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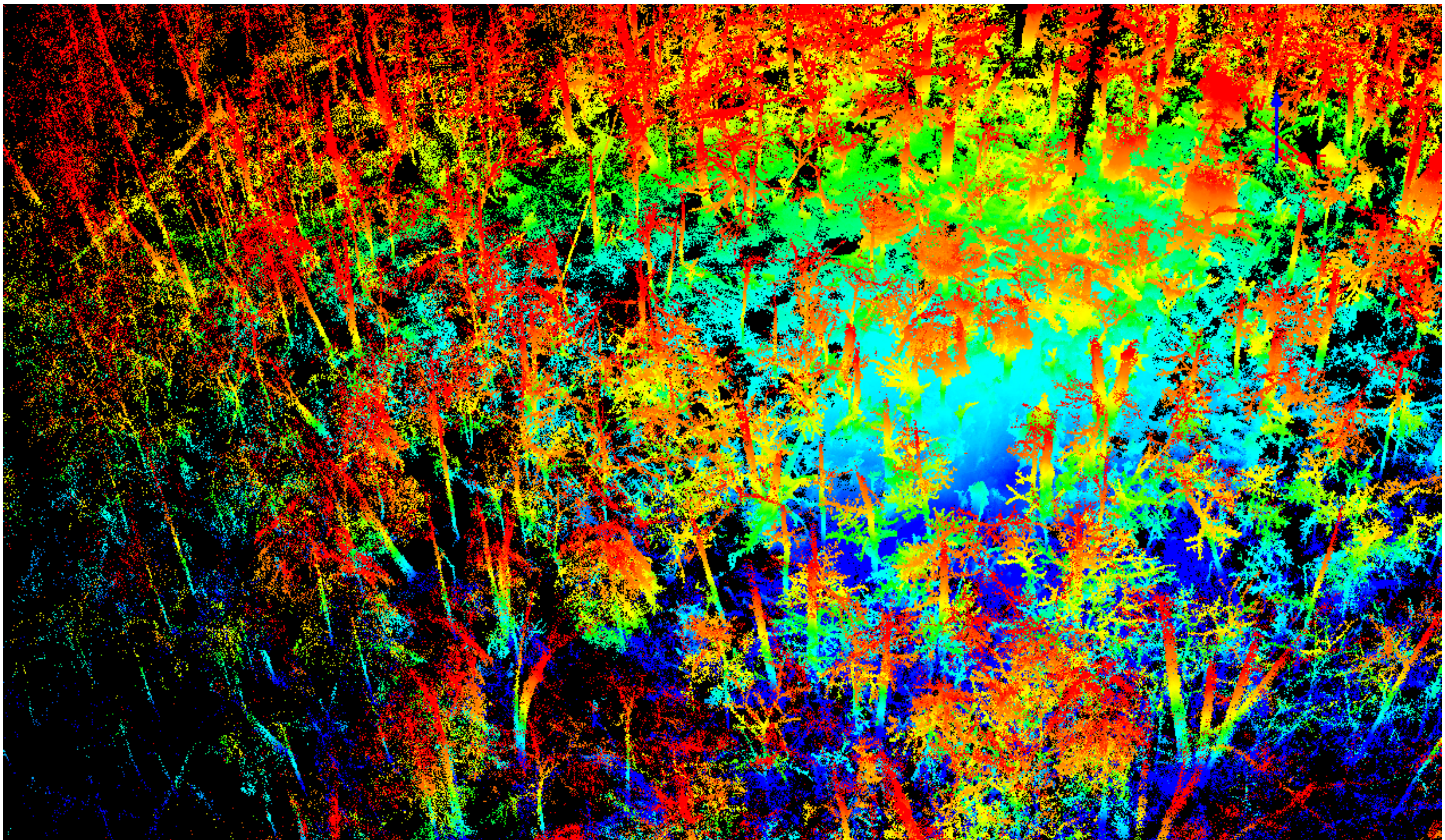

Preliminary Testing of Mobile Terrestrial LiDAR Unit and Future Application Considerations

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ABSTRACT

Mobile terrestrial LiDAR (MTL) systems have the potential to identify individual stems and serve as the basis for autonomous or semi - autonomous machine navigation. A small scale field trial was conducted to determine the accuracy with which a MTL system could map and extract stem positions and characteristics such as DBH. The trial yielded operationally accurate data at distances less than 15m, however, the study highlighted the need to optimize acquisition geometry to satisfy the model's need for more ground reference points at further distances.

