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GENERATING DEM FROM LIDAR DATA – COMPARISON OF AVAILABLE SOFTWARE TOOLS

Karolina Korzeniowska [1], Małgorzata Łącka [2]

[1] Department. of Geographical Information Systems, Cartography and Remote Sensing,
Institute of Geography and Spatial Management, Jagiellonian University,
Gronostajowa Stret, Cracow
[2] MGGP Aero Sp. z o.o
[1] kkorzeniowska@gis.geo.uj.edu.pl, [2] mlacka@mggpaero.com

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ABSTRACT: In recent years many software tools and applications have appeared that offer procedures, scripts and algorithms to process and visualize ALS data. This variety of software tools and of "point cloud" processing methods contributed to the aim of this study: to assess algorithms available in various software tools that are used to classify LIDAR "point cloud" data, through a careful examination of Digital Elevation Models (DEMs) generated from LIDAR data on a base of these algorithms. The works focused on the most important available software tools: both commercial and open source ones. Two sites in a mountain area were selected for the study. The area of each site is 0.645 sq km. DEMs generated with analysed software tools ware compared with a reference dataset, generated using manual methods to eliminate non ground points. Surfaces were analysed using raster analysis. Minimum, maximum and mean differences between reference DEM and DEMs generated with analysed software tools were calculated, together with Root Mean Square Error. Differences between DEMs were also examined visually using transects along the grid axes in the test sites.

1. INTRODUCTION

Airborne Laser Scanning (ALS) technology is one of the highly accurate methods of collecting large volume, georeferenced 3D data (Weed, 2000; Shan, Toth, 2008). Height above sea level is derived from the distance between scanner and scanned ground surfaces, with known position of the laser scanner. The results of this measurement are "point cloud" data representing the terrain surface and various objects. These data can be used in many ways, most applications are based on classification of "point cloud" data to land cover classes. To obtain a Digital Elevation Model (DEM), 3D buildings, power lines or various types of objects represented in the "point cloud", high-quality classification of "point cloud" data is needed (Wang, Tseng, 2010).

Generating DEM is one of the most important issues in various fields of science using surfaces and morphological modeling (Weed, 2000; Rayburg et. al., 2009). During the last decade, several new methods to generate DEMs with high 3D positional accuracy have appeared. Recent research carried out on ALS has shown that it is one of the best solutions to generate DEMs for large areas in short time. Using ALS we collect "point cloud" data with three coordinates: X, Y, Z representing: latitude, longitude and height above sea level. These data contain additional information such as: intensity and number of return, providing many possibilities of data processing and ‘point cloud’ classification (Shan, Toth, 2008).

Many software tools and applications which offer procedures to process and visualize ALS data have appeared recently. The basic functions of these software tools are: visualization of “point cloud” data as 2D and 2,5D surfaces. Most of this software tools offer also scripts and algorithms for “point cloud” data classification to land cover classes, bare earth extraction, generating Digital Surface Models (DSMs) and generating DEMs from points classified as bare earth (Fernandez et. al., 2007). Depending on software tools we use for “point cloud” data processing, and algorithms for bare earth extraction we can achieve better or worse results with respect to the output DEM.

Extraction of bare earth from “point cloud” data can be achieved in various ways. Depending on the concept of the terrain surface we can distinguish filters based on: morphology (Vosselman, 2000), progressive densification (Axelsson, 2000), surface (Kraus, Pfeifer, 2001) and segmentation (Brovelli et. al., 2002). These filters we can divide into those working on point data (Axelsson, 2000; Kraus, Pfeifer, 2001; Vosselman, 2000) and on data in raster format (Brovelli et. al., 2002). Comparison of performance of these filtering algorithms can be found in Sithole, Vosselman (2004).

DEM accuracy is one of the key issues in hydrological (Kenward et. al., 2000; Liu et. al., 2005; Tymków, Borkowski, 2006), geomorphological (Anders, Seijmonsbergen, 2008; Snyder, 2009) and archeological analysis (Riley, 2009; Chase et. al., 2011). Having at disposal a DEM with high accuracy of X,Y and Z coordinates allows to determine flood flows; adding mathematical models helps to delimit areas with high probability of flooding (Tymków, Borkowski, 2006). High accuracy DEMs enable also to detect changes of coastal lines and increase understanding of various phenomena in the coast zone, for example storm damages posing threat to the infrastructure (Dudzińska-Nowak, 2007).

