IFA Symposium – Improving Plantation Productivity

Mt Gambier, 12-14 May 2014

Field Day Tour

Plantation Resource Mapping using LiDAR

Christine Stone (NSW DPI) and Jan Rombouts (ForestrySA)
Airborne Laser Scanners (ALS or Lidar)

ALS systems rapidly emit laser pulses and very accurately record the time, location and quantity of the reflected energy.

First return pulse = upper surface – used for Digital Surface Models
Last return pulse = ground or objects near the ground – used for Digital Terrain Models
Acquisition of Lidar (ALS) imagery

Small-footprint, discrete return ALS systems provide point data (in x,y and z coordinates) which can be viewed three dimensionally as ‘point cloud’ data (sample density 0.5 – 20 pulses per m²) or converted to small cell raster surfaces.

The Lidar points are geo-referenced and classified by the service provider into ground and non-ground point categories.
Routine lidar products include:

- Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) as high spatial resolution raster surfaces derived from the point cloud using a range of surface modelling techniques.

- Canopy Height Models (= Vegetation Elevation Models) are derived from the DSMs and the DTM i.e. Canopy Height Models = DSM - DTM

- The DTMs are used to derive a suite of terrain surfaces including shaded relief, ground slope and aspect, contour lines and drainage line networks.
Applications of shaded relief DTMs

Large windrows beneath unthinned *P. radiata* 1977 AC in Nundle S.F. – access/safety

Lidar-derived drainage lines compared with original API-derived drainage lines
Extraction of data from the Canopy Height Model:

For LiDAR data, the vertical error (z) is usually smaller than the horizontal (x & y) error. The reverse is true for surfaces derived from photogrammetry.

It is now well established that LiDAR can accurately measure canopy height, albeit with a systemic, small negative bias for softwood plantations (usually <1.0 m).
• Numerous software packages are available for deriving these routine surfaces (e.g. LAStools and FUSION and modules within ENVI, ERDAS IMAGINE and ESRI (ArcGIS 10.1)

• There are two primary approaches to extracting Lidar metrics for estimating stand characteristics - i) area-based and ii) individual tree-based methods.

• The area-based prediction of forest inventory attributes is based on a statistical dependency between predictor variables derived from Lidar data and response variables measured from ground plots.

• Numerous modelling techniques have been evaluated e.g. Nearest-neighbour and Random Forest imputation (refer to Jan Rombouts presentation).

• A representative sample of co-located ground measures is essential (e.g. sample size, plot size).
Individual tree detection algorithms:

- Techniques based on individual tree detection do not require a representative set of field plots but the precise location of a fewer number of trees and having lidar data $\geq 2$ pulses m$^2$.

- Numerous algorithms for tree crown detection and delineation exist that use either a rasterized CHM or the normalised point cloud.

- Tree heights are easily derived from tree crown maximas (and hence accurate estimates of height distributions), however, stand stem volume estimates also require crown delineation.
Overall objective:
To deliver analytical and software processes required for the operational deployment of
lidar-derived information into the yield regulation systems practiced by Australian
softwood growers.

• This two year project commenced on 1 November 2012.

• The cash contributions to this project include $172,000 from FWPA and $85,000 from
the six participating companies i.e. Forestry Corporation NSW, ForestrySA, Hancock
Victorian Plantations, HQ Plantations, Timberlands Pacific and Forest Products
Commission.

• The project is currently tracking well against the objectives, is on schedule and within
budget.

• The project has promoted a culture of cooperation and communication amongst
project collaborators and participants.
This FWPA-funded lidar project comprises of five research modules, each with several sub-objectives:

1. Improve automated tree count estimates across the full range of softwood tree densities.

2. Improve the efficiency of inventory sampling designs using auxiliary variables extracted from Lidar data.

3. Develop Lidar-based modelling approaches of volume and product yield estimation = the major research module (Results to be presented by Jan Rombouts).

