UAV-Laser Scanning based Metrics for Individual Tree Volume Estimation across Forest Types

B. Brede[1], N. Barbier[2], H. Bartholomeus[1], R. Bartolo[3], K. Calders[4], G. Derroire[5], A. Lau[1], S. Levick[6], S. M. Krishna Moorthy[4,7], P. Raumonen[8], L. Terryn[4], H. Verbeeck[4], T. Whiteside[3], M. Herold[1]

[1]Wageningen University & Research, Laboratory of Geo-Information Science and Remote Sensing, Wageningen, The Netherlands
Email: {benjamin.brede;harm.bartholomeus;alvaro.lausarmiento;martin.herold}@wur.nl

[2]UMR AMAP, Univ. Montpellier, IRD, CNRS, CIRAD, INRAE, Montpellier, France
Email: nicolas.barbier@ird.fr

[3]Department of Agriculture, Water and the Environment, Supervising Scientist Branch, Canberra 2601, Australia
Email: {Renee.Bartolo; Tim.Whiteside}@awe.gov.au

[4]CAVElab - Computational & Applied Vegetation Ecology, Department of Environment, Ghent University, Belgium
Email: {Kim.Calders; Louise.Terryn; Hans.Verbeeck}@UGent.be

[5]CIRAD, UMR EcoFoG (Agroparistech, CNRS, Inrae, Université des Antilles, Université de la Guyane), Kourou, French Guiana, France
Email: geraldine.derroire@cirad.fr

[6]CSIRO Land and Water, PMB 44, Winnellie, NT 0822, Australia
Email: Shaun.Levick@csiro.au

[7]Department of Geographical Sciences, University of Maryland, College Park, USA
Email: sruthikp@umd.edu

[8]Mathematics, Tampere University, Korkeakoulunkatu 1, 33720 Tampere, Finland
Email: pasi.raumonen@tuni.fi

1. Introduction

Upcoming satellite missions targeting the estimation of forest Above-Ground Biomass (AGB) require an expansion of calibration and validation capabilities (Duncanson et al., 2019). In this context, forest inventories in combination with Allometric Scaling Model (ASM) represent a traditional and well-understood tool. However, ASMs are often based on a small number of harvested trees only, which are typically easier to harvest small trees, resulting in biases in the ASMs (Duncanson et al., 2019).

Terrestrial Laser Scanning (TLS) has been demonstrated to be an unbiased estimation tool for single tree wood volume and AGB, especially in large trees (Calders et al., 2015). However, TLS field data acquisition is labour-intensive and time consuming with a typical productivity of 3-7 days per ha for structurally complex forests (Wilkes et al., 2017). In recent years, Unoccupied Aerial Vehicle Laser Scanning (UAV-LS) has evolved into a mature technique for the collection of point clouds on hectare scales. Pilot studies have already shown the use of UAV-LS for estimation of individual tree metrics (Wallace et al., 2014). A recurring challenge is the accurate automatic segmentation, which is required to allow UAV-LS to be used across large scales. Additionally, structurally complex evergreen tropical forests have not been extensively targeted yet.

In this context, the aim of this study was to explore the potential of individual tree metrics derived from automatically segmented UAV-LS point clouds to estimate tree wood volume across a range of forest sites with varying structural complexity.

2. Data and Methods

2.1 Study Sites

In total, four sites were selected in this study that represent a structural complexity gradient. Speulderbos (The Netherlands) is a temperate mixed forest site containing European beech and oak, as well as Norway spruce, Giant fir and Douglas fir. The Paracou site (French Guiana) is a lowland wet, old-growth tropical forest with more than 750 woody species. Robson Creek (Australia) is a simple notophyll vine forest in the wet tropical NE Queensland. Litchfield (Australia) is a savanna site with a sparse canopy and affected by wild fires.

2.2 TLS and QSM-based Wood Volume Reference

At all sites, TLS data were collected in regular grid patterns with RIEGL VZ-400 scanners, and 10 to 20 m spacing and linking positions with retro-reflective targets following good practice guidelines for

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TLS forest plot surveys (Wilkes et al., 2017). Subsequently, the single scan positions were registered to form a co-registered point cloud per site. In total 200, 204, 200 and 489 individual trees were manually segmented from these point clouds for Speulderbos, Paracou, Robson Creek and Litchfield, respectively. Finally, Quantitative Structural Models (QSM) were built with *TreeQSM* (Raumonen et al., 2013) and tree wood volume was estimated based on the QSM cylinder volumes.