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1. INTRODUCTION

Increased mechanization within the forest sector over the last century has yielded tremendous returns in terms of productivity; however, current and projected workforce shortages within the sector have given rise to a need for reducing the dependence on machine operators and field staff. Traditionally labor intensive tasks such as forest inventory and compliance monitoring could be accomplished, or facilitated through the use of advanced sensor and modelling technology. Eventually, this technology will serve as the starting point for providing real time 'vision' for autonomous or semi-autonomous machines capable of operating with minimal human assistance.

The advances of terrestrial laser scanning techniques for use in forest inventories have been extensively summarized in Liang et al. (2016). Additionally, research on static ground-based LiDAR systems have focused on evaluating stem and stand parameters as well as on tree crowns and fine-scale tree branching structures (Côté et al., 2011 and 2012). Few studies have focused on the use of mobile terrestrial LiDAR data to retrieve these parameters for practical operational applications.

Mobile terrestrial LiDAR (MTL) has the potential to satisfy this need for real time information that can provide metrics such as basal area (BA), stem size and stem position to aid operators and compliance personnel to drastically improve the quality of work while reducing costs. The very dense and instantaneous signal returns from MTL may serve as the basis for machine vision while navigating in challenging environments such as a forest setting for data acquisition, and eventually fully automated harvest and extraction machines (Rossmann et al. 2009).

As part of FPInnovations' goals of adapting technologies to assist the forest industry, we investigated the ability of one such system to accurately detect and map individual stems as well as determine individual stem characteristics such as diameter at breast height (DBH) under a variety of spacing configurations.

2. METHODOLOGY

LiDAR system

The LiDAR unit selected for this test was a Velodyne HDL-32E[1] equipped to a lightweight computer by CGQ[2] (Centre de Géomatique du Québec). The unit has a rotating 360º horizontal field of view and a 40º vertical field of view (+10º and -30º), returns 700,000 points per second and has a return range of 80-100 m.

Plot location and setup

This study was conducted in a permanent sample plot (PSP) maintained by the Northern Hardwoods Research Institute (NHRI) outside of Edmundston, New Brunswick. The 1 ha square plot was a mature, primarily hardwood stand and the trial was conducted at the end of November 2016 in leaf off condition which reduced the problem of occlusion, or obstructions, caused by brush and small trees in the

[1] http://velodynelidar.com/hdl-32e.html
[2] http://www.cgq.qc.ca/

understory. All merchantable trees (≥10cm DBH) were measured and geolocated using a Topcon Hyper SR base station[3] and rover RTK system with a precision of <2 cm.

The plot setup consisted of 3 parallel 20 m transects placed within the 100 m x 100 m plot spaced 20 m and 40 m apart. The transects were designated as A, B, and C with A_1, B_1, C_1 denoting the start positions and A_2, B_2, C_2 denoting the end positions. A/B were spaced 20 m apart, and B/C were spaced 40 m apart giving researchers the ability to pair different transects to create 20 m, 40 m and 60 m spacings to evaluate data accuracy across a range of setups. Data was also gathered at various speeds to enable researchers to compare data accuracy relative to travel speed.

A cable system tethered between trees and elevated about 1.5 m above ground level was used to reduce erratic sensor movements. A self-levelling trolley (figure 1) with a large counterweight allowed the unit to sit above the cable and be pulled along the cable manually by researchers positioned at either end of the cable. Alternatively, a stabilizing gimbal commonly used in the film industry could be installed on the machinery to yield similar results.

