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Aerial Orthophoto and Airborne Laser Scanning as Monitoring Tools for Land Cover Dynamics: A Case Study from the Milicz Forest District (Poland)

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Abstract—The paper presents the results from the study concerning the application of airborne laser scanning (ALS) data and derived raster products like the digital surface model (DSM) and the digital terrain model (DTM) for the assessment of the degree of change of the land use based on the forest succession example. Simultaneously, an automated method of ALS data processing was developed based on the normalized (nDSM) and cadastral GIS information. Besides delivering precise information on forest succession, ALS technology is an excellent tool for time-changes spatial analyses. Usage of the ALS data can support the image interpretation process decreasing the subjectivity of the operator. In parallel, a manual vectorization and object classification (object-based image analysis—OBIA) were performed; both based on aerial orthophoto and ALS data. By using integrated ALS point clouds and digital aerial images, one can obtain fast OBIA processing and the determination of areas where the land cover has changed. The Milicz District (central west part of Poland) was chosen as the test site where ALS was to be performed in 2007, together with the digital aerial photos (Vexcel camera; pixel 0.15 m; CIR). The aerial photos were then processed to a CIR orthophoto. The area of study consisted of 68 private parcels (some of them were abandoned; 68.57 ha; scanned cadastral maps from the local survey office; land use information) in the direct neighbourhood of the State Forest, on which a forest succession could often be observed. The operator vectorized forest (trees and shrubs) succession areas on the 2D CIR orthophoto. They were then compared with the results from the OBIA and GIS analysis, based on the normalized digital surface model. The results showed that areas with high vegetation cover were three times larger than the official land cover database (cadastral maps).

Key words: CIR aerial orthophoto, airborne laser scanning (ALS), object based image analysis (OBIA), GIS analysis, digital surface model (DSM), digital terrain model (DTM), secondary forest succession.

1. *Introduction*

The most common quantitative measurement of the landscape is the type of land use. These days, the most common data source for land use are satellite images, aerial photographs and thematic maps. Another source of the data can also be the digital land cadastre (Lowicki, 2008). The importance of monitoring land use changes to support regional development programs is recognized by the Commission of the European Communities and the European Environment Agency (Commission of the European Communities, 1994). European environmental programs based on remote sensing data carried out in 1990 (Corine Land Cover) are designed to track the dynamics of transformation of the structure of land cover (land use) in the individual EU member states. Subsequent cycles of the project: CLC1990, CLC2000, and CLC2006 have been used to create thematic maps relevant to satellite imagery from LANDSAT and SPOT.

One of the most important landscape geocomponents are forests. Beyond the important economic function (timber production), forests increase biodiversity and play an important role in protecting the soil and water resources. They help shape the quality of life by having an effect on the local climate and beauty of the region. The last official report about the total area of Polish forests shows that 29.2 % of the area of Poland is covered by forests (in our climatic and geographical zone forests are the most natural formation). This percentage differs in various regions, from 21 to 49 %. The forest area per person in Poland is only 0.24 ha and is one of the lowest in Europe. Approximately 81.5 % of forests in Poland are publically owned (Central Statistical Office GUS, 2010). The official map of Polish forests is not

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up-to-date since it does not include the areas of uncontrolled forest successions (Finegan, 1984; Glenn-Lewin and van der Maarel, 1992; Fry and Sarlöv-Herlin, 1997) which occur on fallow land. The problems concerning the land cover changes and forest succession are similar to those of other countries or regions in Central Eastern Europe (Prévosto *et al.*, 2011; Baldock *et al.*, 1996; Fry and Sarlöv-Herlin, 1997; Lindner *et al.*, 1996). This situation calls for an effort to monitor land cover dynamics using remote sensing and GIS technology (Hall *et al.*, 1991; Bergen and Dronova, 2007). It can be accessed from both the manual interpretations of digital aerial images (Wezyk and Pyrkosz, 1999) and high-resolution satellite images (Wezyk and de Kok, 2005) or airborne laser scanning data (Wezyk *et al.*, 2009).

