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Technical Note

Locating individual trees within a forest genetics trial

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Summary: Research is being carried out into methods to characterise individual trees from airborne laser scanning (ALS) data. These methods support the development of a Phenotyping Platform within the “Growing Confidence in Forestry’s Future” research programme. A key requirement is the ability to accurately match trees detected in ALS data with the ground measurements of those trees. Data collected for a genetics trial was used to explore methods for locating individual trees and matching ground and ALS measurements. Errors in Global Navigation Satellite System (GNSS) measurements were found to be large enough to prevent reliable determination of trial boundary locations (marked by pegs), so manual interpretation was used to determine sufficiently accurate peg locations to unambiguously define the trees within trial blocks. Accuracy of detecting trees in the trial was initially 90%, with the main remaining source of error being in the tree detection process. Subsequent manual correction of the tree detection improved overall accuracy in locating trees within the trial to 98%. The procedure developed in this study is proposed as a viable approach to locating individual trees detected in ALS data within a research trial. The method required manual image interpretation to correct GNSS and tree detection errors but this was not onerous and it has been shown to achieve a high level of accuracy.

Introduction

Airborne laser scanning (ALS) data is a form of remotely sensed data being widely adopted for forest assessment^{1,2}. Area-based methods, which characterise trees in small patches (of the order of 0.05 ha in size), are being used as a cost-effective replacement for conventional ground-based inventory methods internationally and locally³⁻⁵.

An alternative approach to analysing ALS data is to use so-called individual-tree methods. Recent research has demonstrated the potential to identify individual trees from ALS data in New Zealand forest conditions^{6,7}. Subsequent research is now underway to accurately delineate the crowns of detected trees and extract crown metrics for use in estimating tree-level measures such as tree height and DBH. Tree-level analysis of ALS, and other remotely sensed data, could have a number of forest management and research applications, including the planned development of a methodology to phenotype individual trees as part of the “Growing Confidence in Forestry’s Future” (GCFF) research programme⁸.

The need to accurately locate individual trees

An important requirement in the development of individual tree methods is the ability to accurately locate trees on the ground after they have been detected in remotely sensed data. Two general issues and applications are important within this process. Firstly, the ability to detect and characterise individual trees could be used to detect individual trees of interest. One notable application is the ability to detect trees exhibiting superior growth in forest stands. Such trees might be visited on the ground and genetically profiled to allow evaluation of breed performance for subsequent use in breeding and deployment programmes. Secondly, ALS-detected trees must also be accurately matched with ground measured trees to permit development and evaluation of methods to estimate tree characteristics from crown metrics. Such methods might be used to obtain tree-level measurements of characteristics such as height for use in operational inventory and research trial measurement. In this study a specific example of the second application is to be investigated.

Current positioning technology

Surveying techniques are typically used to map tree locations in research projects. This provides accurate data for developing and testing individual tree methods but is costly and is therefore usually only carried out on small areas. This approach is therefore of limited use in research and would be impractical for operational applications.

The use of Global Navigation Satellite System (GNSS) technology for determining locations is widespread in forest management and research applications. This technology is perfectly adequate for determining locations in current forest assessment applications such as establishing and relocating inventory and research plots. It is well known that there is error in position reported by GNSS but the true scale of this error under forest canopy is not well recognised. Differential correction by post processing, increased residency time and use of an external antenna can all improve GNSS accuracy. However signal blocking and multi-pathing in forest conditions due to local terrain and overhead forest canopy are significant and largely unavoidable sources of error⁹. Using consumer grade GNSS units, error of 7 m in young forest stands and 10 m under closed canopy conditions have been observed¹⁰. In a subsequent study similar errors were found using mapping-grade GNSS units under canopy¹¹. Investigations carried out using a range of GNSS equipment and test conditions have indicated comparable levels of error in New Zealand forest stands (D Pont and R. Brownlie 2015 pers. comm.).

Positional error of 7 m or more using GNSS in forest or trial conditions is too great for reliable location of individual trees. Tree spacing corresponding to stocking levels of 1200, 600 and 200 stems ha⁻¹ are 2.9, 4.1 and 7.1 m respectively. In order to reliably locate individual trees on the ground GNSS error would have to be less than half the mean tree spacing. In fact tree spacing is variable and thus even lower error would be required to confidently locate any given tree in a stand. Therefore, even at stocking levels as low as 200 stems ha⁻¹, GNSS error is going to be more than twice the level required to reliably identify individual trees.

