FUTURE FORESTS RESEARCH

TECHNICAL NOTE

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Tree Level Analysis of LiDAR

Summary

Light Detection And Ranging (LiDAR) has proved to be useful for a number of forest management applications. International researchers have recognised the potential of detecting individual trees from remotely sensed images but have yet to achieve robust methods to operationalise this potential application. This technical note describes the methodology and accuracy of a promising new VPlot procedure that has been recently developed for detection of individual trees from LiDAR images within the Improved Inventory project.

Early tests of the procedure produced excellent results for tree detection from LiDAR. Stand total tree count was estimated using LiDAR images with mean absolute error near 5% when calibrated using ground truth and 10% using calibration on the image. An accurate tree count can be used to support an alternative form of inventory based on individual tree rather than area-based measurements with likely cost savings. Tree detection also allows development of stocking maps and description of individual tree metrics. Preliminary research shows that these metrics can be used to develop models of tree size and wood quality.

These initial results are encouraging and industry guidance will be used to target on-going research to develop operational applications for tree-level analysis of LiDAR.

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The International Scene

Researchers around the world are avidly researching methods to detect and delineate individual trees from remotely sensed information such as aerial photographs, satellite imagery and LiDAR[1] [2].

Despite a number of international research programmes aimed at tree-level analysis of remote sensed imagery, a significant barrier to operational use remains – the lack of a robust (and preferably automated) method for individual tree detection. Accuracy of tree identification using state-of-the-art methods in a recent evaluation was given as just 35% to 75%[3].

Key researchers have recently formed multi-national collaborative groups to tackle this difficult problem [1] [2] [4]. They are attempting to evaluate different tree detection methods using standardised input data and accuracy measures. These efforts illustrate the high level of interest and effort directed at tree detection.

Potential Benefits

Tree detection will result in cost savings through reduction or replacement of ground inventory operations and higher spatial resolution of information in the form of tree-level rather than stand-level statistics.

Conventional regression-based analysis of LiDAR has proven to provide high spatial resolution, very precise estimates of stand height, good estimates of stem volume and biomass, but only poor to moderate estimates of basal area and stocking. A basic output of tree detection is a map showing within-stand variation in stocking. This output (useful in its own right) should improve estimates of many stand metrics including volume[5]. More significant will be the ability to estimate variables of interest from tree level metrics such as crown area. Predictions of tree-level metrics could include height, DBH, basal area and volume, with potential to extend to estimates of piece size, grade mix, and other tree and log quality measures.

Tree Identification with the VPlot System

A prior FFR Technical Note[6] described the VPlot tree detection system being developed to provide tree counts. Reference was made to an extensive case study at Kaingaroa forest designed to test the accuracy of stand total tree counts from the VPlot system. These tests have since been carried out using high-intensity ground samples to establish reference counts for six stands aged from 7 to 32 years and results are reported here. Two image types, three count methods, two operators and two image processing algorithms were evaluated in the tests.

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Tree Count Performance of VPlot

Preliminary high-level test results are presented to address several key questions about tree counting with accuracy given in terms of the Mean Absolute Error (MAE) of the tree count.

Two image types, namely orthophotos and LiDAR CHM (canopy height model) images, were evaluated. Operators subjectively rated orthophotos as sometimes problematic and LiDAR as noticeably superior. Results from the tests confirmed these impressions showing LiDAR was significantly more accurate with an overall MAE of 7.4% compared to 13.1% for orthophotos. Results for both image types are very respectable in comparison with international results, but also illustrate the overall superiority of LiDAR for tree detection.

Three variations on the basic count methodology were evaluated. Calibration counts made in small bounded tally plots are a key feature of the VPlot system.

1. Calibration counts can be made by an operator on the image (Image method)
2. Calibration counts can be made by installing actual ground plots (Ground method).
3. The visibility of each tree top is evaluated in ground plots (Visible method).

Overall the Visible method was best with a MAE of 4.6% as it takes into account supressed, top-out and multi-leader trees. It was closely followed by the Ground method with a MAE of 5.1%. The Image method had a MAE of 15.3% overall, with an acceptable 9.6% MAE for LiDAR and a poor 22.1% MAE for orthophotos. Closer analysis revealed that Orthophoto results were unreliable, even with the Visible and Ground methods due to poor image quality. In orthophotos where crown lighting was optimal good accuracy (MAE less than 10%) was possible, but often lighting issues caused very poor results.