The topic of the article refers to the assessment of the process of changes in the land cover (land use), mainly including secondary forest succession on arable land based on digital multispectral airborne orthophotos and the airborne laser scanning (ALS) point cloud data. Airborne laser scanning, a type of light detection and ranging (LiDAR) technology, is a modern remote sensing technology used for collecting 3D information (point clouds) and providing precise information about terrain elevation and vegetation structure for large areas (Andersen *et al.*, 2006; Hyyppä *et al.*, 2004; Holmgren and Jonsson, 2004; McGaughey *et al.*, 2004). Acquired 3D point clouds with precise XYZ coordinates constitute the geometric information, and additional information like intensity or echo number is the descriptive data. The ALS technology allows for an exact and quick obtainment of information on terrain elevation (digital terrain model—DTM) and the objects on the terrain surface (digital surface model—DSM). Proper methods of filtration and classification of the point cloud lead to generating very precise DTMs, DSMs and normalized digital surface models (nDSM) representing the approximated surface objects (Axelsson, 2000; Wezyk *et al.*, 2008a, 2010). ALS data has many applications in monitoring land cover dynamics and forest management, but can also be used in ecological research on biomass or carbon sequestration (Goluch *et al.*, 2009; Hollaus *et al.*, 2009; Nyström *et al.*, 2012; Wezyk *et al.*, 2012c). Modern geoinformation technologies such as LiDAR or satellite imagery (VHRS) can be used for mapping the land cover (Höfle and Hollaus, 2010; Rutzinger *et al.*, 2007) and characterizing the vertical structure of vegetation (Ewijk *et al.*, 2009; Hashimoto *et al.*, 2004; Lefsky *et al.*, 2002; Mücke *et al.*, 2010; Wezyk et al. 2008b).

The paper presents an attempt to automate the ALS point cloud processing, integrated with the spatial analyses in GIS. Both, ALS and image data were also subdued to the process of object based image analysis (OBIA). OBIA was selected for the study because this type of image classification is mainly used in the world's leading research centres involved in the processing of remote sensing images (Hay *et al.*, 2005; de Kok *et al*, 2008; Blaschke, 2010). OBIA technology uses both the traditional approach of pixel classification, as well as the logical connections and the geometry of the groups of pixels making specific forms (elements of texture). The use of 3D point clouds from laser scanners, particularly in the aspect of their integration with the multispectral information originating from digital cameras, allows for processing the OBIA type computer programs (eCognition; Trimble GeoSpatial) to significantly enhance the process of image interpretation and diminishing the subjectivity of the operator. The main goal of the presented paper is to identify opportunities where the automatic approach can be used for ALS point cloud data processing and object-based image analyses, when assessing land use changes in Poland.

2. *Study Area*

The study was conducted in the central west part of Poland, in the Dolnoslaskie Voivodeship; the District of Milicz situated in the valley of the River Barycz (the site of the largest landscape park in Poland). The landscape, for the most part, consists of diverse forests and ponds. Forests in this region belong to the Forest District of Milicz and are owned by the Wroclaw Regional Directorate of the Polish State Forest National Holding. The selected area of study (Fig. 1) was the one where the most dynamic

