Airborne Laser Scanning to Digital Elevation Model – LAStools approach

Kovačević, Jovan; Stančić, Nikola; Cvijetinović, Željko;
Brodić, Nenad; and Mihajlović, Dragan

Abstract: ***Airborne Laser Scanning (ALS) is one of the most popular and cost-effective approaches for collecting Digital Elevation Model (DEM) data. This especially applies to large areas, forested areas, areas with dense vegetation and urban environments. The ALS results in a vast amount of data in the form of point clouds. Successful use of such data requires applying semi-automatic and automatic approaches to classify points according to which objects or phenomena it represents. LAStools software package represents a set of highly efficient tools for processing ALS data. Through this study, the functionality of the LAStools software package for DEM generation has been analyzed. The proposed procedure for generating DEM products from ALS point cloud with LAStools has been determined and presented. The study also focuses on the important parameters of each tool in the proposed DEM procedure, with a special focus on advantages and disadvantages, possibilities and limitations.***

Index Terms: ***Airborne Laser Scanning, LiDAR, LAStools, Digital Elevation Model, terrain***

1 Introduction

Airborne Laser Scanning (ALS) has proven to be an extremely effective method for collecting data on the terrain surface over large areas [1]. This especially applies to forested areas, areas with dense vegetation and urban environments, where traditional approaches have limited applicability. ALS produces an extremely large amount of data in the form of point clouds. Besides X, Y and Z coordinates, each point usually stores some additional attributes, such as the intensity, the RGB components (if the ALS system includes a digital camera), etc. The points collected using the ALS method relate to various objects and phenomena present in the area of interest, such as terrain, vegetation, buildings, etc. One of the proven areas of application of ALS point clouds are the classification of points according to which objects or phenomena it represents. Classified point clouds are now considered standard ALS products, useful for various applications. These include, but are not limited to Digital Elevation Model (DEM) generation [2–3], building reconstruction [4], forest inventory [5–6], power line monitoring [7] and so on.

2 Problem Definition

Several algorithms for automatic and semi-automatic classification of ALS point clouds have been developed. They are available within various commercial, as well as open-source software tools. Most of them include approaches for differentiating points into several general classes (terrain, vegetation, buildings, etc.), while some also include specialized algorithms for differencing point clouds into specific classes (like types of vegetation, powerline elements, etc.).

The *LAStools* software package is the flagship product of *Rapidlasso GmbH* and represents a set of highly efficient tools for processing ALS data [8–9]. Using the tools available in the *LAStools* software package, it is possible to perform classification, data splitting, conversion, filtering, rasterization, triangulation, isoline creation, etc. This paper presents the optimal procedure for creating DEM using *LAStools*. The aim of this study includes the assessment of the functionality of the *LAStools* software package for DEM generation, with a special focus on advantages and disadvantages, possibilities and limitations.

Manuscript received September 27, 2022.

J. Kovačević is at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade, Serbia (e-mail: jkovacevic@grf.bg.ac.rs) – contact person.

N. Stančić is at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade, Serbia(e-mail: nstancic@grf.bg.ac.rs).

Ž. Cvijetinović is at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade, Serbia (e-mail: zeljkoc@grf.bg.ac.rs).

N. Brodić is at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade, Serbia(e-mail: nbrodic@grf.bg.ac.rs).

D. Mihajlović is at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade, Serbia (e-mail: draganm@grf.bg.ac.rs).

3 PROPOSED SOLUTION

The *LAStools* software package is organized in the form of separate tools that are specialized for individual and specific tasks. There are dozens of available tools which are separated into three groups. The first group refers to tools that are free to use and are open-source, the second group includes free-to-use, but not open-source tools and the last group consists of closed-source tools that require a license for most commercial or public uses [9].

A total of seven tools have been identified as crucial for DEM generation from ALS data using *LAStools*. These include *lasview*, *lasinfo*, *lasground*, *lasthin*, *las2dem*, *las2tin* and *las2iso*. The proposed procedure consists of several steps (Figure 1). The first step involves an initial check of the point cloud through 3D visualization using *lasview* tool and obtaining a report about the basic characteristics of the point cloud with the *lasinfo* tool. The next step uses the *lasground* tool to filter points which represent terrain. In the next step these points can be used to export DEM in several standard representations: as raster (*las2dem*), Triangulated Rrregular Network - TIN (*las2tin*) and/or isolines (*las2iso*). To reduce the density of points in uniform areas, there is an optional step to perform point cloud thinning with the *lasthin* tool.

