DTM GENERATED FROM LIDAR DATA UNDER FOREST CONDITIONS

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ABSTRACT:

Since laser scanners systems became operational working tools, there have been many studies carried out to find the best way of their utilization. Generating a digital representation of the Earth surface and / or land cover has proven to be the biggest advantage of Light Detection and Ranging (LIDAR) data. The main objective of the presented study is to find out if there are any variations in accuracy between different resolutions of Digital Terrain Models (DTMs) generated from LIDAR data acquired in two seasons. The presented study was carried out in the forest range Głuchów, central Poland, owned by Warsaw University of Life Sciences in Warsaw and containing different types of forests: from one layer stands of Scots pine (*Pinus silverstris* L.*)* to multilayer and mixed stands with Birch (*Betula*), Alder (*Alnus*) and Hornbeam (*Carpinus betulus* L.). Generally flat relief covers the study area, with mean height above sea level around 185 m. The Falcon II airborne laser scanner system from Topographische Systemdaten GmbH (TopoSys, Biberach Germany) was used for LIDAR small footprint data acquisition. For this analysis the data of a flight in May and August 2007 were used. Ground survey data were recognized as reference data. During the 2007 and 2008 field sessions, 95 points spread throughout the area were measured. DTMs were generated in TreesVis software (FELIS, Germany). Models with 1 m, 2 m, 3 m, 5 m, 10 m and 20 m spatial resolution were interpolated. Results showed that if the bias error will be removed from data, even in forested areas measured in spring we can expect a DTM accuracy of 10 – 30 cm, comparing to reference data, for raster resolutions from 1 m to 20 m. Digital ground models up to 5 m can be generated in forested areas without significant statistical differences.

1. INTRODUCTION

Light Detection and Ranging (LIDAR) is an active remote sensing (RS) technique, used for an accurate detection of terrain elevation. First laser (maser) was created in the 1960s (Baltsavias et al., 1999b). In 1990s first operating system was created and new age in Earth surface model generation has began.

A Digital Elevation Model is a digital representation of ground surface topography or terrain. DEM can be represented as a raster (a grid of squares) or as a triangular irregular network (TIN). DEMs are commonly built using remote sensing techniques; however, they may also be built from land surveying. DEMs are often used in geographic information systems (GIS), and are the most common basis for digitally-produced relief maps. DEM is also called Digital Terrain Model (DTM) and generally refers to a representation of the Earth's surface (or subset of this), excluding features such as vegetation, buildings, bridges, etc. Sometimes Digital Terrain Model (DTM) is used in literature as a synonym either of Digital Ground Model (DGM) or Digital Surface Model (DSM).

LIDAR was established as an incomparable tool for obtaining digital elevation data over large areas with very high accuracy of 10 to 15 cm (Guangping, 1998). By using an aircraft as a platform, high sampling rate, low scanning angle and small footprint size, DTM can be obtained even in forested area. This is because more than at least 10% of sent signals reach ground in a wooded area (Chasmer et al., 2004; Hopkinson et al., 2004, Watt et al., 2004).

Because of uncertainty of LIDAR points reflection, methods of filtration and interpolation algorithms strongly influence DTM accuracy. Different algorithms describe surface in different ways (Kraus and Pfeiffer, 1998; Pfeifer et al., 2004; Sithole and Vosselman, 2004; Hyyppä et al., 2004). There is no algorithm for surface interpolation sufficient for all kinds of landscapes and land covers.

There are many different factors influencing a quality of generated DTMs. The horizontal and vertical qualities of a DTM are directly linked to the source of LIDAR data used for its production. Many factors affecting quality are caused by LIDAR system and flight characteristics, from which the most important are as follow: altitude of flight, footprint size, number of points per square meter (pts/m^2), scanning angle. Using last echo cloud points usually gives better results as compared to the first echo cloud point (Hyyppä at al., 2005), simply because the probability of reaching the ground surface is much higher for the last than for the first LIDAR echo. Sometimes, because of LIDAR data filtration during processing, it is better to use both echo cloud points for DTM calculations purpose. Such preliminary step can improve significantly accuracy of generated DTM.

One of the most important non-technical factors is a season of data acquisition. The comparison of the summer and winter DTMs shows high degree of agreement for the non-forested areas. The differences are generally below 0.3 m, large parts are below 0.1 m. This suggests different penetration rates into high and low grass (Wagner et al., 2004).

