A stepwise approach for deriving timber assortments of trees from Terrestrial Laser Scanning data

Alvites C.[1], Santopuoli G.[2], Hollaus, M.[3], Pfeifer, N.[3], Mauro M.[4], Moresi F.V.[4], Marchetti, M.[1], Lasserre, B.[1]

[1] Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, Cda Fonte Lappone snc, 86090 Pesche (IS), Italy. Email: {cesar.alvites, marchettimarco, lasserre}@unimol.it.

[2] Dipartimento di Agricoltura, Ambiente e Alimenti, Università degli Studi del Molise, Via De Sanctis snc, 86100 Campobasso, Italy. Email: (giovanni.santopuoli@unimol.it).

[3] Department of Geodesy and Geoinformation, TU Wien, Vienna 1040, Austria. Email: {markus.hollaus, norbert.pfeifer}@geo.tuwien.ac.at.

[4] Department of Innovation in Biological, Agro-food and Forest Systems, DIBAF, University of Tuscia, 01100 Viterbo, Italy. Email: {f.v.moresi, m.maesano}@unitus.it

1. Introduction

Forests provide many goods and services to humans; one of the main goods provided by forests is roundwood.

The roundwood offers socio-economic and environmental benefits to forest owners and stakeholders, mainly because it plays a crucial role in the forestry production chain (SoEF 2020). The roundwood products can be classified into many timber assortments e.g., pulpwood, saw-log, fuelwood, and other industrial roundwood.

Nowadays, quantitative and qualitative information on timber assortments became crucial for implementing sustainable forest activities. Innovative tools and methods are necessary to facilitate the assessment of timber assortments with high accuracy. Despite the enormous efforts made over the years to improve the accuracy of the estimates, several challenges are still evident, particularly for mixed and multi-layered forests.

For these reasons, this study introduces a stepwise approach for catching timber assortment information of standing trees using Terrestrial Laser Scanning (TLS) data in mixed-species and multi-layered Mediterranean forests (Central Italy).

2. Data and Methods

2.1 Study area and ground truth field data

The study area was located in Bosco Pennataro (41°42′ N, 14° 12′ E), in Molise region (Central of Italy) (Figure 1). Bosco Pennataro is characterized by a high tree species richness and heterogeneity of forest structure, forming a multi-layered and mixed forest.

Field data were collected in 2016 within five squared field plots (hereafter ADS) of 529 m^2 (23m * 23m). All trees with a diameter at breast height (DBH) ≥ 0.025m were measured through the Field-Map tool (https://www.fieldmap.cz/). Many forest-related characteristics surveyed from standing trees were: DBH, tree height (TH), the height of the first attached branch or branch union (TH$_1$).

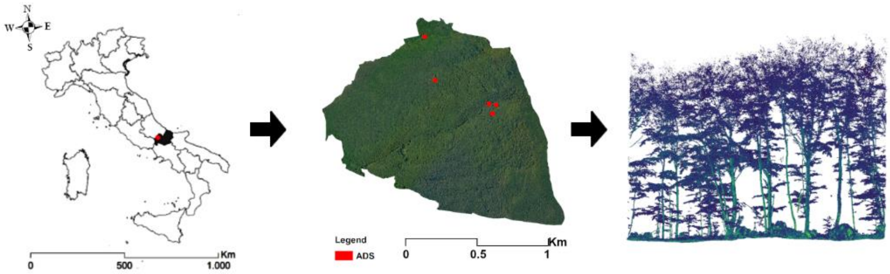

Figure 1 Study area. From left to right: the location of the study area concerning Italy; the distribution of the five squared field plots (ADS) within Mediterranean forests; a vertical slice of Terrestrial Laser Scanning (TLS) data for one ADS.

2.2 Terrestrial Laser Scanning data

The collection of TLS point cloud was carried out in July 2018. The TLS point cloud was acquired using a device named Leica ScanStation P30/40 (hereafter LSS)(https://leica-geosystems.com/it-it/). The horizontal and vertical field-of-view of this device was 360° and 290°, respectively.

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A total of 178 single trees, divided into five ADS, were scanned using the Leica ScanStation P30/40 namely LSS device (about 9 scans for each ADS). To optimize the huge quantity of collected TLS point cloud, we clip each TLS point cloud based on a box dimension of 27m * 27m using many OPALS (Orientation and Processing of Airborne Laser Scanning data) modules, such as opalsImport, opalsAlgebra, and opalsExport (https://opals.geo.tuwien.ac.at/html/stable/index.html). The five TLS scans including the geographic coordinates (i.e. x, y, z) and intensity feature were used as input data for the subsequent steps.

2.3 Ground truth TLS point cloud

Based on the TLS point cloud, some tree variables, as maximum-end diameter, (e.g., trunk base THbase); minimum-end diameter, (e.g. at the end of the trunk assortment – TH_1); trunk length, were manually measured using point picking tool through CloudCompare software. The useful trunk section from TLS point cloud was ranged between THbase and TH_1 (Liang et al. 2018).

