong *et al.* 1992, Hung *et al.* 2002, Pesaresi *et al.* 2001, Thomas *et al.* 2003, Wu *et al.* 2003). The presented work is placed in the stream of these works. Various methods of digital analysis of QuickBird, ASTER and Landsat ETM+ images were examined to assess their usefulness for classifying urban areas with high accuracy. As a result of these works the conclusions, concerning use of hybrid method, based on object-oriented approach and artificial neural networks, were drawn.

2 STUDY AREA

Part of Warsaw agglomeration – the largest city in Poland – was selected as the study area. The chosen area is characterized by high diversity of land cover and land use types. Urban areas with various levels of density of built-up land appear here, as well as industrial / commercial complexes and transportation networks. There are also numerous green areas within the selected site: city parks, gardens, cemeteries and natural grasslands, as well as river and water bodies. Built-up areas subject to dynamic transformation due to rapid development of Warsaw, which justifies selection of this city as a study area for further land cover / land use monitoring.

3 MATERIALS AND METHODS

3.1 *Data used*

Three types of high-resolution and very high-resolution satellite images were used in the research works:

- Landsat ETM+ image (30 m ground resolution);
- TERRA ASTER image (15 to 30 m ground resolution);
- QuickBird image (2.8 m ground resolution).

In the pre-processing phase all three image were geometrically and radiometrically corrected, using Intergraph and ENVI software packages. In order to have appropriate reference material, land cover / land use map, based on analysis of aerial photographs, was prepared for the study area. This map comprised 16 land cover categories, corresponding to Level 4th of CORINE Land Cover map. The legend of the map was adjusted to specific land cover situation, existing within the study area. The prepared map was used as a reference material for further training and validation processes.

3.2 *Applied methods of digital analysis and classification*

3.2.1 *Spectral mixture analysis*

Method of spectral mixture analysis has been developed in order to cope with the problem of mixed signal in case of using high-resolution data of Landsat type for classifying areas with very heterogeneous land cover. This problem was tackled among others by Ridd

(1995), who developed so-called V-I-S model. Each pixel in this model consists of three components: vegetation – impervious surface – soil. In order to assess contribution of each component in the pixel spectral mixture approach was developed. It is assumed in this approach, that resultant signal recorded in the pixel is a combination of pure representatives of land cover classes, so-called endmembers (Dennison *et al.* 2003; Roberts *et al.* 1998). Process of determining endmembers on the basis of hyperspectral or multispectral data consists of the following stages:

1. transformation of original multispectral (hyperspectral) data in order to reduce dimension of spectral space (*Minimum Noise Fraction* - MNF);
2. determination of Pixel Purity Index – PPI;
3. N-dimensional visualization in order to select endmembers for particular land cover classes.

After determination of endmembers three methods of data analysis are available:

- Spectral Angle Mapper – SAM;
- Mixture-Tuned Matched Filtering – MTMF;
- Linear Spectral Unmixing – LSU.

All three methods were examined in the presented works; the results of investigation are given in the next chapter.

3.2.2 *Use of texture measures for analysis of urban areas*

There are several methods of analysis of image texture (Herold *et al.* 2003); two of them were decided to be applied in the presented work. First method called Gray-level Co-occurrence Matrix (GLCM) approximates probabilistic density of pixel pairs; it is well suited to characterizing texture of image with non-regular object shapes. Seven GLCM texture measures were selected to be used for image characteristic: mean, variance, homogeneity, dissimilarity, entropy, contrast and correlation. All these measures were calculated for two images covering study area: TERRA ASTER image and QuickBird image.

In parallel, second method of analysis of image texture, called Occurrence Matrix, was applied This method is characterized by five texture measures: mean, variance, entropy, skewness and data range. Similarly to GLCM approach, all these measures were computed for both images under study.

In order to evaluate usefulness of texture measures for classification, separability analysis of land cover classes was done for both images, considering different combinations of input texture images. The results of this analysis were helpful for making final classification, based on texture measures.

