Comparison and Evaluation of Image Matching and Airborne Laser Scanning Point Clouds for Generating Canopy Height Model

Anna PŁATEK-ŻAK and Dorota ZAWIESKA, Poland

Key words: image matching, airborne laser scanning, Biebrza National Park, Canopy Height Model

SUMMARY

Accurate knowledge of the condition of forests allows for rational forest management. The use of aerial images and airborne laser scanning point clouds is on the rise for this purpose. It will enable to study individual trees and conduct precision forestry. Because photogrammetric data are freely available on the geoportal for the entire area of Poland, there are opportunities to use them on a broader scale in rational forest management. The experiment aimed to evaluate the possibility of using the aerial data to generate the Canopy Height Model. Aerial photos and LiDAR point clouds were used. The data covered the area of the Biebrza National Park. They were obtained as part of the HabitARS project: The innovative approach supporting monitoring of non-forest Natura 2000 habitats, using remote sensing methods. The project was carried out in 2016–2019 as part of the BIOSTRATEG II program and funded by The National Centre for Research and Development in Poland.

The generated Canopy Height Models based on image matching point clouds were compared with those from airborne laser scanning. Canopy Height Model based on airborne laser scanning data proved to be better quality. It maps the shape of the canopies more accurately. The boundaries between tree canopies are more clearly marked on the CHM generated from LiDAR data. Single trees and groups of trees on LiDAR CHM are more distinguishable than CHM based on image matching. Moreover, the boundaries of individual canopies are fuzzy on the CHM generated from image matching point clouds. Many details are smoothed out and indistinct. The most significant differences in height values between models occur on the edges of the forest stand and in the free spaces between trees. The great advantage of LiDAR data is the ability of the laser beam to penetrate through the vegetation. It enables to get more detailed stand characteristics and information about the ground under the vegetation. The image matching point cloud has different characteristics. Vegetation is often a source of errors in matching images. Errors in height appear mainly on the edges of the canopies and shaded areas. However, image matching point clouds can be used in multi-time analyses when LiDAR data is unavailable.

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1. INTRODUCTION

Photogrammetry and remote sensing are widely used in many fields. Modern photogrammetric technologies bring many advantages when used in forestry. Rational forest management is time-consuming (Næsset and Økland, 2002). Inventory of large forest areas has to be performed recurrently and it generates high costs (Stepper et al., 2015a). Aerial images and ALS point clouds provide valuable information about terrain. The issue of how to fully use them in forestry solutions is still a current research problem. Research about Canopy Height Models (CHM) generation methods is still ongoing (Quan et al., 2021; Mielcarek et al., 2018). Based on the photogrammetric data and products, many forest characteristics can be determined. The most important ones include: the height and the diameter of individual trees, the number of trees, the biomass assessment, forest stand cover, indicators describing condition of forest stand and many others (Ullah et al., 2017).

The aim of this study is to compare point clouds from image matching with point clouds from airborne laser scanning in generating Canopy Height Models. The experiment aimed to evaluate the possibility of using the aerial data to generate the CHM. The generated CHMs based on image matching point clouds were compared with those from airborne laser scanning. The correct generation of point clouds allows for obtaining reliable information about the forest biome.
Image matching point clouds are useful in areas where ALS data are not available and terrain inventory is difficult.

The paper is organized as follow. At the beginning, related works are described. The next section refers to material and methods. All stages and intermediate results are described. The last section provides the final results and conclusions.

2. RELATED WORKS

Photogrammetric products are widely used in many areas, including forestry. Point clouds from airborne laser scanning and aerial photos can be a valuable source of information about the surrounding space.

Aerial images are source of remote sensing data that is used in forestry for applications like inventory and monitoring (Hall, 2003; Caylor, 2000). During image acquisition for forestry purposes many factors should be considered, including the season, the time of the flight, the flight altitude, the type of camera, image overlap etc. In forestry, multispectral and hyperspectral images are used (Będkowski, 2010). Aerial photos and their products are used to update forestry databases. Based on orthophotomaps, changes in forest stand boundaries can be detected and many attributes describing forest stand can be determined. Moreover, it is possible to determine tree species based on image classification without field work. Aerial photos can also be used for monitoring natural disaster effects, examining the health condition of the forest stand and planning fire protection by determining dry areas based on vegetation indices (Okła, 2010).