2.3 UAV-LS Segmentation and Metrics

UAV-LS data were collected with a RIEGL RICOPTER with VUX-1UAV. After processing the data into point clouds for each site following recommended procedures (Brede et al., 2017), the point clouds were automatically segmented using a novel individual tree segmentation routine based on shortest-path calculations and adapted to high density UAV-LS data (Raumonen et al., 2021). For each TLS reference tree, the best overlapping UAV-LS tree was identified as the one with the highest Jaccard index or Intersection-over-Union metric based on the voxelised individual tree point clouds. Finally, individual tree metrics were derived from the UAV-LS point clouds: tree heights (H100/H95/H50: difference between highest point/95%/50% percentiles and DTM), crown dimensions (CA: crown area in, CD: crown diameter, CP: crown perimeter), volume based on alpha-hull (V), graph based metrics based on graph-representation of the tree as a side product of the segmentation (GN: number of nodes in the graph, GEL: total edge length in the graph), and compound variables (HCD: H100 times CD, GELCD: GEL times CD).

3. Results and Discussion

UAV-LS metrics displayed different capabilities for explaining the variation in wood volume at each site (Figure 1, Table 1). In particular, H100 and CD behaved asymptotically across sites, effectively limiting capabilities to predict large tree volume with a single structural parameter. On the other hand, CA, V, and GEL were linearly related with wood volume across sites.

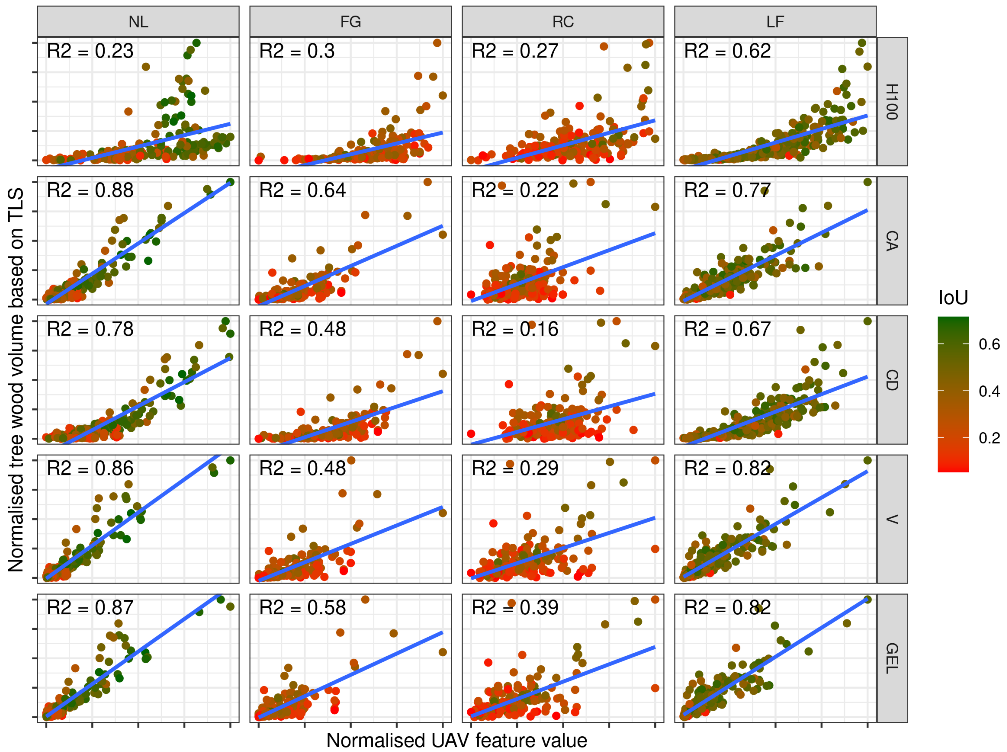

Figure 1: UAV metrics correlation with TLS QSM derived individual tree wood volume. UAV metrics and QSM volumes were normalised to facilitate comparison between sites. Sites: NL = Speulderbos (NL), FG = Paracou (F), RC = Robson Creek (AUS), LF = Litchfield (AUS). UAV metrics were normalised. Metrics: H100 = tree heights, CA = crown area, CD = crown diameter, V volume based on alpha-hull, and GEL = total edge length. Blue lines indicate linear trends. IoU refers to Intersection-over-Union of UAV automatic segmented tree compared to TLS reference tree.

Table 1: Explained variation (R^2) of UAV metric for TLS reference tree volumes.

Group	Metric	NL	FG	RC	LF
Height	H100	0.23	0.30	0.27	0.62
	H95	0.23	0.34	0.19	0.58
	H50	0.25	0.38	0.22	0.53
Crown	CA	**0.88**	**0.64**	0.22	0.77
	CD	0.78	0.48	0.16	0.67
	CP	0.78	0.48	0.17	0.69
Volume	V	0.86	0.48	0.29	**0.82**
Graph	GN	0.87	0.50	0.31	0.81
	GEL	0.87	0.58	0.39	**0.82**
Compound	HCD	0.73	0.53	0.29	0.76
	GELCD	0.84	0.63	**0.40**	0.76

4. Conclusions

This study explored a range of UAV-LS derived metrics for individual tree wood volume estimation, both well used metrics as well as newly derived metrics possible with the high density UAV-LS. In particular, CA and a graph-based metric showed linear relationships with wood volume, making them suitable to build prediction models and scale estimation across UAV-LS covered areas.

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