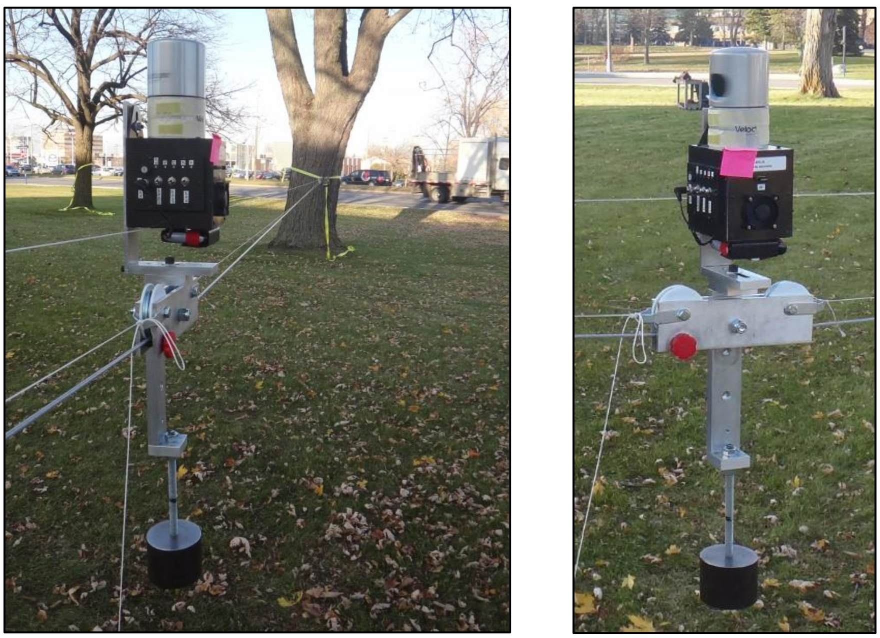

Figure 1. Self-levelling trolley and tethered cable setup

Data processing

The raw data captured by the LiDAR system was processed by Kaarta Inc.[4] and converted to a LAS file format widely adopted to store LiDAR data. The converted point cloud uses a local XYZ coordinate system and is compatible with Computree[5] (v3.0) software which was used to detect and extract individual stem information.

[3] http://www.topcon.co.jp/en/positioning/products/pdf/HiPerSR_E.pdf
[4] http://www.kaarta.com/
[5] http://rdinnovation.onf.fr/projects/computree/wiki/En_dbhAuto_

Computree was used to create a digital terrain model (DTM) as well as to define the required plot size and location for analysis. The computation time was optimized by reducing the LiDAR point cloud density while maintaining sufficient information for stem detection. The density was reduced to a level such that the minimum distance between any two points was 0.5 cm. Individual stem location and diameters were captured using the ONF 2013 extension with default parameters. The software relies on the captured point cloud data to fit cylinders at various heights along the bole (Figure 2) prior to estimating the DBH using the mean value of the cylinders around 1.3 m height. The results including the XYZ coordinates of the center of the stem cross section at 1.3 m and DBH values were exported to Excel and then imported into ArcGIS. Spatial adjustment in ArcGIS was performed to convert the detected center coordinates from local XY to georeferenced coordinates to match with the existing field data collected in the PSP.