Locating trees in a research trial

A current GCFR research project aims to develop methods to correlate tree-level crown metrics from ALS data with ground measurements of trees in a genetics trial. The ALS data will be processed to identify and delineate individual tree crowns and crown metrics are to be derived for each identified tree. In order to correlate ALS-derived crown metrics with ground measurements it is necessary to accurately match the tree crowns identified in the ALS data with the tree locations within the trial. This specific application of individual tree analysis is seen as a useful first step for investigating solutions to the problem of locating individual trees.

Method

Trial data

The Radiata Pine Breeding Company genetics trial was established in 2007 in compartment 76 in Kaingaroa forest to evaluate *Dothistroma* resistance of a number of breeds. The trial comprises 75 blocks measuring 19.2 by 19.2 m. Tree spacing is 3.2 by 3.2 m with 36 (6 by 6) tree locations in each block. Several trees were missing in each block due to mortality. Block corners were marked by pegs and there was some variation in tree spacing and peg positions but overall the layout of the trial was a highly regular grid pattern. A routine ground assessment was carried out in July 2014 when the trial was aged 7 years and from this the presence or absence of trees on the grid within each block was determined.

A set of 31 coordinates were obtained for a subset of block corner pegs around the perimeter of the trial. The peg locations were determined using a Trimble Geo7X mapping-grade GNSS receiver logging at least 200 points (residency of more than 3 minutes), and differential correction was carried out by post-processing.

Airborne laser scanning data

Airborne laser scanning data were collected between 23rd January and 6th March 2014 with an Optech Pegasus scanner operated at a pulse rate of 100 kHz with a target 0.25 m footprint size, achieving an average terrain point separation of 0.3 m. A Canopy Height Model (CHM) image was created for a rectangular area including the trial with a 50 m buffer using the Fusion tool *CanopyHeightModel*¹² (Figure 1).

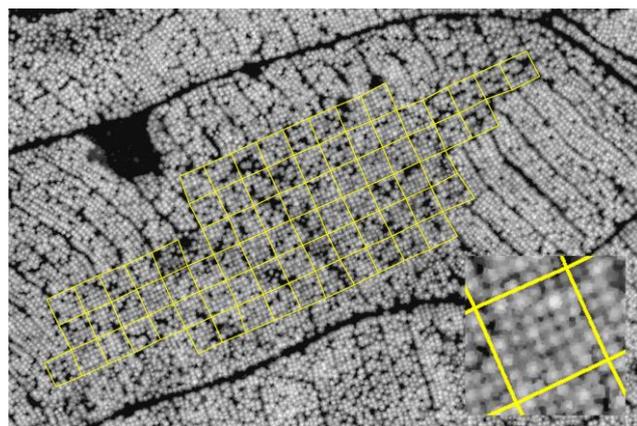


Figure 1. Trial block boundaries shown on CHM image in yellow. Inset at bottom right shows a single block. Block corners were manually digitised on the CHM image.

Manual correction of GNSS error

Peg locations obtained from the GNSS survey were used as a first approximation to establishing trial block boundaries. Plotting the peg GNSS coordinates on the CHM image immediately showed that the

GNSS error was large enough to create uncertainty about peg locations in relation to surrounding trees (Figure 2). The ground data about tree presence and absence within each block provided a form of spatial ‘fingerprint’ that was compared visually with the CHM image to verify the trees belonging to each block. With careful visual interpretation of these sources of information corner peg locations were able to be manually digitised onto the CHM image.

The process started with blocks at the perimeter of the trial having a GNSS location for one or more of the corner pegs. The exact set of trees in the block was identified using the ‘fingerprint’ provided by the ground data. Once the trees belonging to that block were determined the block corner peg locations were manually digitised onto the CHM image at mid-row positions. Once an initial block was digitised, determination of an adjacent block could proceed by advancing six rows or columns in the grid layout, and then confirming the block ‘fingerprint’ with the ground data. This process was repeated until all 75 blocks in the trial (Figure 1) had digitised corner peg locations (Figure 2).

