ACCURACY OF CROWN SEGMENTATION AND ESTIMATION OF SELECTED TREES AND FOREST STAND PARAMETERS IN ORDER TO RESOLUTION OF USED DSM AND NDSM MODELS GENERATED FROM DENSE SMALL FOOTPRINT LIDAR DATA

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ABSTRACT:

The purpose of this study is to categorize how different surface model resolutions impact the estimation of trees and forest stands parameters: number of recognized trees, crown area, treetop location and height of single trees. For forest analysis the following models – DSM (Digital Surface Model) and nDSM (normalized Digital Surface Model) were taken into account. For each model resolutions 0.25; 0.5 and 1.0 m were used. The studies were cared out in 1000 ha area of Forest Experimental Station in Gluchow, owned by Warsaw University of Life Sciences – SGGW, central Poland. Research was based on 34 sample plots measured mainly by airborne laser scanning (LIDAR) and by stereo-photogrammetric observation. Forest structure is mixed, with one layer Scotch pine (*Pinus silverstris* L.) and Common oak (*Quercus robur* L.) stands, as we as with multilayer, rebuild stands. In this paper discrimination between coniferous and deciduous was not made. Stereo photogrammetric measurements were used as a reference data to comparisons to results from LIDAR data processing. System Falcon II (TopoSys GmbH, Biberach Germany) was used for LIDAR data acquisition. Just first echo (FE) cloud point was used in processing. In the presented study the main findings were that for raster resolution 0.25 and 0.5 m number of detected trees was the largest, about 80 % of the reference value and was no statistician significant difference between these two resolutions. The number of extracted trees based on nDSM was slightly larger comparing to DSM. Results show for all 3 raster resolutions tree height estimation were close to the reference data and did not vary significantly between models.

1. INTRODUCTION

One form of output generated form airborne LIDAR data is that of the surface model. Expectation is that each of these models will properly describe a presented surface. Based on surface models from LIDAR data of forested areas it is possible to capture many different tree and forest parameters (Olsson, 2004, Hyyppä et al., 2004) with very accurate results. LIDAR data density and raster resolution models have a principal influence on the accuracy of estimated trees location, crowns delimitations (segmentation), trees heights and resulted forest stands characteristics.

As a reference to the LIDAR data, accuracy assessment data from field surveying was also used. The most important problem connected with using LIDAR data is that measuring trees from ground level can cause errors (Coops et al., 2004; Maltamo et al., 2004). Another difficulty is the accurate measurement of tree position. These factors have fundamental influence on latter analysis because they can distort results based on LIDAR data study.

The results presented in this study mainly deal with just the first level of the forest canopy, where the stereo photogrammetric method was used for reference data acquisition. Research on using stereoscopic measurement of Polish forests started in early 1970's (Piekarski, 1972). There exists a range of literature suggesting that 3D measurements based on pars images gives reasonable and accurate information about the firs forest crown layer (Abraham, Adolt, 2006; Adler, 2001; Akça, 1984; Będkowski, 2005; Duvenhorst, 1998; Feldkötter et al., 1995; Huss et al., 1984; Mauser, 1990).

There were two main goals of this study. Preliminary investigations were made to locate any differences between DSM and nDSM in number of delineated trees. Resolutions of 0.25 m; 0.5 m and 1.0 m were used. Based on the three resolutions of nDSM we examined how crown area, tree height and tree top position is changing. Does resolution of used surface model have any influence on trees parameters or not? The selection of the model resolution is a compromise between expected accuracy and time of data processing.

2. MATERIAL

2.1 Study area

The study plot used is a 1000 ha area of forest experimental station in Gluchow, owned by Warsaw University of Life Sciences – SGGW, central Poland. Different forest types exist in the forested region, from one layer stands of Scotch pine (*Pinus silverstris* L.) and Common oak (*Quercus robur* L.) to multilayer and mixed stands with Birch (*Betula*), Alder (*Alnus*), European beech (*Fagus sylvatica* L.) and Hornbeam (*Carpinus betulus* L.) Age of analyzed stands vary between 30 and 120 years. Generally flat relief covers study area, with mean height above see level around 185 m.

