

VALUING FOREST STAND AT A GLANCE WITH UAV BASED LIDAR

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ABSTRACT:

Comprehensive knowledge of characteristics and variability of any material is essential for its best utilization; hence forest managers are increasingly recognising the importance of resource quality characterisation earlier along the value-chain. Current methods for cruising timber at the stump lack information on branch characteristics and detailed assessment based on terrestrial lidar systems are restricted to sampled trees for assessment at the block level. Rich and dense information on vertical structure of the canopies captured using lidar system from a closer range like on a UAV platform provides a flexible, quick and a cost-effective alternative for assessing forest stands. In this study, along with detailed tree characterisation and variability, we explore the potential of ultrahigh density lidar data acquired from a UAV platform (ULS) to develop a non-destructive estimation of a suite of timber quality determinants like branchiness, clear stem and stem straightness for standing trees, and further determine possible amount of bucking segments (logs) and their expected quality. Validation of the algorithm is tested on white pine stand in Petawawa Research Forest, Ontario, Canada, holds promise in determining spatially-explicit tree level and hence stand quality.

1. INTRODUCTION

Economics of production and marketing of wood products are linked to lumber grade which is influenced by parameters like tree form, size, amount of knots and juvenile wood (Rudnicki & al., 2017, Cown & van Wyk, 2004, Jozsa & Middleton, 1994). Effective assessment of standing timber enables improved production of quality stands and adds value in the entire chain of operations. Quality prediction through traditional timber cruising that are completed before sale provides essential data for determining stumpage and quality based on sampled trees but lacks information on branch characteristics that help in intrinsic wood quality that influences product yield and wood value. Although a variety of tree measurements can be readily obtained using existing traditional tools and techniques through nondestructive means, measuring some of the attributes like those of branch characteristics are exceedingly laborious (van Leeuwenn et al., 2012, Macdonald et al., 2009). Based on the presumption that lidar point distribution is analogous to distribution of biomass in 3D and higher point density can better define tree elements, recent studies have extensively explored terrestrial lidar systems (TLS) in deriving detailed stem profile and branch architecture of individual trees (Olofsson and Holmgren, 2017, Lindberg et al 2012, Maas et al 2008). However, TLS are restricted to gathering data on small spaces, hence these models are rarely extended at a stand level and hence lack portability to operational scales.

Development in miniaturized technology allowed integration of light-weight laser scanning capabilities through full-waveform digitization of multi-targets on a UAV platform (ULS) from lower altitudes (Vepakomma & Cormier 2015). Limited logistics and easy deployment make UAS an interesting platform for forest operations. Ultra high density, short range,

aerial perspective and large field of view give them an advantage over both terrestrial and aerial lidar systems (Wallace et al. 2012, Wei et al 2017), and hence we hypothesise they are more suitable operationally for detailed description of the standing tree and stem characteristics needed for quality assessment.

In this study, we explored the capability of ultra-high density lidar from a UAV platform (ULS) to develop a non-destructive estimation of a suite of timber quality determinants including branchiness and stem straightness for standing trees that help in evaluating potential amount of clear stem, possible bucking segments (logs) and their expected quality. We presume the model aids in individual tree monitoring, assessing stand value, lumber grading and in-forest log sort. The algorithm is tested on lidar data acquired over a white pine stand in Petawawa Research Forest in Ontario, Canada. Preliminary validation through visual assessment against mobile lidar data and conventionally measured 20 matured trees holds promise in determining spatially-explicit tree level and hence stand quality.

2. METHODS

2.1 Test site

The selected study site falls within Petawawa Research Forest (PRF) in Ontario, Canada, that is predominantly white pine mixed with red pine, balsam fir and poplar species (Figure 1). Part of the selected 10.3 ha forested area had recently been harvested under a shelterwood system for managing white pine. The remnant vegetation has a height range of 6 – 36 m., with dense scrub on the floor. The terrain is rocky but fertile, and is relatively flat.