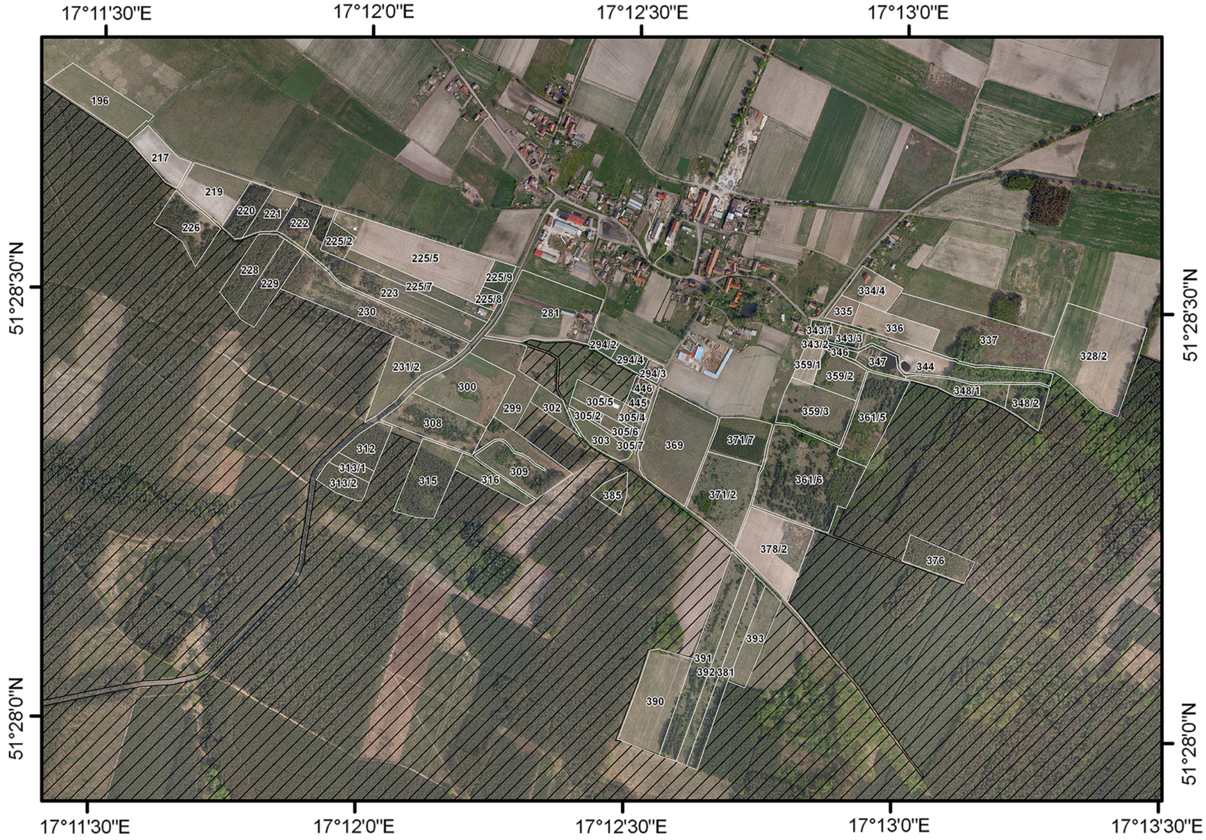

Figure 1
The study area—*numbered parcels with white border* (parcels of State Forest—*line symbol*)

changes in land use, especially uncontrolled secondary forest succession, were observed.

For the Milicz Forest District, the remote sensing data were obtained for the project by financial support from the General Polish State Forests Directorate in the years 2006–2008. There were different GI technologies (airborne and terrestrial laser scanning, photogrammetry) tested in terms of their usefulness in forest inventory (STERENCZAK, 2009; WEZYK *et al.*, 2007, 2008b). The airborne campaign was carried out in July 2007 using the TopoSys glass fibber scanner Falcon II with a so-called "swing mode". The mean relative height of flight was about 550 m above the ground. The mean point density was ca. 14 pts/m^2 (varied from 9 to 18 pts). Single scans were delivered in ASCII format (raw data) as well as raster format (DSM and DTM). The aerial photographs were captured using the Vexcel XP camera in May 2007.

The presented area of study consisted of 68 cadastral parcels (total area equal to 68.57 ha; mean parcel area of 1.01 ha). Areas where secondary forest succession was below 5 % or where the area was built-up were excluded from the study. The remaining parcels were called test areas (32 cadastral plots; total: 40.5 ha). In the test area, the following land-use classes occurred:

- Arable land (A): total area of 27.93 ha, i.e. 69.0 % of test area,
- Forest (F): forest, woodland and shrubs having 6.23 ha; 15.4 %,
- Meadow (M): 2.05 ha; 5.1 %, and
- Pasture (P): 4.29 ha; 10.6 %.