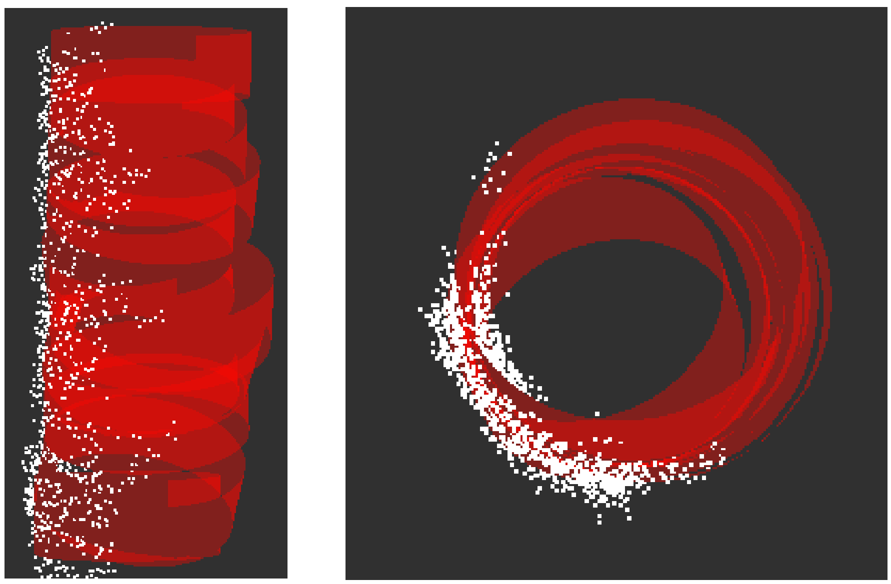

Figure 2. Example of point cloud data and cylinder fitting data from side (left) and top (right) perspectives

Due to mildly undulating terrain within the block, the C_1-C_2 line (Figure 3) was the only transect used in the analysis. Its position at the top of a small hill provided the best available view of the surrounding area. The other two acquisition lines (A and B) produced blind spots on the forest floor which restricted the ability to produce a DTM needed as the ground reference for calculating DBH. We noticed that by reducing the point density, the sensor movement speeds along the same transect line did not significantly affect the end results. Therefore, only the data acquired with the slowest sensor movement speed was used for the following analysis.

Analysis

Along the C_1-C_2 line, 100 m² (5 m x 20 m) fixed area plots were created perpendicular to the LiDAR moving path. These plots were designated as plots 1-5 with 1 being the closest to the moving path and 5 being the furthest (Figure 3). Each plot includes a corresponding pair of subplots on each sides of the moving path. The analysis was only conducted on merchantable trees since smaller trees in the PSP were not measured. Omissions were checked visually using the point cloud to ensure that the trees measured in the PSP were still present at the time of the LiDAR data acquisition, and removed from the analysis if not present.