2.2 Field data

34 sample plots were measured during filed surveying. Field datasets were collected in autumn 2006, in accordance to forest inventory methods. All sample plots were circular, with area 500m^2 (radius 12.61m). For each sample plot the DBH (diameter on the breast height) and position of each tree was measured. The height for 1 tree from each layer was determined by Suunto height meter (Suunto hand-held clinometer). XYZ coordinates of middle point of each sample plot were calculated according to measurements being made using an electronic tachymeter.

2.3 Laser Scanner

Falcon II airborne laser scanner system from Topographische Systemdaten GmbH (TopoSys, Biberach Germany) was used for LIDAR small footprint data acquisition. The TopoSys System is based on two separate glass fiber arrays of 127 fibers each. Its specific design produces a push-broom measurement pattern on ground. For further details see on TopoSys (2004) website. For this analysis the data of a flight in May 2007 was used. The average point density was 20 pts/m². A point cloud was georeferenced in PUWG 1992 - polish coordinate system. The first and last pulse data were collected, (Table 1) due to some delivery problems just the first echo (FE) from the point cloud was used.

Sensor type	Pulsed fiber scanner
Wave length	1560 nm
Pulse length	5 nsec
Scan rate	83 kHz
Scan with	14.3°
Data recording	first (FE) and last (LE) pulse
Flight height	700 m
Size of footprint	0.7 cm

Figure 1. Laser system parameters

Based on FE from LIDAR data digital surface models were generated in TreesVis Software (FELIS, Germany). For more details about software description and implemented algorithms for models calculations see: Weinacker et al. 2004a, 2004b. Generated models have resolution respectively: DTM – 2.5 m; DSM and nDSM – 0.25 m; 0.5 m and 1.0 m. Generated models have an area of 50 m × 50 m and their middle point coordinates were the same as rounded sample plots. The nDSM was created by subtracting DTM from DSM. Pixels from overlapping pixels in both models received new “z” value in nDSM model, similar to real height.

2.4 Photogrammetric data

Recording of all necessary tree parameters was not possible during a field surveying, hence stereo photogrammetric was used as a reference comparison with results from LIDAR data. Stereo photogrammetric measurements were carried out on IR-images with 0.15 m ground pixel resolution. Images were acquired with DMC 2001 ZI/Imaging camera in mid summer 2007. Aerotriangulation of 24 images was made with use of DVP 5.0 software. During 3D stereo models observation top and crown extend of each tree inside 500 m^2 sample plots were vectorized and used for further study.

3. METHODS

All automatically assessed parameters from DSM or nDSM models were compared to stereo photogrammetric measurements.

3.1 Single tree crowns delineation

Single tree delineation was based on a similar method to Heurich and Weinacker (2004) and analysis was carried out using Halcon software (MVTec Software GmbH). For DSM and nDSM models in 0.25; 0.5 and 1.0 m resolutions different Gauss filters were used, depending on the height of surface model. Then the local maxima from the pouring algorithm were extracted. This segmentation method is similar to an inverted watershed-algorithm (Soille, 1999).

Further analysis on nDSM models were carried out. Firstly the ground plan was excluded from the data, once the ground plan had been extracted the segmentation pouring algorithm was applied (Fig. 2, 1). The maximum height for each segment was calculated. Then all pixels inside each segmented region lying below half of maximum height were excluded from the segment (Fig. 2, 2). This procedure is used in Polish forests because in general deciduous tree species have a crown height equal to about half of a tree height, for coniferous it is about 1/3 of tree height for stands for 50-60 years. Because the tree species structures of all sample plots were mixed a 1/2 maximum height was used, as a threshold parameter.

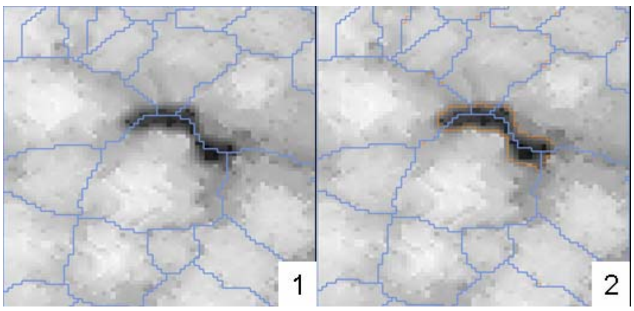

Figure 2. Defining real crown extension

3.2 Accuracy assessments

For the evaluation of the results the photogrammetric defined trees were linked to the LIDAR trees by their position. Tree height comparison between field and photogrammetric measurements was carried out.