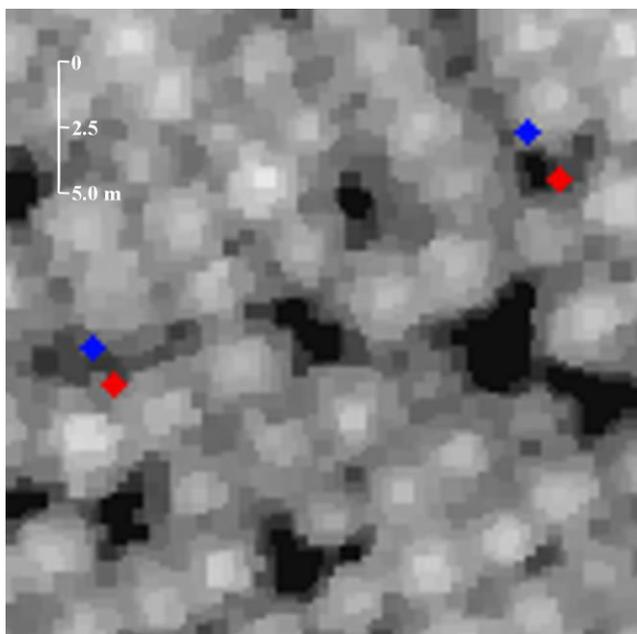


Figure 2. CHM image with two peg locations determined with GNSS in blue and manually digitised peg locations in red.

Tree detection from remote sensing

Tree detection was carried out on a CHM image created from the ALS data over the trial using a manually calibrated process⁶. Subsequent processing of the tree detection results provided tree top locations and crown boundaries (segments) for every detected tree (Figure 3).

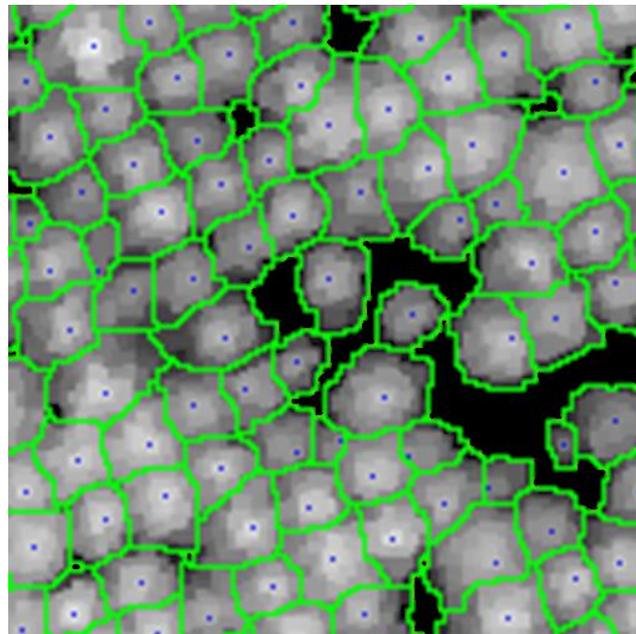


Figure 3. Tree tops (blue dot) and segmented crown boundaries (green) for detected trees within the trial.

Matching ground and detected trees

In the next phase individual tree locations on the ground were estimated within each block. This was done by starting with the manually digitised peg locations for each block and assuming trees to be on a perfectly regular 6 by 6 grid within the block. Theoretical grid locations were thus generated for each tree recorded as present in the ground data. These estimated tree locations are depicted with yellow circles on the CHM image in Figure 4.

