RADIATA MANAGEMENT TECHNICAL NOTE

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Advanced Use of LiDAR Position Report

Summary

In this report we summarise work on the advanced use of LiDAR, both at Scion and internationally. Applications of the technology can be split into three categories:

Area-based LiDAR for volume, biomass and carbon.
Strong relationships have been demonstrated between LiDAR metrics and volume, biomass and carbon using an extensive national dataset. These LiDAR-volume relationships can be generalised across wide environmental gradients, making them potentially useful for estimating wood and carbon volumes for radiata pine plantations throughout New Zealand.

Individual tree LiDAR for stem form and wood quality
The FFR Canopy project has shown that relationships between crown shape and stem form do exist. Current aerial LiDAR is adequate to detect crown shape, and studies on five trees have shown moderately strong correlations between LiDAR-derived crown metrics and DBH, sweep and average internode spacing. These relationships will improve with increased point density. Remotely sensed wood quality information could improve forest inventory and lead to market-driven harvest planning. Internationally, a lot of work at the individual tree level has focussed on species identification in mixed stands. Within monocultures, stem density and straightness are being estimated using individual tree data in distance-dependant growth models.

Waveform LiDAR
Research supported by Scion's capability fund has shown strong correlations between waveform shape and foliage density in radiata pine. This information is useful for assessing tree growth, health and carbon sequestration. Internationally, waveform LiDAR has been used to distinguish conifers from deciduous trees and to provide more detailed LiDAR point clouds. Waveform LiDAR offers a greater level of information at no extra capture-cost.

Authors: Thomas Adams and Michael Watt

LiDAR

LiDAR is increasingly being used by forest managers for inventory and to produce digital elevation models (DEMs). For a brief introduction to LiDAR for forestry see Adams *et al.*[1]. In this tech note we summarise the relevant findings from Scion and international researchers in the three major areas of forestry LiDAR research: area-based LiDAR for forest inventory; individual tree LiDAR; and waveform LiDAR.

Area-based LiDAR for Volume, Biomass and Carbon

Relationships have been developed between LiDAR metrics and stem volume, carbon and biomass, using an extensive national dataset. A strong relationship has been found between LiDAR metrics and stem volume (R^2 = 0.89), and analyses indicate that this relationship can be generalised across a wide environmental range. Relationships of similar strength have been found between LiDAR and both biomass and carbon.[2] Beets *et al*. have shown that LAI and growth rate variation over complex terrain can be captured by LiDAR in a way that is impossible to do using conventional bounded plots.

Individual Tree LiDAR for Stem Form and Wood Quality

If aerial LiDAR data is required at sufficient point density (at least 6 pts per m^2), individual trees can be segmented and characterised. This technique creates the potential to produce maps of wood volume and quality on an individual tree basis.

Work in Objective 4 of the IFS project tested the hypothesis that crown shape and asymmetry could be used as an indication of wood quality, and that crown shape could be sufficiently described by aerial LiDAR. An initial sample of five trees was selected in Kaingaroa Forest, and the stem form was assessed via terrestrial laser scanning. These data were analysed to give indicators of log quality. The trees are being destructively sampled for internal wood properties as part of the IFS destructive sampling project. Tree crowns were segmented from the MfE

Future Forests Research Ltd, PO Box 1127, Rotorua. Ph: 07 921 1883 Email: info@ffr.co.nz Web: www.ffr.co.nz

LUCAS LiDAR data, and metrics were derived to describe them. Figure 1 shows a stem model constructed from the terrestrial laser scanning, with and without the aerial point cloud overlaid.