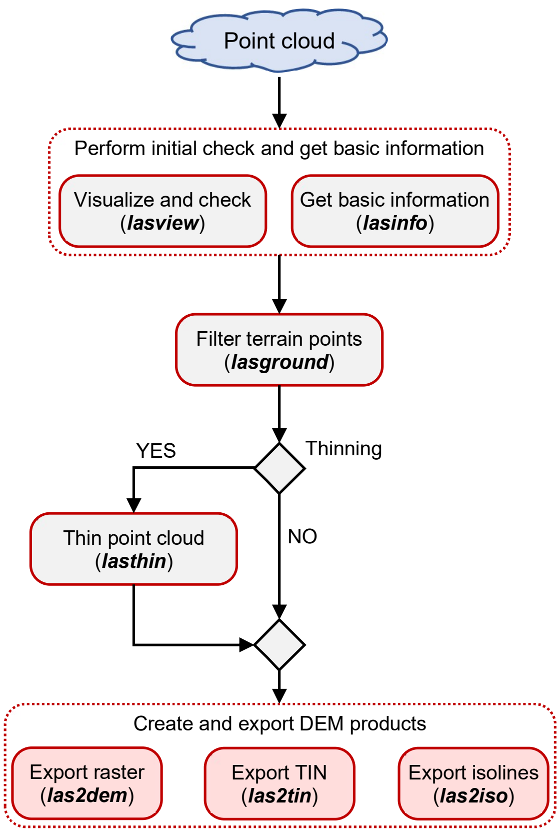

Figure 1: Flowchart diagram of the proposed procedure for generating DEM from ALS point cloud using LAStools

4 EXPERIMENT

4.1 Study Area

The patch of size 1 km × 1 km located east of Arilje, Serbia was defined as a study area (Figure 2). ALS acquisition campaign was carried out in May 2017. using the *RIEGL LMS-Q560* scanning system. During the initial processing, full-waveform signal discretization was performed, with the maximum number of signal returns limited to 5. In addition to signal discretization, initial processing included georeferencing, alignment, and matching of adjacent scan lines. Quality control was also performed using control points and checking the alignment of adjacent scan lines.

Figure 2: Study Area, patch 1 km × 1 km east of Arilje, Serbia

The extracted study area is characterized by different types of relief, different levels of urbanization (number and size of buildings) and variability in the amount and density of vegetation.

4.2 Point Cloud Visualization and Basic Info

The visualization of the point cloud with the *lasview* tool showed that all initial processing steps have been performed successfully (Figure 3). No blunders or artefacts seem to be present, which makes this point cloud usable for DEM generation.

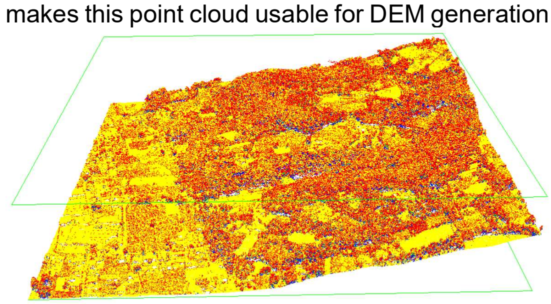

Figure 3: Point cloud over the Study Area colored by several pulse return visualized in lasview

Additionally, *lasinfo* tool was used to gather some basic information and statistics about the point cloud. The most important info from the report shows that the point cloud contains a total of 16 853 017 points, with the distribution according to the number of returns shown in the following figure (Figure 4).

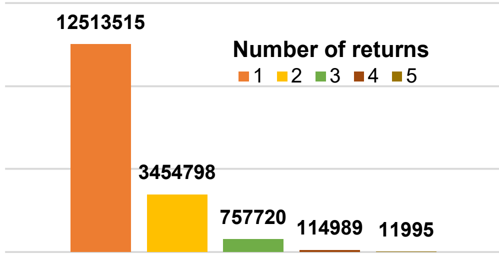

Figure 4: Point cloud histogram based on the signal return number

The calculated points density is 16.85 points/m^2 when all returns are taken into account, or 11.93 points/m^2 when only the last returns are counted. The mean distance between points is 0.24 m for all returns or 0.29 m only for the last returns.