4. Complete an evaluation into the financial feasibility of lidar based inventory.

5. Present an operational-focused data processing workflow for achieving the tasks above (i.e. an operational prototype based on a couple of real datasets).
Use of Lidar point cloud data to improve tree count accuracies
Analysis by Dr Amrit Kathuria (Forest Biometrican NSW DPI)

- Tree crown detection algorithm developed using simulated data (virtual stands ‘constructed’ using lidar data corresponding to real trees).
- Used local (zonal) variables to identify the optimal search window for detecting tree crown maximas.
- The algorithm was validated using lidar data acquired over Green Hills SF.

Example image of the simulated lidar stands
(Therefore the ground-based truth accurately known at the individual tree level)
Use of Lidar point cloud data to improve tree count accuracies:

- Overall, the results for estimating tree counts were more accurate than that obtained using an area-based plot modelling approach. With the added benefit that the location of each tree is determined and therefore corresponding tree height and hence very accurate tree height distributions.

- This individual tree detection model is now ready for inclusion into the plot imputation process.

Matching of the predicted tree tops with the manually delineated trees on the ground in Green Hills SF

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Match</th>
<th>Omission</th>
<th>Split</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
<td>161</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>T1</td>
<td>141</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>T2</td>
<td>189</td>
<td>11</td>
<td>5</td>
</tr>
</tbody>
</table>

Black triangles = manually identified trees and red boxes = predicted trees
Use of Lidar point cloud data to improve tree count accuracies:

Number of trees against the predicted number of trees at the Cpt level. $R^2 = 0.97$

Plot of height distribution of the manually identified and predicted trees at the thinning level.
Tree-level surfaces derived from detecting tree maxima

Classified tree heights from individual tree crown maxima

Stocking (local no. stems/ha) based on individual tree crown maxima
The application of lidar data to reduce sampling intensity of inventory plots in radiata plantations

Analysis by Dr Gavin Melville (Research Biometrican, NSW DPI)

Evaluation of the properties and efficiency gains from Balanced Sampling methodology based on sampling simulations:

- Investigated the properties of *balanced* samples using data from Nundle SF.
- Demonstrated that balanced samples captured more of the underlying dispersion in the design variables which lead to better outcomes for the imputation estimates.
- The RMSE values are reduced markedly when imputation is used in conjunction with balanced sampling and total efficiency gains from this combination are around 10-fold.
- However, this marked efficiency was not observed when using the ForestrySA data, nevertheless, balanced samples have a number of overall desirable features such as quantile coverage and fewer isolated plots which are well suited to the imputation approach.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Estimation</th>
<th>RMSE</th>
<th>Relative efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random</td>
<td>Design-based</td>
<td>836</td>
<td>0.7</td>
</tr>
<tr>
<td>Grid</td>
<td>Design-based</td>
<td>745</td>
<td>1.0</td>
</tr>
<tr>
<td>Balanced</td>
<td>Design-based</td>
<td>295</td>
<td>5.9</td>
</tr>
<tr>
<td>Random</td>
<td>Imputation</td>
<td>320</td>
<td>4.9</td>
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<tr>
<td>Grid</td>
<td>Imputation</td>
<td>311</td>
<td>5.6</td>
</tr>
<tr>
<td>Balanced</td>
<td>Imputation</td>
<td>234</td>
<td>10.1</td>
</tr>
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Relative efficiencies gained when applying different sampling and estimation methodologies using the lidar variable “occupied volume” and imputation method used = nearest neighbour
The application of lidar data to reduce sampling intensity of inventory plots in radiata plantations

Evaluation of a systematic sampling approach combined with nearest neighbour plot imputation and the reference variable mean quadratic height from the Forestry SA dataset.