DEMs with high Z coordinate accuracy are widely applied in landform mapping. LIDAR based DEM with spatial resolution of 1 m may be used to detect discrete landforms like: alluvial fans, glacial landforms, fluvial terraces and rock cliffs (Anders, Seijmonsbergen, 2008).

Shaded relief applied to DEMs derived from correctly classified “point cloud” data may support the detection of archeological object like mounds (Devereux, et. al., 2005), with an effectiveness of almost 90% (Riley, 2009).

Several studies were carried out providing overviews of available LIDAR data software tools, including information about developers, web site addresses to download the software, cost, main purpose of software and analytical capabilities (Fernandez et. al., 2007). There are also other studies which describe possibilities of some specific software, for example those describing potential of Terrasolid (Hejmanowska et. al., 2008; Wężyk et. al., 2008). However, available studies do not include comparisons of software tools in the context of DEM generation results and accuracies.

1.1 Aim of the study

The main aim of this study was to compare algorithms used to classify LIDAR “point cloud” data through a careful examination of DEMs generated from LIDAR data on a base of these algorithms. The algorithms separate LIDAR points into land cover classes, allowing to extract bare earth class representing land surface (DEM). The work focused on the most important available software tools: both commercial (Terrasolid, TLID) and open source ones (Canopy Fuel Estimator [CFE], SAGA GIS).

This work carries useful information on how to process the data and which software parameters should be carefully considered during LIDAR data processing. The study highlights differences in the output DEMs depending on various possibilities of "point cloud" data processing.

2. STUDY AREA

Two test sites in the mountain landscape were selected for the study. Test sites were located in the Podkarpackie Province in the south-eastern part of Poland (fig. 1). Both test sites were situated in the Jasło district; the first test site (test site 1) in the predominantly rural and mountainous part of this district, the other (test site 2) in the urbanized part. The area of each site was 0.645 sq km. Test site 1 was selected to assess the influence of low mountain relief on DEM generation. Test site 2 was selected to assess the influence of infrastructure on bare earth class extraction from the "point cloud".

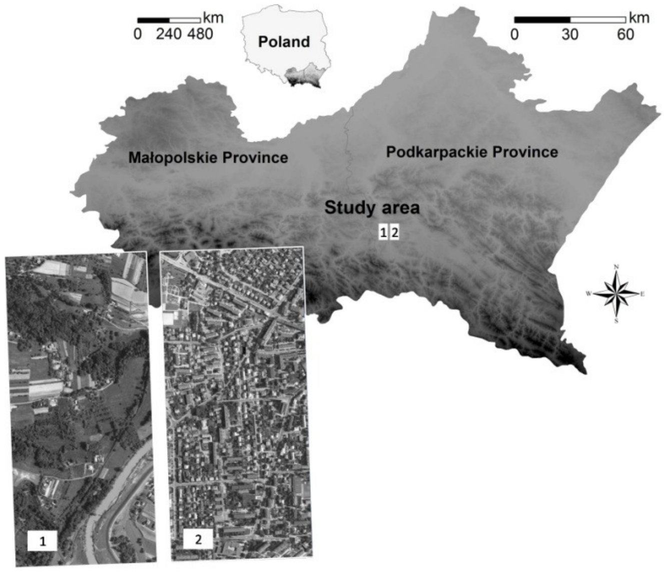


Fig. 1. Test sites in study area: test site
1 – rural mountainous landscapes; test site 2 – built-up (urban) area

3. DATA

Data used in this work (fig. 2) were collected by the MGGP Aero Sp. z o. o. company in June 2010, using LiteMapper 6800i laser scanner. The scanning parameters used to collect data were as follows: minimum point density was 3 points/m², average ground level (AGL) was 1110 m, airspeed was 110 km/h, field-of-view (FOV) was 60° and MODE parameter was set to 5 (300 kHz). Ortophotos with spatial resolution of 15 cm, made from aerial images collected during the same flight as laser scanning data were also used in the study.

