RINGO Readiness of ICOS

Readiness of ICOS for Necessities of integrated Global Observations

Deliverable 1.7

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Revised Scientific-Technical protocol for standardized biomass observations in ICOS by means of ground LIDAR

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Deliverable: Revised Scientific-Technical protocol for standardized biomass observations in ICOS by means of ground LIDAR

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Deliverable Review Checklist

A list of checkpoints has been created to be ticked off by the Task Leader before finalizing the deliverable. These checkpoints are incorporated into the deliverable template, where the Task Leader must tick off the list.

- Appearance is generally appealing and according to the RINGO template. Cover page has been updated according to the Deliverable details. x
- The executive summary is provided giving a short and to the point description of the deliverable. x
- All abbreviations are explained in a separate list. x
- All references are listed in a concise list. x
- The deliverable clearly identifies all contributions from partners and justifies the resources used. x
- A full spell check has been executed and is completed. x

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SUMMARY

This document describes the data-acquisition of forest above-ground biomass (AGB) using terrestrial laser scanning (TLS) in the circular (r=25m) long-term measurement forest sites in the Integrated Carbon Observation System (ICOS). TLS is a non-destructive measurement system, and can produce extremely accurate 3D pointclouds of its surroundings. Pointclouds of individual trees are modelled into cylinder models that allow direct estimation of tree volume, among numerous other structural parameters. With knowledge of wood density, tree volume can be converted to AGB. AGB is measured to estimate Aboveground Net Primary Productivity (ANPP) and lateral carbon flow through harvest.

This protocol is specifically designed for the benchmark **RIEGL VZ series time-of-flight laser scanner** (one such instrument was acquired in 2019 by the ETC in Antwerp). It can be adapted for other scanner types and manufacturers, however, a thorough validation of the scanning results will be needed. Using VZ scanners, the acquired data should be of sufficient quality to apply geometrical modelling. Regardless of the equipment and scanning protocols, all scanning setups should result in pointclouds meeting the following requirements:

- A uniform point density across the sampling site
- Scans that can be accurately coregistered
- Minimised occlusion and noise

After data-acquisition, scans are coregistered into one pointcloud covering the entire sampling site. Next, individual trees are segmented out of the pointcloud. Optional filtering is applied. Individual tree models are constructed using geometrical modelling to infer tree volume. AGB is calculated from volume using wood specific gravity. However, these next steps (the post-processing) are not fully covered in this document.

This document is structured in different sections. The **MEASUREMENTS** section details the scanning preparations (material, weather conditions), the scanning positions in the plot, and the scanner settings.

The **DATA POST PROCESSING** section covers the coregistration of the single scans into a plot-level pointcloud. Software packages for (semi-)automatic tree extraction and geometrical modelling are listed. Novel developments in lidar technology for forest ecology are highly dynamic. We look forward to new contributions of e.g., mobile and airborne laser scanning, further automation of scan processing, and the development of applications. However, this document is restricted to the more established use of TLS for tree volume assessments.

MEASUREMENTS

Sensors and Material needed

Scans are performed with the RIEGL VZ-400 or similar devices.

- RIEGL VZ-400 or VZ-400i and accessories (battery and spare battery, tilt mount, tripod, cables, opt. camera,…) (see Figure 1)
- Reflectors on poles for coregistration
- Circumference tape, 25m (50m) tape
- Numbered flags to indicate scan positions
- Compass

Figure 1: Laser scanner in operation in a beech forest with considerable amounts of standing and lying deadwood. (left) A tripod is used to stabilise the scanner and to gain a higher point-of-view, and (right) the resulting 3D scan, coloured on reflectance.

Spatial and temporal sampling

The continuous measurement plots (CP) are circular plots with surface of 2000 m² and a radius of 25,24m. Class 1 stations should have at least 4 of these plots and Class 2 stations at least two. The location of the CP is discussed and described in the Instruction on Sampling Design. It must be ensured that the 2000 m² area does not overlap between CPs.

Scans for AGB modelling are collected in winter (leaf-off) to minimise occlusion due to leaves in the scan image. For change detection purposes we expect to have useful results from a time interval of two growing seasons or longer between consecutive scan acquisitions, of course, depending on vegetation type and disturbance regimes.

