GEO-OBJECT BASED VHR IMAGE CLASSIFICATION SUPPORTED BY GIS LAYERS AND EXPERT KNOWLEDGE

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ABSTRACT:

The growing needs in obtaining diverse categories of information about Earth surface, including land cover, require the effective and efficient methods of digital analysis to be work out. In contrast to traditional pixel based methods of digital classification, the object based approach allows to increase the set of discriminant features, including elements related to texture, size, shape, widely understood spatial and geographical context. Object based approach often allows within large extent also to omit some problems of traditional pixel based classifiers, which are resulted from high level of heterogeneity of identified areas and the frequent presence of so called statistical noise, considered as a consequence of high spatial resolution. The finally created and identified objects in object based analysis, in their spatial distribution form the more natural image of reality.

The paper presents certain results from the scope of digital analysis of VHR satellite image, where the main goal was to achieve land cover data applying pixel and object based approach. In first case the supervised approach was used with known traditional algorithms. The object based approach was realized based on Definiens Professional set of tools. In the last approach the essential was also to include the certain elements of expert knowledge and ancillary GIS information with the aim to improve the efficiency of method and accuracy of final results.

The given tests were done for the terrain with the diverse level of spatial complexity. For the rural areas the important issue was also to recognize some crops. The results showed (with the certain input assumptions) the positives aspects and limitations of applied approaches and methods, pointing at some visible advantages of object based approach.

1. INTRODUCTION

The usefulness of VHR satellite images for land use and land cover mapping is widely recognized. Due to the their spatial resolution and level of thematic information content, VHR satellite imagery present great potential to meet this requirement. The advantages of this category of imagery are especially visible in spatially and spectrally complex areas; like for example diverse agriculture landscape with small and narrow fields. Due to the spatial resolution of VHR images, the classification problems with mixed pixels widely known for lower resolution images are in this case on second-rate level. However the land cover classification accuracy of VHR images can be significantly perturb by internal variability of the classes and the kind of local statistical noise. This is one of the reasons why the performance of traditional digital image classification algorithms may meet some problems, even when the spatial resolution is improved. So the proper choice of classification method is especially imported for the more complex regions. Existing algorithms and methods can be grouped in different way using various criteria as it is described in literature. For example: the algorithms can be divided into parametric and nonparametric, approaches into supervised and unsupervised or assuming a basic processing unit also into pixel oriented and object oriented. In practise, the land cover classification is often based on the traditional pixel oriented image analysis, but many applications and papers which appeared during last years are successful examples of object oriented image analysis.

The common feature of existing traditional digital image classifiers is the assumption that pixel is a basic processing unit and the assignment of pixel to a certain class is based only on its characteristic related to spectral space. In standard procedures the widely understood contextual information (from spatial domain) is usually not taken into account, what often generates a certain level of limitations.

The object oriented approach as direction in image analysis has already significantly confirmed its usefulness in quite wide range of applications what is well documented in the papers (e.g.: Hay et al., 2003; Lang et al., 2003; Benz et al., 2004; De Kok et al., 2005). Further research and tests as well as next methodological improvements are still needed to increase the efficiency of object based analysis in general, but various experiences seems to be especially important for more complex study sites.

In this paper certain results are presented from the case studies in which different approaches to digital image analysis of very high resolution satellite images were tested, aimed at identification and delineation of land cover elements.

Part of the work is done in the frame of research project (2005-2007) supported by Ministry of Science and Higher Education.

The basic goal of the work in the described part was to evaluate the performance of selected methods for certain level of terrain complexity, assuming the analysis for one date image. For the given rural areas the important issue was also to recognize some crops.

The defined study areas represent a diverse range of terrain characteristics and levels of spatial and spectral heterogeneity.

Two main approaches were applied in digital analysis: 1) pixel based image classification, and 2) object oriented multi-scale image analysis, with classification of image objects extracted stepwise in an image segmentation approach. The first approach includes statistical parametric algorithm (maximum likelihood) and nonparametric neural network algorithm. The object oriented analysis applies Definiens software-based procedures. In the last approach the essential was also to include the certain elements of expert knowledge and GIS related ancillary information with the aim to improve the efficiency of method and accuracy of final results.

2. SHORT CHARACTERISTICS OF CLASSIFICATION TECHNIQUES APPLIED IN THE STUDY

2.1 Pixel based approach

The popular parametric algorithm 'maximum likelihood' (MLC**)** assumes normal distribution for the pixels forming the classes what allows to estimate the unknown distribution parameters from the user selected samples (training areas) and finally defined the discriminant function and decision criterion. The algorithm is generally quite efficient but in more complex reality where the above mentioned assumption is not always meet the results can be ambiguous.