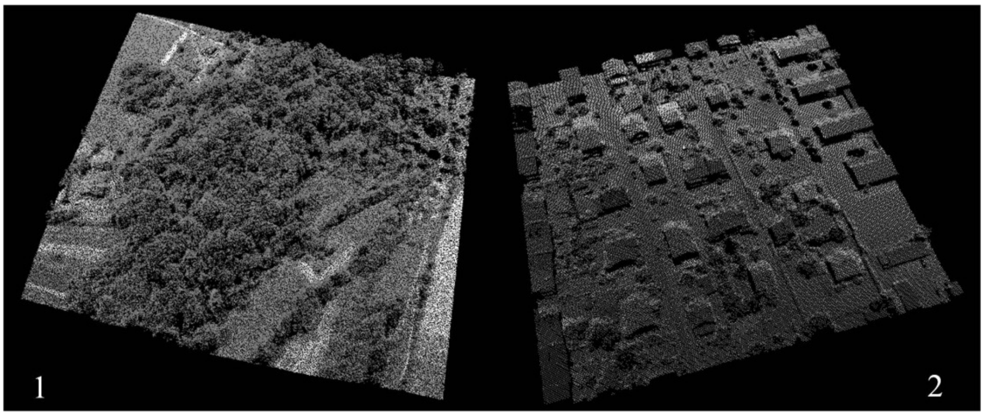


Fig. 2. “Point cloud” data in study area: 1 – test site 1; 2 – test site 2

4. METHODS

One of the most important decisions which has to be taken during LIDAR data processing is related to the selection of filtering methods. The ideal method should be suitable to accurately select bare earth points from “point cloud” data. Majority of bare earth points are points situated at lowest elevation (lowest Z coordinates) or points from the last return. However, in several cases this assumption is not valid, and may lead to errors during DEM generation since non ground points are then used to DEMs generation. In this section possibilities of analysed software tools and parameters used to extraction bare earth class in test sites and DEMs generation were describes.

4.1 Terrasolid (TerraScan)

First, TerraScan (Terrasolid) was used. It possesses several useful options for “point cloud” classification. Extracting bare earth class in this program consists of three steps. The first step is the delimitation of so-called ‘low points’ (points situated lower than ground points). Following options can be chosen: search for single points or group of points (operator can choose maximum number of points), altitude difference and radius to search for other ‘low points’ (TerraScan… 2011). In the study, following parameters were used: maximum amount of group of points – 6, altitude difference was set to 0.5 m and radius – 5 m.

Delimitation of ‘isolated points’ (points with an empty neighborhood, that is no other points can be found within certain threshold distance from a given point, probably due to an erroneous measurement) is a second optional step. A user can select 3D search threshold distance to other closest point – and the minimum amount of points closer than 3D threshold distance, which must be found to define points as correct (TerraScan… 2011). In the study the search radius was set to 5 m and minimum amount of points was set to 1.

The final step in Terrasolid leads directly to finding points which exactly represent the bare earth class. TerraScan builds triangulated surface model. First, selected points with the highest confidence of lying on the ground are selected, then the program adds to the model other points which fulfill specified criteria. One of these criteria is the maximum size of buildings, describing area of search window in which at least one point must be a ground point. Other parameters as iteration distance and iteration angle can also be defined. Iteration distance tells about maximum altitude difference in building triangle (TerraScan… 2011). When triangle is relatively big this parameter is useful and eliminates big differences (for example low buildings are not classified as ground). Iteration angle characterizes angle between an added point and vertex of the closest triangle. When there are small altitude differences in terrain this angle should be smaller, the angle should increase with increasing differences. For the tests, following parameters were applied: max building size 60 m, terrain angle 88°, iteration angle 6°, iteration distance 4 m and reduce iteration angle when edge length < 5 m.