Measurements at each sampling plot

Weather conditions

Wind and precipitation affect the scan images. 'During scanning, wind speeds over 2.5 m/s (around 10km/h or 2 Bft) are highly undesirable. Rain/snow drops, even smaller-sized, will be detected by the scanner and should be avoided. Mist is, to our knowledge, not affecting the scan quality.

Scanning grid

Before scanning, the scanning positions are marked. In the CPs the centre is located. With measuring tape and compass, 13 scanning locations are defined relative to the centre (see Figure 2):

- The centre itself
- 0°, 60°, 120°, …: at 15m from the centre
- 30°, 90°, 150°,…: at 35m from the centre

A small flag or similar temporary indicator is placed to mark the scanning locations. The location should be >1.5m away from any trees or obstructions. If the scanning location is obstructed, it should be shifted towards the nearest available space. (see Figure 1)

Note: This is a rather rigid scan position layout, and adaptations to local forest conditions can potentially improve the overall scanning performance or reduce the time needed for data collection.

Note: In evergreen coniferous forests, it is impossible scan needle-off. In dense stands, this can cause occlusion problems in the upper canopy. Scans from on top of the measurement tower can yield valuable added perspective to tree crowns.

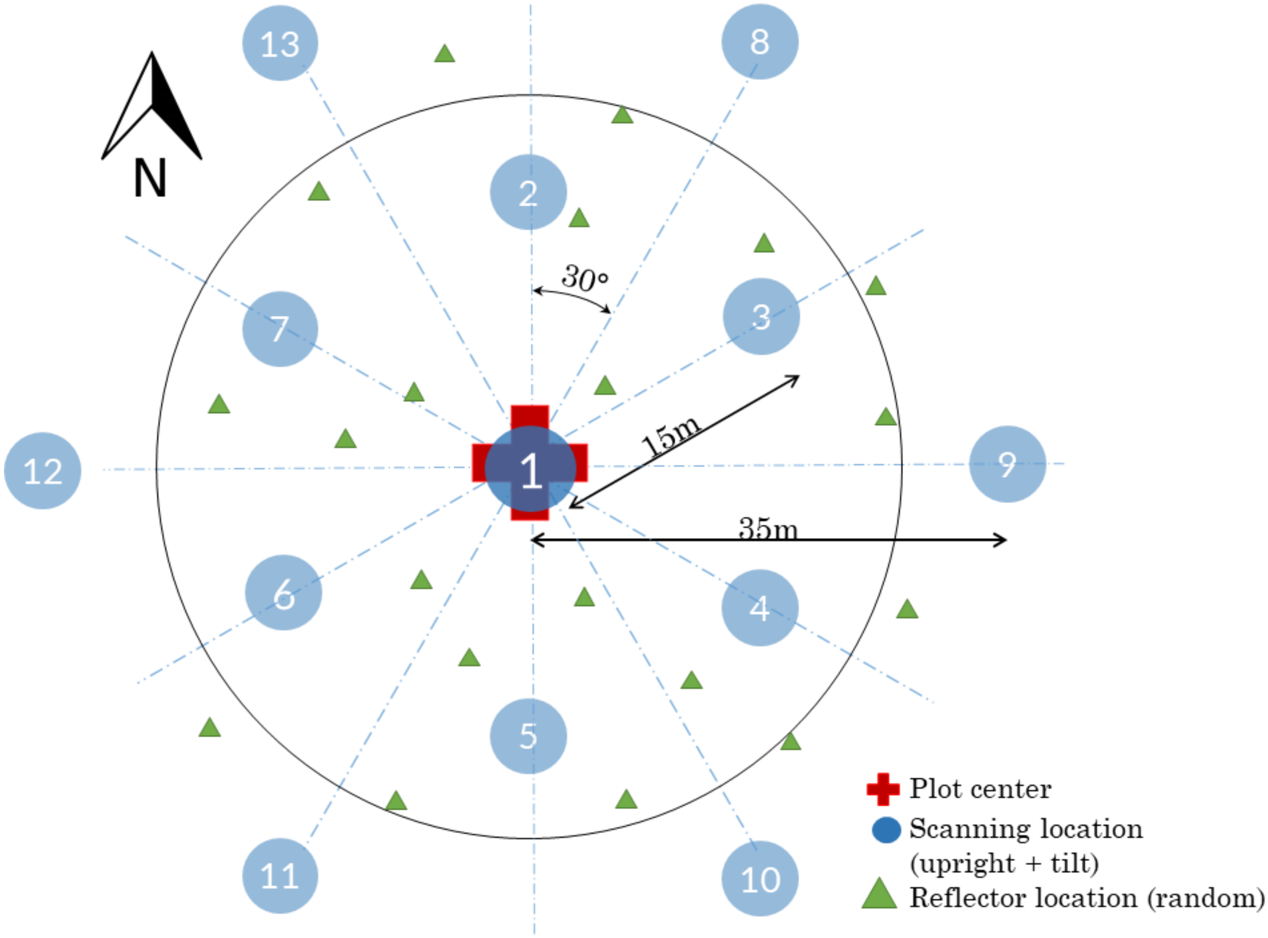

Figure 2: Data-acquisition for geometrical modelling of above-ground biomass with terrestrial laser scanning: scanning pattern in the 25m radius ICOS continuous measurement plots. The scanning chain order is indicated with numbers on the scanning locations. First, the centre location is scanned. Subsequently, starting North, the other locations are scanned in two circles around the centre.

Reflective targets for coregistration: To aid scan coregistration, retro-reflective targets ('targets') are used to link consecutive scans together (see Figure 3). At least four targets, shared between consecutive scans, need to be detected by the scanner for an accurate coordinate transformation in the post-processing. Low understory visibility will require more targets. As a rule of thumb, use 2.5 targets per scan location (i.e., 30 targets in total) that are:

- At least 1.5m from trees, scan locations, other targets, or other obstructions
- Attached on poles, firmly driven into the forest floor

