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APPLICATION OF THE OBJECT BASED IMAGE ANALYSIS OF VHR SATELLITE IMAGES IN LAND-USE CLASSIFICATION

ZASTOSOWANIE OBIEKTOWEJ ANALIZY WYSOKOROZDZIELCZYCH OBRAZÓW SATELITARNYCH W KLASYFIKACJI FORM UŻYTKOWANIA TERENU

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Introduction to object-based image analysis

Land-use cover is one of the basic GIS spatial data layers needed for landscape planning and monitoring dynamic environmental changes. Traditional multispectral image classification techniques are insufficient for extraction of land-use categories with required accuracy from very high resolution imagery. The traditional image classification has been usually performed by a pixel-based classification method based on supervised or even unsupervised approach. Studies on remote sensing data proved that traditional spectral-based methods can result in rather poor or even incorrect classification (Gougeon 1995, Fernández-Manso et al., 2005). An alternative to this can be the object-oriented or so called Object-Based Image Analysis (OBIA) approach. OBIA is a sub-discipline of GIScience devoted to partitioning remote sensing (RS) imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale. At its most fundamental level, OBIA requires image segmentation, attribution, classification and the ability to query and link individual objects (also known as segments) in space and time (http://wiki.ucalgary.ca). OBIA based on the fuzzy logic, allows the integration of a broad spectrum of different object features, such as spectral form, shape and texture. In contrast to classic image processing methods, the basic processing units of object-based image analysis are image objects or segments and not single pixels. Moreover, The classification acts on image objects. Image segmentation can be performed at different levels of resolution, or granularity. Segmentation methods can be categorized into: point-based (e.g. grey-level threshold), edge-based (e.g. edge detection techniques) or region-based (e.g. split and merge) (Haralick, Shapiro, 1985).

OBIA is a hierarchy region merging technique and, therefore, it is regarded as a region-based algorithm, starting by considering each pixel as a separate object. Subsequently, pairs of objects are merged to form larger segments based on a local homogeneity criterion, describing the similarity between adjacent image objects. The pair of objects with the smallest increase in the defined criterion is merged. The process terminates when the smallest increase of homogeneity exceeds a user-defined threshold, the so-called scale parameter (Baatz, Schäpe, 2000). A knowledge-based approach is used to classify objects into information categories, using fuzzy logic based on attributes of image objects and their mutual relations. This classification actively utilizes different levels of segmentation and different classification hierarchy levels, so called class depths (Blaschke et al., 2004).

One motivation for the OBIA approach is the fact that, in many cases, the expected result of most image analysis is the extraction of real world objects, proper in shape and in classification (Fernández-Manso et al., 2005). This expectation cannot be fulfilled by traditional, pixel-based approaches (Baatz, Schäpe, 2000). Much more information is contained in spatial relations of pixels what can be confirmed by some studies presenting that the object-based approach is very promising when classifying VHR data (Baatz, Schäpe, 2000; Benz et al., 2004; Blaschke et al., 2004).

Textural indices have the potential to measure and monitor vegetation structures at landscape scales (Blaschke, 2003). For forest this is related to monitoring on a multi-scale level. Due to recent improvements in hardware and software, it has become easier to deal with textural characteristics of forest cover within the image domain (Wężyk et al., 2004). This allows combining classical theories on statistical textural measures, so called Haralick features (Haralick, Shapiro, 1985), with structural textural measurements (Musick, Grover 1991; Baatz, Schäpe, 2000). Transferability of textural features refers to characteristics of optical data in large mosaics used in seamless data as well as time series over the same area (change detection).

Characteristics of the Polish countryside

The Polish landscape is rapidly changing due to the socio-economical effects of the recent EU membership and its impact on agricultural incomes. An important indicator for this change in the last years was increasing amount of abandoned fields. Imagery from satellite and airborne EO show the effects of forest succession on these abandoned parcels. This happens at such a large scale that it cannot be regarded as incidental but it reveals profound changes taking places in small-scale farming. It is essential for landscape management to combine the interpretation of RS data with social economical factors, EU agricultural policy as well as with cadastral (GIS) information.

The area of Poland is 312.700 km^2 what makes approx. 10% of the total area of the „old" EU members. Population is ca 38.2 mln people (8.5% of UE) and in 2004 38.2% of the total population (14.6 mln) lived.in the countryside. In the period 1996–2002, the farmer population decreased by about 1.08 mln people due to structural changes in Polish agriculture. The average area of a single family-farm is ca 7.5 ha (only 3.31 ha in South Poland; 24.1 ha in

North-West Poland). Between 1996 and 2002, the total area of agricultural parcels diminished from 17.9 mln ha to 16.9 mln ha (by 1.0 mln ha, ca. 5.5%). The number of farms decreased from 2.04 mln to 1.85 mln. In 2002, the area of abandoned parcels was 2.3 mln ha, but due to joining the EU in year 2004, the are of abandoned land decreased to 1.3 mln ha. This means that the area of 16.32 mln ha was used for different agriculture purposes (MLLE, 2005). Land-cover and land-use data are essential for planning and management of agricultural, forest and urban areas. Traditional methods of land-use mapping based on the visual image-interpretation are very expensive and time-consuming and subjective as well.