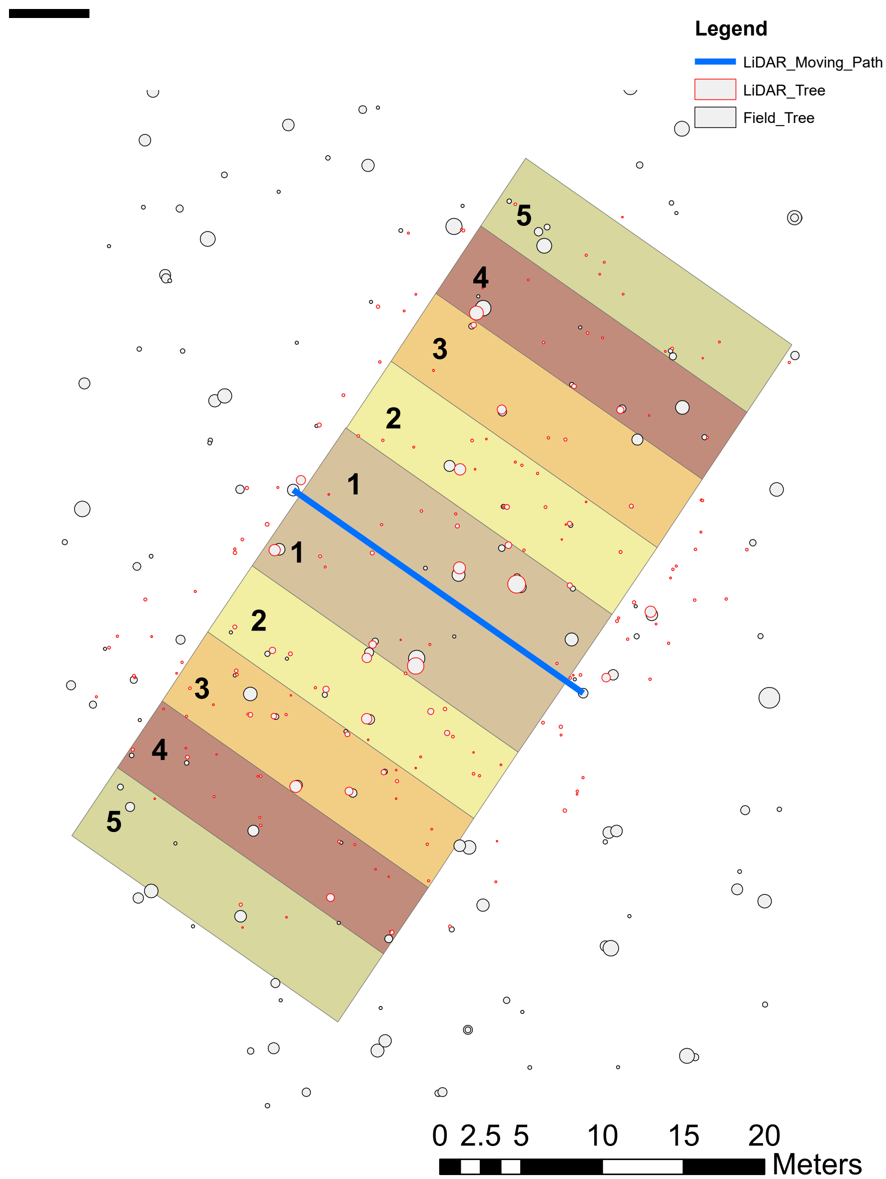

Figure 3. Plot layout along LiDAR sensor moving path C1-C2
Circle size represents relative DBH.

3. RESULTS AND DISCUSSION

The maximum distance at which a stem was detected was 22.5 m. Several limitations in the forest environment contributed to reducing the detection rate at greater distances, including terrain steepness and smoothness, obstructions, and the required point density for creating accurate DTM and cylinder fittings in the adopted algorithm. These limitations also caused omission or commission errors where a tree is either not properly detected or classified, or improperly detected where it does not exist.

Omissions

Omission errors (table 1) are a result of a field tree that was not detected by Computree using the terrestrial LiDAR data. The omission error was 30% for the first 5m adjacent to the travel line as a result of the inability of the LiDAR unit to return ground points at such a close distance, thereby precluding Computree from calculating the tree's DBH. Omission errors were reduced in plots 2-4 (5-20 m) before rising dramatically to 67% in plot 5 (>20 m). This increase in omissions is the result of lower number of ground point returns as the angle between the sensor and ground decreases with the distance as well as reduced line of sight for trees at greater distances due to obstructions.

Table 1. Summary of omission errors by plot

Plot ID	Field Trees (DBH ≥ 10cm)	Matched LiDAR Trees	Omissions	Omission Rate	Cumulative Omission Rate*
1 (0-5 m)	10	7	3	30%	30%
2 (5-10 m)	9	9	0	0	15%
3 (10-15 m)	11	9	2	18%	16%
4 (15-20 m)	12	11	1	8%	14%
5 (20-25 m)	12	4	8	67%	25%

**Based on omission rate by plot*

Commissions

Commission errors (table 2) are interpretation errors caused by the software analyzing points and identifying a tree that does not exist within the PSP. The commission results show an average commission rate of 15% across the 25 m distance, however, when visually analyzing the raw point cloud data, all reported commissions had a stem present, although the software estimated the DBH within the limit of considering the tree as merchantable, i.e. with values ≥ 10 cm. No commissions for trees ≥20 cm DBH occurred. Identification of individual commission errors in the raw point cloud data (Figure 4) showed a trend of improper DBH overestimation or classification of two smaller stems as a single tree with a larger diameter.

Table 2. Summary of commission errors by plot

Plot ID	Predicted LiDAR Trees (DBH ≥ 10cm)	Matched Field Trees	Commissions	Commission Rate	Cumulative Commission Rate*
1 (0-5 m)	9	7	2	22%	22%
2 (5-10 m)	12	9	3	25%	24%
3 (10-15 m)	10	9	1	10%	19%
4 (15-20 m)	6	5	1	17%	19%
5 (20-25 m)	1	1	0	0%	15%

