Assessment of the performance of eight filtering algorithms by using full-waveform LiDAR data of unmanaged eucalypt forest

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Motivation

- While a general understanding of the accuracy of the LiDAR systems has been achieved, the accuracy of the derived DTM from LIDAR data in forest environments has not been thoroughly evaluated mainly in unmanaged eucalypt forests.
- Although the comparison of the performance of several filter algorithms has been assessed quantitatively by using the omission and commission errors, this procedure becomes impractical when the data are collected in unmanaged forested areas with high point densities (>1 pts/m2). This is because the manually classification of the millions of points involved in a single survey is an unfeasible task.

Aims

- Evaluate the strengths and weaknesses of eight filtering algorithms by using the mean, standard deviation and RMSE metrics.

Study area

The study area, with 900 ha, was selected nearby the city of Águeda, in the district of Aveiro, situated in the Northern part of Portugal (Figure 1-a). Its topography varies from gentle to steep slopes, with altitudes varying from 27 to 162 m (Figure 1-b). Being the area dominated by eucalypt plantations, it also includes some pine stands and few built-up areas. The mean tree density is around 1600 trees per hectare. The forest stands in the area comprise regular and irregular spacing plantations, both even and uneven-aged stands, and stands with various undergrowth characteristics (Figure 1-c).

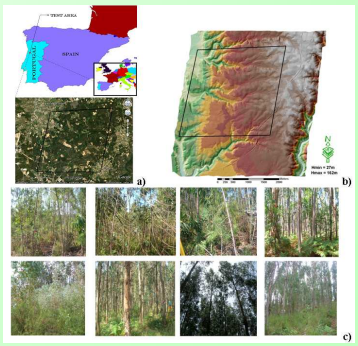
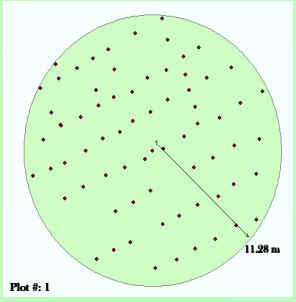


Figure 1: Study area

Data

1. The LiDAR data were acquired on the 14th of July of 2008. The laser system utilized was the Litmapper 5600, operating with a pulse repetition frequency of 150 KHz, an effective measurement rate of 75 KHz and using a half-angle of 22.5º. Thirty overlapping strips (70% of sidelap) were flown from an average flying height above the ground of 640 m with an average single run density of 3.3 pt/m2. The full-waveform laser data were processed with the RiAnalyze software from Riegl. A maximum of 5 returns were obtained with a minimum vertical separation of 50 cm and the average values of laser footprint and point density were 30 cm and 10 pts/m2 respectively.
2. Reference data are needed to verify, in terms of precision and reliability, the DTM produced by means of the laser data and a filtering algorithm. The strategy for the reference data collection was not straightforward. In forest areas, the collection of these data is time consuming, mainly in plots with a high density of shrubs and trees. Furthermore, because the data were georeferenced, geodetic GNSS receivers had to be used. The reference DTM is represented by the coordinates of terrain points located aside trees, which give also the locations of the trees, and by the coordinates of prominent terrain points, like those on breaklines. This information was collected by means of a topographic survey. The coordinate system in which the LiDAR data were collected is the WGS84 UTM zone 29, for X and Y coordinates, and the WGS84 ellipsoidal height for the Z coordinate. Because this is not a local system, the geographic information collected in the field had to be converted to that system by using the Global Positioning System (GPS). To this end, it was decided to attach to each plot two points, named GPS base, whose coordinates were measured with two GNSS receivers. These two points were placed as close as possible to the plot and as much as possible in an opened space. This criterion turned out to be difficult to fulfil in the study area. Finally, 3 174 points were measure on 43 circular plots, of radius 11.28 m, using this methodology.