The paper presents a study on forest succession on abandoned agricultural fields, which is nowadays maybe one of the largest, unmanaged afforestation processes in the EU.

IACS – LPIS data bases

The European Union (EU) grants financial aid to farmers, growing certain crops. In order to administrate and to control the farmers' declarations, the EU decided to establish an Integrated Administration and Control System (IACS) in 1992. Over the years it was found, that the declared areas often do not represent the reality. As a result, the process of declaration should be improved by the establishment of a Land Parcel Identification System, preferably based on orthophotos (http://mars.jrc.it/marspac/PECO; Oesterle, Hahn, 2003). Cornerstone of IACS in Poland is LPIS (Land Parcel Identification System) which is now under development and implementation. LPIS should be build on the agricultural cadastre which is in a transition process from analogue archive maps to a full digital database including correct geometry. The polygons in the LPIS will also be attributed to areas which will be excluded from EU subsidies. This process is related to Phare 2001 EU projects in Poland and other new accessing countries involving VHR satellite imagery (IKONOS, QuickBird) as well as 1:13.000 and 1:26.000 aerial photos. For the revision of the existing cadastre, two standards of the orthophotomaps were applied, depending on image data source qualities (EC, DG JRC 2005):

- **Standard I:** designed for areas with cadastre based on the map 1:5.000. Orthophotos based on the 1:26.000 scale B&W aerial photos covering 156.000 km^2 (about 50% of Poland) ground resolution 0.5–1.0 meter (RMSE = 1.5–2.5 m).
- **Standard II:** designed for areas with cadastre maps 1:2.880 or 1:2.000 (85.000 km^2 of South Poland). Orthophotomaps based on 1:13.000 scale B&W aerial photos with ground resolution 0.25 meter (RMSE = 0.75 m).

The construction of LPIS with direct access to up-to-date high-resolution orthophotos is inevitable. Costs of LPIS are estimated to be 3–4 times higher then the orthophotos production. Within the limits of Standard I an additional 25% coverage of Poland was planned to be covered using IKONOS (50.000 km˛ along frontiers) and "old" Phare 1996–1997 RGB-Orthophotos (based on aerial photos 1:26.000). Important attributes for land use data are parcels divided in two categories: "active functional" and so called "non-functional" which includes those with "changes made by (forest) succession". Here decision must be taken to assign a parcel to be eligible or non eligible to subsidiary financing during the control process. Every year the series of VHR satellite scenes are delivered from JRC (EU) to member countries, including Poland. Here, the agency responsible for the distribution of subsidies is ARiMR (Agency for Restructuring and Modernization of Agriculture) obliged to use the remote sensing information for checking correctness of farmers applications for direct subsidies. Satellite VHR data are expected to increase its dominance in information acquisition on the national level in accordance with EU trends. Nevertheless, the EU funding will be available for afforestation from other sources.

Forest cover in Poland

Obtaining precise information about the amount of forest cover in very short time is an important issue for governmental policy and forest management. Huge deforestation after Second Word War (forest cover dropped to the level of 20.8%) led to a reduction in biodiversity and landscape impoverishment. Afforestation process increased forest cover to 28.6% (8.942.000 ha). The National Programme for the Augmentation of Forest Cover signed by the Polish government in 1995, provides the basis for all work on afforestation. A managed increase in forests is expected to reach forest cover nearing 30% in year 2020 and 33% in 2050. Publicly owned forests predominate in Poland, accounting for 82.6% of the total area, and 78.4% of the total is under the management of the State Forests National Forest Holding. Other 16.1% of Polish forests belong to natural persons (private 900.000 owners – 94% under small-scale ownership where the mean area of a parcel is < 1 ha). In some South regions of Poland private owners (farmers) hold parcels of the size of 0.2–0.3 ha only. These statistics indicate close connection of agricultural and forestry domains in Poland (PGL LP, 2003).

Tasks of Image Analysis

Increasing automatic image analysis

The visual interpretation of large amounts of data is at risk to be outdated by the time the analysis becomes available. This study tests automatic procedures for mapping of forest succession on agricultural parcels from VHR satellite data (QuickBird) as well as from B&W orthophotomaps. The automatic procedures should enable a fast and low-cost RS data interpretation. Due to the large amounts of mosaic parts in VHR data, sampling of classes in each mosaic-tile would be too complex. Therefore full automatic image classification not-requiring sampling methods are welcome to deal with large-area satellite mosaics. Additionally, the RS data fusion with LPIS information will be an integral part of analysis, validation of results classification and conclusion.

Preprocessing and image reinforcement

Texture analysis of imaging data can be separated in statistical textures analysis (Haralick features) as well as structural texture analysis (Musick, 1991). A hybrid textural analysis has been under development which involves a pre-processed edge detection to create the structural part of the texture analysis. The assignment of a weight function in a segmentation process is popular where a panchromatic band (PAN) has a higher ground resolution than other multispectral bands (MS). In this case an increased weight factor for the PAN allows a more detailed object reconstruction. The weight factor influences the complete band information.