3.2.3 *Object-oriented classification of urban areas*

Object-oriented approach is especially useful for analysis of urban areas, as it allows to characterize study area more adequately, taking into account both spectral and non-spectral features of land cover classes. The crucial point in this approach is to make proper image segmentation. Several segmentation parameters – scale, colour, shape and compactness - were studied in the presented work in order to find those optimal for dividing image into proper objects, which would correspond to homogeneous land cover classes. While determining these parameters, set of features optimal for classification of the selected land cover classes was searched, with the main aim to distinguish four levels of density of built-up land with high accuracy. As a result of iterative analysis such a set, comprising both spectral channels, their combinations (NDVI, ratios, brightness) and object relations, was determined. It was later used in conjunction with multi-level segmentation and hierarchy dependence to make final classification of the study area.

3.2.4 *Use of artificial neural networks for classifying urban areas*

Recently neural network approach begins to be applied to classification of remote sensing images with successful results (Paola *et al.* 1995, Kavzoglu *et al.* 2003, Keramitsoglou *et al.* 2005, Stankiewicz 2004). The main advantages of this approach are:

1. Ability to model precisely phenomena through mapping complex, non-linear relations among objects;
2. Control of multidimensionality while modeling non-linear functions;
3. Facilitation of model construction comparing to traditional statistical methods;
4. Easy application through network training on the basis of representative data.

The last feature is a basis for application of neural networks. The are two main algorithms for training network: without and with teacher. The latter one is more commonly used; it is based on collecting the proper representation of input data and output classes. Backpropagation is the most popular way of training; it modifies weights and thresholds in such a way to minimize errors in the application process.

The are several types of artificial neural networks; the most frequently used and therefore applied in the presented works are:

- Multi-layer perceptron – MLP;
- Radial basis function (RBF) network;
- Linear network.

As the process of selecting optimal network is the complex one, the author used in his work Statistica Neural Network software with Automatic Network Designer option, which allows to choose the optimal solution, characterized by the highest quality / lowest errors of training, validation and testing. The input data from the segmented QuickBird image of Warsaw were crucial parameters in the whole process. The following parameters were applied:

- Reflectance in near-infrared band;
- Standard deviation in near-infrared band;
- Ratio for near infrared band;
- Brightness;
- Normalized Difference Vegetation Index – NDVI;
- Texture measure – mean;

- Texture measure – entropy;
- Texture measure – homogeneity;
- Texture measure – dissimilarity.

Eight output classes were assumed to be achieved as a result of neural network analysis:

- Built-up land – high density;
- Built-up land – medium density;
- Built-up land – low density;
- High vegetation;
- Gardens and parks;
- Low vegetation;
- Areas not covered with vegetation;
- Water.

The results of process of network training and further image classification based on these results are presented in the next chapter.

4 RESULTS AND DISCUSSION

4.1 *Results of spectral mixture analysis*

Out of three methods of spectral mixture analysis: Spectral Angle Mapper, Mixture-Tuned Matched Filtering and Linear Spectral Unmixing the latter one proved to give the best results. Using this approach the attempt was done to distinguish 5 levels of density of built-up land on the basis of image representing vegetation contribution. The following classes were discriminated:

- Class 1 – 80 – 100% of built-up land;
- Class 2 – 60 – 80% of built-up land;
- Class 3 – 40 – 60% of built-up land;
- Class 4 – 20 – 40% of built-up land;
- Class 5 – 0 - 20% of built-up land.

The map including five levels of density of built-up land was verified through the use of test areas derived from aerial photographs. Accuracy analysis revealed, that only two categories with the highest level of density were classified with adequate precision. So it was concluded, that application of the method of spectral mixture analysis in case of urban areas is limited to delineation of densely built-up areas, including industrial and commercial zones.

4.2 *Results of the use of texture measures for analysis of urban areas*

Seven categories of urban land cover were studied in this part of the work: 4 levels of density of built-up land, industrial and commercial zones, transportation areas and construction sites. At first texture measures were derived for near-infrared band of

ASTER image, using both approaches for texture calculation: GLCM and Occurrence Matrix. Using separability analysis based on training areas it was found, that GLCM approach is superior to the Occurrence Matrix approach. Nevertheless, some classes of urban land cover were still separated with low accuracy, so QuickBird image was included into analysis to find, if higher ground resolution will give better results of urban class separation. Indeed, usage of QuickBird image improved number of well separated urban land cover classes; especially their separability increased, when texture measures were calculated on the basis of 3 QuickBird bands, including near-infrared and visible spectral channels.