**Based on commission rate by plot*

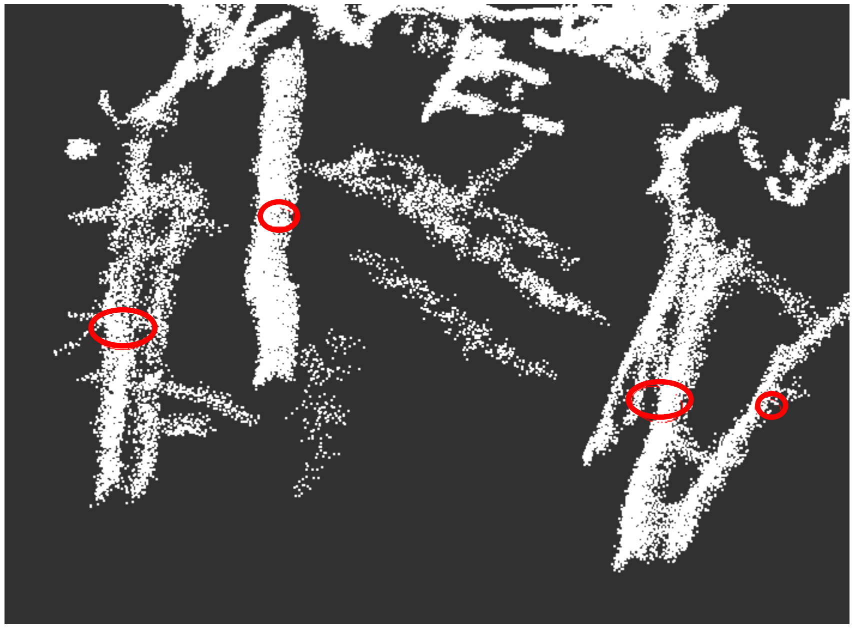

Figure 4. Common commission errors
Red circles represent the diameter at breast height modelled by Computree.
The left most example shows two smaller trees improperly classified as a single stem.
The rightmost examples show an overestimation of DBH by Computre.

DBH accuracy

The average error between DBHs calculated by Computree and their associated paired trees within the first 5 m (plot 1) was an overestimation of about 5 cm. For plots 2-3 (5-15 m), results indicated an overestimation of about 2 cm (Figure 5). At greater distances the average error increased significantly as the point density decreased due to cumulative obstruction effect. The results show that beyond 15 m this data is not reliable for DBH estimation.