For a more detailed manipulation of the objects of interest and not the whole image domain, only specific details inside a single image can be given an 'increased weight' factor by using additional artificial image layers. The objects of interest will be backed-up by underlying 'pixel-artifacts'. Because the artificial layer contains near-zero values for the rest of the image, only preferential image objects will receive this influence. Contrasting edges are here expected to contain the prevailing information.

Image derivatives. Artificial bands are results of image pre-processing techniques such as: edge detection filtering, spectral un-mixing and textural derivatives. Based upon user preferences, the artificial bands can be used to amplify information on a selected type of objects of interest. The first function of artifacts is the forcing of the preferential shape of segmented objects. In a second phase, a customized feature is created for which only extreme dark and bright values play a role in the classification. The artifacts must be reproducible. The absolute grey values of the image artifacts have little meaning. Their relative value and moreover their extreme brightness or darkness allows the class selection. The central strategy of pre-processing leads to the smart positioning of the objects of interest in the extreme parts of the histogram of an artificial band. Sampling of the class inside the image becomes less relevant if objects of interest appear in general in the same extreme position in an (artificial) image histogram. The population of image objects located in the histogram-extreme represents the desired class. Isolated edges can be regarded as structural texture elements. They can incorporate a line of mixed pixels with high variance at the border between two adjacent image objects thus sharing the spectral characteristics of two different distributions. This situation is the most 'normal' one in satellite imagery and has been used frequently in Laplace analysis. Very typical for this type of edge detection is the fact that at least 3 pixels around the edge are influenced by the calculation. The resulting 'blurred' boundaries are here less useful.

Another type of edge detection is the isolation of edge pixels belonging to a homogeneous image object and is not considered as mixed pixels. They belong to the spectral distribution of the image object itself. A good example of this is the dark inside-edge pixels of shadow objects. This type of edge detection is only a single pixel width and it is more useful for sharp line reconstruction. Starting with the original panchromatic image the result of the Lee-Sigma filter is subtracted and an edge image (difference image) is produced. The Lee-Sigma filter only replaces original pixel values with the moving-window (3×3) mean, if 2-sigma values are exceeded; else there is no-change. In case of sharp boundaries, this condition exists and can therefore be extracted from the difference image (Fig. 1). In case of 'no-change' for all pixels within 2-sigma values, the difference image will return near-zero values for the largest part of a VHR satellite image under European environmental conditions. The edges alone might be useful. The next step is to integrate edge-information in automatic vegetation detection. A customized feature can be constructed involving the 'Lee-Sigma' edge-images to be applied to automatic detection of scattered shrub and trees on homogeneous agricultural parcels. The edge-detection images force a split of an object into core and frame (Fig. 1). After segmentation (Fig. 4) the 3 images are combined in a map calculation for each segment. The customized feature visualization can also function as extra input layer for further classification.

The ratio of the original object and its self-derived edges incorporates information about size, homogeneity as well as intensity. The effect of such analysis can be applied to objects characterized by low homogeneity among neighborhoods with high homogeneity (Wezyk et al., 2004). This is the typical condition of stages of forest succession on abandoned agricultural

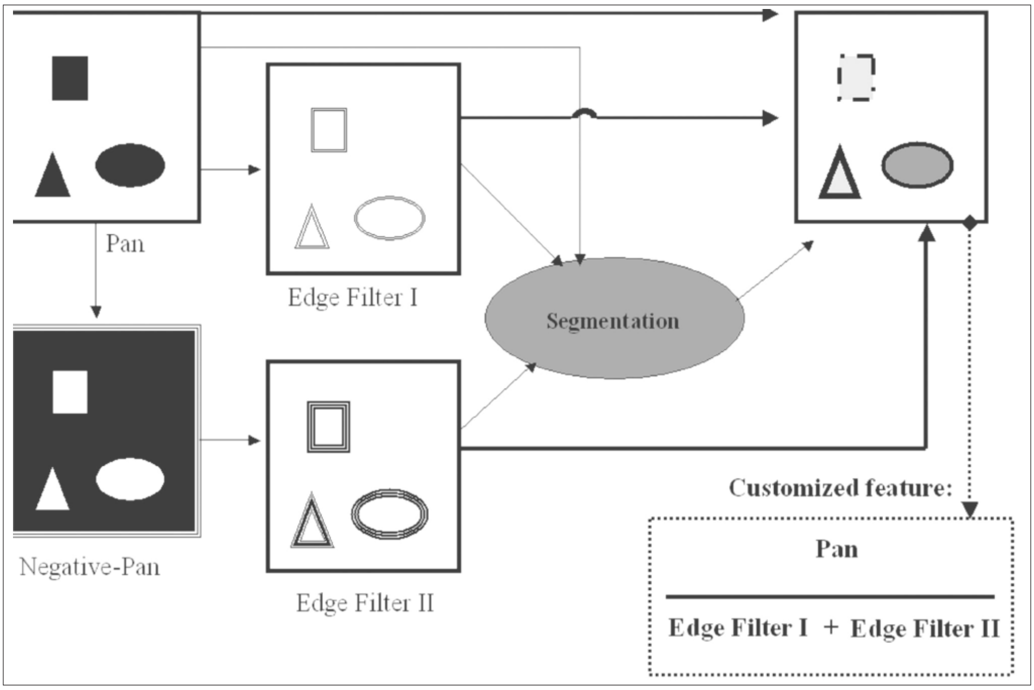

Fig. 1. Workflow of the customized feature

fields. Moreover the different response of this analysis in NIR versus Red band improves the performance.