4.2 TLID

The next assessed program was TLID. This software can produce variety of products from input “point cloud”: classified “point cloud”, DSM, DEM, vector layer of buildings and orthophotomaps (TLID…2011). One of the most important options during terrain model generation is an adequate choice of one of three filtering options: *Rural Area Filtering*, *Urban Area Filtering* or *No Filter*. The best results in both analysed test sites were achieved with *No Filter* option. Next option with an influence on DEM smoothing was *DEM Sensitivity* – higher DEM sensitivity means that surface will be smoother. In the testing, value 10 was chosen, one of the highest possible in the software. The other used options were: near terrain classification 15 cm, filter database edges, variable sensitivity algorithm and building area minimum 1 m. In addition, trees height (min. 50 cm) and radius range may be defined. TLID allows choosing resolution and format of the output DEM – it was chosen IMG (Erdas Imagine) file format (TLID…2011).

4.3 SAGA GIS

SAGA GIS was one of two open source software tools tested in this work. At the beginning “point cloud” data were imported to this program. Additional attributes such as intensity, gps-time, classification, number of return can be imported to this software. As an additional attribute classification from preliminary processing ALS data was chosen, because only this information was available in used data. The first step of analysis was “point cloud” to grid conversion, parameters were defined as follows: cell size 1 m, type of aggregation – first value (which means that created grid should be a DSM). Other aggregation parameters, for example: last value, lowest ‘Z’ or highest ‘Z’ could also be selected. In this study ‘only z’ was defined as an attribute to convert “point cloud” data to grid format. Next step was to filter DSM using *DTM Filter (slope-based)* option which leads to an incomplete DEM with no data pixels. For each of assessed test sites various options were chosen: for test site 1, search radius 30 and approximately terrain slope 50, and for test site 2, 20 and 30, respectively. Finally, interpolation was completed using *Multilevel B-Spline Interpolation* (SAGA… 2010).

4.4 Canopy Fuel Estimator (CFE)

The last tested software was CFE (Canopy Fuel Estimator). It is an open source program with a simple interface. To generate DEM at first we have to create a new project file, and specify input data. Next step was a selection of how to model variables to predict canopy fuel weight, crown bulk density, canopy base height and canopy height over the landscapes. These parameters are also use to extract bare earth class from "point cloud" (Canopy… 2011). One or several models simultaneously can be chosen in the analysis. After several attempts it was decided that the best DEM is received if all models are used. In the last step ground filter options were selected (cell size 1m, smooth 6, other parameters set to default values). CFE was used to bare earth extraction for DEM surface generation. Another application compatible with CFE – FUSION – was used for conversion to raster and to change output DEM format (command 'Create XYZ point data set using surface model').

4.5 Conversion DEMs to raster format

From: CFE, SAGA GIS and Terrasolid DEMs were exported in Surfer GRID format, from TLID DEM was exported in IMG (Erdas Imagine) format. All of exported output DEMs had the same 1 m spatial resolutions.

To assess generated DEMs, reference data were generated using manually filtering "point cloud" data to bare earth class with Quick Terrain Modeler software. In reference dataset bare earth was defined as "topsoil or any thin layering (asphalt, pavement, etc.,) covering it" (Sithole, Vosselman, 2003). To support the classification, orthophotomaps were used as well to verify and interpret uncertain points. "Point cloud" data were separated into bare earth class and points that belong to all other objects on the surface (e.g., buildings, gates, fences, cars, lighting poles, trees, medium and low vegetation, power lines and power poles).

Next, bare earth class was exported to Global Mapper software and converted to IMG (Erdas Imagine) raster with 1 m spatial resolution. IMG (Erdas Imagine) extension was chosen because most of Geographical Information System software tools recommended this data format. Spatial resolution was chosen as 1 m for two reasons. First, it well reflected the point density (3 point/m²), next, the software used for analysis (CFE) uses 1 m as the smallest spatial resolution.

4.6 DEM comparison

Further analysis was conducted using ArcGIS software. First stage was to clip test sites to their boundary, because during the export process pixels with no data value (-9999) were taken into account, which would disturb the statistics analysis.

