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Terrestrial laser scanning point clouds and tree attributes from 55 sample plots at the Evo test site (spring 2024)

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Highlights

- Terrestrial laser scanning dataset from 55 sample plots (32 × 32 m) representing boreal forests of Southern Finland.
- Data was acquired in April–May 2024 using a Riegl VZ-400i scanner, providing multiple returns per pulse.
- Each point is annotated with reflectance, return properties, and tree linkage.
- Crown and stem diameters were derived for further analysis, advancing tree and forest research applications.

Abstract

Terrestrial laser scanning (TLS) is an active remote sensing technique that digitizes trees and forest stands by capturing range measurements, resulting in detailed point clouds. To support the development of computational methods for tree and forest stand characterization, as well as to facilitate the exploration of tree structures, we collected TLS data from 55 sample plots (32 m × 32 m) and 6320 trees in Evo, Southern Finland. Data acquisition was conducted during April–May 2024 using a Riegl VZ-400i terrestrial laser scanner (Riegl Laser Measurement Systems GmbH, Austria), capable of recording up to eight returns per laser pulse. This dataset includes TLS point clouds in the projected coordinate reference system commonly used in Finland (ETRS-TM35FIN). Each point is annotated with reflectance, return number, return count, and height above ground. Additionally, information linking each return to its originating tree is provided. For individual trees, the point clouds were further processed to derive key attributes such as crown projection area, crown diameter, and stem diameter. In addition, tree species was derived by linking the TLS-based tree measurements with field inventory data. Here, we describe and share these curated TLS data files and related tree measurements, which offer a valuable resource for advancing tree- and forest-related research and applications.

Keywords boreal forest; ground-based LiDAR; LIS TreeAnalyzer; point cloud processing; Riegl VZ-400i; tree characterization; tree reconstruction
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1 Introduction

Terrestrial laser scanning (TLS) has enabled researchers and practitioners to collect detailed point cloud data characterizing trees and stands. This active remote sensing technique digitizes objects of interest through range measurements, resulting in point clouds (x, y, and z coordinates representing reflections from objects). TLS has been used in forest mensuration research for approximately 20 years (Liang et al. 2016; Calders et al. 2020). From the early days, the technology demonstrated its power in mapping vegetation structures and trees, particularly in measuring attributes such as location, stem dimensions at multiple heights, and crown properties (Calders et al. 2020). These attributes were often excluded from field surveys due to the lack of efficient measurement methodologies (Liang et al. 2016). The widespread adoption of TLS in forest measurement was hindered by the high costs of the sensors, the lack of algorithms and software, and insufficient general knowledge on how to collect and process the data (Fassnacht et al. 2024). Moreover, the expensive equipment was not always well-suited to varying conditions in the field. It should be also noted that for the basic suite of tree and stand attributes, traditional tools like calipers and clinometers often provided more reliable measurements (Luoma et al. 2017; Liang et al. 2018).

The use of TLS in forest mensuration research and forest research in general has increased significantly. Several research groups are utilizing scanners to measure individual trees and sample plots (Liang et al. 2018; Calders et al. 2020; Fassnacht et al. 2024). Additionally, numerous organizations conducting forest inventories for forest management and planning are increasingly interested in TLS measurements. To enable researchers, but also research, development and innovation professionals to utilize TLS data and understand how it can be used to measure trees and forests, we have collected TLS data from forest monitoring plots distributed around the Evo research area. Subsequently, we have georeferenced the scans to allow users to integrate them with other geospatial datasets. In addition, we have segmented to the georeferenced TLS point clouds, individual trees from the point clouds and determined their location, stem diameter, height, and crown characteristics using commercial software. This allows users to utilize either the collected point clouds from sample plots or the interpreted tree attributes for their research and development purposes.

2 Methods

2.1 Study area and selection of the sample plots

The data collection was conducted at the Evo study site, located in Southern Finland (61°12′N, 25°07′E). The site encompasses typical southern boreal forest conditions, ranging from single-species to mixed-species stands, and from even-aged to multi-layered structures. Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) H. Karst.), birches (*Betula* L. spp.), and European aspen (*Populus tremula* L.) are the main tree species. TLS point clouds were collected from 55 sample plots (32 m × 32 m) to reconstruct the 3D architecture of individual trees across various growing conditions and development phases. The sample plots represent a range of canopy heights and closures in Evo, forming a representative sample of regularly monitored plots initially established in 2014 (see the sampling description in Yu et al. 2015). As such, they encompass diverse forest structures.