The case study of forest succession on the abandoned parcels

Test site and data

For the test study the area of the Mostki cadastre range, in the Staszów county (powiat) in Świętokrzyskie Voivodship in South Poland was selected (Fig. 2). One year earlie a forest inventory project based on the VHR QuickBird image (acquisition on 15.09.2003) was done in neighbouring forest area (Wężyk, Ciechanowski, 2005). As reference data we used a cadastre map of Mostki and Kolonia Bogoria delivered in EWR format (EWMapa software) in Polish coordinate system PUWG1965/I, from the county survey office (PODGiK in Staszów). The TIFF file was exported from EWMapa and georeferenced to another coordinate system PUWG1992/19 using ArcGIS (ESRI). No additional attribute data regarding the owners of the parcel were needed for the study. Also digital forest map (LMN; PUWG 1992/19; SHAPE format) from the Staszów Forest District (PGL LP) was used as forest mask data.

The digitized area from cadastre map was 443 ha with following distribution of the land-use classes: forest (description on the cadastre map: *Ls; Lz*) – 20.79 ha; buildings (*B*) – 15.62 ha; orchards (*S*) – 1.51 ha; wasteland (N) – 0.32 ha; water (*Ws*) – 1.72 ha; meadows

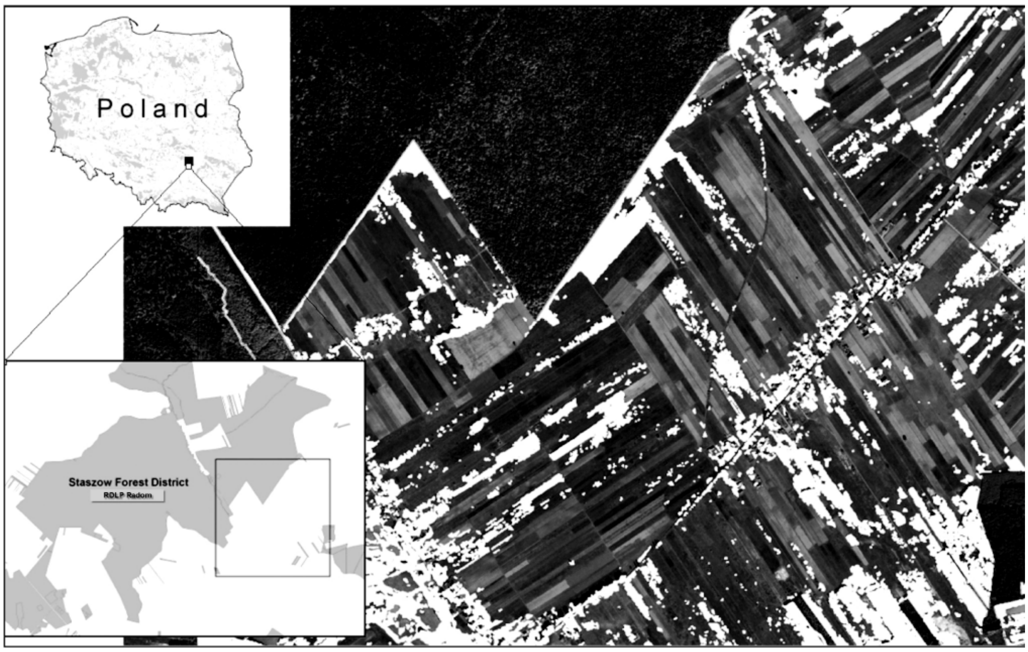

Fig. 2. VHRQuickBird OBIA classification on the test area of the Mostki and Kolonia Bogoria. ”High-vegetation” outside the forest mask is claassified in white color. Smal private forest plots, orchards and agricultural parcel with forest succession are included in the „High-vegetation” class

(Ł) – 20.13 ha; pasture (*Ps*) – 22.06 ha; arable land (*R*) – 360.84 ha. Arable land, meadows and pastures land-use classes have additional description regarding the soil quality (from I – the best one to the VI – the poorest one).

The aim of the study was to find out abandoned agricultural parcels using fully automatic approach of forest succession and deliver statistics for the land-use changes in this area.

