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LIDAR FOR GROUND SURFACE MAPPING IN FOREST ENVIRONMENTS

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Abstract

Remote sensing enables the recording of accurate geomorphological data with the capability to efficiently cover large areas. However, the presence of vegetation makes the use of remote methods for terrain mapping difficult. LiDAR can be a solution for forestry projects, as the laser pulses can cross the entire forest canopy and reach the soil underneath. LiDAR data is stored as 3D point clouds containing the pulse returns from the ground or various objects above it (such as power lines, buildings or vegetation). In order to interpolate an accurate Digital Terrain Model (DTM), the points coresponding to the ground returns have to be extracted from the initial point cloud. This process is called ground-filtering or simply filtering.
This paper aims to provide a performance analysis of multiple algorithms for LiDAR data classification. Algorithm performance is reviewed for the case of mountainous terrain, characterised by moderate and steep slopes and forest vegetation of a generally high consistency. Our findings suggest that the Lasground-new algorithm implemented in the Lastools software package provides the most accurate results, with a Root Mean Square Error of elevation values for the study site of 0.34 metres (with over 80 percent of the area having an elevation error of less than 0.20 metres) and an average RMSE for the field plots of 0.66 metres. Free algorithms such as Maximum Local Slope or gLidar provide relatively similar results in terms of RMSE.
Taking into account the difficult test conditions (topographically complex surface with dense canopy cover) we consider LiDAR data to be a possible solution for collecting geomorphological data for forestry applications, as long as a sampling of elevation at finer scales is not required.

Key words:*ground filtering, forest cover, Airborne Laser Scanning, DTM.*

INTRODUCTION

Ground surface mapping has been an active field of research in remote sensing for the past decades. Major technological improvements have made digital surface representations a common data source for modelling physical processes, in practice or research. Within a GIS context, elevation data is usually stored as a *Digital Elevation Model* (DEM). This model is defined as a regular two dimensional array of sampled heights that describe a surface (Wood, 1996). When the model is a representation of the ground surface, it is referred to as a *Digital Terrain Model* (DTM).
DTM usage is widespread in many fields of research or practice, such as ecological and environmental studies, urban planning, soil science, forestry, watershed management or landscape design (Brovelli et. al, 2004).

A modern development in the field of remote sensing is an optical technology called *Light Detection and Ranging* (LiDAR). LiDAR uses active sensors that illuminate the surface of interest by emiting laser pulses at a very high repetition rate. A receiver measures the intensity of the reflected energy and records the time delay between the transmitted and backscattered pulses (Liang et. al, 2012).
Since laser pulses travel at a known speed (the speed of light), the distance between the sensor platform and the illuminated surface is determined. The platform is equipped with a GNSS positioning system so each pulse reflection (generally referred to as a *return*) is stored as a *x,y,z*data point.Most common LiDAR system are discrete return sensors. These have the capability of receiving multiple signal returns for each transmitted pulse (Hengl and Reuter, 2008). The first return could be at the top of forest canopy, for example. If the

canopy is sparse enough, part of the emitted energy can further travel, until it intersects another object (such as a leaf or tree trunk). Insome cases, a sufficient amount of energy reaches the ground surface so that a ground return is also obtained. This makes the technology particularly suitable in forestry, as ground surface mapping is possible even in conditions of dense vegetation cover. In addition, sampling density ensures that high resolution (sub-meter) terrain models can be obtained (Tarolli, 2014). For these reasons, LiDAR data collection from airborne platforms (*Airborne Laser Scanning* – or ALS) is being used on an increasing basis in forestry applications (Sithole and Vosselman, 2005).

Data recorded with a discrete return LiDAR system is stored in the form of point clouds. Besides position, additional attributes are stored for each point, such as the pulse number, number of returns per given pulse, intensity, GNSS timestamp or scan angle (the angle of the emitted pulse measured from nadir). Since only part of the recorded points are returns from the ground surface, these so-called ground points must be separated from object (non-ground) points before a correct DTM can be modelled from the LiDAR data. This process is the most time-consuming step in LiDAR data processing (Sithole and Vosselman, 2004) and is called*filtering* or *ground filtering*.