There were many investigations carried out to evaluate DTMs with respect to LIDAR systems parameters and flight condition. Additionally, different systems and filtering algorithms were compared. But not much research has been done in model quality comparison for different raster resolutions, especially for DTMs with small pixel sizes (0.5 to 5 m) as well as with quality assessment of DTMs generated in different seasons. For the seasonal influence on DTM accuracy Hyyppä et al. (2005) used data from different years – 1998, 2000, 2003, and acquired by different LIDAR systems: TopoSys I and II. Using data from different years and acquired by different LIDAR system can cause extra errors, because of vegetation changes during the study period and differences in LIDAR system characteristics.

In presented study, LIDAR data from the same year and acquired by one LIDAR system – Falcon II - were used. Thus, for both seasons identical algorithm settings and identical LIDAR systems were used. Under such circumstances it was possible to evaluate influence of seasonal vegetation changes for accuracy of DTMs with different spatial resolutions.

Presented study is a part of unpublished MSc. Thesis (Stereńczak, 2009), UNIGIS Master of Science Programme, Paris-Lodron University of Salzburg, Jagiellonian University, Kraków.

2. MATERIALS

2.1 The Study Area

The study was carried out in almost 1000 ha forest range Głuchów, part of Rogów Forest Experimental Station, owned by Warsaw University of Life Sciences-SGGW. It is located in central part of Poland. Study area is covered by different types of forests: from one layer stands of Scots pine (*Pinus silvestris* L.), 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 stands varies between 50 and 120 years. Generally flat relief covers study area, with mean height above sea level around 185 m.

2.2 LIDAR Data

Falcon II airborne laser scanner system from Topographische Systemdaten GmbH (TopoSys, Biberach Germany) was used for LIDAR small footprint data acquisition. The first and last pulse data were collected in conditions detailed below (Table 1).

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

Table 1 Laser system parameters

For this analysis data from flights on 1-2 May (spring) and 18 August (summer) 2007 were used. The average point density was 20 pts/m² in spring time and about 10 pts/m² in summer time

2.3 Ground Survey Data

Ground survey data were treated as a reference data. They were measured during 2007 and 2008 field sessions. Central points x, y, z coordinates of 95 permanent sample plots were measured. Measurements were done with electronic tachymeter, and results were processed in WinKalk software. Measurement accuracy is ±0.09 m in horizontal plane and ±0.04 m in vertical plane.

Stand parameters (number of vegetation layers, species in the 1st and 2nd forest layers) were determined during field surveying and stereo imagery interpretation, carried out using infra-red images with 0.15 m ground pixel resolution. Images were acquired with a DMC 2001 ZI/Imaging camera in mid-summer 2007.

3. METHODS

3.1 Digital Terrain Models Interpolation

Digital Terrain Models from LIDAR data were generated in TreesVis software (FELIS, Germany), allowing implementation of active contour algorithm for DTM calculation (Weinacker et al., 2004a; 2004b). Last echo cloud point was used for model interpolation. 1m, 2m, 3m, 5m, 10m and 20m spatial resolutions models were generated for two data acquisition seasons: spring and summer.

3.2 Evaluation of the LIDAR-based DTM

For all DTMs, pixels containing 95 ground survey points were identified and selected for analysis. Pixel elevation values were then compared to elevations received during the ground survey using descriptive statistics. Systematic error was calculated as a mean error (ME) between LIDAR-based DTM and reference field measurements:

$$ME = \frac{\sum_{i=1}^{n}\left(Z_{Field} - Z_{Raster}\right)}{n} \quad (1)$$

where: n – number of observations

Z_{Field} – „z" reference coordinate
Z_{Raster} – „z" coordinate - DTM pixel value

Root mean square error (RMSE) was used to quantify random errors:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Z_{Field} - Z_{Raster})^2}{n}} \quad (2)$$

where: n – number of observations
Z_{Field} – „z" reference coordinate
Z_{Raster} – „z" coordinate - DTM pixel value

Bias and random errors were calculated for 12 DTM variants: 6 various spatial resolutions and 2 seasonal LIDAR data sets. Factors such as various spatial resolutions and seasonality were taken into account to assess their influence on differences between reference data and values obtained from different DTMs.