The nonparametric, neural network classifier (NN) can be considered as kind of alternative to the maximum likelihood algorithm. It doesn't need practically the assumption about the normal distribution of classes. There are various NN systems with different architectures. The back-propagation network as type of multilayer feed-forward network is one of widely used and known neural network system. The term 'back propagation' refers to the training (learning) method by which the connection weights of network are adjusted. Learning occurs by adjusting the weights in the node (neuron location) to minimize the difference between the output node activation and the desired output. The error is backpropagated through the network and weight adjustment is made using a recursive method. For multispectral image supervised classification (based on training sites) the NN usually use a back-propagation network that learns using the Generalized Delta Rule.

2.2 Object based approach

It allows to explore in image classification not only digital value of pixel (defined in spectral domain, as the pixel based approach does) but also other features related to shape, size, texture, pattern, widely considered context, and all these features can be as discriminators of visually perceptible objects on the image. In that point the approach can be considered also as significant step in overcoming the recognized limitations of traditional pixel based classification. The key procedure in processing flow of raster object oriented analysis is segmentation. There are many segmentation algorithms. Detailed evaluation of segmentation programs for high resolution remote sensing applications presents Neubert & Meinel, 2003.

The eCognition package was the first general object-oriented image analysis software on the market (Benz et al., 2004). Next name of the software was Definiens Professional (the version used in the described work), and currently one of the version is called as Definiens Developer.

The essential part of the classification scheme with Definiens package is multiresolution segmentation, the patented technology enabling to extract the homogenous structures of objects at different levels of resolution (spatial scale) by applying relevant spectral and spatial related object discriminators. The key issue of the segmentation is the heterogeneity criterion related to primary object features like color and shape. The resulted objects can be characterized by different sets of features defined in spectral and spatial domain. Between sequential layers of different resolution segmentation results a hierarchical network of image objects is constructed. The vertical child – parents relationships in which small objects are sub objects of larger object create together with horizontal context (neighborhood) based relationships a very crucial set of relational information useful for classification steps. The Definiens performs sample-based and knowledge-based supervised classification, or a certain combination of both. The whole classification philosophy in considered procedure is based on fuzzy logic. The frame for the knowledge base for classification is the class hierarchy, which contains all classes of the classification scheme.

Each class can be described by fuzzy rules defined either on one-dimensional membership functions (what enables the user to formulate knowledge about the image content) or on a nearest neighbour classifier (the desired class's properties are determined by 'training' sample objects). Detailed description concerning the algorithm and procedural issues can be found for example in Benz et al., 2004.

3. STUDY AREAS AND DATA

Lowicz study area is a typical agricultural landscape with rural settlements and limited forest areas. The terrain being under consideration (~5 x 6 km) is localized near Łowicz town (central part of Poland). This is an agricultural region with size of farm near to statistical average for the country. The structure of crops is very diversified. There are most of types of crops that occurred in Poland. The relief is almost plain with elevation 90-110 m. The site has partially quite complex spatial agriculture structure with narrow and elongated parcels. The part of QuickBird satellite image registered on 11 May 2004 and processed into pansharp product was used for the study (Fig. 1).

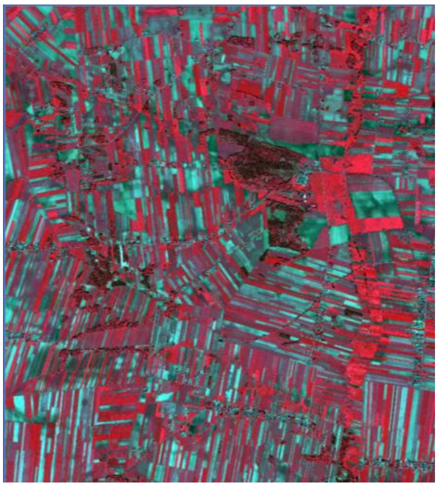

Figure 1. 'Łowicz' study area; QuickBird pansharp color composite

Except winter crops, the significant rest of areas is without vegetation or is covered by initially growing vegetation.

Elk study area (~11 x 9 km) is located in North eastern part of Poland (near Ełk town) and belongs to the south part of Ełckie lake district. The terrain is an example of postglacial rolling landscape with significant presence of moren hills, water areas, forests, and swamps. The terrain elevation is diverse from 114 m until 184m, and the differences are generally not high. Majority of the study area is typical agricultural region with soils of average quality and with size of parcel and farms bigger than ones occurred in the previous study area. The structure of crops is also very diversified with most of types which occurred in the rest of country.
For the purpose of the research the part of QuickBird scene image (Fig. 2) registered on 30 of May 2005 was used and also the GIS auxiliary data like parcel boundaries and land use were included into analysis process.