This study aims to exemplify the workflow involved in the processing of ALS data collected for a forested area, in order to obtain an accurate ground surface model. The issue of laser pulse ground penetration in dense canopy conditions is considered, along with its impact on the representation of small-scale landforms.

MATERIALS AND METHODS

The study site covers an area of 4.80 km^2 and is located in the Vâlcea county of Romania, in the region of the Lotru River Valley. The area is mountainous, characterised by steep slopes and a highly variable topography. Most of the area is covered by beech and spruce forest stands (Figure 1). For comparison purposes, part of the study area is open terrain (meadows, riparian areas) or built-up areas. LiDAR data was collected for the study area from an airborne platform in 2008, using a *RieglLMS-Q560*LiDAR system. The survey was carried out in summer, during full-leaf phenophase. The number of recorded points is aprox. 24 million, with an average density of 5.16 points/m^2.

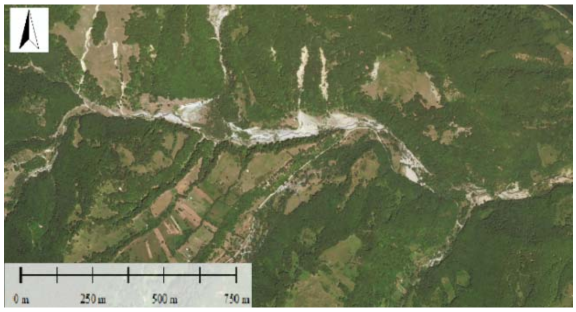

Figure 1. Extent of study area

LiDAR filtering was carried out by the company responsible for data collection, using the commercial filtering algorithm in *Terrascan* (Terrasolid). This filter is similar to the TIN (*Triangular Irregular Network*) densification algorithm developed by Axelsson (2000). A grid with a cell-size defined by the user is overlaid on the LiDAR point cloud.

Afterwards, for each cell, the point with the lowest elevation is added to a set of *seed* points. These points serve as the basis for generating a TIN, which represents a rough estimate of the ground surface. In an iterative process, this TIN is then densified by adding additional points to it. Whether a point is added to the TIN or not depends on its distance to the nearest TIN facet and angles to its nodes (Figure 2). The final TIN should resemble the bare-earth surface and all of its nodes are considered to be ground points. The rest of the points are considered to be above-ground.returns and are discarded from the point cloud.

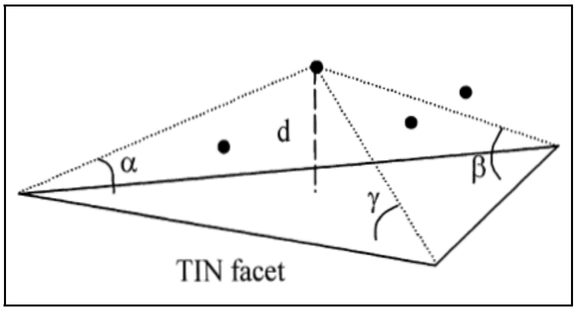

Figure 2.Elements considered when determining if a point is added to the TIN: distance to TIN facet (d) and angles to TIN nodes (α, β, γ). Illustration from Axelsson (2000).

The filtering result was improved by manual corrections. Extensive visual analysis did not highlight any significant filtering errors. Theeffect that filtering has on the generated surface model is presented in Figures 3-4.
The number of points classified as *ground* is aprox. 3.4 million, with an average density of 0.69 points/m^2.