Aerial laser scanning technology also has many applications in forestry. The main application is Canopy Height Model (CHM) generation (Ullah et al., 2017). It provides information about absolute height of trees and the spatial structure of the forest stand. If data from many periods is available, forest stand growth can be determined (Będkowski and Wężyk, 2010). It is possible to detect individual trees and determine their characteristics. It allows to conduct "precise forestry" (Wężyk, 2006). The technology can be used in hard-to-reach areas, as the laser beam penetrates through the vegetation cover and reaches the ground surface (Będkowski and Wężyk, 2010).

The generation of CHM is still a current research problem. There are many research that compare different methods of CHM generation (Quan et al., 2021; Mielcarek et al., 2018).
One of the main problems during CHM processing is the appearance of data pits, which reduce the CHM quality (Quan et al., 2021; Mielcarek et al., 2018). Many methods of pit-free CHM generation are being developed and tested (Khosravipour et al., 2014; Khosravipour et al., 2016; Hao et al., 2019; Ben-Arie et al. 2009; Quan et al., 2021; Mielcarek et al., 2018). The main issue is to maintain balance between keeping correct height value and crown shape smoothing.

In many countries ALS data is the main source for generating CHM, but there are places where ALS point cloud is not acquired often. In such situations, the possible solution is to use aerial images which are acquired more often and regularly (Ullah et al., 2017; White et al., 2015). It is possible to generate dense and highly accurate point clouds using image matching algorithms. Many forests metrics like height or volume can be determined based on image matching point clouds with accuracy similar to accuracy for ALS-based metrics (White et al., 2013). Combination of using aerial imagery with ALS-based Digital Terrain Model can aid in forest management (Stepper et al., 2015b).

3. MATERIALS AND METHODS

3.1 Area of interest

Area of interests is located in eastern Poland - Podlaskie voivodeship, the district of Mońki, Trzcianne (Figure 1). It is characterized by high biodiversity and it is located in Biebrza National Park (Figure 2). It is a home of many protected species of plants and animals, e.g. *Anemone sylvestris L., Aquilegia vulgaris L.* etc.

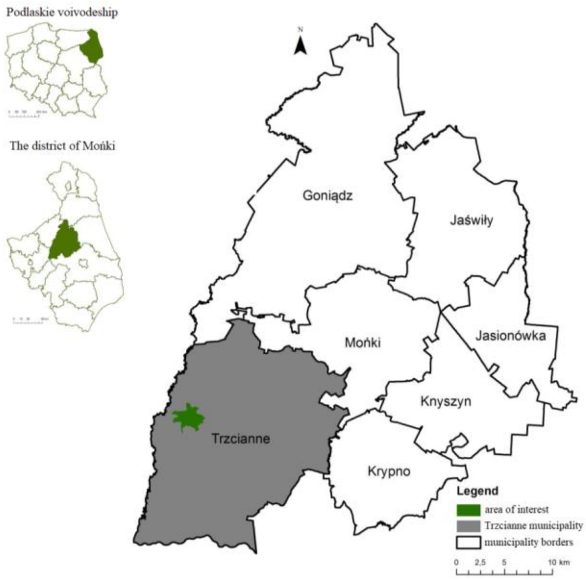


Figure 1 Location of area of interest according to the administrative division

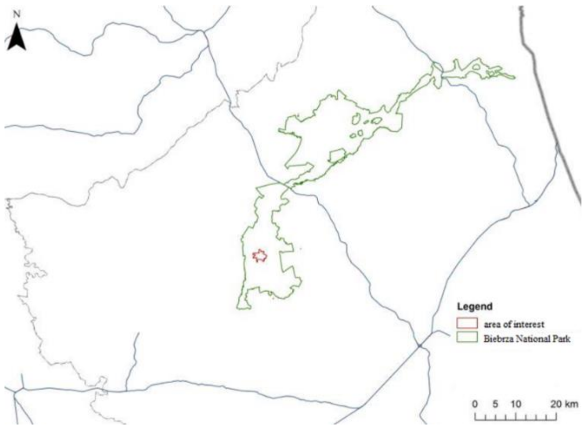


Figure 2 Location of area of interest in Biebrza National Park

3.2 Data

The data used in experiments was acquired as part of the HabitARS project: The innovative approach supporting monitoring of non-forest Natura 2000 habitats, using remote sensing methods. The project was carried out in 2016–2019 as part of the BIOSTRATEG II program and funded by The National Centre for Research and Development in Poland.

