Determining the location of trees and their log products within a stand

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Abstract

This paper describes research on methods to identify the locations of trees and their log products within a forest area.

Three approaches are considered. The first uses geostatistical procedures to interpolate between values measured on plots with known locations. The remaining two methods are based on remotely sensed information. One combines satellite imagery with stand maps and inventory plots in a multi-source inventory procedure. The other uses automatic image processing of large-scale aerial photography to identify the location of each individual tree in a stand, with the potential for combining this with individual tree measurement and sampling schemes.

The research has shown that techniques based on locating the positions of individual trees appear to show the most promise.

KEYWORDS: Forest inventory, geostatistics, satellite imagery, image processing

Introduction

To market the products of a forest organisation a match must be obtained between the needs of potential customers and those products which the organisation can supply. In the past, there was a lengthy delay between the decision being made to fell a block of trees and the time to delivery of the timber, panel or paper products to the customer.

The timing of the decision was mainly production driven, derived from the long-term yield regulation and management plan, and modified by operational logging schedules. Producing the end-product, sawing, peeling or pulping, was carried out with only limited ability to take into account the short term needs of the market. However, current mechanised logging, high speed processing facilities, and short drying or pulping schedules, can reduce to less than a week the time between making a decision to harvest a stand and producing the deliverable end-product. Logging and processing operations can be just in time, where trees of the appropriate quality are felled only when required to fill an end-product sales order.

Within the constraints imposed by longer term plans, advances in harvesting and processing have the potential to allow the forest industry to become more market driven. To achieve this it is necessary to identify the locations of those trees that can most efficiently yield the required volumes of wood products. With this data, the forest can be considered as a warehouse of potential log products.

The area of a stand of trees can be large, covering several logging settings and the variability across a stand can be high. A harvest plan will comprise many potential logging settings and for optimum decision making each will require accurate and detailed inventory, to a strict level of precision. Inventory using only ground-based techniques to achieve this precision requires a high proportion of the trees to be measured. Such detailed inventories are expensive, and can only be carried out at this intensity on a cursory, quickly executed basis.

As a consequence, the planning of logging operations is forced to place great reliance on past experience, theoretical models and ocular estimates. Currently, the best estimate for the next week's production in a stand is what was produced last week. The results from such assessments are not ideal for quantitative, computer-based planning in a rapidly changing market-driven environment.

Inventory procedures need to be improved so that the geographic location of trees, and their flexibility to yield differing volumes and types of logs are known precisely. To achieve this, research is required to improve:

- software systems for pre-harvest inventory, integrated with an inventory plot data base and a company’s Geographical Information System (GIS) e.g., MARVL (Deadman and Goulding, 1979, Gordon et al., 1995)
- the accuracy of measurement of external features of stem quality on standing trees, such as branch sizes and positions, stem sweep, and intrinsic wood quality, and the way size and quality can be projected into the future, e.g., PhotoMARVL (Firth et al., 1999)
- the spatial resolution of inventory, so that results can be geographically represented at an acceptable level of sampling precision across the stand's area
- methods to keep track of trees and logs during harvest, and to forecast what can be harvested during the next few weeks

This paper describes research on one aspect of these requirements - that of defining methods which can provide information on the spatial characteristics of trees and their products within a forest area.

Spatial Distribution

In New Zealand plantations, trees are planted in rows laid out fairly precisely, and the tree-planters are able to correctly space the trees within the rows to achieve the prescribed number per hectare. Even so, the trees are not in a perfect matrix, and rows waver around natural obstacles. In unthinned stands, mortality due to competition can be severe after age 20.
Many stands are thinned at least once. Production thinning usually involves the removal of access rows, with selective thinning in between. Especially with machine thinning, clumps of trees can be missed, or trees felled to leave gaps for equipment manoeuvrability. Also, pruning standards may not be uniform across a block. These operational factors, combined with micro-site differences, cause spatial variability between and within what appear to be uniform stands. This spatial variability has important implications for the precision of forest inventory. The standard pre-harvest inventory method used by New Zealand and Australian forestry companies is the Method of the Assessment of Recoverable Volume by Log-types, MARVL. A key feature of the system is that it recognises that merchantable yields depend on the types of log-products to be harvested and on their relative values. When these change, the volumes of the various products harvested will change.