<table>
<thead>
<tr>
<th>Sample size 30 or 300 plots/sample</th>
<th>Sample</th>
<th>Estate-level RMSE (%)</th>
<th>Planning Unit RMSE (%)</th>
<th>Plot level RMSW (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Random</td>
<td>Sample</td>
<td>0.7</td>
<td>2.6</td>
<td>17.9</td>
</tr>
<tr>
<td>Large Systematic</td>
<td>Sample</td>
<td>0.5</td>
<td>2.5</td>
<td>15.9</td>
</tr>
<tr>
<td>Small Random</td>
<td>Sample</td>
<td>3.3</td>
<td>5.6</td>
<td>23.7</td>
</tr>
<tr>
<td>Small Systematic</td>
<td>Sample</td>
<td>2.6</td>
<td>5.1</td>
<td>21.0</td>
</tr>
</tbody>
</table>

- Gains in precision are consistently achieved by the use of systematic or balanced sampling strategies, however, the magnitude of these gains are dependant on the structural characteristics (e.g. uniformity) of individual estates.

- We have also evaluated a range of variable selection techniques and identified the Genetic Algorithm as well suited to optimising the set of lidar variables for both the sampling design and imputation modelling process.
Bringing it all together:
The operational stages in an integrated lidar based inventory solution

A data work flow solution for a lidar-based forest inventory program suggested by Brian Rawley (Silmetra PL, NZ).
A data work flow solution for the plot imputation system as suggested by Brian Rawley (Silmetra PL, NZ).

More than one solution will be recommended; differing in the degrees of analytical complexity and precision.
Points to consider with the deployment of Lidar data into yield estimation systems

• The cost of collecting information should not be greater than the benefit from the use of that information (to be confirmed with a cost/benefit analysis).

• However, costs associated with Lidar data acquisition, processing and analysis are task dependant.

• Lidar survey costs vary depending on point density, flying height, complexity of the flight plan, swath width and flight time.

• These flight parameters are, in turn, influenced by the extent of the area, the fragmentation of the estate and complexity of the terrain.

• Most missions will cost at least $10,000 for hire of the aircraft and pilot.

• First acquisition provides numerous tangible and intangible benefits from the high spatial resolution terrain surfaces.

• The wall-to-wall census provides increased precision of estimates especially for management planning unit – level inventories.

• Improved efficiencies for ground-based sampling is achieved (i.e. fewer plots required).
Proposed FWPA project:
“Deployment and integration of cost-effective, high spatial resolution, remotely sensed data for the Australian forestry industry”

This project aims to provide data workflow and analytical solutions required for the operational deployment of high spatial resolution data acquired by UAVs and light aircraft into resource information systems managed by the Australian plantation and native forest growers. Due to commence 1 June 2014 with ten companies wanting to participate.
Key tasks within this proposed Project are:

1) Optimise the acquisition, processing and use of hybrid canopy surface models (using lidar and optical point data clouds; parameterization & calibration) acquired by light aircraft and UAVs.

2) Compare the acquisition costs, data quality and classification accuracies of multispectral data captured by UAVs and light aircraft for mapping: weeds; survival counts; coppice condition and post-harvest residues.

3) Evaluate and adapt the lidar modelling approaches developed in PNC303-1213 for stand variables associated with hardwood plantations and native forests.

4) Provide recommendations on the most cost-effective acquisition specifications and optimal sampling design strategies for lidar and digital camera data across a range of resource assessment tasks.
Can photographic imagery acquired from light aircraft and UAV platforms be used to generate 3 dimensional, dense point cloud data that reliably describe plantation or forest canopies?

Lidar provides very high accuracies, especially for the terrain attributes but is more expensive to capture than aerial photography and this has prompted the evaluation of composite ‘optical-lidar’ canopy maps.
Comparison between lidar and image-based point clouds

There has recently been a significant improvement in photogrammetry algorithms and software.

However, aerial photography cannot penetrate through forest canopies. Therefore, a cheaper solution is through composite ‘optical-lidar’ CHMs whereby pre-existing lidar-derived DTMs are combined with photogrammetry-derived DSMs, to produce affordable updates of the CHMs which can then be used for modelling stand inventory estimates.

Figure 8. Differences in DSI- and ALS-derived canopy height models in mature Scots pine stand. Small canopy openings are missing from the DSI.