The main data was the aerial images. It was obtained during three data acquisition missions:

- 04-05 June 2016,
- 28 August 2016,
- 15 September 2016.

Images were acquired in east-west direction and were taken using the IGI DigiCAM system and Hasselblad digital camera with 50 mm fixed lens. Image resolution is 8176x6132 pixels. Examples of images covering selected area are presented below (Figure 3).

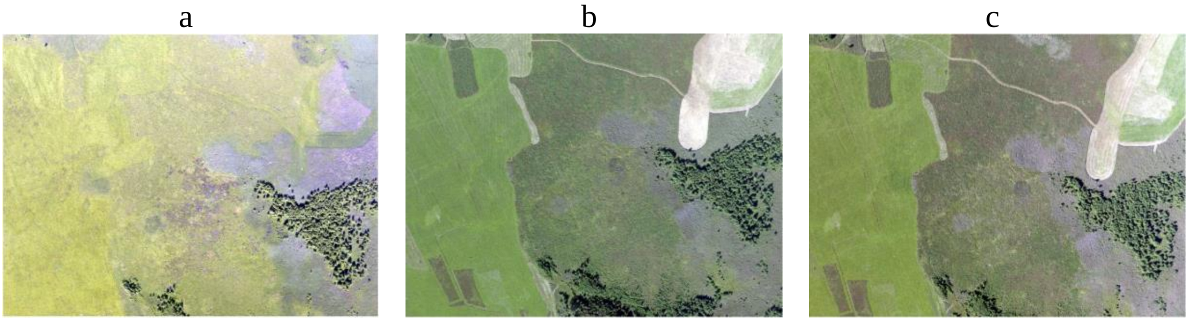


Figure 3 Examples of images covering selected area are presented above. Obtained on a) 04-05 June 2016, b) 28 August 2016, c) 15 September 2016. Progress in vegetation growth and meadow mowing are shown on them.

ALS point clouds were used as the input data. They were acquired during the same mission as images. Riegl LMS-Q680i scanner was used. The average density of point clouds equals about 15 points per m^2.

3.3 Methodology

3.3.1 Image adjustment

For the area of interest ground control points were not set due to wetland and hard-to-reach terrain. Thereupon image adjustments were conducted based on exterior orientation parameters. They were measured with GPS and INS. Image overlap is sufficient. There is lesser overlap on the borders of the block (Figure 4).

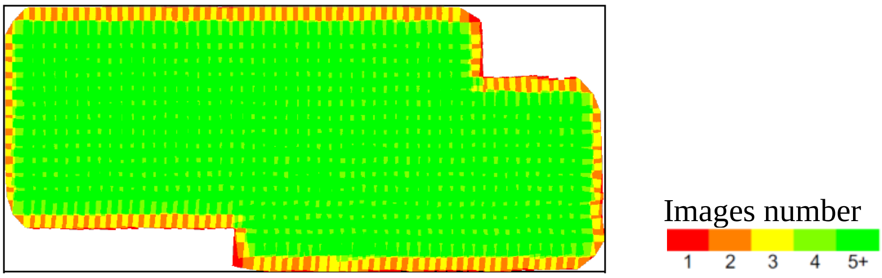


Figure 4 Image overlap for image Block from 04-05 June 2016.

Image processing was done in Pix4D Mapper software. The errors of determined exterior orientation parameters in coordinate system ETRS89 / Poland CS92 are similar to the expected accuracy of the exterior orientation elements obtained by measuring the position of the camera in flight with a GPS and INS receiver. In hard-to-reach areas, it is often not possible to set up ground control, but direct georeferencing ensures that satisfactory accuracy is obtained.

3.3.2 Dense point clouds generation

First, Pix4D Mapper software was used for generation of dense point clouds for data from June 2016. Different input setting were tested (Table 1**Error! Reference source not found.**).