Coregistration is a sub-centimetre accurate operation. It is imperative targets do not move during the entire scanning operation – if by accident targets are moved, they are taken out permanently from the scanning site. For the same reason, we advise to complete scanning within the same day as leaving the reflectors in the forest overnight might attract unwanted disturbance. Varying the height of the reflectors improves the coregistration accuracy ($\Delta Z > 0.5$m). Note: the RIEGL VZ-400i features an automatic registration using an inertial measurement unit (IMU). In principle, targets are not required for this. Consecutive scans should be less than 10-15m apart.

Figure 3: Retro-reflective target positioning: targets are put on poles, firmly planted in the forest soil and at ~1.5m from trees for improved visibility. Photo-degradable forest tape (orange) helps to find all the poles back after scanning.

Scanner configuration

[For Riegl VZ-400 or similar devices] For every location, an upright and a tilted scan are performed in order to get a full hemispherical view. Other scanner types might be making full hemispherical images in one operation (see Figure 4).

Upright configuration:

- Angular sampling interval: 0.04 degrees
- Laser Pulse Repetition Rate: 300 kHz
- Minimum range: 0.5m

Tilted position: The configuration for the tilted position is the same as the upright position, except that it is tilted 90 degrees. For scan positions at the plot border, the scanning axis is perpendicular to the plot centre (view is inwards). For inner scan positions, choice of scanning direction is free, but should be consistent

Figure 4: Riegl VZ-400 time-of-flight terrestrial laser scanner at work. An upright scan can rotate 360° with a 100° viewing angle (left). Adding an tilted scan (right), will produce a view above the scanner. If the two are combined from the same scanning position, a full hemispherical view is produced.

Scanning chain

[For the Riegl VZ-400] Every location is first scanned upright and then tilted. The centre point is taken as the first location. For the upright scan on the first location, position estimation is done (via the inclination sensors in the scanner). No position estimation is needed for the other scan locations. The scanning chain is detailed in Figure 2.

***Optional*: canopy images**

Some scanners can connect to a camera for the collection of RGB values. We refer to the respective manuals of the scanner manufacturers for calibration and data-acquisition guidelines. RGB values are not needed for geometrical modelling, but provide useful information for visualisation and classification.

Estimated timing

Plot layout preparations take about one hour to complete. With the above scanner configurations, a single location (upright and tilted position) takes 10 minutes, including moving the scanner to the next location. The entire 25m radius forest plot take 3-3.5h in good weather conditions and with a trained two-person team. A useful source on data acquisition with TLS is [1].