Next, shaded relief from all DEMs (fig. 3) were generated using

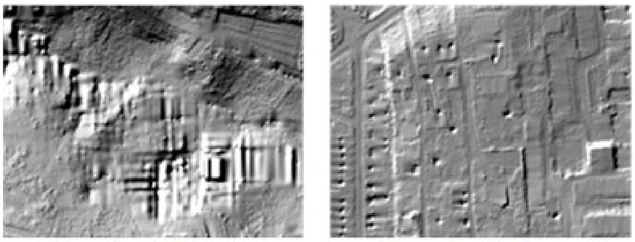
Surface Analysis tool (Hillshade) from Spatial Analyst Tools toolbars. All hillshade surfaces were generated with default 315° azimuth and 45° altitude. Shaded relief were used to visually check output DEMs and were useful to manually erase mistakes from the reference data.

Next, statistical parameters describing differences in height above sea level between a given analysed DEM and the reference DEM were calculated using Raster Calculator in Map

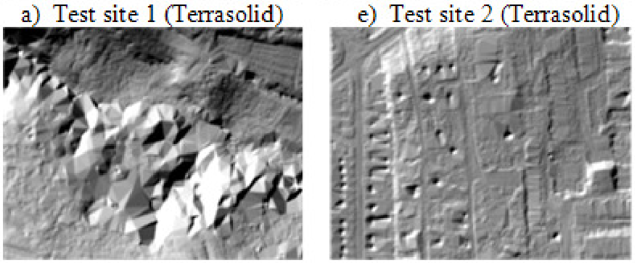
Algebra toolset. Differences were exported in raster format with an IMG (Erdas Imagine) extension and 1 m spatial resolution.

Minimum, maximum and mean differences between analysed DEMs and reference DEM, together with Standard Deviation (SD) and Root Mean Square Error (RMSE) were then calculated. These parameters were calculated with decimetre accuracy. It depended on vertical error of collected data (10-15 cm).

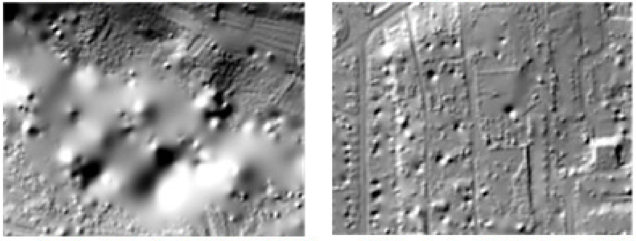
Differences between DEMs were also examined using transects along the grid axes in the test sites. Transects presents differences in elevation between DEM from analysed software tools and reference data.



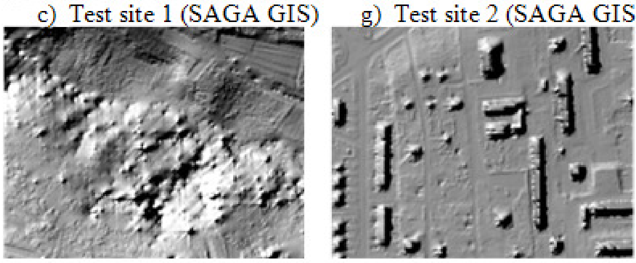
a) Test site 1 (Terrasolid) e) Test site 2 (Terrasolid)



b) Test site 1 (TLID) f) Test site 2 (TLID)



c) Test site 1 (SAGA GIS) g) Test site 2 (SAGA GIS)



d) Test site 1 (CFE) h) Test site 2 (CFE)

Fig.. 3. Digital Elevation Models in test sites, generated on base of analysed software tools

5. RESULTS

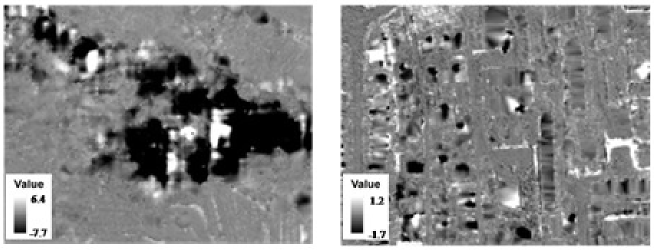
Statistics illustrate that lowest differences (negative pixel values with highest absolute values) – were observed in Terrasolid software for the test site 1 and in CFE for the test site 2 (tab. 1, fig 4). The highest differences were observed in CFE in both test sites (maximum value equal 22.0 m). Minimum and maximum differences do not allow to conclude which software tools achieve better results, because it is possible that only a few pixels have that extreme value. Better parameters to test the accuracy of output DEMs are mean value and standard deviation of differences. The smallest mean differences were observed in SAGA GIS (test site 1) and in TLID, SAGA GIS and Terrasolid (test site 2).