2.2 Measurements

TLS measurements were carried out under leaf-off conditions between April 22 and May 14, 2024, using a Riegl VZ-400i (Riegl Laser Measurement Systems GmbH, Austria) time-of-flight terrestrial laser scanner (Table 1). We generated hemispherical point clouds by combining two different scanning configurations. In the scanner's standard upright configuration, it provides a 100° vertical and 360° horizontal field of view. To achieve a full field of view, we used a tilt-mount between the scanner and the tripod, enabling the scanner to be rotated 90° from its upright orientation. This setup resulted in a 360° vertical and 100° horizontal field of view in the tilted position. Each plot was scanned from nine different locations (scan positions) arranged evenly around the sample plot, spaced approximately 16 m apart to ensure comprehensive coverage of the plot area. Upright scans were conducted at all nine locations, while tilted scans were performed at alternating positions (Fig. 1). One to three additional scan positions were added for plots 1013, 1014, 1016, 1031, 1037, 1041, 1055, 1057, 1089, 1092, 1112, 1120, 1132, 2028, and 2113, to account for vegetation complexity or challenging topography. During data acquisition, the scanner employed integrated global navigation satellite system (GNSS) and inertial measurement unit (IMU) sensors to estimate its position and orientation in real time. This functionality enabled on-board co-registration of scans without requiring external reference targets.

Table 1. Terrestrial laser scanning data acquisition parameters.

Parameter	Details
Acquisition Dates	22 April – 14 May 2024
Conditions	Leaf-off
Scanner Model	Riegl VZ-400i
Measurement principle	Time-of-flight
Wavelength	1550 nm
Laser Beam Diameter (at exit)	7 mm
Beam Divergence	0.35 mrad (at the $1/e^2$ points)
Beam Diameter at 10, 20 and 30 m	10, 14, 18 mm
Pulse Repetition Rate	600 kHz
Maximum Returns per Pulse	Up to 8
Scan Pattern	'Panorama 40'
Angular Resolution	0.04°
Point Spacing at 10 m	3.5 mm
Vertical Field of View	100° (Scan Position, upright), 360° (Scanner tilted 90°)
Horizontal Field of View	360° (Scan Position, upright), 100° (Scanner tilted 90°)

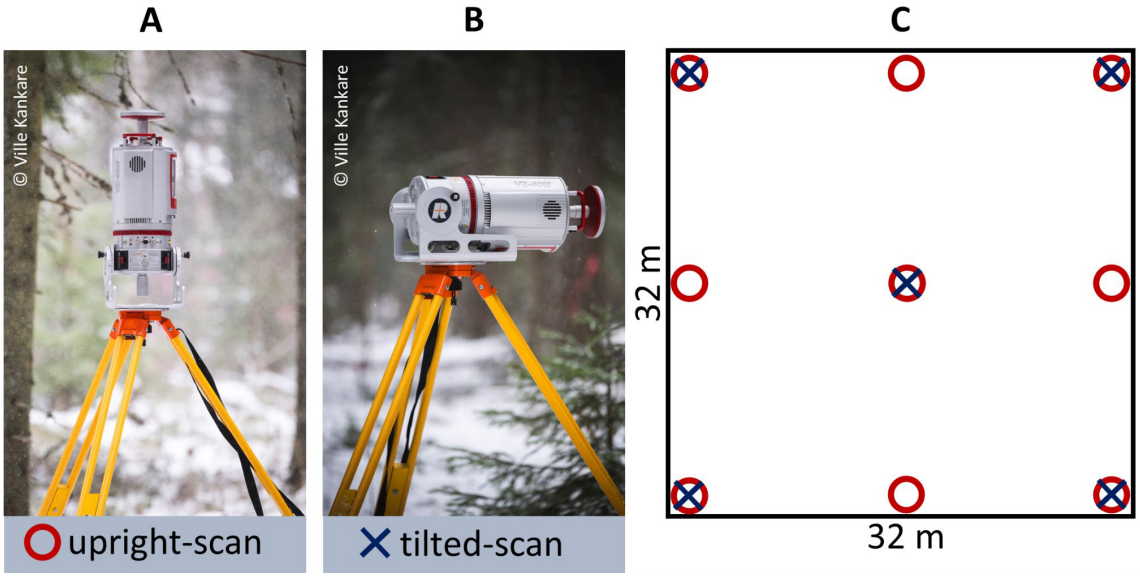


Fig. 1. Illustration of the applied point cloud data acquisition setup. A Riegl VZ-400i terrestrial laser scanner equipped with a tilt-mount to capture both upright-positioned (A) and tilted scans (B), enabling a combined 360° vertical and horizontal field of view. Nine scan positions were utilized to capture the full extent of the sample plots (C).