Table 1 Tested settings of dense point cloud generation in Pix4D Mapper

Variant	**Parameters**			
	Image scale	**Points density**	**Minimal image number**	**Matching window size**
1	1	*optimal*	3	7
2	0,5	*optimal*	3	7
3	0,25	*optimal*	3	7
4	0,13	*optimal*	3	7
5	0,5	*high*	3	7
6	0,5	*low*	3	7
7	0,5	*high*	2	7
8	0,5	*high*	4	7
9	0,5	*high*	5	7
10	0,5	*high*	6	7
11	0,5	*high*	3	9

Generated point clouds based on image matching were compared with ALS data. For each variant cloud-to-cloud distance and average density were determined (Table 2). Variant 7 has the lowest value of cloud-to-cloud distance and one of the highest average point density. Out of all tested variants, variant 7 turned out to be most satisfying. All other sets of images were processed using the same settings.

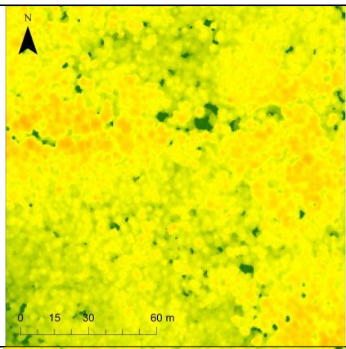
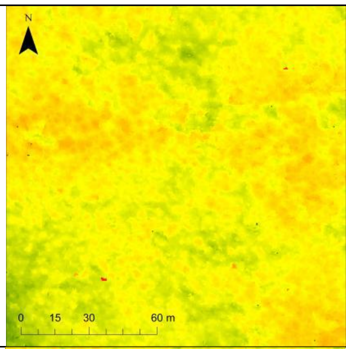
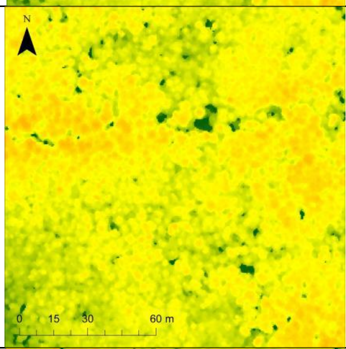
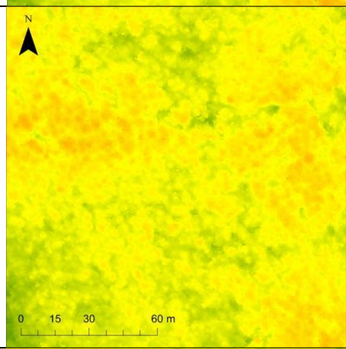
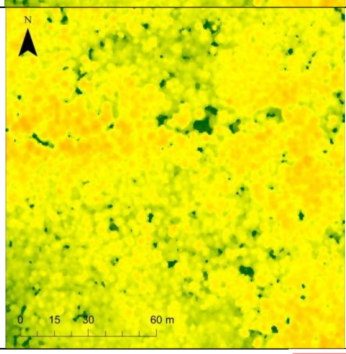
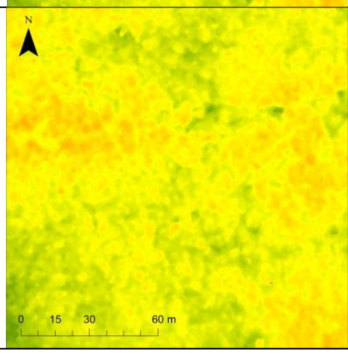
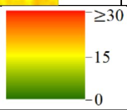
Table 2 Comparison of dense point clouds variants

Variant	**Average cloud-to-cloud distance [m]**	**Standard deviation of cloud-to-cloud distance [m]**	**Average density [points/m^2]**
1	0,525	0,292	23,5
2	0,378	0,463	6,4
3	0,407	0,473	1,4
4	0,471	0,507	1,3
5	0,409	0,474	21,0
6	0,391	0,472	1,5
7	0,320	0,445	25,5
8	0,392	0,471	22.3
9	0,407	0,476	21,5
10	0,421	0,478	20,6
11	0,391	0,476	23,8

3.3.3 Canopy Height Model generation

The next step of experiment was Canopy Height Model generation (Table 3). CHM was generated in FUSION software. Median filter with window size 3x3 pixels was used. It ensured proper smoothing of tree crowns, removal of unnecessary details and noise, and maintaining the actual height values of the forest stand.