Firstly the number of trees was calculated in each plot. All crowns for which more that 50 % of crown area were inside a sample plot were used in the analysis. 804 polygons meet this criterion. Later for crown area, height and tree top location more that 140 trees were merged. For this analysis the same 2.5 m resolution DTM was used.

4. RESULTS

4.1 Numbers of detected trees

	Reference number	DSM		
		0.25 m	0.5 m	1 m
No. trees	804	647	629	422
% recognized	-	80.5	78.2	52.5
R^2	-	0.91	0.93	0.59
Stand. dev. [%]	-	10	10	14
Mean. [%]	-	82	80	57
Max recognized [%]	-	100	100	88
Min recognized [%]	-	62	60	33
Multi shoots [%]	-	11	9	6
		nDSM		
		0.25 m	0.5 m	1 m
No. trees	804	655	629	425
% recognized	-	81.5	78.2	52.9
R^2	-	0.91	0.91	0.45
Stand. dev. [%]	-	10	10	15
Mean. [%]	-	83	80	57
Max recognized [%]	-	100	100	88
Min recognized [%]	-	62	60	26
Multi shoots [%]	-	14	9	9

Table 1. Comparing of results from stereo photogrammetric measurements (Reference number) and from LIDAR data (DSM and nDSM) for number of detected tree

Above table (Table 1) shows that the raster resolution has an influence on the number of detected trees. When the raster size is increasing, the number of detected trees decreases. No statistically significant difference exists between 0.25 m and 0.5 m raster resolution. Generally if the structure of the first layer was homogeneous, the percentage of the estimated number of trees went to 100 (example: sample plot E30 – Pine 68 years old). The worst results were noted for samples with varying structure and mixed species composition (example: sample plot J30 – Pine in age 115 years and Oak in age 60 years).). Similarly, low numbers of detected trees were calculated for two stands, the youngest analyzed stands (F42 – age 35 years, H30 - age 24 years). For nDSM model with 0.25m resolution the best result for all sample plots was achieved in the total number of detected trees and for mean percentage for all analyzed plots

4.2 Accuracy of tree height measurements

Presented below (figure 3) is a high coefficient of determination height from LIDAR data versus stereo photogrammetric measurements. No statistically significant difference between results from field tree height measurements and photogrammetric tree height assessment could be denotes.

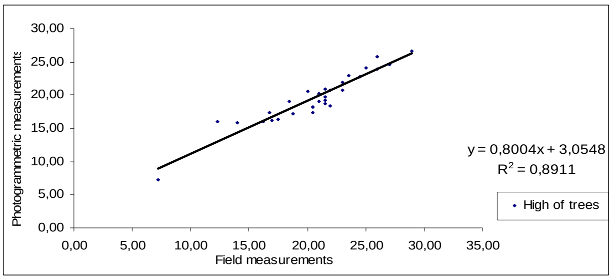

Figure 3 Photogrammetric measured height versus field height measurements for 31 trees

Table 2, below, presents differences in high estimation for different raster resolution nDSM models. Photogrammetric measurement gave systematic underestimation of tree height compared to methods based on LIDAR data. No statistically significant differences between raster model resolutions were noticed.

No. of trees - 143	H (reference) versus H from nDSM		
	0.25 m	0.5 m	1 m
R^2	0.95	0.95	0.95
	Difference: H (ref.) - H (nDSM)		
Sum [m]	- 76.73	- 76.89	- 78.15
Stand. dev. [m]	0.79	0.78	0.79
Mean. [%]	- 0.54	- 0.54	- 0.55
Max + [m]	0,92	0,90	0,93
Max - [m]	- 4,58	- 4,58	- 4.58
Min + [m]	0.01	0.02	0
Min - [m]	- 0.01	- 0.01	- 0.01

Table 2. Comparison of results from stereo photogrammetric measurements (H reference) and from LIDAR data (nDSM) for tree height computation

4.3 Accuracy of tree crowns area measurements

High coefficients of determination crow area were calculated for 0.25 and 0.5 m resolution nDSM (Fig. 4).