4.3 Terrain Points Filtering

Terrain points filtering is the procedure of classifying points into groups of those that belong to the terrain and of all other points. *Lasground* tool within *LAStools* is intended for this purpose. The tool filters terrain points using a variation of the Axelson algorithm based on TIN refinement [10]. First, the initial set of points belonging to the terrain surface is determined. Based on a coarse grid with a cell size specified by the '***-step***' parameter, a set of points with the lowest height is determined in each cell element. The initial TIN is created using all the lowest points in each grid element. Then, each remaining point that represents the last pulse return is analyzed to see if it belongs to the terrain. Based on the '***-bulge***', '***-spike***' and '***-stddev***' parameters, the point is included in the TIN or not. This way, the TIN is successively refined until all candidate points are checked. Finally, the '***-offset***' parameter is used, which enables all points within a defined distance of the created TIN to be considered as terrain points candidates.

What turns out to be the biggest problem of filtering terrain points using the *lasground* tool is the impossibility of defining parameters that will effectively determine terrain points for various types of relief. Instead, it turns out that the optimal parameters for plains and hills are opposite. To obtain good results, it is necessary to divide the area according to the type of relief that is dominant and then adjust the filtering parameters to each type of relief separately. That way, after filtering the terrain points independently for each segment, they can be merged back into a single-point cloud.

An example of successfully performed segmentation, terrain filtering of each segment and merging the filtered segments back into a single point cloud can be seen in the next figure (Figure 5).

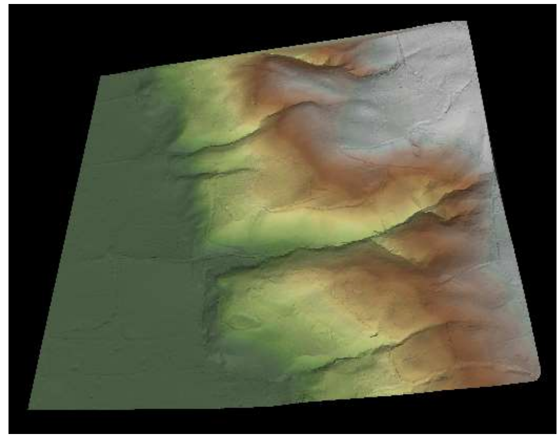

Figure 5: 3D view of terrain surface after filtering terrain points

The biggest observed shortcomings and errors in filtering terrain points include:

- although the line joining the segments follows natural lines and does not cross over artificial objects, it can still be visually identified in certain parts; additionally, some errors that are directly the result of the segmentation and the subsequent joining of segments have been observed;
- the low vegetation points are commonly classified as terrain points, especially in the mountainous area (Figure 6 - a); this is a compromise necessary for a good representation of surface morphology (slopes, cuts, sudden changes, etc.) without cutting off the hilltops;
- the '***-bulge***' and '***-spike***' parameters are important and should be set to preserve terrain morphology, but this can also lead to some unwanted anomalies and artefacts, especially pronounced on steep slopes (Figure 6 - b).

4.4 Thinning of Terrain Points

As a result of terrain points filtering, over 2.5 million terrain points were determined. It is clear that such a large amount of data is not necessary for all parts of the area, i.e. it makes sense to throw out (thin out) some redundant points. The basic idea of thinning implies that the number of points should be reduced as much as possible, while at the same time the quality of the representation of the terrain surface should be reduced very little [7]. Thinning the point cloud can be done with the *lasthin* tool. *Lasthin* uses a simple algorithm which first creates a uniform grid (with a cell size defined by '***-step***' parameter) over the area and then retains the points in each grid cell according to a certain rule. The adaptive thinning option ('***-adaptive xx yy***') is particularly suitable, as the thinning is done taking into account that the points of the new TIN do not vertically deviate from the complete set of points by more than ***xx*** value, and the maximum distance between the points can be ***yy***. This was the variant that was applied in the experiment and it resulted in the reduction of the number of terrain points by ≈80%.