3. Materials and Methods

The following remote sensing data (imagery + ALS data) and cartographic materials were applied in the study:

a) imagery data (2007);

- digital aerial photos (Vexcel XP camera; GSD 0.15 m; bands: R, G, B, NIR). The aerial photos were processed in RGB orthophotos (GSD 0.25 m),
- CIR—“true orthophoto” as products of the linear scanner TopoSys (GSD 0.25 m),

b) ALS data-point clouds (TopoSys 2007 Falcon II; 14 points/m^2; FE/LE). Filtering, ground classification, models: DTM, DSM, nDSM,

c) cadastral data (parcels + land use) obtained from the District Centre of Surveying and Cartography Documentation in Milicz (data of 30 December 2003).

The selected area of study was one where the most dynamic changes in land use were observed. These were cadastral parcels in the vicinity of forest grounds (a buffer zone of approximately 200 m) making the property a State Forest (Forest Division Milicz, Pracze, Fig. 1). This area was characterized by frequent cases of secondary succession of forest-type vegetation (trees and shrubs) occurring mainly on arable land and grass areas (meadows, pastures).

Three different methods of data input and processing were used:

- manual (on-screen) vectorization of the secondary forest succession areas (trees and shrubs): orthophoto (RGB) and true orthophoto (RGB + NIR),
- GIS spatial analyses based on the normalized digital surface model (nDSM) form ALS point cloud data,
- object based image analysis (OBIA) based on the ALS and image data.

The purpose of manual vectorization was to determine the areas affected by the succession of secondary forest vegetation within the subsequent cadastral parcels using traditional means of photointerpretation of airborne orthophotos (orthophotos and “true orthophotos” from a linear scanner). This step was carried out in an ArcGIS (Esri) environment. The operator vectorized high vegetation as the outlines of trees, bearing in mind that in the orthophoto an improper situation (shifting) of the tops of high trees can occur depending on the distance from the main point in the image.

Despite this, the automation process of ALS point cloud was made to determine the borders of the vegetation cover (land use). The first stage was a preprocessing of ALS data and tiling it into squares of 500 × 500 m. These tiles were then processed in TerraScan (Terrasolid Ltd.) with user-defined macros to classify points to the ground class. This class was used to generate DTM by the active TIN method (Axelsson, 2000). This model was necessary for the normalization of ALS point clouds which is a process of converting the height of trees and buildings to their relative values. Normalized ALS point clouds were then subjected to algorithms (FUSION software; McGoughey, 2007) generating surfaces approximated by the highest points of the first laser reflections (nDSM); preserving local maxima and minima by applying proper smoothening filters. The size of the approximated nDSM pixel was set to 0.25 m. The studies were carried out in three versions of nDSM pixel “Z” values: above 1.0, 2.0, and 3.0 m, representing various heights of secondary forest vegetation above the ground. The automation of the GIS-based analysis of nDSM was performed in ArcGIS Model Builder (Wezyk *et al.*, 2009; Fig. 2), containing steps including map algebra and zonal statistics.

A further step of the work was object classification based on cadastral data, image data, and the processed ALS point clouds (nDSM). The scheme of the OBIA processing (eCognition; Trimble Geospatial) is presented in Fig. 3. Processing using the OBIA approach is based not on single pixels, but on objects—groups of pixels representing various features. In the first step, the pixels are segmented into objects, then the objects are assigned to land cover classes defined by the user. In fact, the process can be expanded on and can consist of many steps of reshaping, resegmentation, and reclassifying of the initially created objects. This may seem complicated, but it allows the creation of so-called rule-sets for processing large amounts of datasets without any user interaction (Gao and Mas, 2008). Object-based image analysis can be used to process different types of spatial data like raster satellite images and vector GIS data, as well as ALS point clouds. The OBIA approach was started by distinguishing “vegetation” and “nonvegetation” classes using spectral information (NDVI value). Then the “vegetation” class was