Figure 5: A slice from a coregistered pointcloud at the FR-FON site in Barbeau, combining 26 scans from 13 positions. The scanning grid is designed to capture full 3D pointclouds inside the CPs. Vegetation and measurement masts outside the CP are also partly covered. However, for volume reconstructions they are not sufficiently complete.

DATA POST-PROCESSING

Data post-processing of TLS scans for tree volume estimation usually follows these three steps:

1. Coregistration of individual scans into one pointcloud using coordinate transformations
2. Segmenting individual trees within the plot
3. Volume modelling of individual trees

This section is based on processing RIEGL VZ-400 data with RiScan Pro software (coregistration) and tree segmentation with *treeseg* algorithm (https://github.com/apburt/treeseg). Volume modelling is done with quantitative structure modelling (QSM) after [2].

Coregistration

Coregistration of the scans is performed in RiSCAN PRO. First, all upright scans are linked in a chain from position 1 up to 13. Consecutively, all tilted scans are registered with its respective upright scan. Upright-tilt registration can be achieved with either a tiltmount calibration or using reflectors.
Settings to find reflectors are:

- Search radius: 1.0 m
- Max. diameter: 0.5 m
- Max. deviation: 20
- Min. reflectance: 4.00 dB

Settings to find corresponding reflectors between scans and perform scan position rotation/translation are:

- Min. amount of corresponding reflectors: 4
- Max. tolerance: 0.02 m

If multiple solutions are found, (i) one that minimises the standard deviation of the residues is preferred, and (ii) the quality of the linkage is checked manually. After linking all the scans, a multi-station adjustment fine-tunes the coregistration. First, plane patches are extracted. Next, two (three if needed) consecutive adjustments with decreasing search radius (from 0.1 to 0.05 m) are performed, and Gaussian residuals are checked. The result is a fully coregistered pointcloud (see Figure 5).

Note: For scanners using an IMU manual, coregistration becomes obsolete; it is replaced by RIEGL's Automatic Registration feature.

Tree segmentation with *treeseg*

We refer to [3] and https://github.com/apburt/treeseg for a full description of a semi-automatic tree segmentation algorithm. The basic idea is locate the trees in a scanned area by finding cylindrical stem parts in a pointcloud slice a few meters above the forest floor. These parts ('seeds') are then grown downwards to extract the tree stump and upwards to extract tree crowns, based on cylinder fitting, Euclidean clustering, and region-based segmentation. Depending on forest type and crown closure, a certain percentage of trees needs to be segmented manually. It is advised to check all final trees thoroughly for segmentation commission/omission errors. Manual segmentations can be done in e.g., *CloudCompare*. Usually, spectral filtering and downsampling of the pointclouds is also performed to remove noisy points and to reduce the amount of data storage needed. It also enables faster processing of the pointclouds into structure models.

Quantitative structure modelling

QSM is performed with the tool *treeQSM* from [2]. *treeQSM* requires an optimisation of input parameters, which can be achieved by computing QSMs over a range of realistic input parameter combinations, followed by a best-model selection. For instance, the optimal parameter combination can be selected based on a minimisation of the mean point-model distance. Since *treeQSM* is stochastic in nature, identical input parameters can produce slightly different QSMs. By making e.g., ten reconstructions per input parameter combination, a standard deviation on the total tree volume can be calculated. Clean, non-obstructed,