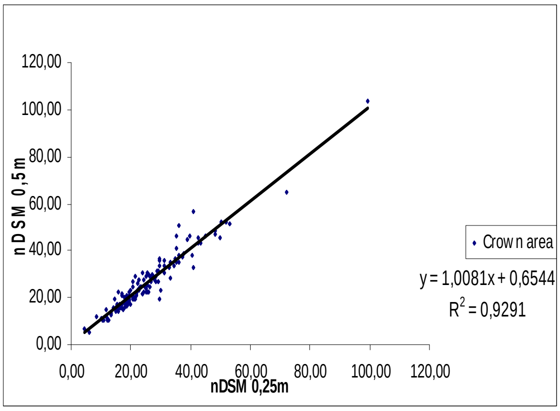

Figure 4. Tree crown area from 0.25 m resolution nDSM versus 0.5 m resolution nDSM

Generally crowns areas delineated from nDSM models were larger compared to stereo photogrammetric measurements. No statistically significant differences between results from tree raster model resolution were noticed. Range calculations between the largest and smallest differences of crown area for 0.25 m model resolution reached a minimum value and were equal of 84 m^2. Maximum overestimating of crown area were calculated for 1m resolution nDSM. Mean differences between 0.5 m and 1.0 m nDSM resolution are very similar (-10.50 and -10.44 respectively).

No. of trees - 140	Difference: Crown area DVP – Crown area nDSM					
	0.25 m		0.5 m		1 m	
	[m^2]	[%]	[m^2]	[%]	[m^2]	[%]
Mean diff.	-9.64	-74	-10.50	-80	-10.44	-80
Stand. dev.	6.61	58	7.29	62	9.36	76
Max	3.09	34	3.74	41	6.10	27
Min	-40.25	-316	-38.58	-305	-44.43	-361
	DVP versus nDSM crowns area					
R^2	0.72		0.69		0.58	
	Crown area nDSM 1 – Crown area nDSM 2					
	0.25 - 0.5 m		0.25 – 1.0 m		0.5 – 1.0 m	
	[m^2]	[%]	[m^2]	[%]	[m^2]	[%]
Mean diff.	-0.86	-4	-0.81	-5	0.06	-2
Stand. dev.	3.46	14	6.51	35	6.26	33
Max	9.95	34	14.07	53	14.82	55
Min	-15.77	-50	-29.30	-206	-26.03	-212
	nDSM 1 versus nDSM 2 crowns					
R^2	0.93		0.79		0.81	

Table 3. Comparing results from stereo photogrammetric measurements (Crown area DVP) and from LIDAR data (Crown area nDSM) for tree crowns area

4.4 Accuracy of tree top position measurements

Tree top location from nDSM data were recorded as the centroid of a region defined by pouring algorithm as a local maximum. 3D measurements in stereo models were carried out as a reference for analysis. We can observe that with raster size increasing differences between tree top and photogrammetric measurement also increased (Tab. 4). For nDSM 0.25 and 0.5 m resolution mean differences between tree top positions have the smallest value. No statistically significant difference between 0.25 m, 0.5 m and 1.0m raster resolution were found in 2D and 3D space.

No. of tree tops - 143	DVP versus nDSM 2D		
	0.25 m	0.5 m	1.0 m
Mean [m]	0.67	0.71	0.77
Stand. dev. [m]	0.40	0.42	0.47
Max recognized [m]	2.59	2.85	2.92
Min recognized [m]	0.00	0.11	0.08
	DVP versus nDSM 3D		
	0.25 m	0.5 m	1.0 m
Mean [m]	1.06	1.08	1.14
Stand. dev. [m]	0.62	0.64	0.66
Max recognized [m]	4.61	4.61	4.65
Min recognized [m]	0.13	0.14	0.13
	nDSM versus nDSM 2D		
	0.25-0.5 m	0.25-1.0 m	0.5-1.0 m
Mean [m]	0.23	0.41	0.41
Stand. dev. [m]	0.15	0.26	0.32
Max recognized [m]	1.29	2.25	2.50
Min recognized [m]	0.00	0.00	0.00

Table 4. Comparing of results from stereo photogrammetric measurements (DVP) and from LIDAR data (nDSM) for tree top position in 2D and 3D space

5. DISCUSSION

Analyzing first layer stands is important for forest management. Usually within this level of forest there exists the whole stand volume and its biomass element. Its influence on understory vegetation and stand structure define the ecological and social function of forest.