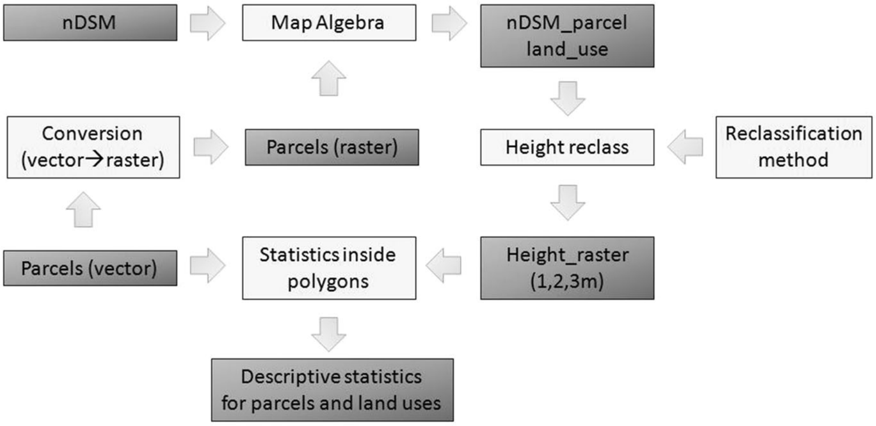

Figure 2
A model of the automatic processing of normalized ALS point cloud and cadastral data with GIS analyses

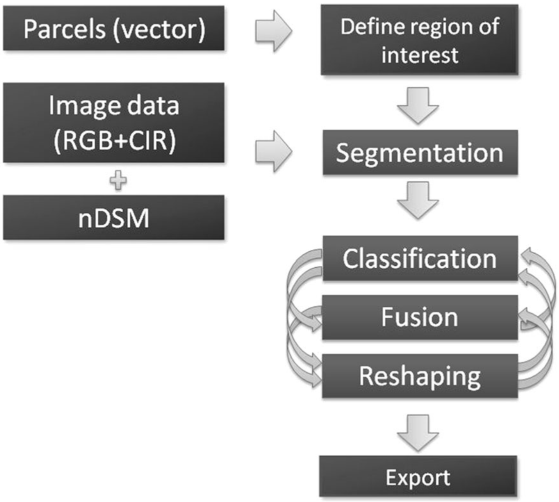

Figure 3
The scheme of object based image analysis (OBIA)

processed using the information stored in digital height models (nDSM) leading to precise borders of low and high vegetation. The minimum sampling unit was equal to 4 m^2.

4. *Results and Discussion*

The borders of the secondary forest succession determined in the process of photointerpretation by the operator "on screen" with digital airborne orthophotos (RGB and CIR), and the nDSM are presented below (Fig. 4).

Automatic determination of the borders of class "vegetation" was carried out step-by-step, applying object based classification (Fig. 5). The process of classification was carried out using the cadastral parcels as the borders of analysed area. For each parcel the vegetated areas were classified by using the multiresolution segmentation algorithm (eCognition) based on the single multispectral bands (R, G, B, NIR) and NDVI layer. "High vegetation" was classified afterwards using the geometrical information (height) stored in nDSM layer. This step was performed using a given threshold value of 1.0 m to distinguish between "low" and "high" vegetation classes within the general "vegetation" class. The final objects representing the high vegetation within the borders of each parcel were a subject of automatic revision to point out areas of potential misclassification due to inaccurate parcel borders. The final result of the carried out object classification was compared to the results of the spatial GIS analyses, mainly based on the transformed ALS point cloud (Fig. 6).

The result of the "on screen" photointerpretation, the GIS analysis nDSM, and the OBIA approach (Table 1) were very similar compared to the assigned classes and the area of distinguished objects. This can also be observed in Fig. 6. This means that the automatic method of delineating "high vegetation" can be used on large areas and provide very accurate results. The analyzed area revealed that the "Forest" (F) class having an area three times larger than the