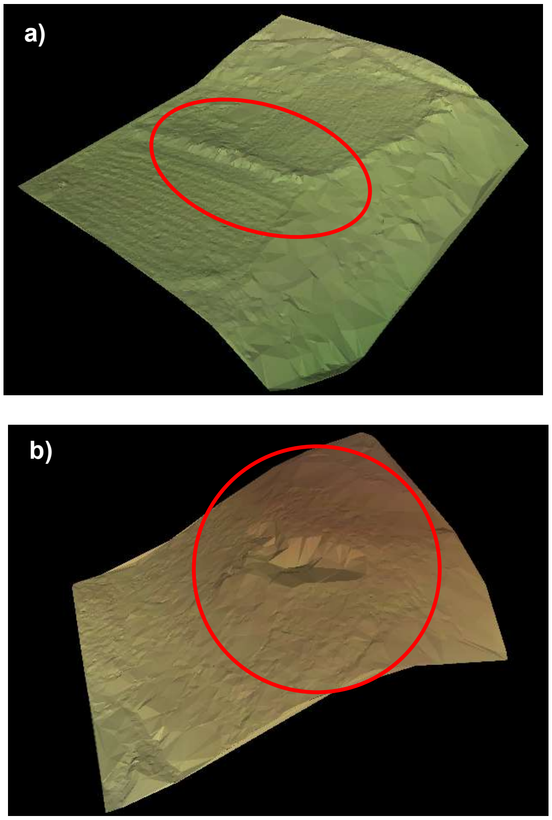

Figure 6: Errors in filtering terrain points
a) A "hole" was created on the slope due to the dense and high vegetation and the large slope of the surface
b) Classification of low vegetation points as terrain points

4.5 Create and Export DEM Products

Creating and exporting different DEM products are very straightforward operations in *LAStools*. Three different DEM representations have been considered: raster, TIN and isolines.

The DEM raster is created using the *las2dem* tool. The tool does not have a large selection of parameters available. The most important is the pixel size of the resulting raster, which is defined by the '***-step***' parameter.

Isolines can be created in Esri Shapefile format as line entities using *las2iso* tool. Equidistance was set to 5m and among the other parameters, '***-concavity***', '***-clean***' and '***-smooth***' proved to be the most important. To avoid deformations at the edges of the area, '***-concavity***' needs to be set to a small value. The '***-clean***' parameter successfully removes unwanted artefacts in the flat area (occurring due to small and slow height changes), and '***-smooth***' parameter ensures that the created isolines are not rough.

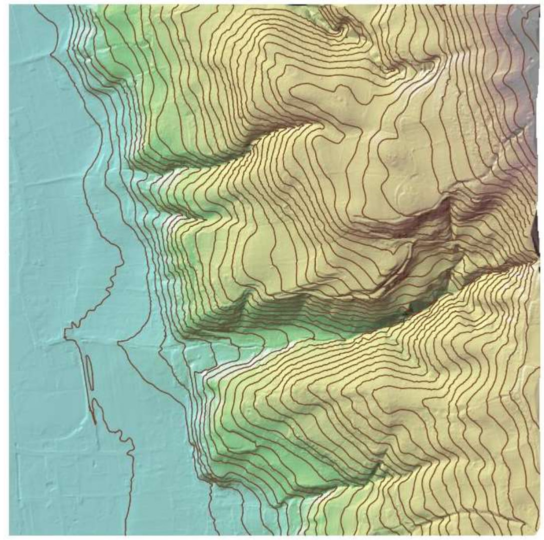

Figure 7. Created and exported raster DEM with overlaid isolines

The TIN representation can be exported using the *las2tin* tool. It should be taken into account that all previously used tools use TIN in the background, meaning that the optimum TIN parameters are already indirectly determined. This means that any refinement in the TIN output needs to be considered in the previous steps, and *las2tin* export parameters should match them.

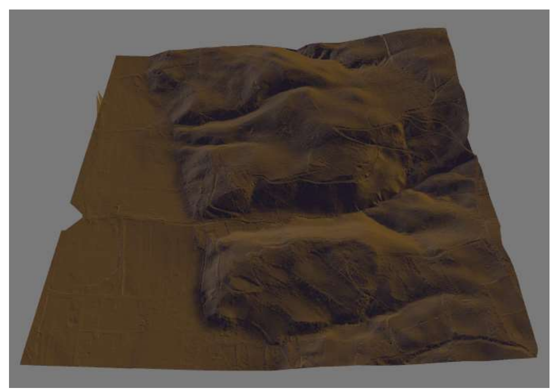

Figure 8. Created and exported TIN

5 CONCLUSION

LAStools software package is one of the solutions that successfully solves the problem of ALS data processing and DEM generation. The package is mainly oriented towards the middle and final level of LiDAR data processing, meaning that it is assumed that the cloud of points has already been created and used as input. Additionally, several tools can be used to correct errors that occurred during the creation of the cloud of points. From the moment the cloud is created, *LAStools* covers the entire production process to the final topographic products.

