Assessing Approaches to 3D Tree Reconstruction from Terrestrial Laser Scanning Data

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1. Introduction

3D reconstruction of tree models is useful for a wide range of fields and a number of methods have been proposed using terrestrial laser scanning (TLS) data to generate visually realistic results, but the results vary among different methods and parameters settings.

To quantitatively validate the reconstructed models, one way is to use synthetic point clouds simulated from tree models with known architecture, but the reference models are not real trees which cannot represent evaluation in real nature environments. Another common approach is to compare model estimations with manually measured data obtained from harvested trees or segmented branches. Destructive sampling is a reliable way to provide real ground-truth reference, but the process of manual measurements is time-consuming and laborious, resulting in small size of datasets with simple structure in existing literatures.

When it comes to specific assessment metrics, a number of global indices are summarized to evaluate geometry reconstruction, for example, average distance between the input points and the generated model (Du et al., 2019), absolute and relative error of tree parameters such as branch length, diameter and volume (Lau et al., 2018). Although these indices provide a general assessment of geometry quality, there is a possibility of getting the right answer in a wrong way. On the other hand, topology reconstruction is more difficult to validate. To assess the accuracy of branch order, Lau et al. (2018) visually paired each manually measured branch to the model counterpart, and used a confusion matrix to reveal the accuracy, but they only considered branches that could find a pair in modelled results, so the overall accuracy was high up to 99%. Boudon et al. (2014) proposed an evaluation framework that detects similarity of topological structure between two skeleton models, but it only applies to skeleton-based reconstruction methods and needs experienced researchers to manually define tree skeletons for reference. Therefore, a universal and comparative method to validate 3D tree models is still lacking, especially regarding topology, while the correct topological connection is the prerequisite for retrieving accurate tree structure parameters.

This work validates two widely used reconstruction methods, TreeQSM (Raumonen et al., 2013) and SimpleTree (Hackenberg et al., 2015), using simulated point clouds based on TLS-measured forest structure. The evaluation demonstrates that the simulation approach based on TLS-measured tree structure can be an alternative way to assess QSM reconstructions, but further studies are needed for both geometry and topology assessment.

2. Data and Methods

2.1 Simulated TLS Point Clouds

A Monte-Carlo ray tracing library, librat (Disney et al., 2006), was used to simulate 1 ha plot of tree models from leaf-off Wytham Woods 3D models (Calders et al., 2018). Scans were simulated with the same parameter settings as the real TLS scanning described in Calders et al. (2018). Then the simulated point clouds were downsampled and individual trees were extracted (Figure 1). We selected five trees with a range of sizes from three species for further tree reconstruction and validation.

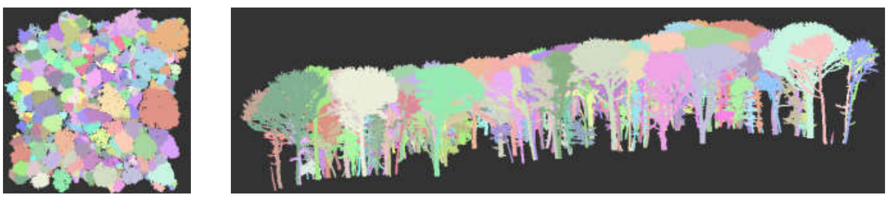

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Figure 1 Simulated point clouds of 3D trees measured in Wytham Woods (coloured by individual tree). Left: top view. Right: Front view.

Table 1 Characteristics of five tree models used in simulation. (X and Y coordinates denote the trees' location in the simulated plot.)

Tree ID	X (m)	Y (m)	Height (m)	DBH (cm)	Species (Common name)
ww_60	42.1	170.8	21.5	66.1	Acer pseudoplatanus (Sycamore)
ww_81	133.1	162.3	22.5	99.7	Quercus robur (Oak)
ww_446	86.7	110.9	30.5	146	Acer pseudoplatanus (Sycamore)
ww_827	103.2	136.8	24.5	28.9	Acer pseudoplatanus (Sycamore)
ww_1361	126.9	120.4	23.4	21.8	Fraxinus excelsior (Ash)

2.2 Reconstruction and Validation of 3D Tree Models

The reconstruction methods compared here are TreeQSM and SimpleTree. As TreeQSM has been constantly updated over the years but many research had been conducted using version 2.0.0, so we compared both the old version (v2.0.0) and a newer one (v2.3.1). For each tree point cloud, the candidates of input parameter sets were selected by an open-source software optqsm (Burt, 2019), and hundreds of quantitative structure models (QSMs) were generated from all combinations of input candidates. The optimal QSM is selected based on the metric of 'all_mean_dis', i.e., minimizing the mean of point to cylinder distance from all cylinders. In SimpleTree software, we used the plug-in 'QSM spherefollowing method – advanced for plot' which does not require input parameters from users.