Results of OBIA

According to the pre-processing workflow (Fig. 1), a customized feature was constructed for the PAN band of a QuickBird scene (Fig. 5). This is done for the Red as well as the NIR band. This leads to an eCognition project containing 9 image layers e.g. three original bands: PAN, Red and NIR as well as 3 pairs of ‘Lee-Sigma’ combinations (positive/negative, Fig. 1). The customized feature for the Red band has a typical result for complex artificial objects. Buildings and other constructions contain a lot of contrasting edges. Therefore in the visualization of this customized feature, all buildings appear dark (lowest part of the histogram). Vegetation with complex shadow casting and sharp edges in the Pan and NIR do not respond similarly in the Red band. This is due to a reduction in the reflection of the Red light for both crowns and shadows.

All vegetation areas that do not cast or contain shadows have higher values in all of the three visualizations of this customized feature. The lowest part of the histogram of the customized feature [Pan / (Edge I + Edge II)] thus contains 3 classes: Infrastructure (buildings, roads), Shadows and High Vegetation. Due to extreme low values in the customized feature of the Red band and very low panchromatic intensity values, the classes: 'Infrastructure' and 'Shadows' can now be easily separated. The 'High Vegetation' class remains. This class contains different forest types as well as 'forest succession' stages on agricultural fields. If the cadastral information indicates to the existence of an agricultural parcel, the extraction of forest succession is simple. More complicated are separations between two classes: 'forest regeneration' and 'forest succession' inside the forest area as well as the separation between 'forest succession' and 'fruit/berry orchards' outside the forest border. The scattered nature of the succession can be separated from densely covered and closed canopy stands. However there is a transition from scattered to dense forest vegetation (Fig. 2 and 6).

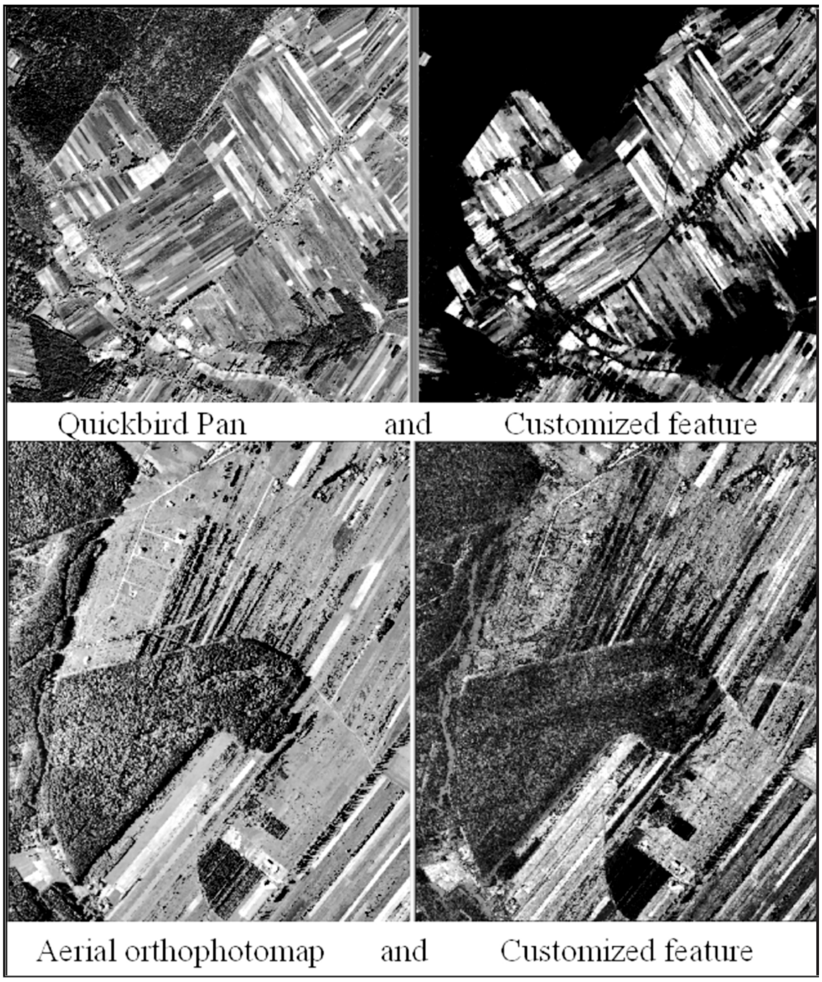

Fig. 3. Two top images; a QuickBird PAN band and the visualization of the customized feature (from Fig. 1). Below the same customized feature on a subset of the 8-bit orthophotomap from a scaned aerial imagery (B&W, scale 1:13.000)

The same procedure was tested on a set of B&W orthophotomaps with similar results. However the 8 bit scanned images lack the spectral resolution comparing to the 11-bit QuickBird image (Fig. 3). The separation of vegetation and buildings/infrastructure as complex edge-containing objects in homogeneous environments becomes therefore less effective. Here the cadastral information, especially about settlements per plot becomes a necessity for further full automatic approach.