LIDAR data gives us the possibility to analyze deeper into the forest cover, analyze almost each tree separately. Depending on the LIDAR data point density we are able to interpolate raster models with very small pixels, which can help make our analysis more accurate. Models themselves become large if constructed from pixels pertaining to increased resolution, which in turn impacts on the analysis time, increasing the cost. Therefore it is important to find a balance between raster pixel size and intended accuracy. Usually parameters based on single trees are used for stand characteristics (Nuske, Nieschulze, 2004; Weinacker et al. 2004b). The presented work aims to find a balance between acquisition time and accuracy, and check the statistical output due to model resolution.

The results show that the number of detected trees is varying between analyzed raster resolutions (surface models resolutions: 0.25 m 0.5 m and 1 m). For 0.25 m and 0.5 m resolution no statistically significant differences were found. When the pixel size of model represented 1.0m, the number of recognized tree significantly decreased. The reason of it can be relatively small size of crowns while trees growing in dense stand. Analyses based on nDSM models are slightly more accurate. Number of detected trees for 0.25 m and 0.5 m reached about 80 %. If we take in to account that more of the sample plots were covered by mixed stands of varying age this result can be assigned as reasonably accurate.

In the presented report height estimation from the LIDAR data was found by interpolating the surface models from the raw point cloud. Interpolation always causes the underestimation of real tree height. It can be expected that for increasing pixel size tree height underestimation will increase also. But the presented study shows that there is no statistically significant difference between 0.25 m and 1.0 m raster resolution (mean difference: -0.54 for 0.25 m and -0.55 for 1 m raster resolution). Prior to carrying out these study similar results for height assessment from LIDAR data to stereo photogrammetry were expected.

Estimation of crown area based on different nDSM models always overestimate area compared to stereo photogrammetric measurements. This can be explained by, during 3D observations we are not able to properly locate where the end of the crown is because small branches are invisible. Usually, then, tree crown will be underestimated. Another consideration is that the pouring algorithm completely divided the analyzed surface, so no gaps between extracted crowns segments occur. Even extra processing based on maximum height does not exclude all gaps between crowns. The reason for it is that on each step algoryth works on filtered surfaces.

The general finding based on presented study is that the best for assessment of above parameter is to use nDSM with 0.5m resolution. For this resolution the highest number of trees was detected and height estimation is similar to raster with 0.25 m resolution. Raster 0.5 m is four times smaller than 0.25 m resolution, so without failure of accuracy we can safe hard drive space and analysis time.

6. CONCLUSIONS

Main finding from above study is that 0.25 and 0.5 m raster resolution are the best for selected forest parameters extraction. Model resolution with 1.0 m do have a larger influence on the number of recognized trees, which is crucial parameter for stand volume calculation based on existing models for polish forest. nDSM model is perfect surface for acquisition above described parameters.

As presented in other studies the laser scanner measurements show pretty accurate results for tree height estimation. No matter if 0.25, 0.5 or 1.0 m raster resolution will be used there is no statistically significant difference between their results.

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REFERENCES

Abraham J., Adolt R. 2006. Stand height estimation using aerial images and laser datasets. EARSeL - Proceedings of the *Workshop on 3D Remote Sensing in Forestry*, Austria.

Adler P., 2001. Einsatz digitaler Photogrammetrie zur Beschreibung von Waldbeständen – am Beispiel der digitalen photogrammetrischen Erfassung der Level 2 Flächen Baden-Württembergs. Dissertation, Albert-Ludwigs-Universität, Freiburg im Breisgau.

Akca A., 1984. Zur Zuwachsschätzung mit Hilfe von Kronenmessungen im Luftbild. Allgemeine *Forst- und Jagdzeitung* 6, pp. 136-141.