Table 3 Canopy Height Models generated based on ALS and image matching point clouds from three data sets acquired in three different periods

<table>
<tr><th>Data acquisition period</th><th>ALS point cloud</th><th>Image matching point cloud</th></tr>
<tr><td>04-05 June 2016</td><td>
</td><td>
</td></tr>
<tr><td>28 August 2016</td><td>
</td><td>
</td></tr>
<tr><td>15 September 2016</td><td>
</td><td>
</td></tr>
<tr><td colspan="3">Forest stand height [m] 
</td></tr>
</table>

The differences between CHMs generated based on ALS and image matching point clouds are not significant, but CHM based on ALS point cloud has clearly marked boundaries between individual tree crowns. Tree crowns are visible with the most details. Whereas, the tree crowns boundaries of CHM based on image matching point cloud are fuzzy and the free spaces between the trees are also not visible enough. These free spaces were usually shaded in the photos and the errors in height values can occur in these places.

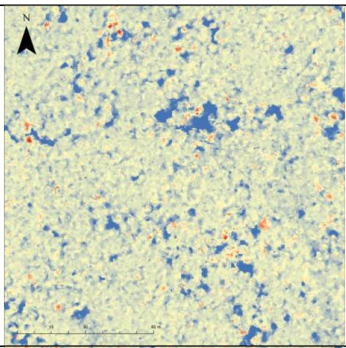
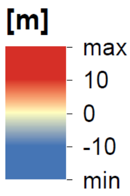
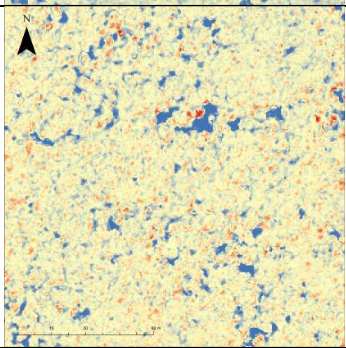
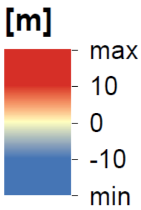
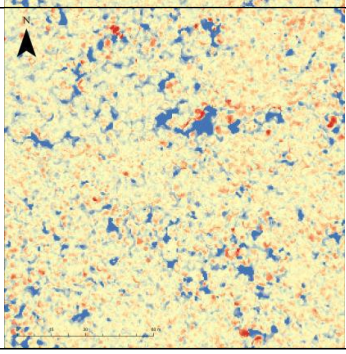
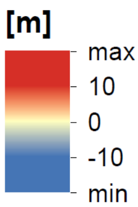
4. RESULTS

4.1 Height values comparison

Image matching point clouds were compared with ALS point clouds based on generated CHMs in terms of the height values (Table 4). For dense forest stand, the highest height differences are found at the edges of the crowns and in shaded areas. Shaded areas cause errors in determining the correct height values. Details are not visible on them, which has already been noticed in the visual assessment of the generated CHMs.

For the ecotone between dense forest stand and the open space of meadows and peat bogs, the greatest height differences occur in shaded areas and at the edges of the forest. The absolute values of the height differences reach over 10 m. For single trees, the highest differences are found at the tree crown edges.

Table 4 Height differences between Canopy Height Models generated based on ALS and image matching point clouds from three data sets acquired in three different periods

Data acquisition period	Height differences values	Legend
04-05 June 2016		
28 August 2016		
15 September 2016		

The highest mean value of absolute height differences occurs for data from 28 August 2016. For the Pix4D program, the RMS value for the three campaigns is approximately 0.50 m (Table 5).