Results of GIS spatial analysis

For the main GIS spatial analysis only following the land-use classes: arable land, pasture, meadow and wasteland were taken into consideration (area of 403.35 ha) as reference for the study of forest succession (Fig. 2 and Fig. 6). The remaining classes naturally also included the 'forest succession' class but in this case the interpretation was not really clear. The class 'buildings' showed about 20% of 'forest succession' what could be interpreted as single trees around the houses. 'Orchards' were classified with the 34% of cover of high-vegetation and in this stage of the study it was not possible to distinguish between forest and fruit trees. Land-use class 'forest' presented coverage of high-vegetation around 80% what is connected to the pure forest stands on these areas. The most important classes and their 'forest-succession' content are presented in Table.

Generally, the analysis of the OBIA intersected by the land-use classes showed that forest young stage is occupying ca. 44.87 ha (Tab.) what makes 11.1% of the investigated classes. The main forest succession (83% of phenomenon) happen in the arable-land (R) on the area of 37.24 ha (Tab.) and especially on very poor-quality soils (class VI – 15.64 ha; 16.4% of the RVI). Of course it was expected that the parcels with the poorest soil would be first subject to the process of the forest succession that is the climax stage in this climate zone. Similar situation was observed on the pasture (P) – 4.46 ha (class VI – 20.5% covered by the young forest). Abandoned meadows (class V) were under trees canopy on the area of 3.03 ha, what means that 15% was just 'lost' for agriculture. The highest share value of the forest succession rate present land-use wastelands but due the small area of those parcels they play a marginal role (0.14 ha covered by trees; 43.9 %).

Table. Results of the GIS spatial analysis between the reference data (cadastre) and the OBIA gathered forest succession areas

Land-useclass	Area of land-use class [ha]	Area of the forest succession [ha]	Share of forest succession in land-use class	Distribution of forest succession
Arable land (R)	360.84	37.24	10.3%	83.0%
Pasture (Ps)	22.06	4.46	20.2%	9.9%
Meadows (Ł)	20.13	3.03	15.0%	6.7%
Westeland (N)	0.32	0.14	43.9%	0.3%
SUM	403.35	44.88	11.2%	

Conclusions

During the control process of farmers declarations, decisions must be taken to assign the land-use of parcels in two categories: "active-functional" (eligible) and "non-functional" (non-eligible), which includes those with "changes made by (forest) succession". The VHR object-based image classification immediately generates the class where 'functional' is doubtful when scattered forest vegetation is found on the parcel. Detailed automatic mapping of forest succession related to abandoned agricultural parcels using VHR–EO data is possible. The class of 'high-vegetation' has a "fingerprint" signature in a special customized image layer which makes automatic classification possible. The desired objects of interest (OOI) are located within the histogram-extreme of all mosaic parts of the mapping area. The possibility to predict the location in (artificial) feature space reduces considerably the need for locating the OOI inside the image domain and therefore the sampling procedure. An image classification method that replaces „Training & Test Areas" with a „Histogram-sampling" technique shows peradventures in stable and transferable classification protocols. An initial calibration of the 'Quintile' of the histogram's can rely on existing cadastral and GIS information, i.e. CORINE land-cover and SILP (Forest Information System of Polish State Forests). The 11-bit QuickBird data is well suited for separating textured objects like buildings and high-vegetation. For 8-bit orthophotomaps, cross-confirmation with existing cadastre is a necessity.

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Streszczenie

Trendy panujące w teledetekcji wskazują jednoznacznie na kierunek stosowania całkowicie samodzielnych metod automatycznej klasyfikacji dużych mozaik ortofotomap lotniczych i satelitarnych. Zautomatyzowany proces pozyskiwania i zarządzania dużymi zbiorami danych teledetekcyjnych został już w zasadzie osiągnięty, a jego logiczną kontynuacją jest w pełni automatyczna interpretacja obrazu. Wybrane klasy CLC2000 (Corine Land Cover) takie jak: woda, las, obszary antropogenicznego pochodzenia czy tereny rolnicze posiadają bardzo specyficzną charakterystykę będącą kombinacją właściwości spektralnych i tekstury. Stąd też klasy te mogą być poddawane sekwencyjnemu procesowi klasyfikacji (zapisanego w tzw. protokole programu eCognition; Definiens) zwanego OBIA (obiektowa analiza obrazu; synonim - klasyfikacja obiektowa), który może wskazać tzw. „kandydatów" dla powierzchni treningowych i testowych w obszarze analizowanego obrazu.

W zaprezentowanej metodzie, selekcja pól treningowych i testowych tradycyjnie dokonywana przez operatora, została znacząco zredukowana bądź też nawet całkowicie zaniechana. Te subiektywne zazwyczaj decyzje, które obszary nadają się, a które nie jako wzorce to klasyfikacji, zastąpiono hierarchicznym procesem (protokół eCognition) ich wyboru. Zapewnia to opisywanej metodzie OBIA większą obiektywność. Sukces działania w pełni automatycznych procedur analizy obrazu można osiągnąć w przypadku klas pokrycia terenu o unikatowej charakterystyce spektralnej i teksturze (ang. fingerprint).

