

RAPID CHARACTERISATION OF FOREST STRUCTURE FROM TLS AND 3D MODELLING

A.Burt¹, M.I.Disney^{1,2}, P.Raunonen³, J.Armston^{4,5}, K.Calders⁶ and P.Lewis^{1,2}

¹ Department of Geography, University College London

² NERC National Centre for Earth Observation

³ Department of Mathematics, Tampere University of Technology

⁴ Centre for Spatial Environmental Research, University of Queensland

⁵ Remote Sensing Centre, Queensland Government

⁶ Laboratory of Geo-information Science and Remote Sensing, Wageningen University

ABSTRACT

Raunonen et al.[1] have developed a new method for reconstructing topologically consistent tree architecture from TLS point clouds. This method generates a cylinder model of tree structure using a stepwise approach. Disney et al.[2] validated this method with a detailed 3D tree model where structure is known *a priori*, establishing a reconstruction relative error of less than 2%. Here we apply the same method to data acquired from *Eucalyptus racemosa* woodland, *Banksia ameula* low open woodland and *Eucalyptus* spp. open forest using a RIEGL VZ-400 instrument. Individual 3D tree models reconstructed from TLS point clouds are used to drive Monte Carlo ray tracing simulations of TLS with the same characteristics as those collected in the field. 3D reconstruction was carried out on the simulated point clouds so that errors and uncertainty arising from instrument sampling and reconstruction could be assessed directly. We find that total volume could be recreated to within a 10.8% underestimate. The greatest constraint to this approach is the accuracy to which individual scans can be globally registered. Inducing a 1cm registration error lead to a 8.8% total volumetric overestimation across the data set.

1. INTRODUCTION

Forest structure is a key component in understanding the remotely sensed signal across wavelength domains from optical, through thermal and microwave[3]. Quantification of structure is therefore required to validate estimates of forest state and dynamics while also providing exciting opportunities if used in conjunction with remote sensing models[4]. Such models can be used for canopy parameter algorithm development and instrument sensitivity analysis[5].

The limitation to such progress is the robust capture of 3D structural information. Direct field measurements are limited practically to a few key measurements including diameter-at-breast height, crown extent and height/height-to-crown. These measurements are used to form the basis of allometric relationships and scaling laws for structural definition[6] whose validity and cross-species applicability has been readily challenged[7]. Allometric

relationships which relate diameter-at-breast height and height to biomass are also key to inventory estimates of forest biomass across large areas[8].

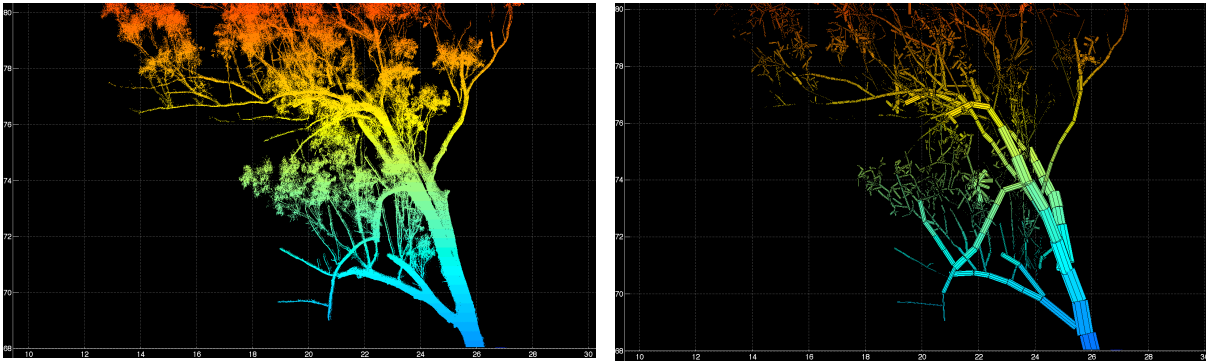
TLS has the potential to offer an independent alternative for rapid yet accurate yield of information containing 3D structure[9]. One substantial prerequisite is the capability to transform TLS point clouds into a topologically-structured description of vegetation that includes the association of individual points to foliage and woody material. A number of approaches have been developed to automate tree reconstruction from TLS data[10] and if this were to become routine it would enable rapid development of 3D structural models. However, a significant difficulty arises in authenticating the accuracy of TLS reconstruction; given the difficulties of accurately measuring structure, most approaches rely on canopy-level or statistical comparisons for assessment.