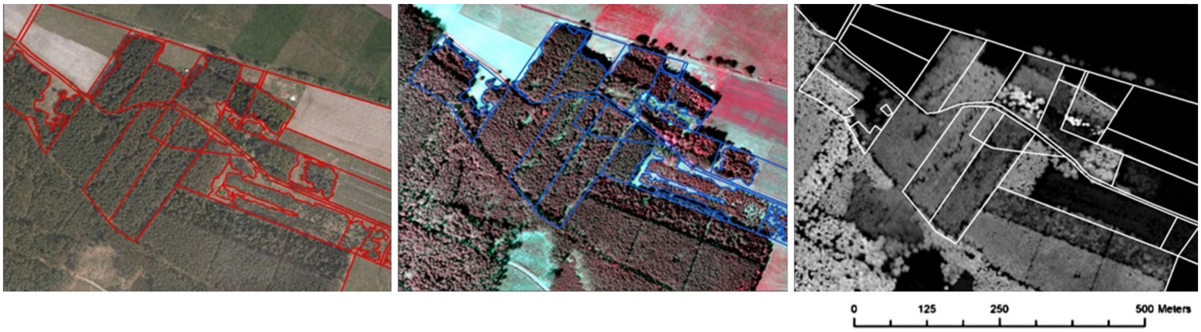

Figure 4
The result of the process of photointerpretation and on-screen vectorization made by the operator on airborne orthophotos and nDSM (from the *left*: RGB orthophoto, true orthophoto CIR and nDSM)

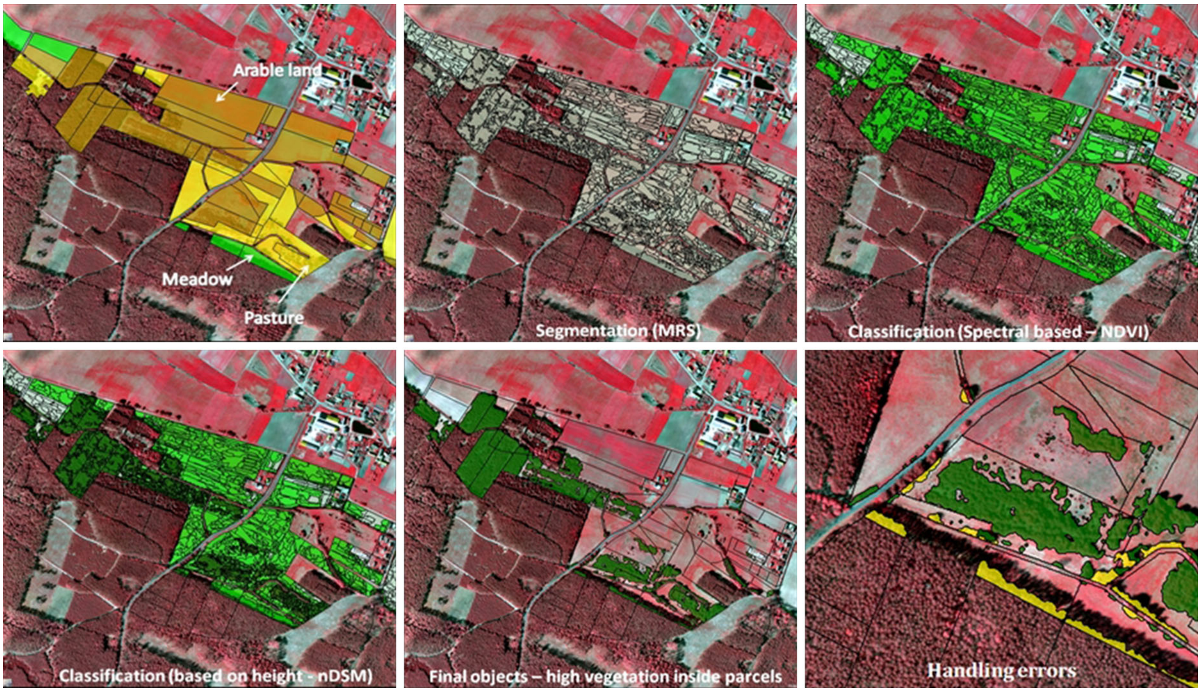

Figure 5
Steps of the OBIA

reference data stored in the cadastral databases (District Centre of Surveying and Cartography Documentation in Milicz; PODGiK). The "Forest" (F) class replaced the "Arable land" (A)—11.06 ha (27.3 %), "Pastures" (P)—1.77 ha (4.4 %) and "Meadows" (M)—0.68 ha (1.7 %). The inventory based on the remote sensing data showed that 81.9 % of the "Forest" (F) class was formed from arable land (A), 13.1 % from "Pastures" (P) and 5.0 % from "Meadows" (M). This confirms the problem commonly mentioned among the secondary forest succession on abandoned arable land where the agriculture has been stopped (Wezyk and de Kok, 2005; Bowen *et al.*, 2007; Oikonomakis and Ganatsas, 2012; Ruskule *et al.*, 2012; Susyan *et al.*, 2011; Zhang, 2005).