The smallest dispersion from mean value was observed using CFE (test site 1) and Terrasolid, SAGA GIS (test site 2). The highest SD (2.3) was observed in CFE in urban test site 2 (tab. 1). RMSE showed that the best accuracy was achieved on a base of CFE (test site 1) and Terrasolid, SAGA GIS (test site 2), it also showed that the lowest accuracy was observed using CFE (test site 2), where RMSE was 2.4 (tab. 1).

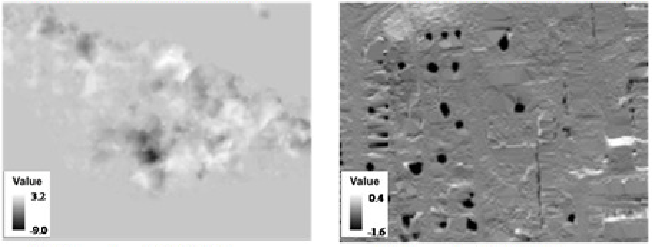
Two transects, 200 m long, from N to S direction (fig. 5, 6) were computed. Transects clearly presented differences between analysed DEMs and the reference DEM for both test sites (fig. 7, 8).

Tab. 1. Differences in meters between analysed DEMs and reference DEM: A – Terrasolid; B – TLID; C – SAGA GIS; D – CFE

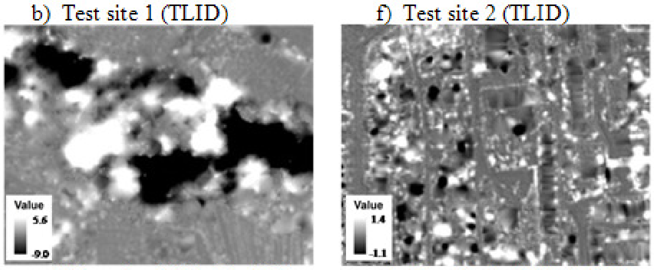
	Min	**Max**	**Mean**	**St.Dev.**	**RMSE**
Bare earth DEM in test site 1					
A	-12.5	8.3	-0.1	0.7	0.7
B	-11.6	4.0	-0.1	0.5	0.5
C	-12.9	7.7	0.0	0.8	0.8
D	-7.9	13.9	0.1	0.4	0.4
Bare earth DEM in test site 2					
A	-2.3	2.4	0.0	0.1	0.1
B	-3.4	5.9	0.0	0.2	0.2
C	-2.8	2.3	0.0	0.1	0.1
D	-3.7	22.0	0.7	2.3	2.4



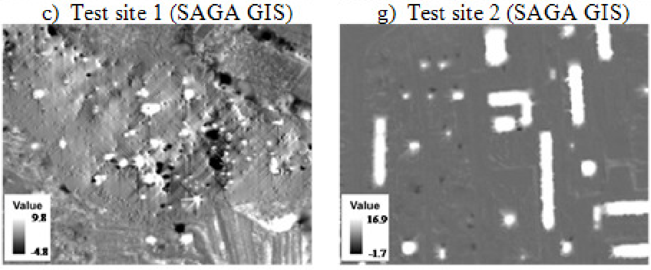
a) Test site 1 (Terrasolid) e) Test site 2 (Terrasolid)



b) Test site 1 (TLID) f) Test site 2 (TLID)



c) Test site 1 (SAGA GIS) g) Test site 2 (SAGA GIS)



d) Test site 1 (CFE) h) Test site 2 (CFE)

Fig. 4. Differences between analysed DEMs and the reference DEM

First transect in test site 1 crossed the valley covered with trees. The highest differences were observed between 60-180 meters where only CFE had errors lower than 2 m. For other DEMs errors were highest than 3 m.