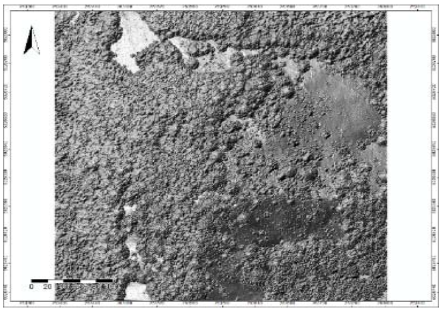

Figure 3. Surface model of forested area interpolated from all LiDAR returns

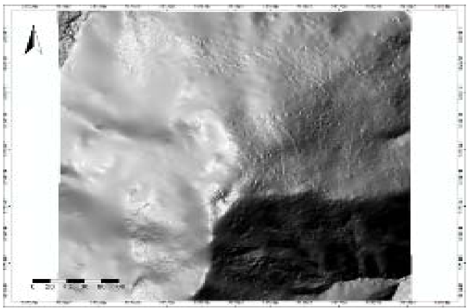

Figure 4. Surface model of forested area interpolated from LiDAR returns classified as *ground* (bottom)

A Digital Terrain Model of the study area was generated at a 0.5 meter resolution, using the *Thin Plate Spline* (TPS) algorithm (Briggs, 1974). Previous research suggests that TPS can generate smoother, oscillation-free surface models from LiDAR data when compared to other interpolators (Evans and Hudak, 2007;Mongus and Žalik, 2012) . Specifically, a variant of TPS implemented in SAGA GIS was used (Donato and Belongie, 2003), which involves the creation of a TIN from the scattered data points. Afterwards, a spline function is fitted to each TIN facet. This method ensures that the resulting DTM has no gaps, even in areas were point density is significantly reduced. The amount of interpolation artifacts in areas of low point density is also reduced.
For comparison purposes the *ASTER* (*Advanced Spaceborne Thermal Emissions and Reflection Radiometer*) Global DEM (ASTER, 2009) was used. Since the 30-arc seconds resolution of the dataset corresponds to a pixel size of 30x21 metres at the latitude of the test area, the raster data was resampled at a 21x21 metres resolution to generate square pixels.Landform feature classification maps were generated using the method proposed by (Wood,1996) and implemented in the Lanserf software (Wood, 2009). The kernel size for feature extraction is 5x5 cells for the ASTER GDEM dataset and 210x210 cells for the 0.5 metres resolution DTM interpolated from the ALS data. This leads to both feature extractions having the same scale of analysis (105x105 metres).

RESULTS AND DISCUSSIONS

The DEM of the study area is presented in figure 5. It can be seen that the ground surface model is relatively smooth, even though some areas are characterised by a rough surface representation. This could be caused by the presence of shrubs or other low-lying vegetation. LiDAR returns from this vegetation might not have been completely filtered out, due to their low height above ground.
An important aspect to consider regarding the use of LiDAR to map forested areas is the effect of dense canopy cover on the laser pulse penetration. There is a clear difference of ground point density between forested and non-forested areas (Figure 6). Even though theoretically the laser pulses can cross the entire forest canopy, and some of them clearly do, the data shows that in dense canopy conditions the ground point density is significantly reduced (Figure 7). Ground point density for maximum canopy density is 0.10 point/m^2, a decrease of 86 percent from the average point density of 0.69 points/m^2 of the study area. Note that these values are based on what are *classified* as ground points, not on what are certainly ground points. However, the effect of incorrectly classified points on the average values presented is likely insignificant.
This sparse distribution of ground points in forest environments makes the choice of interpolator very important. For this study, the TPS (TIN) algorithm in SAGA GIS was chosen because it leads to less pronounced artifacts in the DTM raster structure in areas where points

are scarce, as opposed to other common interpolators (Figures 8-11).