2.3 Point clouds from the sample plots, including segmentation by individual trees

The individual scans were co-registered and merged using RiSCAN PRO software (version 2.19.3), provided by the scanner manufacturer. To reduce oversampling of surfaces close to the scanner – such as the ground and lower stem sections – the merged point clouds were thinned using 1-mm voxelization. This decimation did not affect the point density of surfaces farther from the scanner, such as upper tree crowns, where the original density was preserved. The point clouds were delineated considering sample plot borders while preserving a buffer around the plot to include neighboring trees for those located along the plot edges. Individual tree detection and segmentation were carried out using the LIS TreeAnalyzer extension, a plugin within RiSCAN PRO developed by Laserdata GmbH (Innsbruck, Austria; Groiss and Handl 2024). Ground points were first identified following Axelsson's method (2000), enabling the creation of a digital elevation model. Subsequently, Z-coordinates were normalized to represent height above ground. Tree identification began with the extraction of a horizontal slice of the point cloud, 30 cm thick, where stem cross-sections were expected to form circular patterns. This slicing was conducted between heights of 1.5–2.5 m, depending on sample plot structure and e.g. the presence of understory and branching density.

To enhance detection accuracy, the extracted slice was filtered to exclude points likely originating from branches rather than stems. This was achieved using scanner-derived attributes: Reflectance (distance-corrected laser pulse intensity, measured in dB) and Deviation (a measure of waveform distortion, represented as an integer between 1 and 20). Preliminary experiments indicated that smooth surfaces, such as the stems, exhibited high Reflectance values and low Deviation values. Based on these findings, points with Reflectance < -2.5 dB or Deviation > 3 were filtered out.

The filtered points were assumed to form circular clusters representing stem cross-sections when projected onto the XY plane. A Hough Circle Transform algorithm, following principles described by Illingworth and Kittler (1987), was employed to identify these circular shapes with a minimum separation of 0.1 m. The identified circles were evaluated based on two metrics produced

by the LIS TreeAnalyzer plugin: 'circle completeness', which assessed the extent of the stem circumference captured, and 'goodness of fit', which quantified how well the circle matched the point distribution. These metrics aided manual validation in identifying false positives, such as points representing branches or undergrowth that were mistakenly segmented as trees. Trees missed by the automatic detection process were manually force-identified to ensure all stems were segmented.

The identified tree locations served as seed points for a bottom-up segmentation process, which delineated individual trees, including their stems and branches, within the sample plot point cloud. This segmentation used a 3D Dijkstra Region Growing algorithm, as described by Bremer et al. (2018), to determine the shortest paths from seed points to the top of the canopy. Points connected to the same seed via the shortest path were assigned to the same tree. To address occlusion-related gaps typical in TLS data – especially in the upper crown regions – path discontinuities up to a maximum gap size of 0.6 m were allowed. A minimum height threshold of 1.5 m was also applied to exclude seedlings and low vegetation from segmentation as trees. Points not associated with any identified tree were not omitted but assigned a classification 'not a tree' (tree ID = 0).

A total of 6320 trees were segmented from the point clouds, with an average of 115 trees per sample plot, ranging from 30 to 369 trees. Based on the tree segmentation, the following attributes were derived for each tree:

- Stem diameter: Measured by a circle fit into points at the height where the tree was identified.
- Tree height: Calculated as the vertical range of the tree's point cloud.
- Crown projection area and crown diameter: Determined from the properties of a polygon enveloping the tree point cloud projected onto the XY plane.
- Circle completeness and goodness of fit: Metrics related to the Hough circle detection method used for tree identification. These metrics reflect the reliability of tree identification and diameter measurement (see the description above).

To address the 1–2 m GNSS localization accuracy during data acquisition, the dataset was georeferenced against real-time kinematic GNSS-measured tree maps from the 2014 field inventory (Yu et al. 2015). For each sample plot, correspondences were established between the XY coordinates of TLS-segmented trees and field-measured trees. These matches were used to compute a 2D rigid transformation (XY translation and Z-axis rotation) to spatially align the datasets.

In addition, tree species information was extracted from the 2014 field inventory data for trees where this information was available. It should be noted that species data were not available for: 1) buffer trees located outside the sample plot borders but included in the dataset, and 2) trees that were not measured in 2014 because their diameter did not exceed the 5 cm threshold. The tree species distribution is presented in Table 2.

Automatic point cloud processing methods (Yrttimaa et al. 2020) were applied to derive stand-level forest inventory attributes from the tree-segmented point clouds. These attributes include the number of trees per hectare, mean basal area, total stem volume, as well as basal area-weighted mean diameter and -height. In addition, basal area proportions for Scots pine, Norway spruce, and deciduous trees were computed based on 2014 field inventory data. These metrics provide context for data users by describing the structural conditions of the sample plots.

3 Data records

In Table 2, we have described all the data records that have been shared.

Table 2. Data record and their descriptions. ETRS-TM35FIN (EPSG:3067) is a projected coordinate reference system (CRS) commonly used in Finland. N2000 is the used vertical reference system. Tree species distribution is presented for tree attributes. For stand-level forest inventory attributes, the minimum–maximum ranges as well as mean values (in parenthesis) across the sample plots is presented.