The goal of the paper was to define the possibilities for detecting vegetation classes in an automatic way using ALS and the image data. The authors proved that it is possible by using GIS spatial analysis

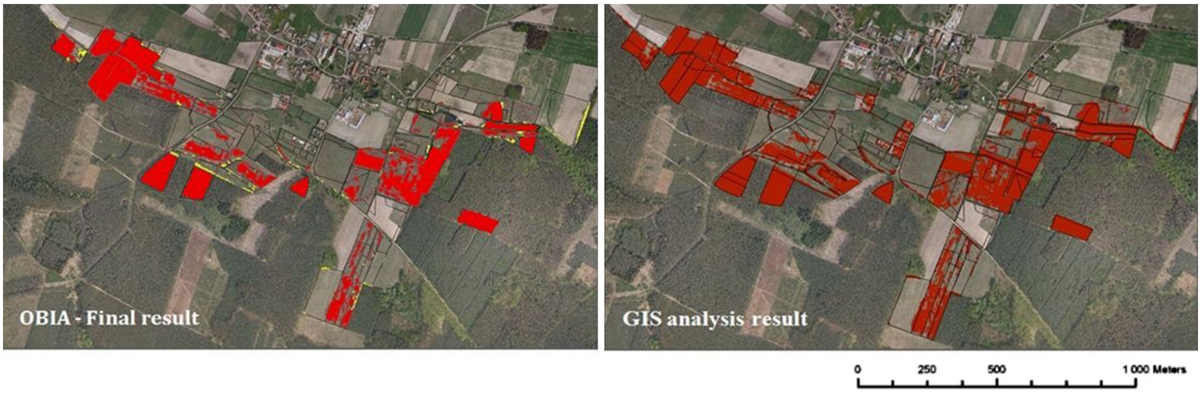

Figure 6
The results of OBIA classification and GIS analysis (ALS data)

Table 1

The total area of land used in the test area based on cadastral data, transformation of ALS data, OBIA classification, screen vectorization of orthophoto RGB and true orthophoto CIR (Mean and SD—calculated without cadastral data)

Land use	Total area (ha)					Mean (ha)	SD (ha)
	Cadastral data	ALS	OBIA	ORTHO RGB	True ortho CIR		
Arable land (A)	27.93 (69.0 %)	16.91 (41.8 %)	16.53 (40.8 %)	17.34 (42.8 %)	16.71 (41.3 %)	16.87 (41.7 %)	0.35 (0.9 %)
Meadow (M)	2.05 (5.1 %)	1.30 (3.2 %)	1.29 (3.2 %)	1.47 (3.6 %)	1.42 (3.5 %)	1.37 (3.4 %)	0.09 (0.2 %)
Pasture (P)	4.29 (10.6 %)	2.45 (6.0 %)	2.30 (5.7 %)	2.63 (6.5 %)	2.71 (6.7 %)	2.52 (6.2 %)	0.19 (0.5 %)
Forest (F)	6.23 (15.4 %)	19.84 (49.0 %)	20.38 (50.3 %)	19.05 (47.0 %)	19.66 (48.5 %)	19.73 (48.7 %)	0.55 (1.4 %)
Total	40.50 ha						

and ALS data processing. By analysing the results of the automatic ALS data processing, nDSM representing vegetation cover above 1.0 m above the ground gave results closest to the results of manual photointerpretation of airborne RGB orthophotos (19.84 ha, 49.0 %, Table 1). For the other options of analysis: nDSM >2.0 m and >3.0 m, the presence of secondary forest vegetation in the area was respectively: 18.06 ha (44.6 %) and 16.35 ha (40.4 %).