It can be concluded that the *LAStools* software is intuitive and that the available documentation shows the functionalities of each tool in a good way, precisely and concisely, with numerous guidelines for the correct selection of parameters. The biggest drawback of the package is that each tool applies the specified parameters to the entire input dataset, i.e. there are no internal mechanisms for adjusting defined parameters to different types of terrain and/or different levels of urbanization. This problem can be overcome to some extent by segmenting the area according to the prevailing characteristics. On the other hand, it is evident that all tools cope very well with a large amount of data, whereas with the distribution of processing by processor cores it is possible to achieve very high performance.

The individual tools used in the experiment proved to be up to the tasks for which they were intended. As a key component of the production process, one can certainly single out the filtering of terrain points with the *lasground* tool. The quality and success of all subsequent steps and created products depend on it. All tools have a large selection of parameters that enable customization of the resulting products following the specific needs of the user. Through visual analysis, it was determined that the quality of all created products is satisfactory. Still, the big problem can be the appearance of unwanted artefacts and the merging of neighboring objects as a result of terrain filtering errors and insufficient density of points.

Acknowledgment

This research was partially supported by the Serbian Ministry of Education, Science and Technological Development under grant no. 200092.

References

[1] M. Elmqvist, E. Jungert, F. Lantz, Å. Persson, U. Söderman, and P. O. Box, “TERRAIN MODELLING AND ANALYSIS USING LASER SCANNER DATA,” p. 8.

[2] P. Axelsson, “DEM Generation from Laser Scanner Data Using Adaptive TIN Models,” 2000, vol. 33, pp. 110–117.

[3] X. Meng, N. Currit, and K. Zhao, “Ground Filtering Algorithms for Airborne LiDAR Data: A Review of Critical Issues,” *Remote Sensing*, vol. 2, no. 3, Art. no. 3, Mar. 2010, doi: 10.3390/rs2030833.

[4] N. Yastikli and Z. Cetin, “Classification of raw LiDAR point cloud using point-based methods with spatial features for 3D building reconstruction,” *Arab J Geosci*, vol. 14, no. 3, p. 146, Jan. 2021, doi: 10.1007/s12517-020-06377-5.

[5] A. M. Lechner, G. M. Foody, and D. S. Boyd, “Applications in Remote Sensing to Forest Ecology and Management,” *One Earth*, vol. 2, no. 5, pp. 405–412, May 2020, doi: 10.1016/j.oneear.2020.05.001.

[6] D. S. Boyd and F. M. Danson, “Satellite remote sensing of forest resources: three decades of research development,” *Progress in Physical Geography: Earth and Environment*, vol. 29, no. 1, pp. 1–26, Mar. 2005, doi: 10.1191/0309133305pp432ra.

[7] Y. Jwa, G. Sohn, and H. Kim, “Automatic 3d powerline reconstruction using airborne lidar data,” *IAPRS*, vol. 38, Jan. 2009.

[8] C. Hug, P. Krzystek, and W. Fuchs, “Advanced lidar data processing with LasTools,” p. 6.

[9] “LAStools,” *rapidlasso GmbH*, Oct. 02, 2012. https://rapidlasso.com/lastools/ (accessed Sep. 25, 2022).

[10] P. Axelsson, “Processing of laser scanner data—algorithms and applications,” *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 54, no. 2, pp. 138–147, Jul. 1999, doi: 10.1016/S0924-2716(99)00008-8.

Jovan Kovačević, PhD works as an assistant professor at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade. He graduated with a Bachelor of Geodesy in 2015, defended his master’s thesis in 2017 and received his doctoral degree in 2022. His main research areas are remote sensing, photogrammetry, GIS and machine learning.

Nikola Stančić is a PhD student and works as a teaching assistant at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade. He graduated with a Bachelor of Geodesy in 2015 and defended his master’s thesis in 2017. His main research areas are GIS, spatial data management, remote sensing and location-based services.

Željko Cvijetinović, PhD works as an associate professor at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade. He graduated with a Bachelor of Geodesy in 1989 and received his doctoral degree in 2005. His main research areas are digital terrain modeling, GIS, photogrammetry and LiDAR.

Nenad Brodić is a PhD student at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade. He graduated as a Bachelor of Geodesy in 2010 and defended his master’s thesis in 2012. He works as a teaching assistant at the Faculty of Civil Engineering, University of Belgrade. His main research areas are LiDAR, GIS, remote sensing and spatial data management.

Dragan Mihajlović, PhD works as an associate professor at the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade. He graduated as a Bachelor of Geodesy in 1980 and received his doctoral degree in 1991. His main research areas are photogrammetry, remote sensing, GIS and 3D modeling.