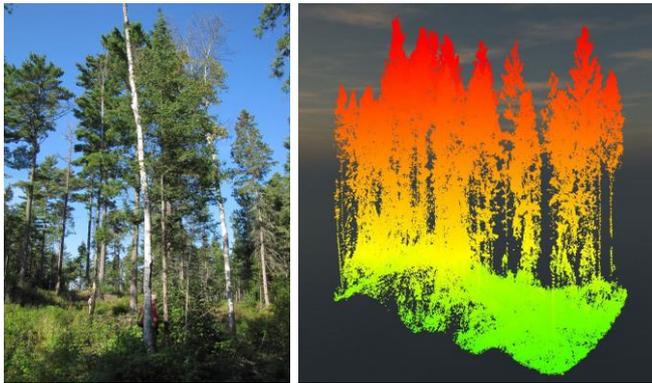


Figure 1. Ground photo of parts of the test site and 3D point distribution of UAV lidar of a sample site

2.2 Lidar data

Riegl VUX-1 lidar system mounted on Renegade UAS helicopter was flown over the 10 ha. test site during September 2016 in 8 flightlines at 150 m altitude with a speed of 20 knots. (Table 1). Over 18 control points measured with Leica iCON survey grade RTK GPS were used for data validation. A calibration pattern is flown at the RME Geomatics test facility to compute the roll, pitch and heading offsets for the IMU and laser scanner. Overall an RMSE of 0.04m was estimated in Z. Data provider's classification after visual spot checks was accepted for this study.

To assess geospatial and vertical accuracy of Riegl Vux-1 lidar, several terrain targets and 10 randomly distributed paired-individual trees (of DBH > 8 cm) were precisely located using a survey grade precision (of sub centimeter accuracy) RTK DGPS on ground.

Specification	
Total weight (kg)	3.5
Wavelength (nm)	1550
Beam divergence (mrad)	0.5
Max. FOV	330
Max.Pulse Frequency (Hz)	820000
Scanning method	Time of flight
Number of echoes	Unlimited
Recording Intensity (bits)	16
Detection range (m)	530

Table 1. Specifications of Riegl VUX-1 lidar system

2.3 Validation dataset

Total tree height with a Vertex from two vantage points, DBH and crown diameter in two cardinal directions were noted for 20 randomly selected individual trees on the site. Branchiness (proportion of space filled with branches) was estimated visually in several segments of the tree. In addition, for a more detailed validation (in progress now), we destructively harvested 10 trees and manually measured all branches over 10 cm. and the stem diameter along the tree length. Prior to the harvest, these trees were also individually scanned using geoSLAM ZEB-REVO handheld 3D laser scanner.

2.4 Extraction of wood quality determinants

Individual tree crowns were extracted based on marker-based watershed algorithm from a Gaussian filtered digital surface model derived from the lidar data. Based on maximum elevation on the surface, estimated DBH based on allometry and intensity rules were used to filter points belonging to shrubs and low vegetation around the tree base. Lidar vegetation returns with each delineated segment are used for reconstructing 3-D voxelised structure and estimation of individual tree metrics. Lidar return filled in voxels represent woody or foliage part of the tree.

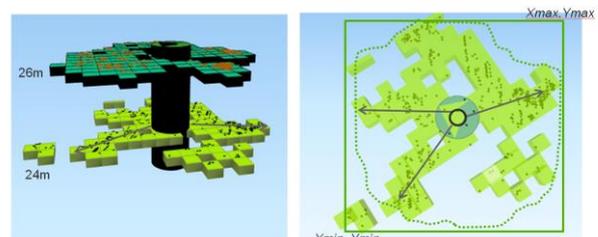


Figure 2. Profiling branches at a given height h along the stem and estimation of the crown dimension

Within a voxel framework, non-parametric regression is adopted to derive individual crown profiles as a function of lidar density/intensity within the extracted tree envelopes (total). Stem height, crown diameter, tree height, various height percentiles and location of the crown base are directly estimated from the fitted regression. . Crown diameter was defined as the vertical projection of the longest diameter of the crown on the ground. Average of the length of the sides of the rectangle that inscribes the delineated crown is approximated as crown diameter (Figure 2).

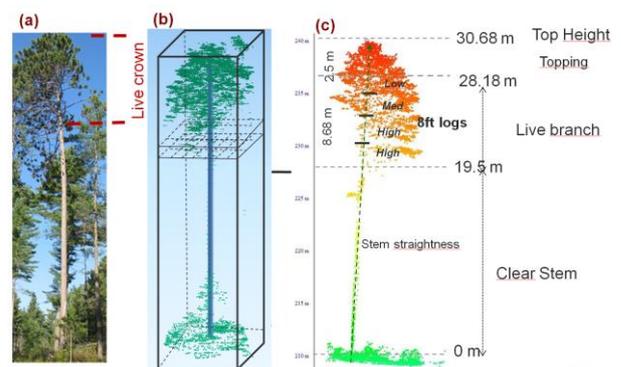


Figure 3. A sample of the estimation of wood quality determinants of individual white pine tree (a) tree in the field (b) its lidar point distribution and voxelisation (c) extracted quality determinants

2.4.1 Branchiness (live crown) and clear stem: Starting from the base, a circle fitting method is applied at regular height steps to reconstruct diameter profile along the stem. Cylinders were fit to represent the section of the stem. Sinuosity between centroids of the circles provided an estimate of stem straightness. Branches were estimated by connecting the voxels attached to the stem cylinder using a neighbour tracing algorithm (Figure 2). Knot surface area at the branch location is estimated based on branch length (Lemieux et al 2001).