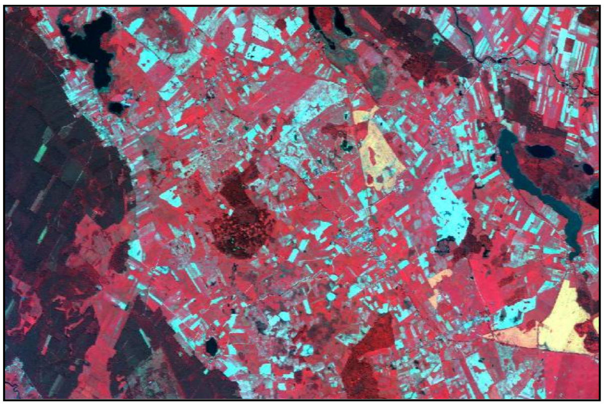

Figure 2. 'Ełk' study area, QuickBird MS color composite

As it can be visible on the color composite (Fig. 2) for the majority of the agricultural areas the vegetation is already well grown (winter crops, grass on the arable land). Significant part of vegetation cover is on the sprout stage (spring crops). The rape is very easy to identify due to its phonological stage on that time. There are still quite big areas with not growing yet crops (potatoes, maize, beets, and other vegetables).

4. METHODOLOGY AND RESULTS

Due to the fact that described part of the work was considered generally as comparative study, for both sites similar methodological scheme was applied. The supervised approach was used as a basic solution for all variants of classification, assuming the same set of training areas in all trials per site, and the preference for effective variant of procedures which at the same time should be generally less scene dependent and not too complex to be also easier for repetition. The last assumption was especially dedicated for object oriented type of analysis with Definiens where a lot of options and levels of complexity are possible in practice. The maximum likelihood classifier is considered for both study areas as a basic one in the frame of pixel based classification approach. For the 'Ełk' study area the neural network based classifier was additionally applied as an example of pixel based classification.
The sample-based nearest neighbour classifier was selected as essential part of the object oriented procedure but with useful and effective knowledge-based extensions for some classes. Such approach seems to be more likely applicable in wide operational practice as well.
For each study area the detailed preparatory type of analysis was done in order to recognize the level of spatial and spectral complexity and to properly define the necessary assumption for the research, including also the number and definitions of the target land cover classes. To support the preliminary decisions concerning the last issue (i.e. definition of the potential classes) the standard procedures were applied with clustering trials, divergence tests, initial classifications. The necessary sets of representative training areas were prepared as well as test areas for the final verification of classification results.

4.1 Lowicz test site

The final set of classes consists of: vegetation (well grown), vegetation in initial stage (weak), bare wet soil, bare dry soil, buildings (settlements), roads, shadows, coniferous forest, deciduous forest, water. For the date of image registration the spectral signatures of meadows and winter crops were very similar what was the reason to consider them as one class in classification process.

ML classification results

For the maximum likelihood classification the overall Kappa index of agreement achieved value 0.86. The distribution of user's and producer's accuracy values is presented in Fig. 1.

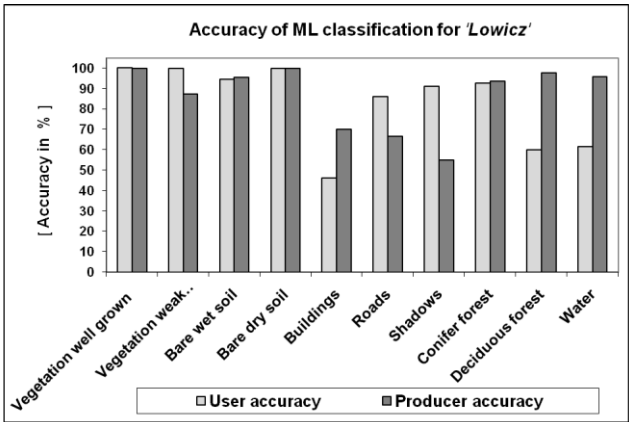

Figure 3. User's and producer's accuracy of maximum likelihood classification for 'Łowicz' study area.

The brief review of the accuracy indicators from the Fig. 1 points at observation that some classes achieved clearly low accuracy (especially: buildings, roads). The recognized above kind of problems seems to be typical ones and generally can be often met using traditional classifiers.

Object based classification results

The applied object based classification assumed the sample-based nearest neighbour classifier as essential part of the procedure, but as it was already mentioned before, with the important component in the form of useful and effective knowledge-based extensions for some classes, especially those weakly classified by ML classifier. The useful set of spectrally and spatially oriented features was a subject of many trials.