Table 5 Differences in height values between Canopy Height Models generated based on ALS and image matching point clouds from three data sets acquired in three different periods

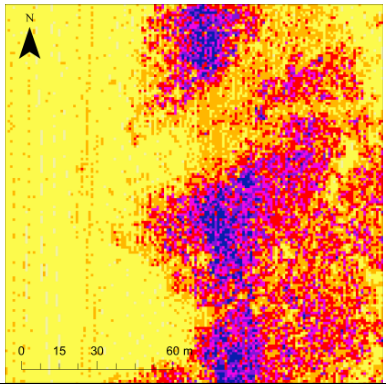
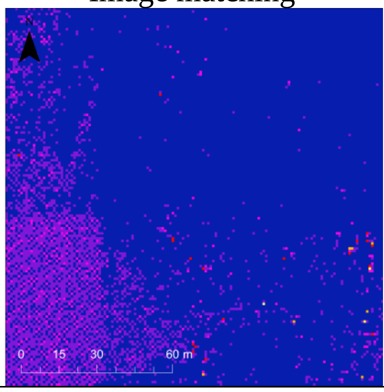
Data acquisition date	Mean value of absolute height differences [m]	RMS values [m]
04-05 June 2016	0,41	0,52
28 August 2016	0,68	0,47
15 September 2016	0,23	0,50

4.2 Point cloud density comparison

As a part of the experiment, the densities of point clouds were compared (Table 6). ALS data density is diverse. The highest density of the point clouds occurs at the area with forest stand. For areas with medium and high vegetation, the point clouds density exceeds 100 points per 1 m^2. For areas with low vegetation, the density reaches 15 points per 1 m^2. The increased density in areas with high and medium vegetation results from the multiple reflection of the laser beam from the trees and the ground.

Density for the point clouds from the image matching is homogeneous and similar for the entire area. The density is up to 250 points per 1 m^2. Lower density occurs on the edges of the image block. This is due to the smaller image overlap in this places. The average density equals 30 points per 1 m^2.

Table 6 Density comparison for ALS and image matching point clouds acquired on 15 September 2016

ALS	Image matching	Legend [points/m^2]
		1 - 5 6 - 10 11 - 15 16 - 20 21 - 25 26 - 30 31 - max

4.3 Terrain profile comparison

Terrain profiles for the point clouds were compared. Profile for ALS point cloud (Figure 5) shows that these data presents the surface of the terrain correctly, even under dense vegetation. On the other hand, the result for image matching point cloud is worse (Figure 6). Slight noises are visible on the terrain profile, especially in flat areas like roads, but the shape of the individual trees is very well mapped.

Figure 5 Profile of area with road and roadside group of trees for ALS data from 04-05 June 2016

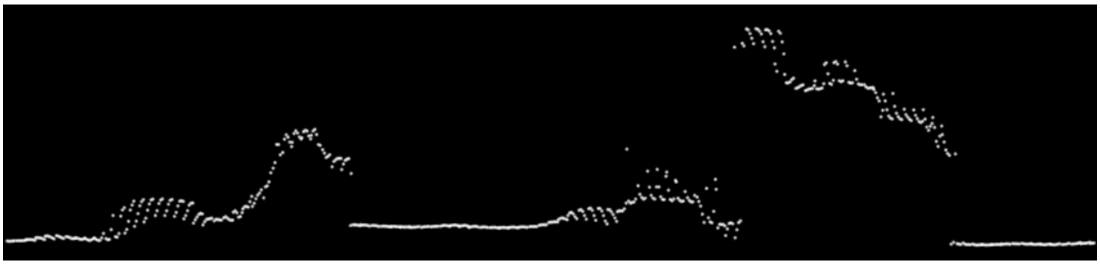


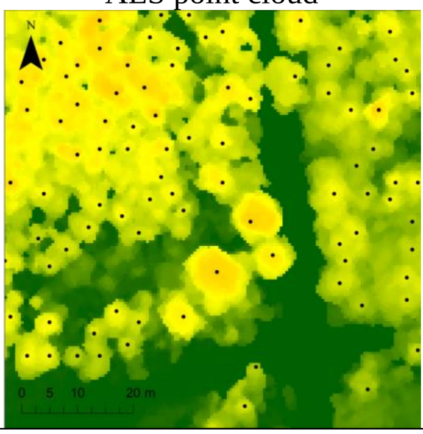
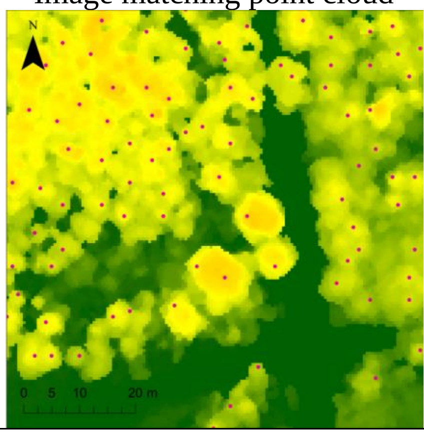
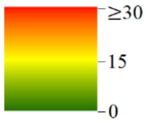
Figure 6 Profile of area with road and roadside group of trees for image matching point cloud from 04-05 June 2016