Tree topping was identified and eliminated by localising stem diameter that is below 10 cm on the fitted stem structure (Figure 3). Stem below the crown base is identified as clear stem.

2.4.2 Log quality assessment in live crown: Stem along the living crown is then segmented into 8ft long logs (2.44 m). Quality of the individual log was assessed as a proportion of knot surface area on the log.

2.4.3 Stem straightness (clear stem) and tree leaning: Tree leaning was estimated as the angle of deviation of the tree top (highest point) and the centroid of the lowest part of the extracted stem. Stem straightness was assessed using sinuosity in segments of 2 m along the clear stem. The length of the segment was selected based on the least reliable distance for which a sweep could be determined using lidar data. Assuming a sweep of 4 cm, a 5% deviation from straightness of the segment is considered as crooked.

It may be noted that bucking decisions are market driven and what we have considered here is an example using the smallest log length that is normally put in the market.

3. RESULTS

3.1 Capability of UAV based lidar

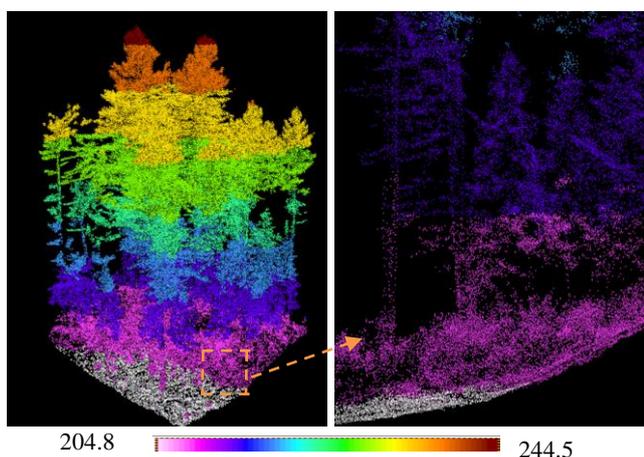


Figure 4. Lidar point cloud on a multi-storied stand (left) and enlarged details of the floor (right)

UAV based lidar was seen to have unique advantage of ultra-high resolution data capture, ease of deployment with targeted approach to forest monitoring at a significantly lower cost compared to any platform (Jaakkola et al 2010, Brede et al 2017). In this experiment, with an average point density of over 150 hits/m² general structure of the forest was ably captured

with distinguishable clear stems of the trees even in dense multi-storeyed canopies as well as distinguishable features on forest floor (Figure 4). Up to 7 returns were recorded with 20% of them describing sub canopy and nearly 3.2% of all the returns reaching the floor for reconstructing accurate terrain surface.

TREEID	Total Ht (m)	DBH (cm)	C Dia (m)	Live Branch (m)	Clear Stem (m)	# branches	Tree Lean (°)
1667	29.89	41.6	8.32	11.39	18.5	48	8.9
1958	34.45	52.1	9.35	7.45	27.0	12	6.5
297	18.87	21.4	8.93	13.37	5.5	38	11.6
906	34.18	51.5	9.13	24.18	10.0	67	5.6
2603	30.30	42.5	9.23	12.30	18.0	38	3.5
1804	30.14	42.2	9.53	4.14	26.0	9	6.90
1742	33.63	50.1	9.66	12.63	21.0	35	5.20
817	30.67	43.3	8.25	11.17	19.5	35	4.60
1162	21.92	26.3	6.52	5.92	16.0	19	14.30
1141	17.62	19.5	6.88	9.62	8.0	16	5.80
1598	27.42	36.5	8.49	3.92	23.5	12	9.70