To evaluate the model results, common tree parameters that can be obtained from both methods are compared with the reference values from original tree models.

3. Results and Discussion

The comparison results of three tree parameters are presented in Figure 2. Both methods showed the capability to retrieve highly accurate tree height (bias less than 1%), whereas for DBH estimates, SimpleTree models had 10% underestimation on average, and the possible reason for this is the under-fitting phenomenon in the main trunk of the large trees in this test (Figure 3). In terms of volume, models reconstructed from SimpleTree tended to overestimate the crown and resulted in an overall 38% overestimation in total volume among these five trees. On the contrary, both versions of TreeQSM mis- or under-fitted twigs, so the total volume estimates are slightly lower than the reference values. Compared between two versions, the newer one had less underestimation in total volume, which is mainly attributed to reconstructing more small branches that the older version did not fit. Further quantitative comparison using more trees and more metrics in both geometry and topology will be conducted. Preliminary results would suggest that for applications focusing on volume aspect, e.g., non-destructive estimation in above-ground biomass through TLS-QSM method, TreeQSM v2.3.1 is a better choice, but for applications beyond volume, we recommend examining other metrics as well.

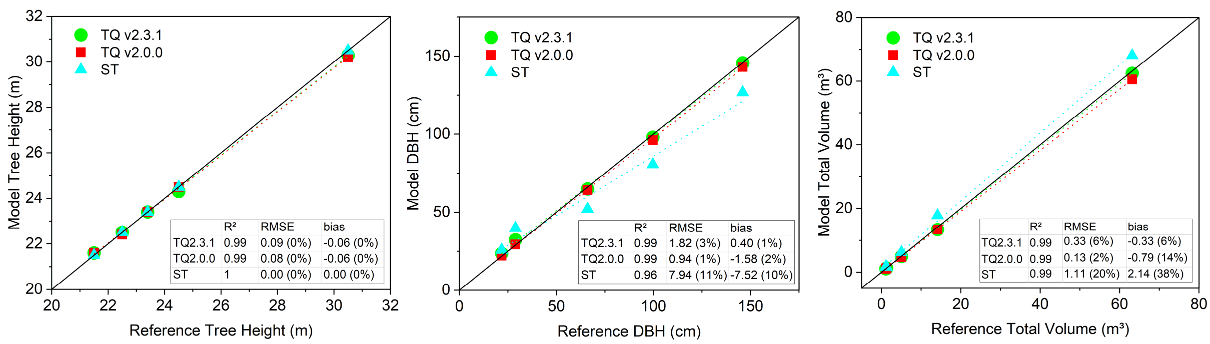

Figure 2 Comparison between reference values and model estimations from two versions of TreeQSM (TQ v2.3.1 and TQ v2.0.0) and SimpleTree (ST).