Here, we present a method of combining TLS data with a new reconstruction approach. Resulting 3D reconstructions are used to simulate TLS for the field site with identical sampling characteristics utilising a radiative transfer model. This allows a direct comparison of the simulated and measured reconstruction to assess the algorithm accuracy.

2. METHOD

The method consists of four stages: i) acquisition of TLS data; ii) global registration of point clouds and individual vegetation extraction; iii) reconstruction of isolated vegetation structure; iv) TLS simulation of *iii* and subsequent 3D reconstruction of individual trees in the simulated point cloud.

This results in a dataset that is both realistic in structure (derived originally from field-measured TLS data) but for which we have complete knowledge of tree structure. In this way we are able to isolate errors due to sampling, instrument characteristics and the 3D reconstruction method independently.



Figures 1 and 2 - TLS point cloud (left) and 3D cylinder reconstruction (right), colour mapped to height, dimensions in metres

2.1 Data acquisition

TLS data was collected from Brisbane Forest Park and Cooloola National Park in November 2012 across three vegetation types: i) *Eucalyptus racemosa* woodland; ii) *Banksia ameula* low open woodland; and iii) *Eucalyptus* spp. open forest. A RIEGL VZ-400[11] scanner was used to collect the full waveform with an azimuth/zenith resolution of 0.04° at a wavelength of 1550nm and beam divergence of 0.35mrad. This instrument is extremely portable and single 30° - 130° zenith, full azimuth scans can be conducted within 2-3 minutes while a tilt mount provides the functionality for full hemispherical coverage. Scans were taken at two locations in plots *i* and *ii* and four locations at site *iii*.

2.2 Vegetation extraction from TLS point clouds

Calibration targets included in individual scans were identified by RIEGL RiSCAN PRO[12] software for global plot registration. Errors associated with this registration process which include perturbations experienced during scanning were in the order of 1cm with isolated incidents observed up to 14cm. The consequence of this is an increase in apparent branch radius, or even in extreme cases, duplication. Dependant upon the application, this error is potentially significant and must be acknowledged, such as in the case of biomass estimation where volume is proportional to the square of the radius.

A C++ library based on the open-source Point Cloud Library[13] was used to develop a semi-automatic extraction of individual trees from the global point clouds. This was achieved in three steps: i) identification and segmentation of the ground plane, reducing the point cloud to vegetation only; ii) recognition and isolation of individual crowns through a Euclidean cluster extraction; and iii) a second cluster extraction algorithm to remove undesired understory from these individual entities.

2.3 Reconstruction

3D tree structure was reconstructed from TLS point clouds using the method developed by Raunonen et al. [1]. The method reconstructs global 3D tree architecture step-by-step via an advancing collection of small local point cloud sets. This stepwise approach does not require general assumptions concerning tree structure and allows

global reconstruction from a series of smaller, more computationally manageable independent subsets of local surface patches. The method results in a database of structural characteristics which, in addition to the topological representation of tree structure, can be used to describe trunk/branch diameter, length, location, and branch angular distributions and position. The method is scale independent and can be used to reconstruct the cylinder model accurately down to the measurement accuracy of the laser scanning. Recent application of this algorithm alongside the methodology of this report using a 3D growth model derived Scots pine indicated volume and branch length could be reproduced with a relative error of less than 2% post-optimisation[2]. Figure 1 presents an isolated tree from the woodland dataset that has been reconstructed in figure 2.