To extract the timber assortment information of trees, we selected all trees having a DBH > 0.20m. To improve the characterization accuracy of each trunk section, we divided and classified the logs into merchantable logs (2.5m ≤ length of log ≤ 3m) and non-merchantable logs (2.5m < length of log).

Qualitative and quantitative information for both types of logs was gathered through vary log measurements e.g., straightness (STR; cm m^{-1}; equation 1), tapering (TAP; cm m^{-1}; equation 2), minimum-end and maximum-end diameter of logs (Dmax and Dmin; m); length of log (L; m) (Nosenzo 2007).

2.4 TLS analysis

Four steps were implemented for computing the TLS point cloud: a) timber-leave discrimination; b) tree detection and DBH estimation; c) stem reconstruction and d) timber assortment assessment.

The timber-leave discrimination was performed using geometric-based features from TLS point clouds through Random Forests algorithm. The tree detection allows us to find the tree position and to estimate the DBH of detected trees. The stem reconstruction, corresponding to the trunk section of detected trees, was based on a cylinder-fitting approach implemented in opalsDBH OPALS module. The timber assortment assessment provides both qualitative and quantitative information of trunk sections from standing trees (Figure 2).

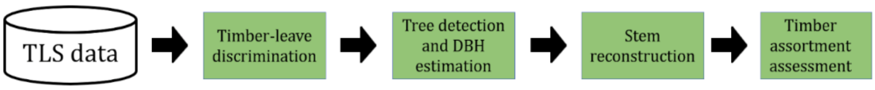

Figure 2 Workflow of Terrestrial Laser Scanning (TLS) processing. The green rectangles represent the steps. DBH is the diameter at breast height.

3. Results and Discussion

3.1 Timber-leave point clouds discrimination

Results revealed that Random Forests algorithm has accurately discriminated the timber from the leaves points in a mixed-species and multi-layered forest, and it was supported by a similar great accuracy (0.98), sensitivity (0.98), and specificity (0.98) values obtained for all five squared field plots, namely ADS. Despite the optimal performance showed by Random Forests, we observed an occlusion effect from large to small trees. It was more evident in the understory layer. However, these occlusion factors were worsened in trees having lianas (Vicari et al. 2019).

3.2 Tree detection and DBH estimation

We detected 151 out of 178 observed trees, reaching an average detection rate accuracy equal to 84.4%, with a high uniformity/similarity among the ADS, based on the standard deviation values (SD = ± 4.7%).

All trees with a DBH > 0.30m were detected. The comparison between predicted and observed DBH measurements from correctly detected trees has outlined that the linear model excluding outlier values was more accurate (R-squared = 0.84; RMSE = 0.02m) than that including outlier values (R-squared = 0.67; RMSE = 0.08m). The problem to identify the trees with a DBH lower than 0.30m might be supported by the shadow effects from large to small trees and/or from branches to trunk, TLS point cloud quality, error in the assembly, the verticality of stems, the non-circular shape of the trunk and the tree species composition (Liang et al. 2018).

3.3 Stem reconstruction

We reconstructed 47 out of 70 observed trees using TLS point cloud through a cylinder-fitting approach, reaching an average stem reconstruction accuracy equal to 67.2%, with a low similarity/uniformity among the ADS (SD = ± 14.86%). Results indicated that more than three-quarters of the trunk section was described by cylinders. The factor conditioned the reconstruction of trees was straightness of trees, the difference of cylinder diameter, TLS point cloud quality, and the forest structure.

3.4 Timber assortment estimation

Results about timber assortment quantification demonstrated that nearby 75% of logs provided by reconstructed trees were quantified, particularly, 134 out of 179 merchantable logs and 34 out of 40 non-merchantable logs were quantified.

As regards Timber assortment classification, results demonstrated that 8 out of 11 assortment types were more accurate, based on the small difference between predicted and observed quantity of merchantable logs (± 2 units). We observed that a part of the logs was “missing” in both log types. We assumed that the occurrence of this problem might be associated with the irregular stem form (i.e. stem straightness) and the irregularities on the bark (i.e. geometry defects: knots, bulges, microhabitats).

4. Conclusion

This study introduces a stepwise approach for extracting the timber assortment information of standing trees using TLS point cloud in a mixed species and multi-layered Mediterranean forest. This is very important to assess and implement sustainable forest management.

Moreover, four conclusions may be drawn from the stepwise approach used for analysing the TLS point cloud. First, accurate timber-leaves discrimination favoured the reconstruction of dominant trees species; second, this stepwise approach proved to be more efficient for large trees (> 0.20m of DBH) and it is advantages for timber assortment assessment; third, the cylinder-fitting approach was powerful, despite the straightness of trees; fourth, the forest structure, bark surface, and microhabitats can influence the success of the reconstruction of trees. Our approach better works in veteran trees, this is a significant outcome, because this approach is focused on trees with a greater timber volume.

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