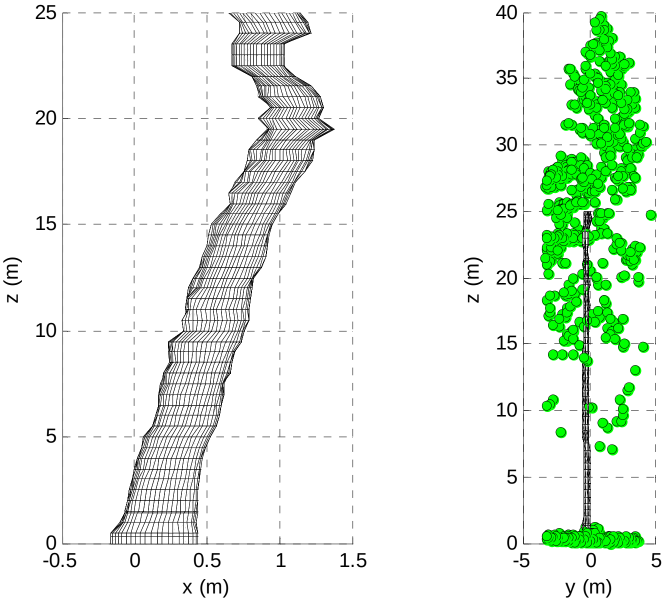

Figure 1: TLS stem model with (right) and without (left) overlaid ALS data

We found that whilst features of the crown appear to correspond to log quality, aerial LiDAR at 8 pts m^{-2} does not give a sufficiently detailed description of the crown to robustly infer it. Moderately strong correlations were found between crown area and DBH (R^2 = 0.48), crown area and sweep (R^2 = 0.43) and crown density and internode distance (R^2 = 0.43). Metrics that required an estimate of the stem location underneath the crown (such as circularity or asymmetry) did not show strong correlations with stem form, due to the fact that aerial LiDAR shows only the canopy, and the precise stem location is not known. Higher point densities are expected to improve the crown information and hence improve the correlations. This project is extensively written up in a conference paper to be delivered at SilviLaser 2011 in Hobart, Tasmania [3].

Next year these relationships will be tested over a greater number of trees. When the destructive sampling project provides information on the internal wood properties of a larger sample of trees, potential relationships between these and crown shape and asymmetry will be investigated.

If individual tree LiDAR can give information on internal wood properties, DBH, sweep and internode distance, this information will be of great value to forest managers. It would improve forest valuation, harvest planning and inventory stratification.

Internationally, work at the Forestry Commission UK has been finding tree locations (based on crown tops) and canopy diameter for Sitka spruce, and feeding these into TASS, a Canadian distance-dependent individual tree growth model. The trees were grown forward 20 years and the tree lists were then put into Forestry Commission's ConTQ timber quality model to estimate wood density and stem straightness. No testing of the results has been possible due to the lack of historical LiDAR[4], but the results are a good indication of the future directions for LiDAR.

Other relevant work includes Reitberger *et al.*,[5, 6] who are segmenting LiDAR in 3D and using similarity metrics to distinguish correctly coniferous from deciduous trees with 80% accuracy. Ko *et al.* at York University in Toronto, Canada, are using a Hough transform (which finds lines) on very high density 40pts m^{-2} LiDAR to identify individual branches. This is being used for species identification and also to estimate stem position.[7]

Other researchers are looking at crown volume as an estimator of stem volume, although results have been better as a sum over a stand than for individual trees.[8, 9] At Scion we have found that crown area gives a better estimation of volume and DBH, because crown volume is highly dependent on obtaining returns from the base of the canopy, which is problematic in highly stocked stands.

Waveform LiDAR

Research supported by Scion's capability fund has shown that waveform LiDAR can yield extra information on the nature of foliage. Using the shape of the waveform as well as the distribution through the canopy, we were able to explain 69% of the variation in Leaf Area Density (LAD) for ten sample plots in Puruki forest. Figure 2 shows raw waveform data overlaid with the corresponding discrete returns.

International work with waveform LiDAR has focussed on resolving returns too close together to be detected by regular discrete-return LiDAR systems, which offers more returns from within the canopy. The waveform shape has also been used for species identification [6].

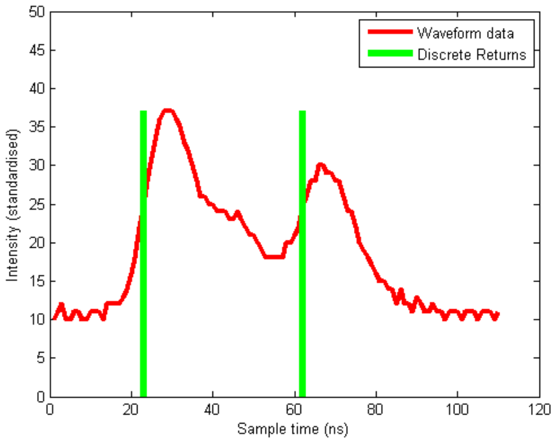

Figure 2: Raw waveform LiDAR vs. discrete-return LiDAR

The benefit to industry of full-waveform LiDAR is that it offers a greater amount of information than discrete-return LiDAR without increasing the flying time and hence costs.

Summary

We recommend that the industry focus on applying LiDAR for DEMs and area-based estimates of volume, carbon and biomass, as these applications are relatively low risk and likely to provide cost effective improvements to industry practice. However, it is necessary to keep up-to-date with advanced LiDAR research to capitalise on further opportunities once the methodology reaches maturity.

Forest managers can use the relationships developed in the Canopy project to describe the spatial distribution of total standing volume throughout their forests to improve inventory, valuation and harvest planning. The Canopy project and other projects have shown that there is the potential to obtain additional information on foliage density and stem form at an individual tree level once higher point density and waveform LiDAR are available at reasonable cost. Further research next year will test these relationships on more trees, and will investigate links between crown shape and internal wood properties.

These advances have the potential to progressively deliver an on-time, on-demand, spatially precise remotely sensed forest inventory system that can potentially be used to record growing stock and forest condition efficiently and quickly.

References

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