2.4 TLS Simulation

3D models arising from the reconstruction were used to simulate TLS of the data sites using *librat*, a Monte Carlo ray tracing (MCRT) radiative transfer model of canopy scattering built upon *ararat/drat*[14]. Two separate simulations were undertaken: i) TLS simulation using the sampling characteristics of the RIEGL VZ-400 (sim1); and ii) *i* with a bias included to represent a 1cm registration error (sim2), achieved by offsetting individual scans from *i* during global registration. While the simulation characteristics are equivalent to that of the sensor, the reduction of returns due to occlusion arising from the influence of other vegetation in the field has not been included.

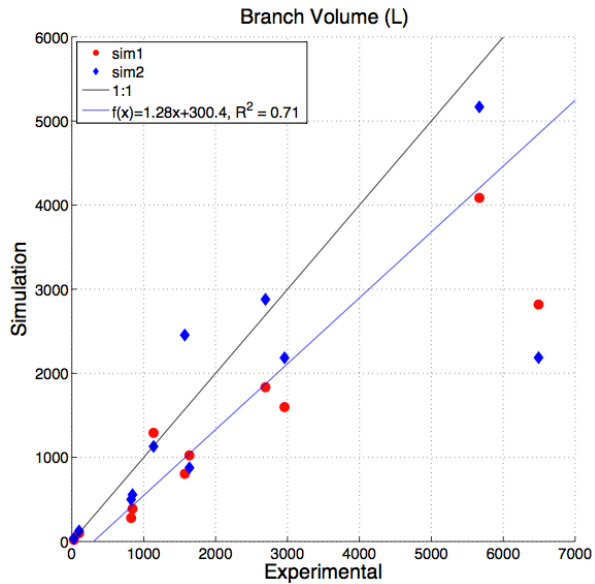
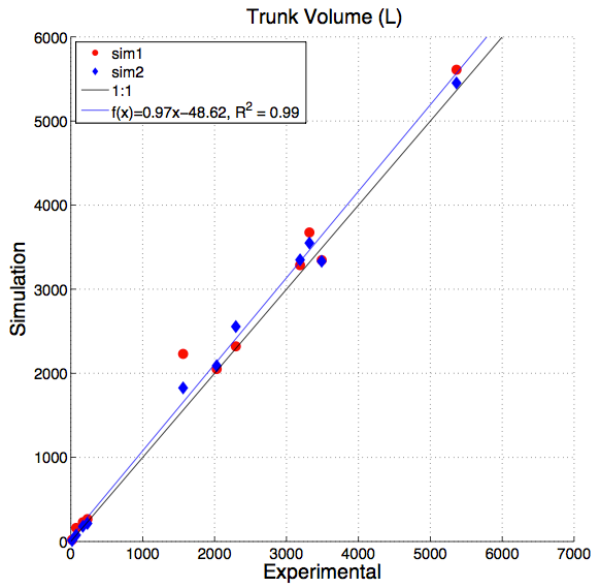
3. RESULTS

A summary of the reconstruction parameters for all three datasets is given in table 1. The error in each case is the percentage error in the 3D models reconstructed from the MCRT simulations, with respect to the known 3D model values.

The defining statistic across the full data set is the total volumetric underestimation of 18.1% and 10.8% in sim1 and sim2 respectively. This arises from a significant underestimation in branch volume and a small overestimation in trunk volume. Figures 4 and 5 provide scatters plots of the individual trunk and branch volumes for the experimental and simulated data sets.

	Exp	sim1	%err(sim1)	sim2	%err(sim2)
Total Volume (L)	45689.2	37434.8	-18.1	40736.1	-10.8
Trunk Volume (L)	21736.4	23194.1	6.7	22637.6	4.2
Branch Volume (L)	23952.8	14240.7	-40.5	18098.4	-24.4
Total Height (m)	184.5	184.8	0.2	184.4	-0.1

Table 1 - Summation of reconstruction volume and height across the data set for experimental (exp) and simulated (sim1) models. Relative percentage error of the simulation with respect to the experimental values



Figures 3 and 4 - Trunk (left) and branch (right) volume scatter plots of experimental reconstructions against simulated reconstructions (sim1 and sim2) with subsequent linear fit

The two scatter plots and their linear fits illustrate the linear conformity in the trunk volume overestimation while the larger scatter in figure 4, as shown by the R^2 value of 0.71 indicates various factors affecting the relationship - particularly for the two cases with the highest experimental volume.