4. RESULTS

4.1 General Data Statistics

Table 2 shows summary statistics of differences between reference and evaluated data for 95 points in 2 seasons and for 6 raster resolutions (95×2×6=1140).

Table 2 Summary statistics for differences between reference and evaluated "z" values

Count	1140
Mean value [m]	-0.10
Standard deviation [m]	0.46
Minimum [m]	-4.50
Maximum [m]	2.55
Range [m]	7.05
Stnd. skewness	-25.14
Stnd. kurtosis	131.41

In this case, the standardized skewness and kurtosis values are not within the range expected for data with a normal distribution. Range has occurred to be relatively large, however, majority of results felt in a range between -1 to +1 m (Figure 1).

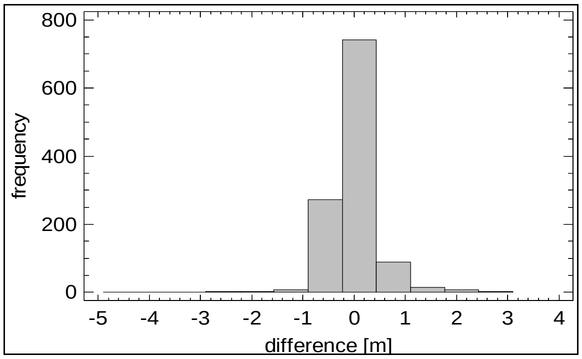

Figure 1 Histogram for differences between reference and evaluated "z" values

4.2 Comparing Differences Between Reference Data and Data from Two Seasons (Spring and Summer) for Different Spatial Resolutions

Table 3 presents values of mean and RMS error for various raster resolutions of digital terrain.

Table 3 General statistics values of DTMs for each raster resolution

Raster resolution	RMSE [m]	Mean [m]	Max. [m]	Min. [m]	SD [m]
1	0,45	-0,18	2,36	-0,98	0,41
2	0,43	-0,16	2,41	-0,96	0,40
3	0,37	-0,16	1,71	-1,16	0,33
5	0,38	-0,13	1,53	-1,36	0,36
10	0,52	-0,04	2,03	-2,87	0,52
20	0,72	0,21	2,58	-4,45	0,69

Results presented in the table 3 show some trends in mean error values. Generally it becomes smaller in magnitude and sign changes from "+" to "-" with increasing pixel size. If we distinguish two seasons it can be noticed that starting from 2 m resolution spring models values are always smaller comparing to spring values, up to 30 cm for 20 m DTM resolution.

Strong correlation between errors values and raster resolution was noticed (Figure 2). If seasons will be taken in to account this correlation is even higher especially for mean error value for sprig based data models, and equal R=0.999. Value for RSM error for summer model was the smallest (R=0.889)

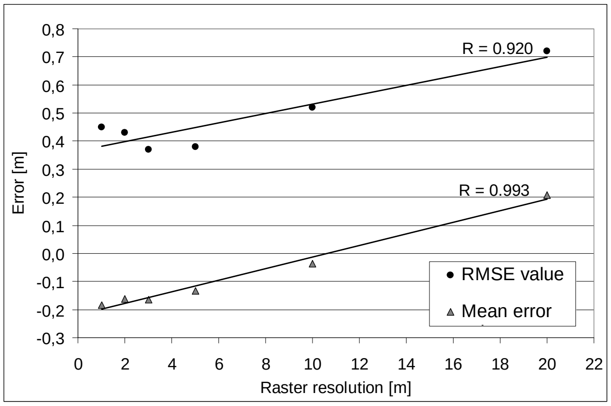

Figure 2 Correlation between ME, RMSE and raster resolution

Additionally large correlation between RMS error and mean error was found (Fig. 3). Correlation is describe the following equation: RMSE = 0,8455×ME + 0,256 [m]. As it is shown below this can be used for DTM resolutions from 1 to 20 m.