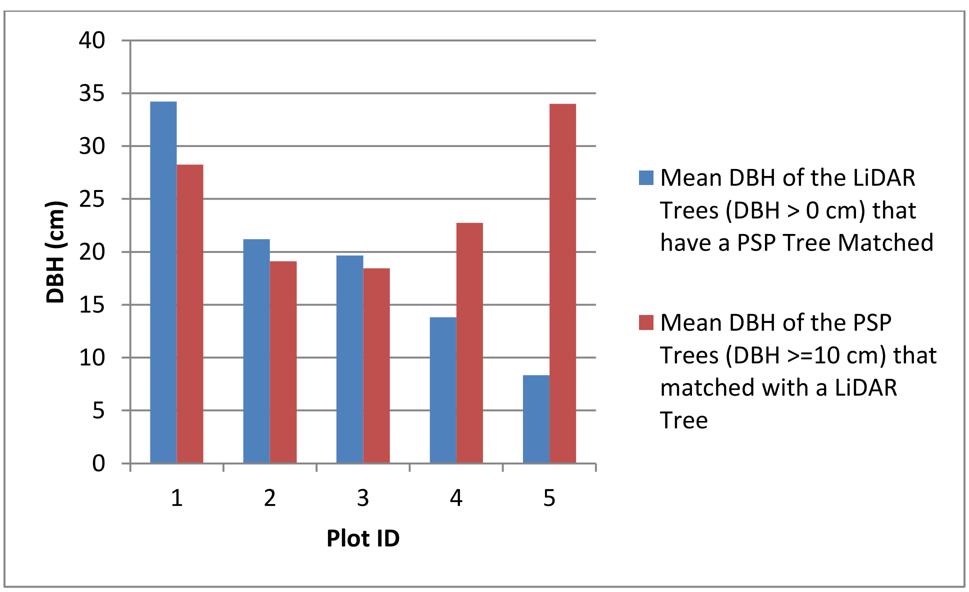

Figure 5. Average calculated DBH and actual DBH of paired trees by plot

The lower density of points at greater distances particularly affects the ability of the software to determine the size of the larger stems (Figure 6). Stray points from branches, or stem points are potentially excluded due to the lack of points above or below those captured (Figure 7, left). The ability of the software to accurately estimate DBH relies on having an adequate number of points to superimpose cylinders that fit among the points while maintaining a taper that matches a typical tree. This low point density caused by visual obstruction (Figure 7, left) is further compounded by wounds and other defects (Figure 7, right) that are symptomatic of mature hardwoods and would further reduce the software's ability to identify individual stems based on the default parameters.

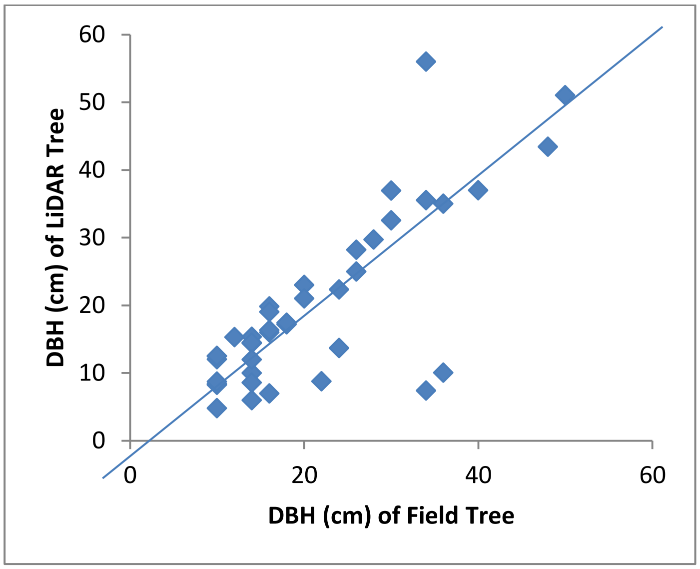

Figure 6. Actual DBH vs LiDAR calculated DBH of all matched pairs in all 5 plots

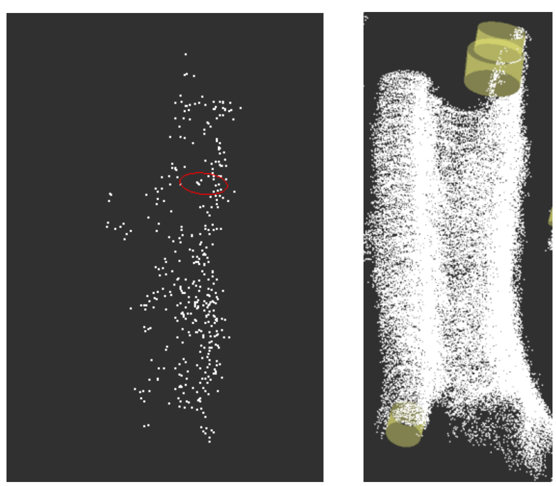

Figure 7. Left: low point cloud density causes the software to apply a best fit while ignoring points that may indicate a larger stem; right: Growth defects of mature hardwoods create uncommon bole shapes that the software cannot interpret properly

Evaluation of the plots by basal area (figure 8) shows the impact of the omission effect as distances increase from the transect line. BA in plots 1 and 2 is overestimated when including all detected stems including commissions (figure 8, left), primarily as a result of DBH overestimation which results in smaller trees being included. Results indicated a slight decrease in measured BA due to undersized stems being excluded when filtering out commission errors (Figure 8, right). The overestimation of basal area using only matched trees shows a need for calibration of the parameters used for calculating DBH. As distance increased above 10m, basal area is increasingly underestimated as the compounding effects of DBH mismeasurement and omissions become more common, especially among larger trees as previously reported. Despite the challenge of using LiDAR to measure basal area at distance, potential applications over short distances (<10 m) remain promising once DBH calculation parameters are adjusted to account for this overestimation.