Będkowski K., 2005. *Fotogrametryczna metoda oceny stanu i zmian wysokościowej struktury warstwy koron w drzewostanach*. Wydawnictwo SGGW, Warsaw, pp. 216.

Coops N.C., Wulder M.A., Culvenor D.S., St-Onge B. 2004. Comparison of forest attributes extracted from fine spatial resolution multispectral and lidar data. C*anadian Journal of Remote Sensing* 6, pp. 855-866.

Duvenhorst J., 1998. Photogrammetrie und Luftbildinterpretation für bestandes- und stichprobeweise Forstinventuren. Möglichkeiten und Vorschläge für neue Konzepte in der Forsteinrichtung. Dissertation, Albert-Ludwigs-Universität, Freiburg im Breisgau.

Feldkötter Ch., Henjes M., Lucaschewski I., 1995. Analytische Auswertung einer CIR-Luftbildzeitreihe zum Nachweis von Veränderungen der Vitalitäts- und Wuchstumsparameter eines Fichten-Kalkungsversuchs. Beisch T., Akça A., Komp K.U. (Hrsg.): Fernerkundung und Geo-Informationssysteme in der Ökologie der Landoberfläche, Göttingen, pp. 49-62.

Heurich M., Weinacker H., 2004: Automated tree detection and measurement in temperate forest of central Europe using laserscanning data. *Proceedings of the ISPRS working group on Laser-Scanners for Forest and Landscape Assessment*, Germany.

Huss J. [Hrsg.], Akca A., Hilderbrandt G., Kenneweg H., Peerenboom H.G., Rhody B., 1984. *Luftbildmessung und Fernerkundung in der Forstwirtschaft*. Herbert Wichmann Verlag, München.

Hyyppä J., Hyyppä H., Litkey P., Yu X., Haggrén H., Rönnholm P., Pyysalo U., Pitkänen J., Maltamo M. 2004. Algorithms and methods of airborne laser scanning for forest measurements. "Laser-Scanners for Forest and Landscape Assessment". *Proceedings of the ISPRS working group on Laser-Scanners for Forest and Landscape Assessment*, Germany.

Maltamo M., Packalén P., Yu X., Eerikäinen K., Hyyppä J., Pitkänen J., 2004. Identifying and quantifying heterogeneous boreal forest structures using laser scanner data. . *Proceedings of the ISPRS working group on Laser-Scanners for Forest and Landscape Assessment*, Germany.

Mauser H., 1990. Analytische Stereoauswertegeräte bei der Kronenzustandserhebungen. *Österreichische Forstzeitung* 12, pp. 39-41.

Nuske R. S., Nieschulze J., 2004. Die Vegetationshöhe als Werkzeug zur Ermittlung von Bestandeshöhen*. Allgemeine Forst- und Jagdzeitung* 1/2, pp. 13-21.

Olsson H., 2004. Summary of the Scandlaser 2003 workshop and recent development in Sweden. "Laser-Scanners for Forest and Landscape Assessment". *Proceedings of the ISPRS working group on Laser-Scanners for Forest and Landscape Assessment*, Germany.

Piekarski E., 1972. Czynniki wpływające na dokładność określania wysokości drzew stereoskopowymi przyrządami fotogrametrycznymi. *Zeszyty Naukowe SGGW, Leśnictwo* 17, pp. 135-153.

Soille, P., 1999. Morphological Image Analysis, Springer, Berlin, 316 p.

TopoSys, 2004. http://www.toposys.de/toposys-de/unternehmen/images/aktuellespdf/PressReleaseUsedFalcon-EN.pdf. (accessed 26 Apr 2008)

Weinacker, H., Koch, B., Weinacker. R. 2004a. TREESVIS - A software system for simultaneous 3D-Real-Time visualization of DTM, DSM, Laser raw data, Multi-spectral data, simple tree and building models. *Proceedings of the ISPRS working group*

on Laser-Scanners for Forest and Landscape Assessment, Germany.
Weinacker H., Koch B., Heyder U., Weinacker R. 2004b. Development of filtering, segmentation and modeling modules for lidar and miltispectral data as a fundament of an automatic forest inventory system. *Proceedings of the ISPRS working group on Laser-Scanners for Forest and Landscape Assessment*, Germany.

APPENDIX

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