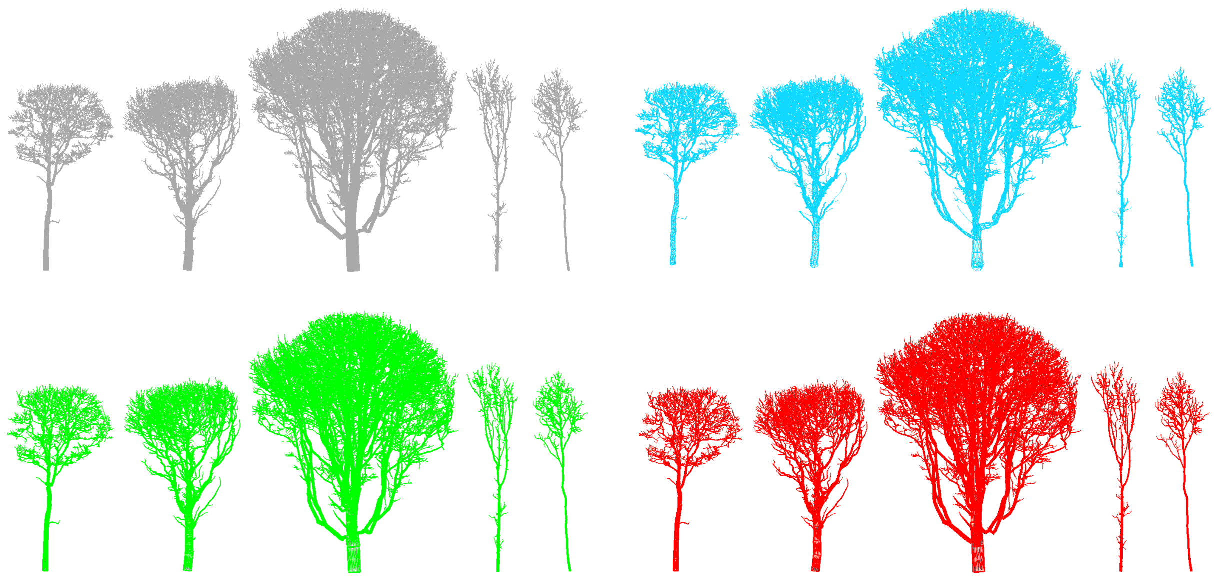

Figure 3 Simulated point clouds (grey) of five tested trees and their corresponding reconstructed QSMs from SimpleTree (blue), TreeQSM v2.3.1 (green) and TreeQSM v2.0.0 (red). The Trees ID from left to right are ww_60, ww_81, ww_446, ww_827 and ww_1361, respectively.

4. Conclusions

A universal and comparative method to validate 3D tree reconstruction methods is still lacking, especially regarding topology. One of the challenges is to obtain a good benchmark dataset of point clouds with comprehensive manual measurements of the reference trees. We evaluated two versions of TreeQSM and SimpleTree models with simulated data based on TLS-measured forest structure, and the results show that the newer version of TreeQSM retrieved better results in volume aspect. Further studies are needed for both geometry and topology assessment, which will benefit optimal model selection and promote the development of methods to reconstruct more complete and authentic tree models that can advance understanding of tree structure and function.

References

Boudon F, Preuksakarn C, Ferraro P, Diener J, Nacry P, Nikinmaa E & Godin C, 2014, Quantitative assessment of automatic reconstructions of branching systems obtained from laser scanning. *Annals of Botany,* 114(4)**:** 853-62.

Burt A, 2019, *optqsm* [Online]. GitHub. Available: https://github.com/apburt/optqsm [Accessed 2020].

Calders K, Origo N, Burt A, Disney M, Nightingale J, Raumonen P, Åkerblom M, Malhi Y & Lewis P, 2018, Realistic Forest Stand Reconstruction from Terrestrial LiDAR for Radiative Transfer Modelling. *Remote Sensing,* 10(6)**:** 933.

Disney M, Lewis P & Saich P, 2006, 3D modelling of forest canopy structure for remote sensing simulations in the optical and microwave domains. *Remote Sensing of Environment,* 100(1)**:** 114-132.

Du S, Lindenbergh R, Ledoux H, Stoter J & Nan L, 2019, AdTree: Accurate, Detailed, and Automatic Modelling of Laser-Scanned Trees. *Remote Sensing,* 11(18)**:** 2074.

Hackenberg J, Spiecker H, Calders K, Disney M & Raumonen P, 2015, SimpleTree —An Efficient Open Source Tool to Build Tree Models from TLS Clouds. *Forests,* 6(12)**:** 4245-4294.

Lau A, Bentley L P, Martius C, Shenkin A, Bartholomeus H, Raumonen P, Malhi Y, Jackson T & Herold M, 2018, Quantifying branch architecture of tropical trees using terrestrial LiDAR and 3D modelling. *Trees,* 32(5)**:** 1219-1231.

Raumonen P, Kaasalainen M, Åkerblom M, Kaasalainen S, Kaartinen H, Vastaranta M, Holopainen M, Disney M & Lewis P, 2013, Fast Automatic Precision Tree Models from Terrestrial Laser Scanner Data. *Remote Sensing,* 5(2)**:** 491-520.