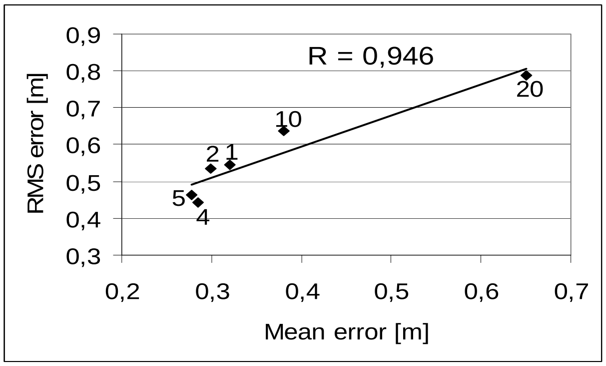

Figure 3 Correlation between ME and RMSE values for 6 used raster resolutions

If seasonality will be taken in to account, it can be seen (Table 4) that model generated from LIDAR data acquired in spring are more accurate. But there is not large difference (but statistically significant at the 95,0% confidence level) between two seasons for all data used in analysis.

Table 4 General statistics values of DTMs resolution for two year seasons

Season of the year	RMSE [m]	Mean [m]	Max. [m]	Min. [m]	SD [m]
Spring	0,39	-0,02	2,58	-0,82	0,39
Summer	0,58	-0,13	2,41	-4,45	0,56

Figure 4 presents error values in order to raster resolution and season. Generally it can be noticed that error values computed for model generated from summer LIDAR data are larger that from spring LIDAR data. Generally it can be noticed that mean values for summer time have more variation compared to spring time where results achieve much smaller range.

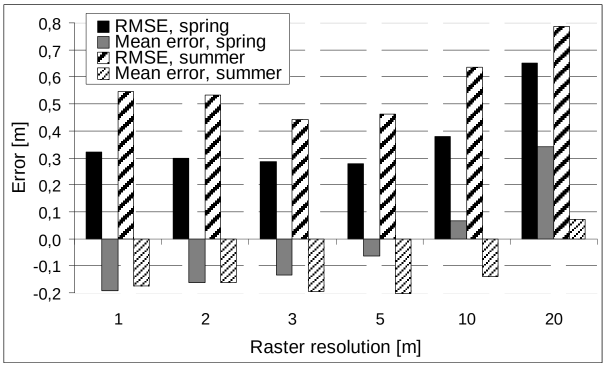

Figure 4 RMSE and ME values in order to seasonality and DTM resolution

ANOVA analysis carried out in Statgraphics software proved that raster resolution and seasonality do have a statistically significant effect on error at the 95.0% confidence level. But raster resolution from 1 to 5 m do not shown statistically significant differences at the 95,0% confidence level.

5. DISCUSSION

Differences between reference data and digital terrain models were analyzed with respect to season of LIDAR data acquisition and raster resolution. Range between maximum and minimum difference was 7.05 m, which is relatively large. Value -4.5 meters was received for 20 m pixel DTM under young pine stand and value 2.55 meter was received similarly for 2m DTM und 50 years old pine. Both models were generated based on summer LIDAR data.

As can be seen (Figure 1), 99% of results are in range of ±1 m. Mean error had similar (Gorte et al. 2005, Yu et al. 2004) or rather small values (-0.10) comparing to other study (Reutebuch et al., 2003), but SD had two times larger value than in other studies (Reutebuch et al., 2003; Wack and Stelzl 2005). This can be caused by different structure of forest and mixed forest species composition.

In presented study no statistically significant differences in accuracies were found for DTMs generated from spring-based LIDAR data, with spatial resolutions ranging between 1-5 m, while further decrease of DTM pixel size led to significant increase of DTM errors. Especially 10 m and 20 m rasters resolution large variations and errors were noticed in both year seasons. This can be due to the selected algorithm of interpolation. Additionally, we can presume that for smaller pixels we are either under a crown or in a crown gap, therefore pixels are relatively homogenous (the local environment is constant). If pixel of analysis is getting larger, it extends not only within the crown or gap area, but rather across a heterogeneous mixture of various conditions.

For 1, 2, 3, and 5 m spring raster resolutions, respectively, all differences have values between -1 and +1 m. For 10 and 20 m raster resolutions there are more pixels underestimating real "z" coordinate and the underestimation is larger – more than 2 meters. Such situation is different for summer data based terrain models. Its differences have higher variation and larger values. Seasonal changes do have influence on received values making larger variation during leaf-on year period. But influence in general have smaller value that it was expected.

Presenting study was carried out in specified environment and used model were interpolated in TreesVis. Generally acquired results proved that using LIDAR data, acquired in any time during the year, can give satisfactory results even in forested area.

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