Based on the results of presented work, it can be concluded, that the state-of-the-art remote sensing technologies can replace the operator manual works for determining the borders of the land cover (land use) classes (Bork and Su, 2007; Falkowski *et al.*, 2009; Singh *et al.*, 2012; Suzanchi and Kaur, 2011). Pioneer work on automatic image classification was focused on the apparent spectral similarity of neighbouring pixels in optical remote sensed satellite data. With increasing spatial resolution, many neighbouring pixels in an earth observation satellite image are registered over the identical class of land cover type. Only the spectral properties of this object might reveal right information (de Kok and Wezyk, 2008). The previous works based on the data acquired by AISA hyperspectral scanner showed that not only the high spatial resolution is important for the land cover classification, but the high number of spectral bands as well (Wezyk and Wertz, 2005; Ustin *et al.*, 2004). Modern spatial data acquisition technologies like airborne laser scanning and satellite images can be used for automatic land cover mapping. The layers representing spatial extent of various objects are very valuable, especially when the 3D geometrical information stored in the ALS point clouds is taken into consideration. The integration of the geometrical (ALS) and radiometric (multispectral) information make it possible to achieve high quality of the image classification (Hill *et al.*, 2002; Tompalski and Wezyk, 2012).

The automation of the ALS point clouds processing with GIS analysis and OBIA tools, allow for the obtainment of very accurate borders of the land cover classes compared to traditionally applied photointerpretation and "on-screen" vectorization methods, but in a more objective and efficient way. The OBIA classification of multispectral airborne orthophotomaps (RGB + CIR), together with the application of the ALS products, produces more accurate results. Integration of these two types of datasets helps to derive land cover maps with additional attributes. The use of normalized ALS point cloud data improves the quality (accuracy) of the classification as well as allows for a height differentiation in vegetation classes, e.g.: low, medium, and high, or even to distinguish single trees (Chubey *et al.*, 2006; Wezyk *et al.*, 2012a, b).

5. Conclusions

The secondary forest succession on abandoned arable land in Poland is very common, particularly on weak quality sandy soils and in the neighbourhood of existing forest complexes. ALS technology can provide very precise information on the dynamics of this process. It allows a significant increase of the automatic detection process and the assessment of the dynamics and subsequent phases of forest succession in areas where agriculture has stopped.

Additionally, ALS is a perfect tool for the analysis of ongoing land cover changes and can significantly help in the process of photointerpretation of airborne orthophotos generated in a standard way based on DTM, which usually leads to problems with the geometry of high objects (treetops). Subjectivity of the interpretation of airborne photo materials (2D) can be significantly limited with the support of ALS point clouds or products of their processing, like e.g. nDSM.

Thanks to the availability of ALS data in Poland (e.g., The Information System of the Protection of the Country against extraordinary threats; ISOK), the quality of spatial models and environmental decisions is gradually improving. The results of the ISOK programme, covering approximately 60 % of the Polish territory with ALS data and airborne photos (and the planned continuation of the project in the years 2014–2016), can provide the means to fully automate the process for determining proper forest and succession borders. However, the automation of transforming large ALS datasets and high-resolution multispectral airborne images is still a great challenge in terms of their processing. Additionally, the technology of introducing large format digital cameras and the application of proper algorithms (stereo-matching) in the first ISOK project period (2011–2013) allow the automatic generation of DSM for the areas where ALS data was not obtained. Collectively, it gives great possibilities of 3D GIS analyses and automation in determining borders of vegetation cover (land use) classes.

It can be concluded, that the remote sensing technology provides accurate information about spatial and temporal distribution of land cover classes. Combining the 2D spatial location and data with time factor enables the monitoring of vegetation changes types. The use of aerial photographs has become more popular during the last several decades. The integration of photogrammetry with other technologies, such as LiDAR, GNSS or GIS, is applied for example in the mapping of the different types of land cover (land use), soil mapping or in the forest inventory research.

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