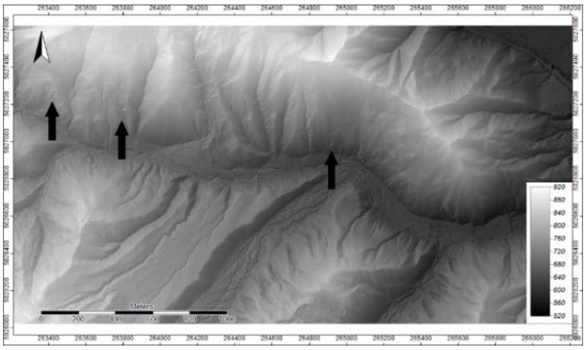

Figure 5.DTM of study area. Arrows indicate rough surfaces, most likely the effect of non-ground LiDAR returns not filtered out.

The feature classification maps generated from the ALS DTM and ASTER GDEM, respectively, are presented in figures12-13. Visual analysis indicates that, as expected, ALS data, with its sampling of elevation at a much higher resolution, leads to a more detailed representation of terrain features (even though the scale of analysis for both datasets is the same)

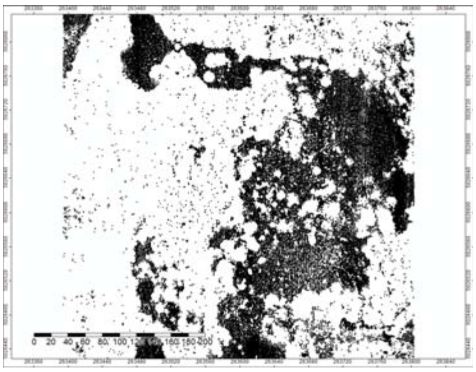

Figure 6. Ground point density in forested (left) areas vs. open terrain (right).

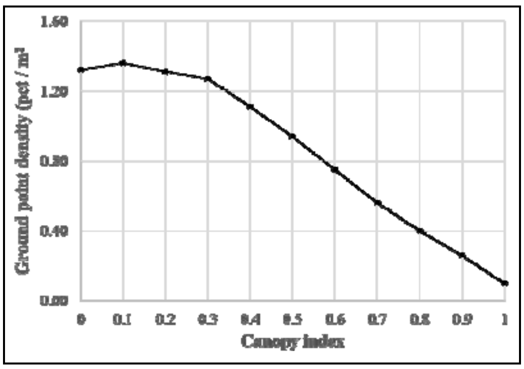

Figure 7.LiDAR ground point density in relation to canopy density index.

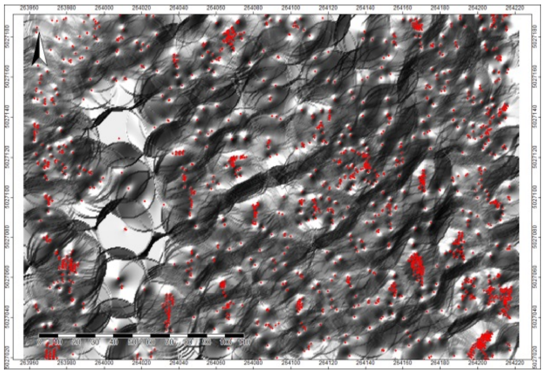

Figure 8. DTM for subset of study area, interpolated with IDW (*Inverse Distance Weighted)*