The other transect crossed the buildings and a road in test site 2. Differences between analysed DEMs were smaller than in the rural area (test site 1). Highest errors occurred in CFE, in locations of buildings crossed by the transect.

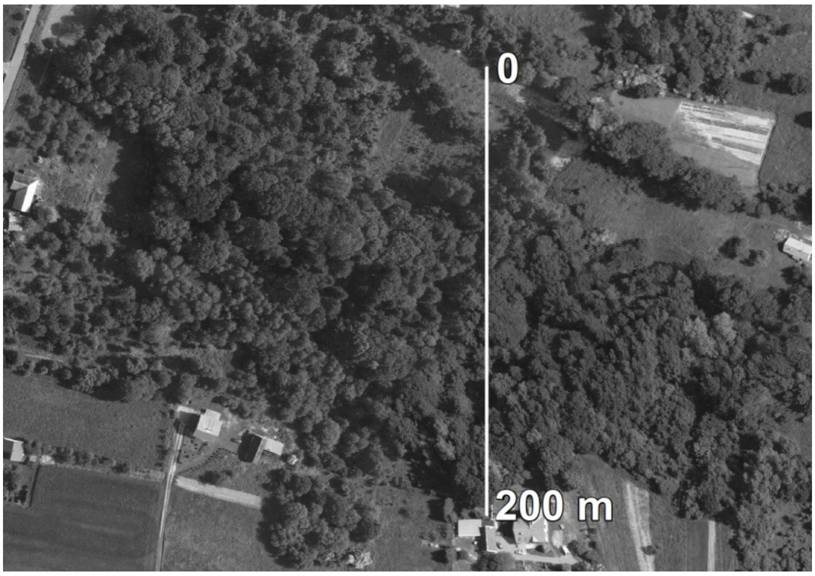


Fig. 5. Transect along the grid axes (the test site 1)

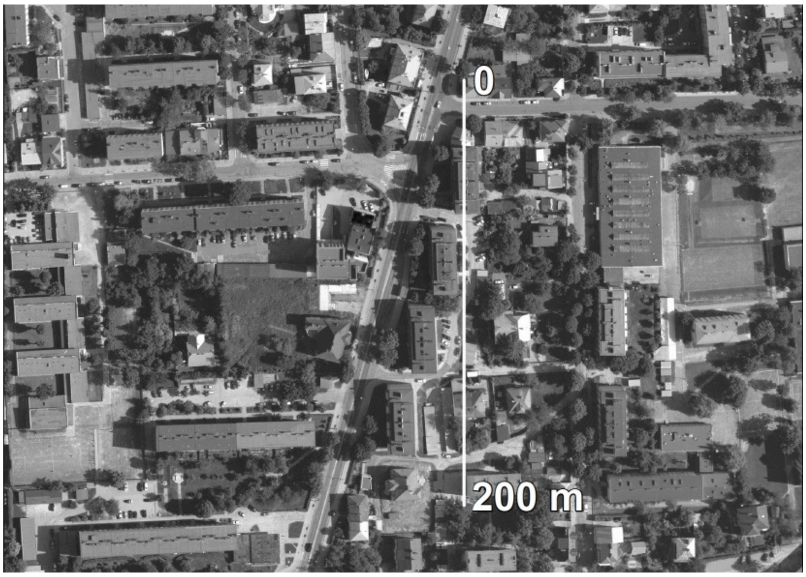


Fig. 6. Transect along the grid axes (the test site 2)

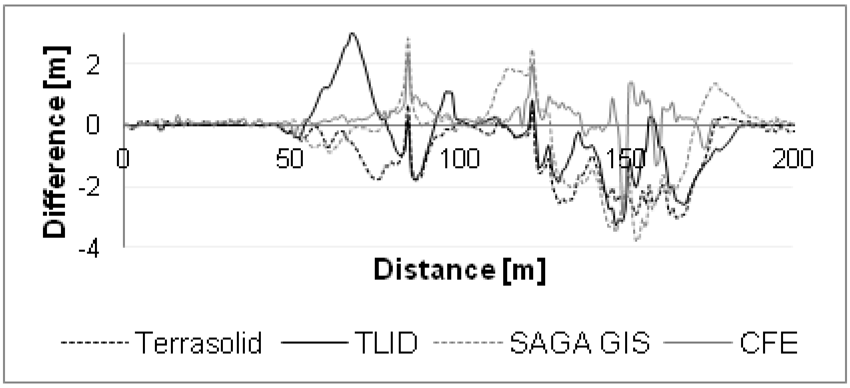


Fig. 7. Transect – differences between DEMs generated using the analysed software tools in test site 1