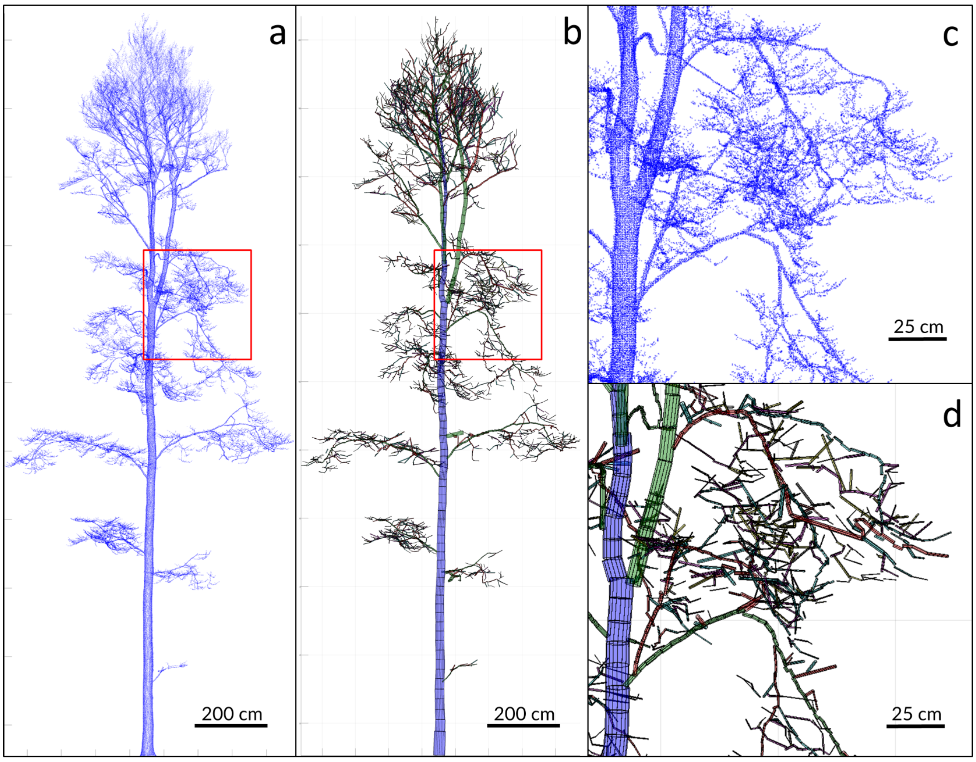

Figure 6: A pointcloud of a 21m tall beech tree, collected in winter (a) and its conversion into a quantitative structure model or QSM (b). The QSM is represented by a series of connected cylinders, in this render coloured on branching order, with blue the main stem, green as first branching order, red as second order, etc. Magnifications of the pointcloud and model in (c) and (d). Faraway and finer branches are harder to correctly model than close-by, larger surfaces.

correctly segmented pointclouds, reconstructed with appropriate input parameters, will render stabile models and hence have a low standard deviation on the volumes of repeated runs (see Figure 6).

Alternative tools for post-processing

Alternatives for coregistration

Most scanner manufacturers have proprietary coregistration software, e.g., Faro Scene, Leica Cyclone. The new Automatic Registration 2.0 (RIEGL) allows a substantially faster scanning procedure (multiple ha/day) by eliminating the need for reflective targets and by automating the coregistration process.

Alternatives for tree segmentation

CompuTree (computree.onf.fr, [4]) and 3D FOREST [5] are point cloud processing software packages with a built-in semi-automatic tree segmentation functionality. Trees can be segmented by manual clipping too (in point cloud software as CloudCompare).

Alternatives for volume modelling

SimpleTree [6] (also as functionality in CompuTree [7]) is an alternative QSM method to [2]. Several more recent techniques are in full development.

DATA STORAGE

Using the above scanner settings, one scan location (upright + tilt) uses about 600 Mb. An entire plot will require between 8 to 15 Gb of memory.

Outputs of TLS forest data acquisition campaigns can be shared/stored in various stages of the processing – some examples:

- The unprocessed scans (direct download from the scanner)
- Coregistered pointcloud; either as one large pointcloud, or as individual scans with their respective coordinate transformation matrix
- Coregistered and segmented pointcloud; e.g. classified in ground returns; vegetation returns containing individual trees.
- As QSMs (matlab file)

MAINTENANCE

Regular scanner maintenance should be performed as indicated by manufacturer instructions. This typically consists of a routine maintenance every second year, which requires shipping the instrument back to its factory. Lenses of the scanner and camera can be cleaned if necessary using cleaning cloth for glasses. After mounting the external camera a short mounting calibration is needed (for RIEGL VZ-series type of scanners).

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ANNEX 1 - List of abbreviations

AGB	Above-ground biomass
ANPP	Aboveground Net Primary Productivity
CP	Continuous measurement plots
ETC	Ecosystem Thematic Centre (of ICOS)
IMU	Inertial measurement unit
QSM	Quantitative structure modelling
RGB	Red, Green, Blue
TLS	Terrestrial laser scanning