Systemy eksperckie wymuszają przebieg określonych procesów takich jak: od poziomu Danych do Informacji oraz od poziomu Informacji do Wiedzy. Pomimo takiego przebiegu od Danych do Informacji, systemy IACS/LPIS bazują w swej dużej części na informacjach składanych przez rolników. Bezpośrednie powiązanie danych satelitarnych z systemami GIS może przynosić duże profity dzięki wdrażaniu dostępnych już inteligentnych metod przetwarzania obrazu.

Prezentowana praca demonstruje najnowocześniejsze metody (eCognition ver.5) i procedury aktualizacji warstw GIS (LPIS) oparte na automatycznym generowaniu informacji na podstawie wysokorozdzielczych obrazów satelitarnych QuickBird. Artykuł pokazuje możliwości zastosowania automatycznych procesów do ilościowej analizy dynamiki klas pokrycia terenu, w tym szczególnie, naturalnej sukcesji leśnej jaka najczęściej zachodzi na opuszczonych gruntach rolnych w południowej części

Polski. Zastosowana klasyfikacja OBIA oraz analizy GIS wykazały istnienie 69,28 ha obszarów o charakterze sukcesyjnym zajmujących 16,2% terenu badań.
Zautomatyzowane pozyskiwanie informacji zawartych w wysokorozdzielczych obrazach satelitarnych staje się koniecznością w kontekście podejmowania najlepszych decyzji uwzględniających dynamikę naturalnych procesów zachodzących w krajobrazie rolniczym.

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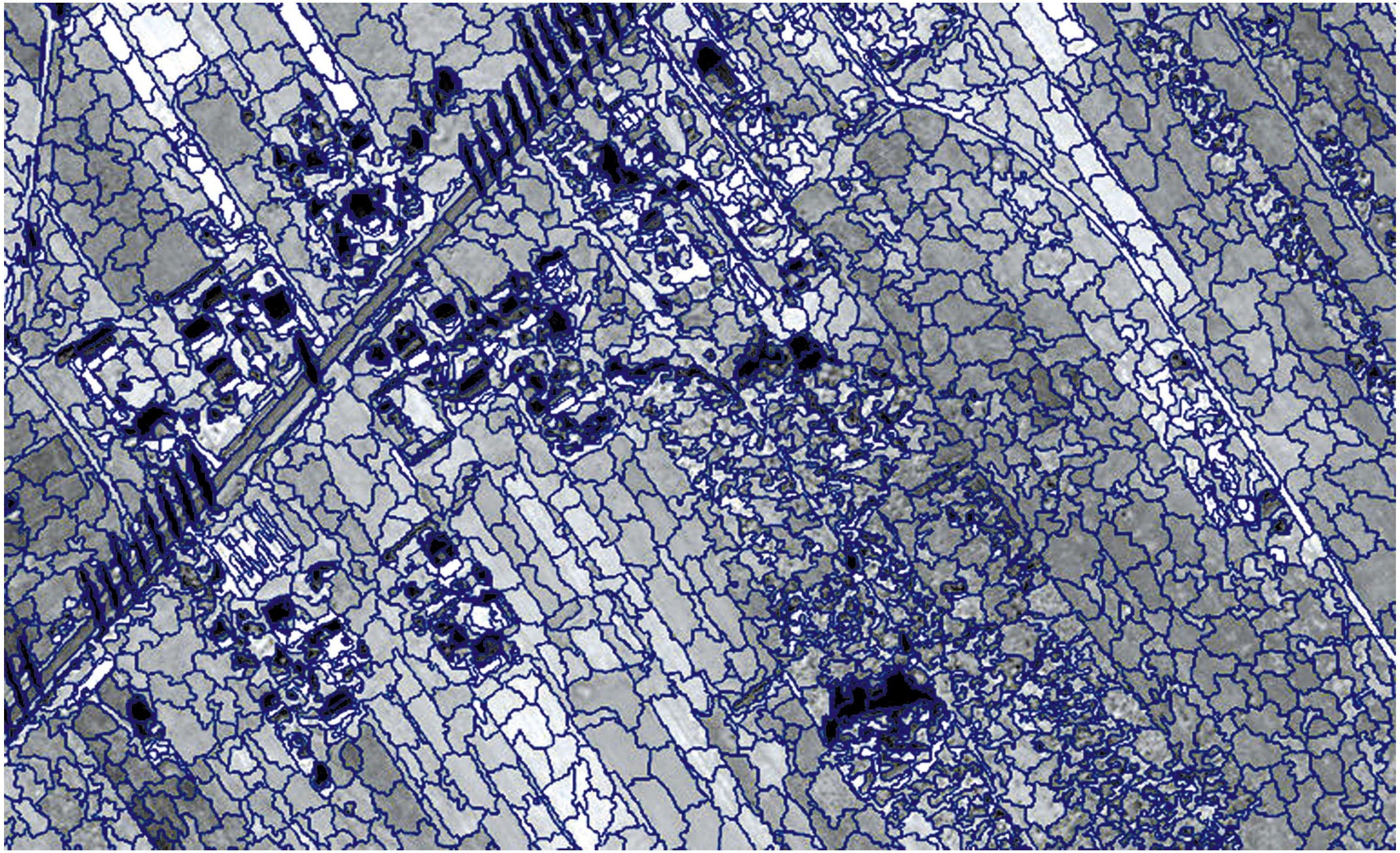