Two operators carried out all count tests in order to determine the repeatability of counts from the VPlot system. For LiDAR images there was negligible difference between operators using the Ground and Visible methods (0.3%) and only a small difference (3%) when using the Image method. These results indicate a high degree of repeatability when using LiDAR images. Overall MAE for orthophotos was similar (approx. 10%) for both operators but at the stand level, results were highly variable between operators, showing poor repeatability. Particularly large differences between operators (approaching 30%) were seen with the Image method on orthophotos.

The ability to count trees using the Image method is highly desirable as it does not require ground calibration plots, unlike the Ground and Visible methods. Time must still be spent by an operator making calibration counts on images, but this can be done more economically and safely than with ground plots. The Image method appears viable with LiDAR images, with MAE substantially less than 10% for two thirds of the stands evaluated. But for the remaining one third of stands individual MAEs were in the order of 20%. Investigation showed the larger errors were a result of issues in interpreting the LiDAR images by the operators. More experience with LiDAR images and on-going developments in image preparation are expected to eliminate such large errors. It seems likely that accurate counts from LiDAR images will be possible with the Image method, at least in certain circumstances. The most promising condition is in stands that have recently received a thinning where LiDAR provides an excellent image for identifying individual crowns. MAE for two post-thin stands was less than 2%.

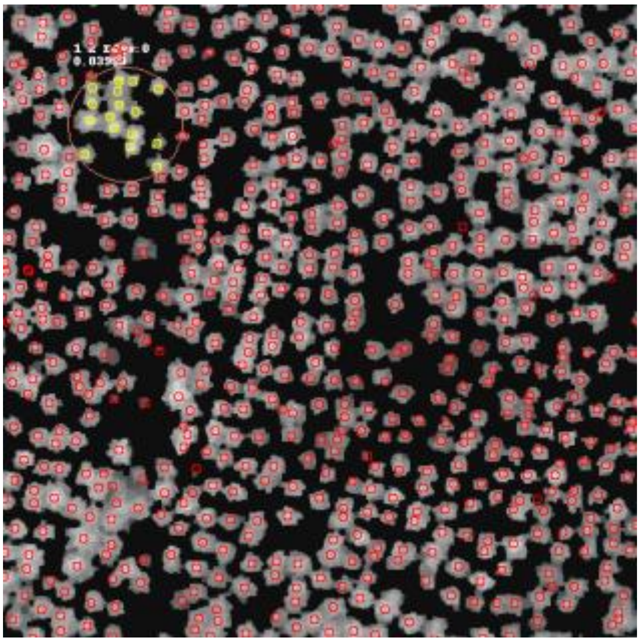

Fig. 1. Tree detection result for a post-thinning stand. Red circles on tops of detected trees. Trees within a calibration plot at top left marked with yellow circles.

LiDAR images were used to evaluate two completely different tree detection algorithms: TIMBRS[7] and an algorithm based on the Watershed method. The differences in MAE from the two algorithms were

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generally 2% or less at the individual stand level and just over 1% on average for each of the three count methods. The lack of a significant difference means the automated Watershed algorithm can be used in preference to TIMBRS which requires an operator.

Operational Considerations

Tests have shown the VPlot system can provide accurate and reliable tree counts from LiDAR images. The methods using ground truthing (Visible and Ground) are the best. On-going research will continue to refine the potential for counts from LiDAR using the Image method.

The ground calibration plots required for the Ground and Visible methods are quick and easy to measure with field trials indicating a plot can be assessed in less than 10 minutes. Assessment of plot tree count usually takes less than 5 minutes, the extra time is required to obtain an accurate GPS location. Analysis indicates calibration plots should be sized to include an average of 20 trees and placed on a randomly oriented grid to obtain a 1% area sample, similar to conventional inventory practice. For mid-rotation and pre-harvest inventories a sample of trees is cruised for subsequent estimation of log grade mix. In these applications a ground crew must visit the stand already and the additional effort to measure calibration plots does not make a large impact on time in the field.

If reliable counting can be developed with the Image method then the need for ground calibration plots could be dispensed with. This may be particularly useful for less intensive inventory at younger ages where stand boundaries, stocking, height and DBH are measured.