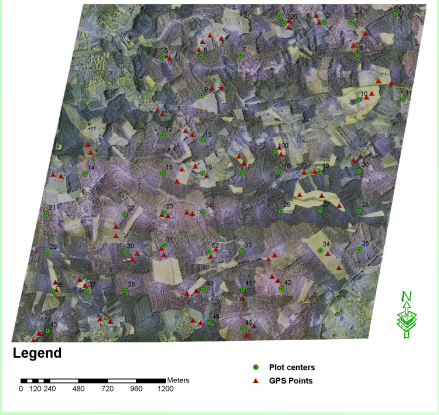


Figure 2: a) DTM points inside the plot n#1. b) Location of the plot centers and GPS bases

Filtering methods

As stated above, seven of the eight filters tested are implemented in the free software ALDPAT®. The eighth filter is the well-known Axelsson filter (ATINT) implemented in the TerraScan® software:

1. Elevation threshold with expand window (ETEW)
2. Iterative polynomial fitting (IPF)
3. Polynomial two surface fitting (P2Surf)
4. Maximum local slope (MLS)
5. Progressive morphology 1D (PM1D)
6. Progressive morphology 2D (PM2D)
7. Adaptive TIN (ATIN)
8. Adaptive TIN in TerraScan® (ATINT)

4. Procedure to assess the performance of the filters

The filters performances are assessed by estimating the accuracy of the DTM produced by filtering the LiDAR data. This accuracy assessment relates to the estimation of the mean, standard deviation and RMSE of the residuals or differences (dz) between the Z values of the reference points and those at the same locations of the LiDAR terrain points.

5. Results and final considerations

Figures 3, 4 and 5 illustrate, respectively, the estimated values for the mean, standard deviation and RMSE, of the residuals obtained in the 43 circular plots and by using the eight LiDAR filters.

Table 1 shows the same results for the eight filters when considering all the plots together, i.e., the 3 174 control points located within the 43 circular plots.

Statistical parametric tests of hypotheses were carried out to compare the mean and standard deviations of the residuals. By using a 5% level of significance the null hypothesis, i.e., the assumption that the mean values are equal was rejected (except for the mean of residuals obtained by using the P2Surf and ATINT filters). For the same level of significance, the tests indicate that the standard deviation values obtained with the filters P2Surf and ATINT are statistically equal and smaller than those obtained by using the other filters. These results show that both filters P2Surf and ATINT have similar performances, which are superior to those of the other filters. The ATIN filter, which is a different implementation of the Axelsson algorithm, has surprisingly the worst performance. In spite of these conclusions, the differences in the accuracy of the various DTM (maximum 6 cm) are not significant for work carried out in a forest environment.

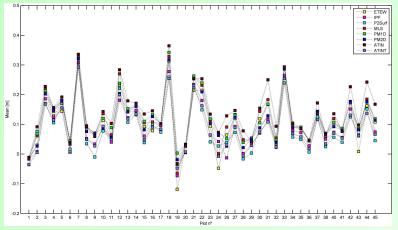


Figure 3: Values of the Mean of residuals per plot for the eight filters.

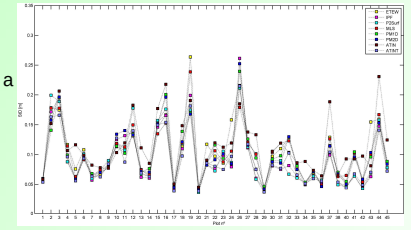


Figure 4: Values of the Standard deviation (STD) of residuals per plot for the eight filters.

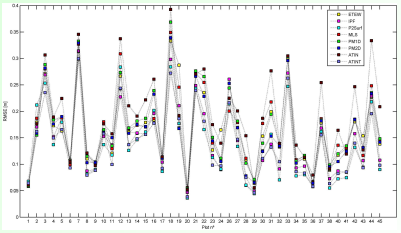


Figure 5: Values of the RMSE of residuals per plot for the eight filters.

	ETEW	IPF	P2Surf	MLS	PM1D	PM2D	ATIN	ATINT
Mean	0.1	0.09	0.08	0.12	0.12	0.11	0.14	0.08
STD	0.15	0.14	0.13	0.14	0.14	0.14	0.15	0.13
RMSE	0.18	0.16	0.16	0.18	0.18	0.18	0.21	0.15

Table 1: Mean, standard deviation and RMSE values (in meters) of residuals obtained by using the eight filters on LiDAR data within the 43 plots together.

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