Firstly, the expected impact of the global registration inaccuracy, observed up to 14cm, has a fundamental impact on structural reconstruction that is independent of the algorithm. Including a 1cm registration error in sim2 induced an 8.8% increase in total volume and reduced branch underestimation by 16.1% while having a negligible effect on trunk volume. The consequence of this error is an increase in cylinder radii and hence volume of sim2 over sim1. This is corroborated by the branch volume distribution in figure 5 for an individual tree from the *Eucalyptus* spp. open forest data set. While the included 1cm error in sim2 illustrates the severity of the issue, accurately simulating this global error consistently for the data acquired in the field is problematic. The contribution of this error from the instrument is a function of distance to the target while more variable factors such as wind compound this expression further. This infers partially contradictory sampling characteristics have been used in the TLS simulations when considering any volumetric under/overestimation.

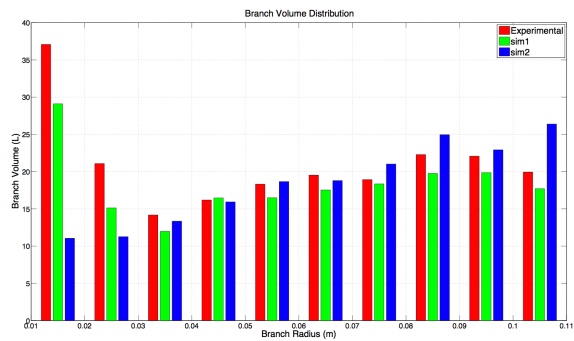


Figure 5 - Branch volume distribution across the radius range of 0.01m to 0.1m for an individual tree from the *Eucalyptus* spp. open forest data

Second, the absence of leaves from the simulated TLS datasets (present in the field measured data) has the expected impact of reducing reconstructed branch volume. Returns from leafy material encompassed in the reconstruction will have the effect of thickening branches. As seen in the branch volume distribution in figure 5, a greater volumetric contribution from the smaller radius branches is evident in the experimental reconstructions when compared to the simulation reconstructions. The RIEGL VZ-400 captures the full

waveform LiDAR return and this holds the potential for improved reconstruction, by assisting in the separation of leaf and woody material. For example Elseberg et al.[15] recently demonstrated the capability of the instrument to detect vegetation in urban environments whilst Zhao et al.[16] also demonstrated in a proof of concept study that knowledge of the scattering properties of individual returns can be readily used to identify foliage from woody material.

Finally, a constant overestimation in trunk volume would suggest that the classification of branch and trunk is not working optimally. This increase in trunk volume would have a consequential lowering of branch volume. The overall impact of this on total volume compared to the above issues is very limited.

The clear trend shown in table 1 and the comparisons that can be drawn from figure 4 highlight how important the TLS data acquisition stage is to the accuracy of the 3D reconstruction. The few extreme cases of volumetric underestimation shown in the scatter plots arise from the cumulative effects of the registration error exacerbated through the large quantity of foliage included within the reconstruction.

4. CONCLUSIONS

We have tested a new 3D reconstruction method for tree structure from TLS and shown it capable of reproducing total volume to within ~10% of actual across 11 trees at varying distances and LiDAR resolutions. This is despite the influence of the independent issue of global scan registration which has a significant impact. Inducing a 1cm global registration error leads to an 8.8% increase in total volume and at present is the key limitation in the accuracy of TLS point cloud 3D structural reconstruction using this method. We have also demonstrated the robust nature of the reconstruction algorithm with data acquired from *Eucalyptus racemosa* woodland, *Banksia ameula* low open woodland and *Eucalyptus* spp. open forest.

As a result of this and the corroborating conclusions of Disney et al.[2] we believe this method combined with the sampling characteristics and portability of the RIEGL VZ-400 sensor provide a wealth of exciting opportunities ranging from independent biomass estimation through to validation of allometric scaling.

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