Using results of the analysis it was decided to make supervised classification based on texture images derived from QuickBird image. 7 classes of urban land cover were taken into account, as well as 5 non-anthropogenic categories (coniferous forests, deciduous and mixed forests, grasslands, gardens and water). The final classification map was verified with the use of test areas. Results of this verification revealed, that for some very heterogeneous urban classes accuracy of their recognition was not satisfactory due to pixel-based approach, so it was decided to examine object-oriented approach for that purpose.

4.3 *Results of object-oriented classification of urban areas*

Final classification of the study area, based on QuickBird image, was done with division into 9 land cover categories, including 4 classes of density of built-up land. Classification map, as previously, was checked with the use of test fields, in order to assess accuracy of recognition of land cover classes, especially those related to urban land cover types. The results of accuracy analysis are presented in Table 1.

As it can be seen for Table 1, overall accuracy can be acceptable, nevertheless some classes, especially those with medium levels of density of built-up land reveal quite low accuracy of recognition. Therefore, the attempt was undertaken in the presented work to combine object oriented approach with application of neural networks.

4.4 *Results of using neural networks for classifying urban areas*

As it was mentioned in the previous chapter, 9 input parameters were derived from the segmented QuickBird image for representatives of 8 land cover classes. At the end of

Table 1. Results of accuracy analysis for classes of built-up land.

Class of density of built-up land	Producer's accuracy (%)	User's accuracy (%)
1–25% built-up land	87.4	61.2
26–50% built-up land	70.8	93.5
51–75% built-up land	77.8	81.9
76–100% built-up land	94.2	77.8
Overall accuracy 79.8%		
Kappa coefficient 0.7262		

Table 2. Results of network training for 9 input parameters and 8 land cover classes.

No	Type of network	Training quality	Validation quality	Testing quality	Training error	Validation error	Testing error
1	Multi-layer perceptron 9:9-12-8:1	1.00	0.97	0.98	0.04	0.29	0.22
2	Radial basis function network 9:9-49-8:1	0.99	1.00	0.95	0.06	0.10	0.10
3	Linear network	0.72	0.68	0.65	0.25	0.29	0.27

Table 3. Results of accuracy assessment of classifications based on neural network approach.

Type of land cover	Multi-layer perceptron		Radial basis function network	
	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)
Built-up land – high density	93	100	63	100
Built-up land – medium density	97	97	87	70
Built-up land – low density	75	93	75	93
High vegetation	85	96	81	81
Low vegetation	93	96	76	96
Gardens and parks	78	67	83	70
Areas not covered with vegetation	100	100	87	100
Water	96	100	92	100

training process within neural network approach the following results, included in Table 2, were obtained:Two first methods, presented in Table 2, delivered almost equally good results in training neural network so both of them were applied for further works. Analysis of sensitivity of particular input parameters, included in the process of training, enabled to select those, which have the most important impact on the final classification results. Out of initial 9 input parameters 5 of them were selected: NDVI, IR albedo, standard deviation of IR albedo, entropy and dissimilarity. These parameters were used for preparing final classification maps. Results of accuracy assessment of these maps are presented in Table 3.

The overall producer's accuracy was 89.6% for multi-layer perceptron and 80.5% for radial basis function network; for user's accuracy 93.6% and 88.8%, respectively. So, multi-layer perceptron type of neural network proved to be better in applying it for classification of urban areas, delivering acceptable results for almost all land cover classes.

5 CONCLUSIONS

Several methods of data analysis and classification were examined in the presented work. As a result of the study it was found, that hybrid method, which combines object-oriented approach in its segmentation phase and neural network approach in its data analysis/classification phase, is the best solution for preparing land cover map for urban areas with high level of accuracy. The applied method enabled to distinguish three levels of density of built-up land with average accuracy 88%. It should be mentioned that final quality of classification depends much on proper segmentation of satellite image and selection of appropriate input parameters, describing most precisely land cover classes to be recognized. Neural network analysis in conjunction with object-oriented approach allows to make selection procedure with high level of reliability, thus ensuring adequate classification performance.

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