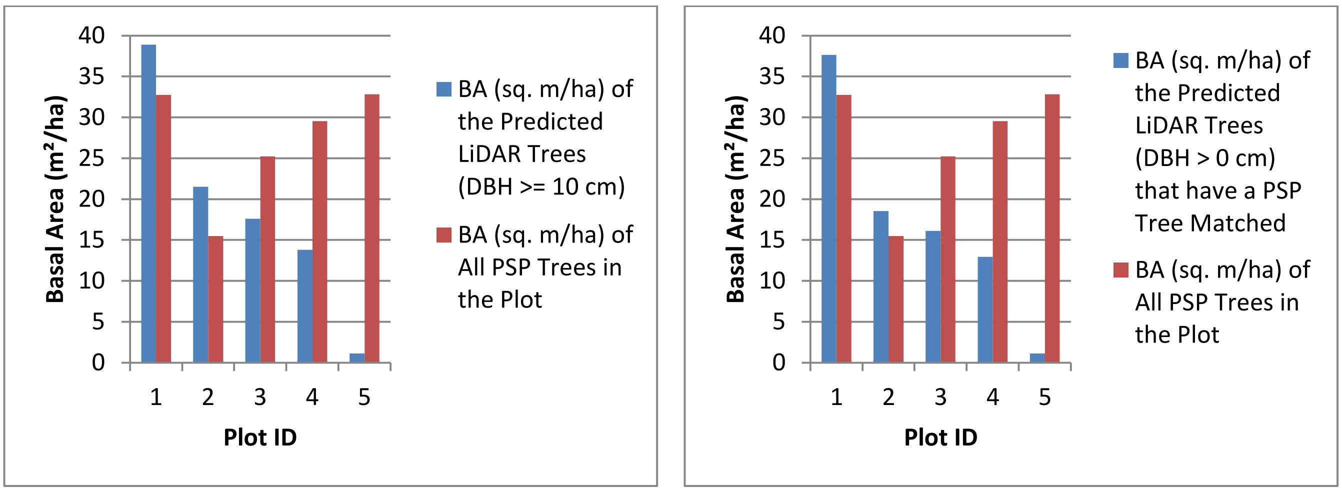

Figure 8. Left: Raw predicted basal area including commissions for trees ≥10cm; right: Predicted basal area for PSP matched trees ≥10cm

4. CONCLUSION

The capability of the system to accurately detect and measure stems at distances less than 15 m has the potential to reduce the reliance on manual labor for activities such as inventory, tree marking in partial cuts and compliance monitoring in the immediate future. The accuracy of DBH measurements within 2 cm at distances less than 15 m is already within operational needs and should be tested further under different forest conditions. The basal area measurements showed acceptable errors within a 10m radius, however beyond this point the effect of omissions and underestimation of DBH provide inaccurate results. Mature hardwood stands which tend to suffer from growth defects caused by wounds and less predictable stem forms when compared with softwoods are likely to be the most challenging conditions to implement this new technology. Future studies should focus on softwood stands with flatter terrain conditions. The field of vision of the unit combined with its position around 1.5m above ground level and terrain resulted in a high number of omissions that could easily be avoided by elevating the position and changing the angle during data collection. This perspective would likely also permit parallel collection paths to be combined to yield a more complete 360° point cloud capable of reducing many of the challenges experienced when analyzing a single collection line. In addition, new algorithms will be shortly implemented and made available to estimate DBH with improved efficiency and robustness in natural forest conditions.

Despite the observed challenges, the benefits of terrestrial LiDAR in terms of cost of implementation when compared to aerial LiDAR as well as the benefits of real time data remain attractive to the forest industry. Refining the acquisition methods and processing parameters have the potential to greatly improve success rate of the existing software. The limitations of the system are lessened when taking into account the freedom from time constraints related to time of day and fatigue issues that humans suffer from. These successes at short distances can provide a basis for future autonomous machine navigation, and eventually a fully automated harvest system capable of meeting the needs of the future forest industry.

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