Table 2. Estimated characteristics of a few sampled trees

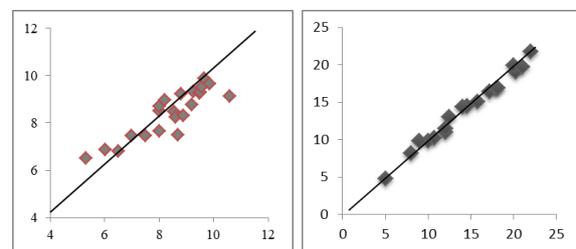


Figure 5. Validation of the estimated crown diameter (left) and crown base height (right) against field measured trees

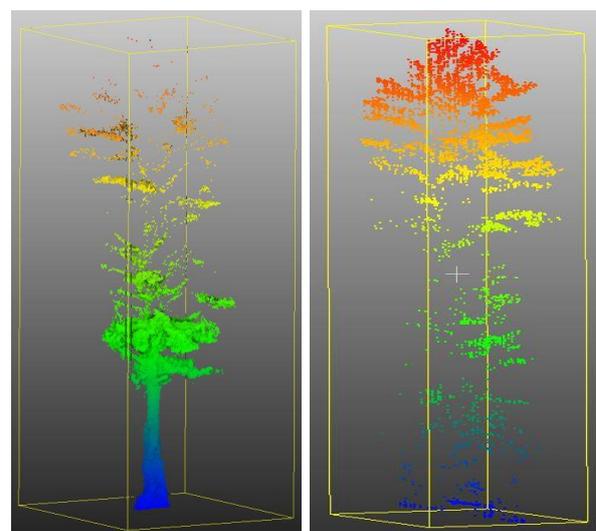


Figure 6. Visual and manual assessment using ZEB REVO GeoSLAM data captured below the canopy against extracted and measured tree from ULS data from above the canopy

(right). This a sample of a white pine tree extracted from the midst of a dense stand.

Estimated total tree height, crown base height (and clear stem), crown diameter and branchiness of a small stand using the model is presented in Table 2. compare well with traditional field measurements (Table, 2, Figure 5). Branchiness in practice is coarsely classified in segments along the stem and our model showed over 98% match in the sampled trees. Stem leaning was confirmed as whether leaning or not showed a 100% agreement. Independently all the parameters were validated visually using a co-registered ZEB REVO geoSLAM lidar data (Figure 6). In addition, a more intensive validation based on detailed measurements made on harvested trees is in progress.

TREEID	Along the clear stem	Along the crown		
	Consecutive 2m straight sections*	Number of 2.44 m logs		
	(S -Straight; C-Crooked; N : No data available)	HIGH	MED	LOW
1667	C,S,S,S,N,N,S,C,S	4	0	0
1958	S,C,C,C,C,C,C,C,S,C,C,S	2	0	0
297	S,C,N	3	1	0
906	C,C,S,S,N	4	2	0
2603	S,N,S,S,S,C,C,S,N	4	0	0
1804	C,S,S,N,S,S,S,S,C,C,S,C,N	1	0	0
1742	S,S,S,S,S,S,C,C,C,S	3	1	0
817	C,S,S,S,S,S,S,C,C,N	3	0	1
1162	S,C,S,C,S,C,S,N	2	0	0
1141	C,C,S,N	3	0	0
1598	C,C,C,C,S,N,N,N,S,C,C,N	1	0	0

*Example: In tree 1742, consecutive S S,S S,S,S of 2 m logs result in 12m straight section of the stem

Table 3. Estimation of log quality determinants of a few sampled trees;

A detailed assessment of possible bucking segments (logs) along the crown with their expected quality, and amount of consecutive 2 m long straight segments possible along the clear stem is presented in Table 3.

This is an example of using the estimated quality determinants (branchiness, clear stem, crown diameter, stem straightness) that could be extrapolated for qualitatively determining the log sort based on subjective bucking decisions.

The study shows that ULS provides dense and rich data for detailed description of the standing tree and stem characteristics needed for quality assessment. The proposed and adopted models could reliably estimate the wood quality determinants like canopy base height, clear stem, branchiness and stem straightness besides the tree form metrics. The data had been sufficient to further determine possible amount of bucking segments (logs) and their expected quality.

4. CONCLUSIONS

Knowing the value of the forest stand before it is harvested helps in the predictability of the expected wood product basket. The availability of quick turnaround, flexible, low cost, rich and highly accurate scanning through remote sensing technologies like UAV based lidar (ULS) offers great potential for automated bucking where each tree can be analyzed at the stump for optimizing its market value. This, in fact, is an effort in progress and we intend extending the model to other economic softwood species in Canada.

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