4.4 Chosen forest stand characteristics comparison

4.4.1 <u>Individual tree tops</u>

Tree tops locations were generated for different data sources (Table 7). 4728 tree tops were obtained for ALS data and 4644 tree tops were obtained from image matching point cloud. The number of tree tops from image matching point cloud is similar to the number of tree tops from ALS data. The location of tree tops does not differ significantly.

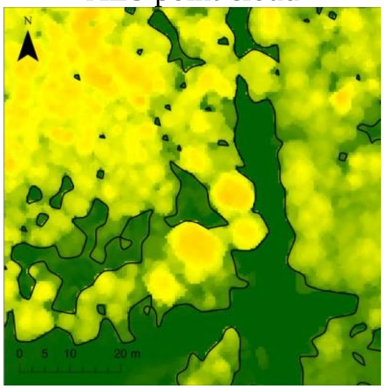
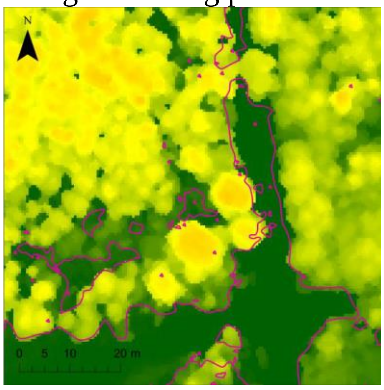
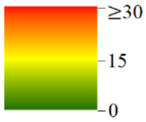
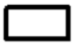
Table 7 Tree tops comparison

ALS point cloud	Image matching point cloud	
		Forest stand height [m]:  Tree tops based on ALS data: ✸ Tree tops based on image matching point clouds: ✸

4.4.2 Forest stand boundaries

The boundaries of forest stand higher than 3m were generated (Table 8). There are differences between boundaries depending on data source. The boundaries generated based on ALS data have the most of free spaces between trees. The boundaries based on image matching point cloud differ from the one based on ALS data. There are shifts in the outer border of the forest stand. In addition, there are less free spaces between trees.

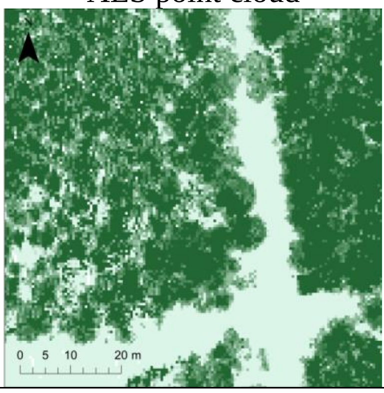
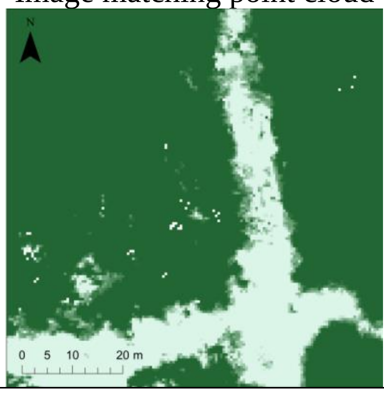
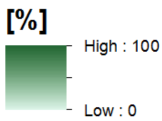
Table 8 Comparison of forest stand boundaries

ALS point cloud	Image matching point cloud	Forest stand height [m]:
		 Forest stand boundaries based on ALS data:  Forest stand boundaries based on image matching point clouds: 

4.4.3 Forest stand cover

The possibility of determining the forest stand cover was also tested (Table 9). Firstly, forest stand cover based on ALS data was analyzed. In forest-covered areas cover has values in the range of 60-100%. In open spaces, values closer to 0% are dominant. For image matching point cloud, forest stand cover values are more homogenous. The majority of values are either 0% or 100%.