Considerable part was also dedicated to find proper parameters for certain membership functions.

For example, for the roads the adequate membership function was defined based on ratio of two measures, i.e. width and length; in case of buildings the geometric features and corresponding membership functions were related to the area and shape measures.

The Fig. 3. presents received accuracy measures for final object based classification. The overall value of Kappa for this case is equal 0.96.

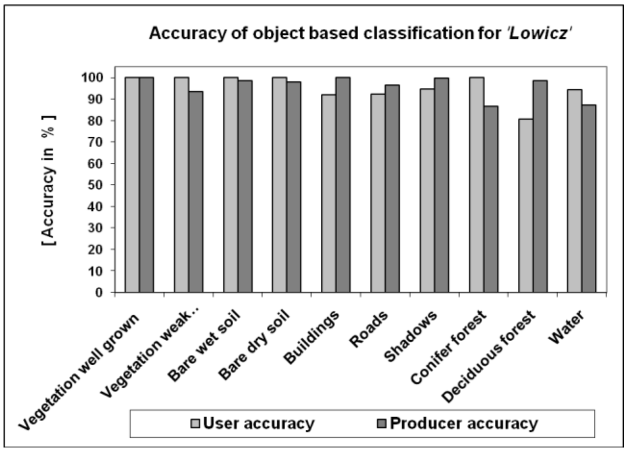

Figure 4. User's and producer's accuracy of object oriented classification for 'Łowicz' study area

The obtained values of considered accuracy indices show significant increase comparing to the corresponding values of ML classification. It is quite clear visible for such classes like buildings, roads, decid. Forest, and water. There is no doubts that this improvement was possible due to the significant extension of feature space.

Quite high values of accuracy measures were also confirmed by additional options of quality evaluation (available internally in Definiens package as a kind of more relative assessment) using so-called classification stability. As it is known such procedure is possible due to the fact that classification is based on fuzzy concept in which the image object has a membership degree to more than one class. The special tool allows in that case to generate the evidence about the potential ambiguity by checking the differences in degrees of membership between the best and the second best class assignments of each classified object.

4.2 Ełk test site

The terrain in this case is more complicated spectrally and spatially speaking. Part of the heterogeneity has its origin in the category of landscape, i.e. postglacial rolling one, but there is also influence of the date of image acquisition and corresponding to that time the phonological stages of different vegetation cover. After the preliminary analysis, the set of target classes was defined as follows: shadows, roofs, roads, bare soil, shrubs, coniferous forest, deciduous forest, meadows, unused land, grass on arable land, rape, reed, water, spring crops, winter crops. For this study area the performance of neural network classification was also tested.

MLC classification results

The overall Kappa is equal 0.57. The values of user's and producer's accuracy of maximum likelihood classification are showed in Fig. 5. Many made trials confirmed that between some potential land cover classes there are strong overlaps in spectral signatures. It concerns for example the meadows and winter crops, but also roads (not asphalt ones), roofs, and arable lands.

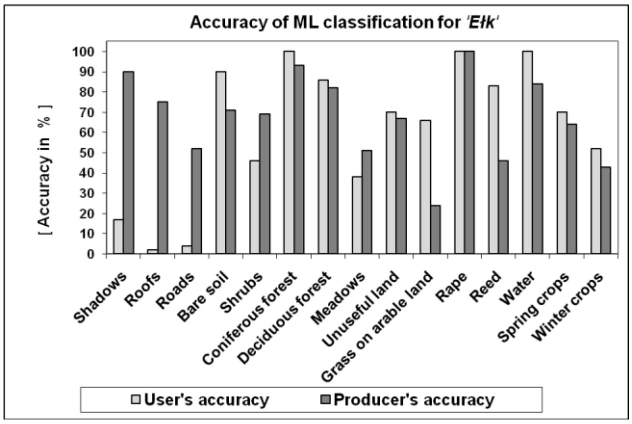

Figure 5. User's and producer's accuracy of maximum likelihood classification for 'Ełk' study area

Some problems occurred also for part of water areas covered by algaes. Another example of quite strong correlation in spectral space is set: arable land, shrubs, and reed. The most visible and easy for separation is rape class with low correlation with other classes.

NN classification results

As it was already mentioned, for this study area the neural network based classification available in PCI Geomatica was used as well. The supervised NN procedure assumed the same set of target classes and training areas as it was defined for ML classification. Due to the spectral and spatial complexity of the given study area there was necessary to define and test many variants of NN networks for training. Each time the values of specific errors obtained during the training process i.e. individual error and normalized total error were subject of analysis in order to find the optimal NN architecture. More details concerning the applied back-propagation in NN classifier can be find in PCI Geomatica Help Manual (version 10). The process was significantly long, what was (besides the mentioned above reasons related to heterogeneity of the terrain) also caused by the size of digital data set.