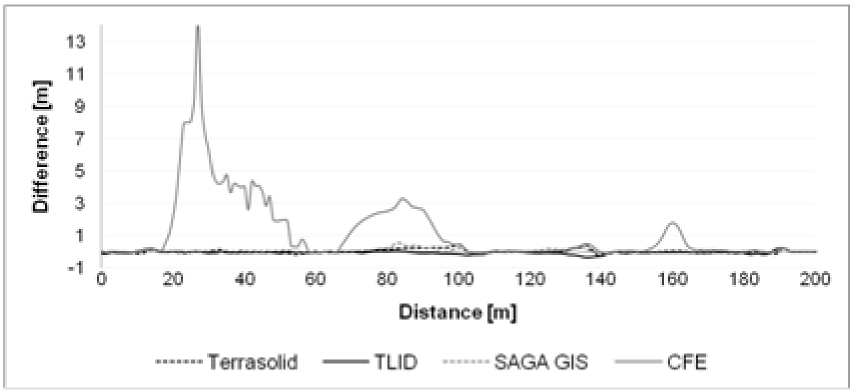


Fig. 8. Transect – differences between DEMs generated using the analysed software tools in test site 2

6. DISCUSSION

Results achieved in this work show that "point cloud" classification is the most important issue in the process of DEM generation from ALS data. Various accuracy can be achieved depending on used algorithms. Algorithms available in the analysed software were based on different concepts to generate DEMs. SAGA GIS generates DEM from raster DSM on a base of terrain slope and search radius assumptions. Canopy Fuel Estimator uses complex mathematical formulas to compute parameters of trees needed to detect forest areas. TLID and Terrasolid use parameters of ground surface objects.

The achieved results showed that all of available software tools give good results eliminating non ground points from the bare earth class in agricultural areas and along roads. Only some errors occurred on slopes with low gradients and low density built-up areas. Most errors occurred in areas with high slope gradients (ravines, deep valleys), in forested and densely built-up areas. The SAGA GIS generated many errors in high-density forest and built-up areas, and also in water class. Better results, but only in rural areas, were achieved by using CFE. The best results in both test sites were achieved through TLID and Terrasolid software tools; in addition only Terrasolid software tool offered a possibility to remove errors manually.

However, it should be mentioned, that achieved results depend also on spatial resolution of generated DEMs. This factor has a strong influence on the detail of computed surfaces. For example, with an increasing pixel size, the small discontinuities of the terrain are ignored and the variability of the terrain is reduced.

Furthermore, the results are influenced also by a relatively low "point cloud" density. Increasing the density would provide better results in forested areas, because it would increase probability of bare earth hits. However, the season of data acquisition has a greater impact on accuracy in forested areas than low point density. More hits from ground will be obtained in early spring or late autumn, when there are fewer leaves on the trees.

7. CONCLUSIONS

Comparison of four software tools designed to process "point cloud" data was presented in this work. Two of them were open source (SAGA GIS and Canopy Fuel Estimator) and other two were commercial (TLID and Terrasolid). Analysis included comparison of algorithms used to classify LIDAR "point cloud" data through a careful examination of DEMs generated from LIDAR data on a base of these algorithms. On a base of statistical analysis, carried out for two test sites it was proved that various software tools lead to different results, in terrain modeling, depending on parameters used and type of the terrain.

This study showed that the analyzed software tools do not allow a fully correct automated classification of "point cloud" data; hence a manual intervention is always needed to eliminate non-ground points from the bare earth point class. Therefore, further work is needed to find new algorithms to automatically remove the errors from LIDAR-based DEMs.

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