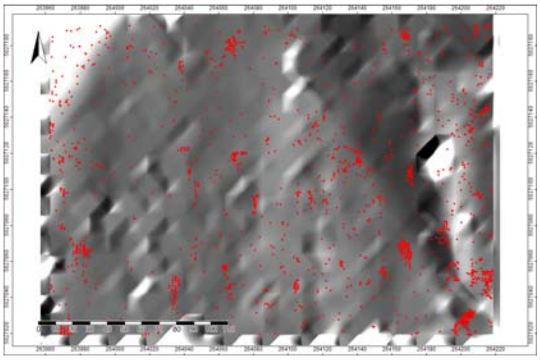

Figure 9. DTM for subset of study area, interpolated *Cubic Spline*

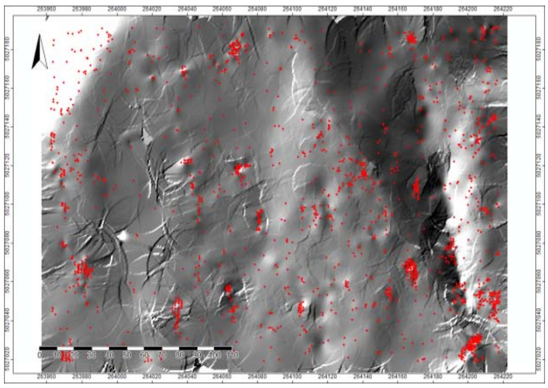

Figure 10. DTM for subset of study area, interpolated with TPS (*Thin-Plate Spline*)

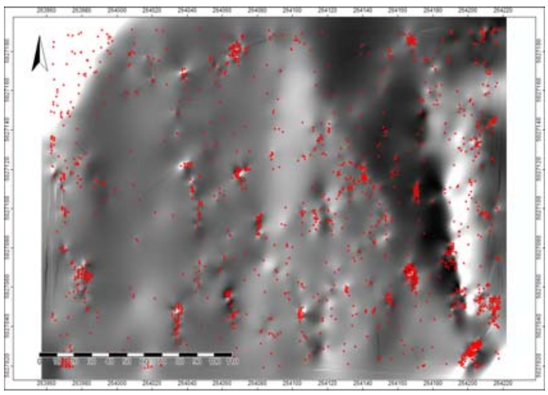

Figure 11. DTM for subset of study area, interpolated with TPS-by-TIN
(*Thin Plate-Spline by Triangular Irregular Network*)

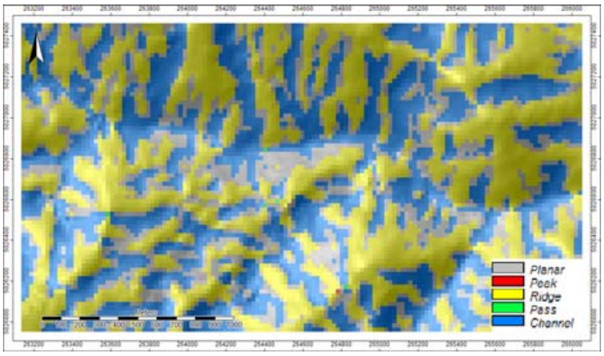

Figure 12. Feature classification map generated from ASTER GDEM

CONCLUSIONS

LiDAR is a recent development in the field of remote sensing that is of interest to many fields of research, including forestry. Laser pulses have the capability to cross through the forest canopy, therefore mapping the vertical structure of the forest and the ground surface underneath it. However, it has been shown that the ground penetration rate is significantly decreased in high consistency forest stands, at least when data is collected during full-leaf phenophase. The penetration rate is expected to increase for mapping campaigns carried out in leaf-off conditions. Nevertheless, even at lower ground point densities, the interpolated DTMprovides a detailed representation of micro-topography.

Since only a small percentage of the point cloud generated by ALS data collection represent ground returns, data processing involves filtering the dataset. As incorrect filtering is one of the main sources of elevation error (Hodgson and Bresnahan, 2004) in a DTM generated from LiDAR data, the choice of filtering algorithm is very important. Furthermore, areas with a complex topography and dense forest cover are among the most challenging conditions for any filtering algorithm (Guan et. al, 2014; Montealegreet al, 2015). In these conditions, manual corrections of filtering results are most likely necessary.

The uneven distribution of ground points (very dense in open terrain, sparser in forested areas) makes choosing an interpolator for DTM generation a non-trivial task. Spline interpolators, while more computing-intensive than linear ones (such as IDW), like the *TPS with TIN* algorithm used for this study, lead to a smoother surface, with less artifacts.

As long as these considerations are taken into account, LiDAR technology can provide a solution for mapping forest environments, providing accurate DTMs at a high-resolution (sub 1-meter) that capture small-scale features of the land surface.

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