Although there were numerous trials in looking for the optimal NN architecture, finally the best classification variant brought the results comparable to the ones achieved using traditional ML classification. The adequate accuracy numbers are presented in Fig. 6, overall Kappa value is equal 0.58, what is very close to the value from ML classification.

Besides some exceptions, generally the distribution of user's and producer's values is quite similar to the one represented by ML classification result. The last observation confirms the necessity to improve the classification procedure by applying the features from spatial domain.

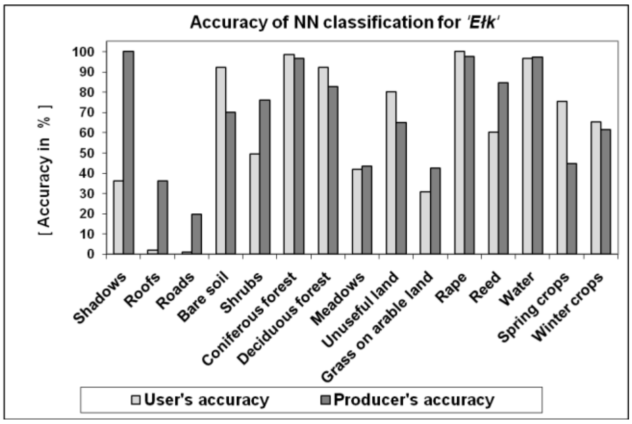

Figure 6. User's and producer's accuracy of neural network based classification for 'Ełk' study area

Object classification results

The diverse spatial structure of the considered study area caused the necessity to apply more rigorous appropriate segmentation strategy allowing to obtain objects on certain scale levels as more realistic representation of given classes in respect of their objects size and specific distribution. For the purpose of the analysis the auxiliary GIS data like parcel boundaries and land use were included in segmentation and classification process respectively. On the stage of classification process for some classes the feature space was significantly increased and appropriate inputs related to knowledge-based extensions were defined - especially for the classes weakly classified by ML classifier, i.e. roofs (buildings), roads, shadows.

Finally, for the optimal result of object based classification the overall Kappa value is equal 0,73. The Fig. 7 presents the distribution of user's and producer's indicators.

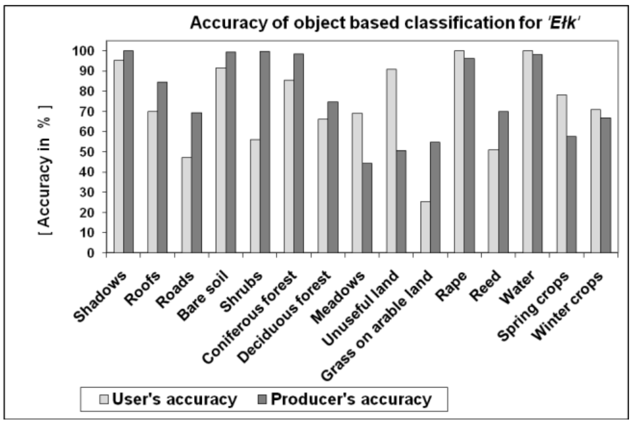

Figure 7. User's and producer's accuracy of object oriented classification for 'Ełk' study area

The obtained accuracy values confirmed better performance (comparing to ML classifier) of object based classifier for the classes where the features related to geometry and texture of objects can be applied. For other classes where texture oriented features with effective influence on final result are more difficult to define, the spectral features are more dominated and because of that for these classes the accuracy is more similar to the values obtained for traditional pixel based ML classification. This observation is of course related to the given results, and ought to be considered together with all assumptions taken for the presented research work as well as characteristic of data set and study area.

5. CONCLUSIONS

The obtained positive results of object based classifications can be considered as next example in this field of applications. As it was mentioned before, the study areas are quite different in respect of spatial and spectral complexity of distinguishable objects in reality. It had a significant influence on the final results obtained for both sites. There is also visible influence (according to known rules) of time relationship between the date of image acquisition and crop calendar in case of crop identification. For the acquisition in time with low level of differences between land cover forms and higher homogeneity, the rule of spatially oriented discriminative features becomes weaker. But even that, the obtained accuracy numbers for object based classification for both areas confirmed that this approach to image analysis can be (to a certain degree) definitely considered as more effective important alternative to classic methods for identification of land cover forms. As the results confirmed the efficiency of the object oriented approach generally was significant in more heterogeneous, textured areas.

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