Fig 4. Objects as a result of VHR QuickBird segmentation of agriculture landscape of Mostki cadastre range (eCognition; source DigitalGlobe)

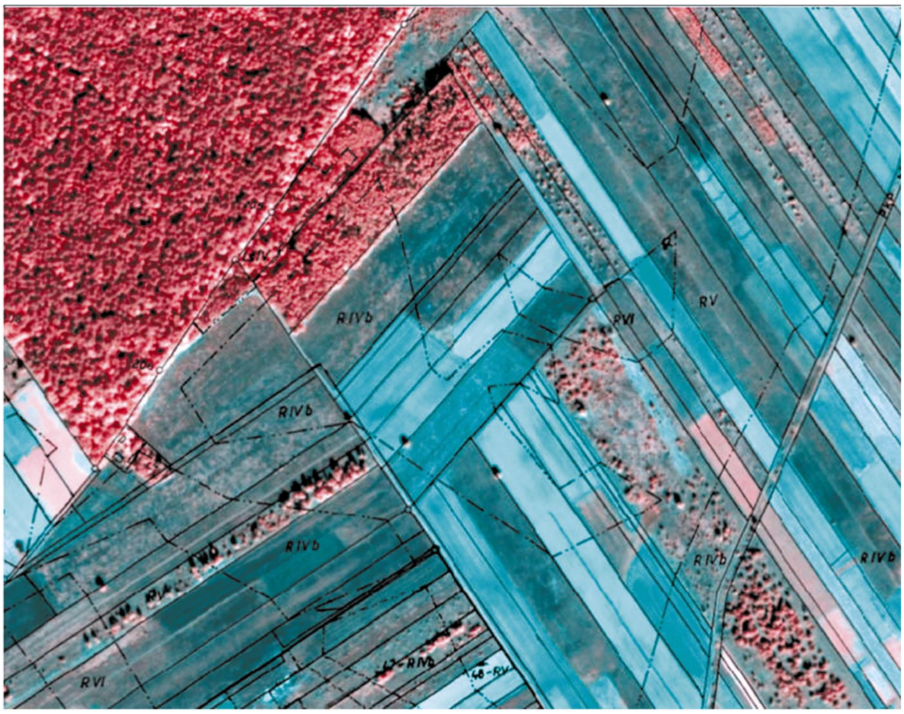

Fig. 5. VHR QuickBird composition (bands: 432_PAN) overlapped by the cadastre map of Mostki (labels of the land-use classes: R – arable land; Ls – forest; I-IV the best to poorest soil). Source: PODGiK Staszów and DigitalGlobe.

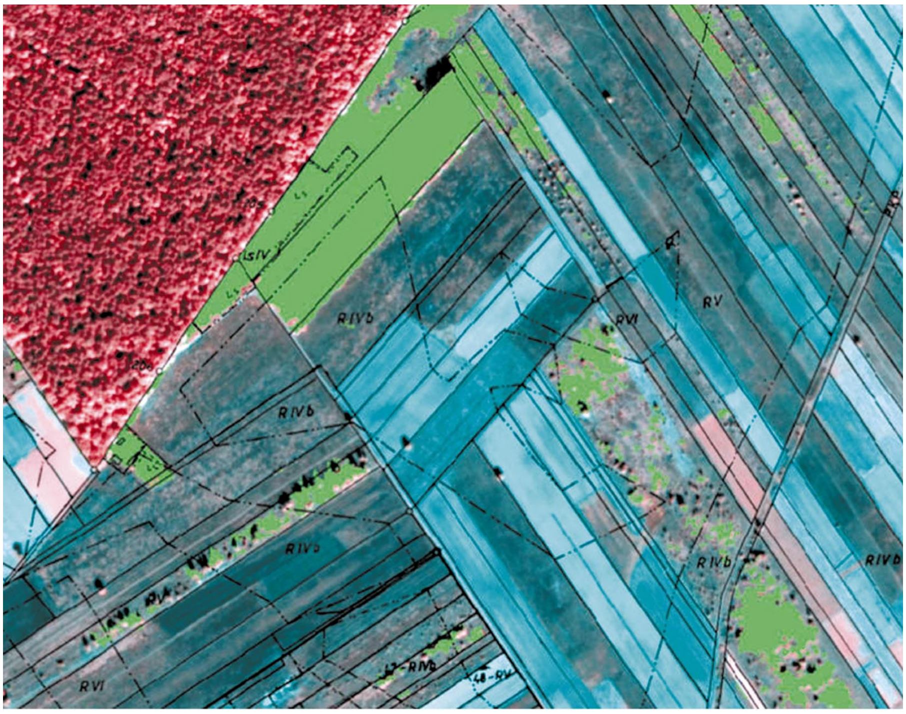

Fig. 6. QuickBird composition (bands: 432_PAN) overlapped by the result ob OBIA classification (in green – forest succession) and cadastre map of the Mostki. Source: PODGiK Staszów and DigitalGlobe.