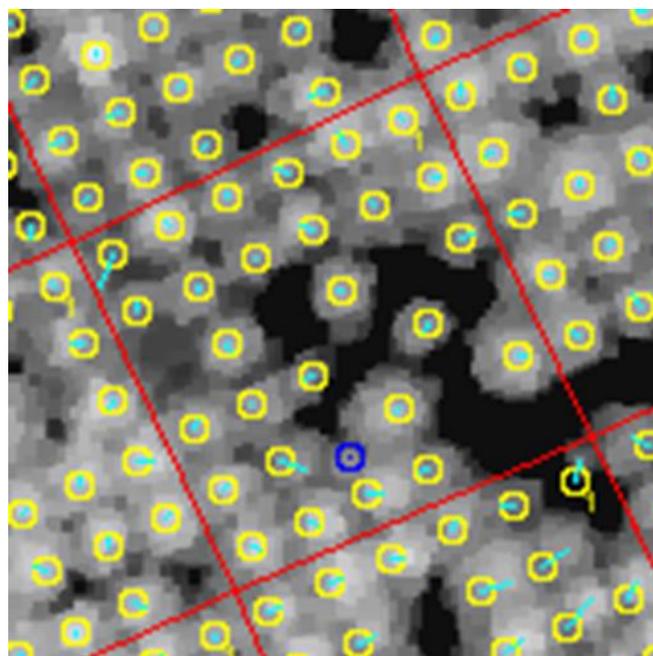


Figure 4. Block boundary derived from digitised peg locations in red. Estimated ground tree locations (yellow circle) assuming a grid within the block, connected to ALS-detected tree tops with a cyan line. Top of a falsely detected tree (commission) shown in blue.

A matching process was then carried out to link detected tree tops and estimated ground locations for the trees in each block. The matching process was applied one block at a time, finding the nearest detected tree top within the block for each ground tree (Figure 4). This matching process allowed for error from a number of sources; such as error in digitised peg locations, tree locations deviating from theoretical grid positions and the tree tops not directly aligning with their bases due to lean.

Quantifying matching accuracy

Accuracy was quantified using omission error, commission error and overall accuracy measures, calculated using a conventional method of error matrix assessment¹³, as shown by Equations (1-3).

$$CE = \frac{N_{det} - N_{cor}}{N_{det}} \quad (1)$$

$$OE = \frac{N_{ref} - N_{cor}}{N_{ref}} \quad (2)$$

$$OA = \frac{N_{cor}}{N_{cor} + (N_{det} - N_{cor}) + (N_{ref} - N_{cor})} \quad (3)$$

Where *CE* is commission error (falsely detected trees), *OE* is omission error (trees not detected), *OA* is overall accuracy taking omissions and commissions into account, N_{cor} is the number of correctly detected and matched trees, N_{det} is the total number of trees detected by the algorithm within the trial, and N_{ref} is the number of reference trees counted on the ground. All tree detection error measures were multiplied by 100 to be expressed as percentages.

After applying the initial tree detection process, 61 of 2196 ground trees were not matched with detected tree crowns, giving an omission error of 2.78%. Of the 2255 trees detected within the trial 120 were not matched to a ground tree giving a commission error of 7.82%. Overall accuracy taking into account omissions and commissions was 89.82%.

The omission and commission trees from the initial detection were verified on the ground. Omissions were found to be due to small trees being merged with adjacent tree crowns in the CHM image. Commissions, the main source of tree detection errors in this study, were found to result from large branches, forks, or multiple-leaders being subdivided as two or more trees in the CHM image.

Manual correction of tree detection

Erroneous tree crown segments were edited manually to provide a more accurate tree detection result. Edits involved creating new segments where trees were omitted and merging segments where commission errors occurred. This was done with reference to the estimated tree ground locations, observations made on the ground, the CHM and crown boundaries from the initial tree detection

process. This process typically took just 1 to 3 minutes per correction and the interpretation required to determine the necessary edit was straight-forward.

Overall accuracy of locating trees was significantly improved after manual correction of the tree detection process. There were 5 of 2196 ground trees not matched with detected tree crowns giving an omission error of 0.23%. Of the 2218 trees detected within the trial 27 were not matched to a ground tree giving a commission error of 1.44%. Overall accuracy was improved to 98.34% by manual correction.

Conclusions

In this study trees detected in remotely sensed ALS data were located on the ground within a research trial. The two main sources of error in locating individual trees were GNSS error and error in tree detection. Both sources of error were able to be reduced through a combination of ground observations and manual image analysis. The overall accuracy of the tree location process within the trial was 98%. The combination of tree detection, use of ground observations and manual image analysis provided a viable method for locating individual trees in a research trial and was shown to have delivered a high level of accuracy.

Future work will need to investigate methods for locating remotely detected trees on the ground in managed forest plantations with more variable spacing. The current study has given insights into some of the methodological issues and it is likely to take significant efforts to find approaches and solutions to this much more difficult problem.

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