Data record	Description	Data format
Tree-segmented point cloud data	A point cloud file (one per each sample plot) containing the following attributes for each point record: - X coordinate (Easting) [m], ETRS-TM35FIN (epsg: 3067) - Y coordinate (Northing) [m], ETRS-TM35FIN (epsg: 3067) - Z coordinate (Height) [m], N2000 - Reflectance (distance-corrected intensity) [dB] (stored as Extra Field) - Return number - Number of returns - Scan position ID (stored as Point Source ID) - Height above ground level [m] (stored as Extra Field 'h') - Tree ID number (stored as Extra Field 'treeid')	.laz (version 1.4)
Tree attributes	A text file containing the following attributes for each tree segmented, in the order of their appearance: - **x**: X coordinate of stem cross section mid-point (Easting) [m], ETRS-TM35FIN (epsg: 3067) - **y**: Y coordinate of stem cross section mid-point (Northing) [m], ETRS-TM35FIN (epsg: 3067) - **z**: Z coordinate of stem cross section height [m], N2000 - **plot_id**: Sample plot ID number - **tree_id**: Tree ID number - **tree_sp**: Tree species: *n* 0 = not defined 1882 1 = Scots pine (*Pinus sylvestris* L.) 1811 2 = Norway spruce (*Picea abies* (L.) H. Karst.) 1415 3 = Birches (*Betula* L. spp.) 989 4 = European aspen (*Populus tremula* L.) 71 5 = grey alder (*Alnus incana* (L.) Moench) 44 6 = common alder (*Alnus glutinosa* (L.) Gaertn.) 1 7 = rowan (*Sorbus aucuparia* L.) 68 9 = *Larix* spp. 1 10 = Fir (*Abies* spp.) 6 11 = unknown species 29 12 = common juniper (*Juniperus communis* L.) 3 - **stem_diam:** Stem diameter at the height of tree identification [m] - **tree_height**: Tree height [m] - **crown_area:** Crown projection area [m^2] - **crown_diam**: Crown diameter [m] - **circle_compl:** Circle completeness [%] (related to Hough circle finding) - **goodness_of_fit:** Goodness of fit [%] (related to Hough circle finding) - **pts_on_circle**: n.o. points on the fitted circle (related to Hough circle finding) - **slice_height**: point cloud slicing height (± 0.15 m) for tree identification	.csv (comma delimited)
Forest inventory attributes	A text file containing stand-level forest inventory attributes for each sample plot, in the order of their appearance in the file: - **plot_id**: Sample plot ID number - **x**: X coordinate of sample plot center (Easting) [m], ETRS-TM35FIN (epsg: 3067) - **y**: Y coordinate of sample plot center (Northing) [m], ETRS-TM35FIN (epsg: 3067) min–max (mean) - **N**: number of trees per hectare 166–2080 (697) - **G**: mean basal area [m^2/ha] 4.9–50.9 (30.2) - **V**: total stem volume [m^3/ha] 40.9–625.1 (324.0) - **Dg**: basal area-weighted mean diameter [cm] 16.9–45.2 (28.7) - **Hg**: basal area-weighted mean height [m] 11.8–31.5 (22.1) - **Pine_BA%**: Scots pine basal area perc. [%] 0–99.9 (55.5) - **Spruce_BA%**: Norway spruce basal area perc. [%] 0–100 (26.7) - **Birch_BA%**: Deciduous trees basal area perc. [%] 0–99.3 (17.8)	.csv (comma delimited)

4 Technical validation

The relative 3D positioning accuracy of points in the TLS data is 3 mm at 50-m distance, according to the manufacturer's test protocol. Data georeferencing achieved an absolute localization accuracy of <3 cm when referenced to the 2014 tree maps. Tree identification was manually controlled as an attempt to identify as many trees as possible, yielding 90% overall accuracy when compared against field inventory data that was not, however, inspected for possible missing trees due to harvesting or natural disturbances. It is likely that small trees in the most complex sample plots have remained undetected due to incomplete point cloud reconstruction as typical to TLS-based forest characterization within the study site (Liang et al. 2018; Yrttimaa et al. 2019, 2020).

Usage notes

The data is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) license and is openly available at: https://doi.org/10.23729/fd-5a800660-8bd8-35ef-ac9f-ac5c45f7fa77.

Supplementary files

Metadata of research data.pdf, available at https://doi.org/10.14214/sf.24066.

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Authors' contributions

Tuomas Yrttimaa (Conceptualization, Supervision, Methodology, Writing – original draft), **Lauri Liikonen** (Investigation, Formal analysis, Data curation, Writing – review and editing), **Aapo Erkkilä** (Investigation, Formal analysis, Data curation, Writing – review and editing), **Mikko Vastaranta** (Conceptualization, Resources, Funding acquisition, Project management, Writing – original draft).

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