An algorithm is under development to extract information about each tree identified in a LiDAR image. Tree locations define stocking which can be mapped at high resolution, a useful output in its own right. As estimates of stem stocking almost always improve estimates of total volume derived from LiDAR, maps of stocking could provide a useful additional explanatory variable[5].

Applications

Inventory, mapping and scheduling operations could all benefit from the high resolution, spatially explicit, descriptions derived from tree-level analysis of LiDAR.

Accurate tree counts can be used in an alternative approach to forest inventory. In conventional inventory, measurements from area-based samples, in the form of plots or transects, provide per hectare estimates of desired attributes such as stem volume. These are multiplied by stand area to obtain stand-level estimates. However, an alternative approach is possible if accurate tree counts are available. This uses measurements from individual trees to estimate means per tree. These are multiplied by the total tree count to obtain stand-level estimates. The trees can be sampled as individuals or in clusters such as bounded plots.

Aerial images are typically visually interpreted to guide manual stand mapping. Satellite or LiDAR imagery could be used to increase automation and accuracy of this process. Image processing can be applied to create a map of crown cover showing stand boundary and internal gaps to a chosen resolution. Figure 2 shows an example generated from a LiDAR image where boundaries and gaps are mapped to 2m resolution. This approach could provide the basis of an accurate, automated, system for mapping and determination of stocked area.

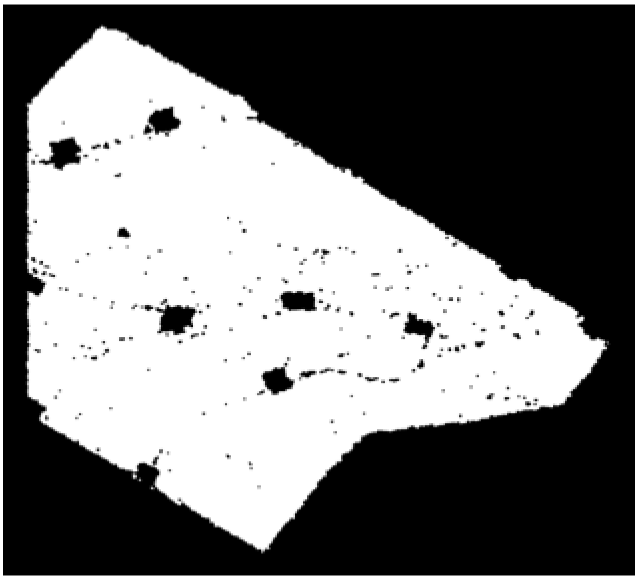

Figure 2. Additional processing of a crown map produced by tree detection generates a map of crown cover (white). Gaps (black) within the stand greater than a chosen threshold size (2m in this case) are visible.

The tree detection method outlined here could be used to quantify survival after establishment. In recent testing, age 5 trees were reliably identified from LiDAR collected at 4 pulses per metre but higher resolution might be needed for younger ages.

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However LiDAR cannot differentiate live, dead or unhealthy trees, so spectral imagery may be better for this application.

Maps of stand height produced by conventional LiDAR analysis when linked to height growth models, are easily sufficient for silvicultural scheduling, with no need for tree level height information. Tree level mapping of stocking could be useful to identify which stands require thinning, the likely intensity of a required thinning, and could be used to stratify within-stand thinning operations.

Conventional LiDAR analysis is generally applied with a square grid, for example a 20 by 20m grid having a spatial resolution of 400m^2. Currently this method provides estimates of mean height at the resolution of the grid. Tree delineation could be used to estimate individual tree heights.

Segmentation of the crown for each tree also allows production of a range of crown metrics (e.g. crown area) that can then be used to predict important tree measures. In a pilot study[8] on a set of pre-harvest *Pinus radiata* stands, crown metrics were used to estimate plot average DBH and standing tree acoustic velocity (STAV, highly correlated with log and timber stiffness) with R^2 of 0.70 and 0.69, respectively. These results demonstrate significant potential for tree-level analysis of LiDAR, in which crown metrics for individual trees can be used to estimate key variables used in forest management.
Mid-rotation and pre-harvest inventory is used to obtain information about potential yield in terms of grade mix. For these applications it is likely that tree-level analysis could contribute to increased spatial resolution and accuracy of estimates. The ability to estimate tree level information, including grade mix and wood quality (in the form of stiffness) is being investigated by David Pont in a PhD research project. On-going consultation with industry is required to better define operational applications for tree-level LiDAR analysis.

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