Table 9 Comparison of forest stand cover

ALS point cloud	Image matching point cloud	
		

5. CONCLUSIONS

During experiment it was analysed if point clouds based on image matching can be useful in Canopy Height Model generation and whether this method is comparable with ALS for this application. Using commercial software for aerial images processing, it is possible to generate point clouds with various parameters that can be used for Canopy Height Model generation.

During experiments Canopy Height Models were generated based on both ALS data and image matching point clouds. This two data types are useful for CHM generation but some differences can be noticed in tree crowns shapes. The boundaries between individual trees are more clearly visible on the CHM based on ALS data. Whereas, the tree crowns boundaries of CHM based on image matching point cloud are fuzzy and the free spaces between the trees are also not visible enough. The greatest height differences occur in shaded areas and at the edges of the forest stand. The absolute values of the height differences reach over 10 m. Shaded areas cause errors in determining the correct height values. ALS data density is diverse. The highest density of the point clouds occurs at the area with forest stand. Density for the point clouds from the image matching is homogeneous and similar for the entire area.

Based on generated CHMs selected forest stand characteristics like tree tops location, forest stand boundaries and forest stand cover are determined. The number of tree tops from image matching point cloud is similar to the number of tree tops from ALS data. The location of tree tops does not differ significantly. There are differences between boundaries depending on data source. The boundaries generated based on ALS data have more free spaces between trees. The boundaries based on image matching point cloud has shifts in the outer border of the forest stand in comparison to ALS point clouds.

The image-matching point cloud has completely different characteristics than the ALS point cloud. It is not possible to obtain information about the land under the surface of the forest stand. Vegetation is a source of errors in image matching. This is due to the similar texture and repeating elements. Errors in height occur mostly on the edges of the crowns and the entire stand, as well as in places of shade.

To develop the Canopy Height Model, it is better to use data from airborne laser scanning. It more accurately reflects the shape of the crowns. It presents details of objects and have an adequate point density. The ability of the laser beam to penetrate through the vegetation is a great advantage. It is possible to get more detailed characteristics of the stand and information about the ground under the vegetation.

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BIOSTRATEG II program and funded by The National Centre for Research and Development in Poland.

Wojciech Ostrowski, BEng, MSc has also contributed to this experiment realization. He had answered with unfailing patience numerous questions and shared his knowledge and experience in selecting parameters for the processing of aerial photos.

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BIOGRAPHICAL NOTES

Anna Płatek-Żak is a teaching and research assistant at Warsaw University of Technology in Department of Photogrammetry, Remote Sensing and GIS in Faculty of Geodesy and Cartography. She is a graduate of two faculties – Geodesy and Cartography (specialisation: Photogrammetry and Remote Sensing) and Environmental Development, Planning and Management (specialisation: Environmental Constraints in Spatial Planning). She has experience in projects for the European Space Agency and The National Centre for Research and Development. Her research specialization is aerial photogrammetry, remote sensing and 3D visualisation of spatial data.

Dorota Zawieska is the head of Department of Photogrammetry, Remote Sensing and GIS in Faculty of Geodesy and Cartography at Warsaw University of Technology. She has graduated the Faculty of Geodesy and Cartography, specialisation: photogrammetry. Her doctor's thesis „Evaluation of the usefulness of the projection moire effect in photogrammetric surveys of deformations of the backbone" was awarded by the Rector of the Warsaw University of Technology. She was a supervisor in many grants. She is the author of more than 70 publications. Her research specialisation is close-range photogrammetry, 3D modelling and visualisation of objects, digital image processing, integration of multi-source photogrammetric data, utilisation of terrestrial laser scanning and digital images in various sectors of economy, in particular in protection of the cultural heritage.

CONTACTS

Anna Płatek-Żak, BEng, MSc
Warsaw University of Technology, Faculty of Geodesy and Cartography,
Department of Photogrammetry, Remote Sensing and Spatial Information Systems
Pl. Politechniki 1
00-661 Warsaw
POLAND
Email: anna.platek@pw.edu.pl

Dorota Zawieska, BEng, PhD, DSc
Warsaw University of Technology, Faculty of Geodesy and Cartography,
Department of Photogrammetry, Remote Sensing and Spatial Information Systems
Pl. Politechniki 1
00-661 Warsaw
POLAND
Email: dorota.zawieska@pw.edu.pl