The results provided from the MARVL inventory method have been sufficiently accurate and useful for the amount of pre-harvest inventory in New Zealand to have greatly increased over the past decade. However, to estimate population totals within the confidence intervals desired by management requires 20 to 50 or more plots, involving two or more days work for a single field crew. Reducing the area inventoried does not necessarily reduce the variability between plots. Providing estimates for smaller and smaller sized areas is therefore limited by the amount and cost of the additional field work required. Precise information is not available when areas contain fewer than 12 to 15 plots.

To provide forest inventory with spatial resolution sufficient to capitalise on advances in harvesting and processing and to meet ever more rapidly changing market demands, three approaches are being considered. The first uses geostatistical procedures to interpolate between values measured on plots with known locations. The remaining two methods are based on remotely sensed information. One combines satellite imagery with stand maps and inventory plots in a multi-source inventory procedure. The other uses automatic image processing of large-scale aerial photography to identify the location of each individual tree in a stand, with the potential for combining this with individual tree measurement and sampling schemes.

**Geostatistics**

A difficulty with New Zealand forest inventory plots is the high between-plot variance, due to a relatively small plot size. The plots are usually less than 0.06 hectares in area, or have a basal area factor which counts eight to ten trees per point. The variability is very noticeable when predicting "rare" products, which may not be present in every tree, but which are valuable none the less.

A first attempt by the authors fitted a spline curve to data from 58 closely spaced inventory plots in an individual stand to predict a 2.5-D surface of the geographical distribution of volume in stands. No trend or pattern could be detected by visual analysis of the resulting surface and it was felt that non-statistical, numerical analysis techniques were inadequate for addressing the inherent variability of the data.

Geostatistics may overcome some of these problems by mathematically expressing the way in which merchantable volume or other parameters such as basal area change over the land surface, based on the distance and direction separating sample locations with measured values. A semi-variogram is constructed to describe the variance of the parameter over the surface.

The technique of Kriging fits a mathematical model to the variogram which is then used to provide unbiased estimates over that surface, interpolating between the known points. Kriging uses a weighted linear sum of the data, where the weights depend on the position of the unknown point relative to the known measurements, and the relationship of the known measurements to one another (Oliver and Webster, 1991).

An estimate of the precision for each of the estimated values is also provided. Gunnarson et al. (1998) describe the potential of Kriging to assist in Scandinavian forestry, including the estimation of total standing volume, and its subdivision by species classes.

Hock et al. (1993) used Kriging to provide estimates of site index across the 160,000 ha Kaingaroa forest, interpolating between estimates provided by permanent sample plots, combined with other available measurements. Hock et al. (1998) used geostatistics to predict the distribution of site index and basal area index at age 20 (SI20 and BA20 respectively), where:

- SI20 denotes age 20 site index
- BA20 denotes the basal area at age 20 of the top 100 trees per ha

These two measures of productivity were interpolated across northern Kinleith forest using tree growth data from 110 permanent sample plots. For each plot, growth curves were used to derive the two measures of productivity. Semi-variograms were constructed for each data set. Investigation of the data indicated that excluding some outliers substantially improved the variance and fit of the semi-variograms. The respective semi-variograms for SI20 and BA20 were used in the Kriging process to interpolate these measures of productivity across the study site. The BA20 values estimated across the northern Kinleith forest using Kriging are shown in Figure 1.

Data outliers can result from a range of factors, including errors in measurements or microsite variations. Checking and perhaps re-measuring inventory plots that result in the outliers is recommended. Although the outliers may be valid values, they may excessively influence the model fitted to the semi-variogram, and thus the Kriging, which may then produce erroneous predictions. A potential disadvantage of the technique is that the analysis methodology is unique for every situation, which prevents a standardised procedure from being applied to data by non-specialist staff.
Multi-source Inventory Incorporating Satellite Imagery

The intensity (brightness) values in a satellite image change in response to variations in tree size and vigour as expressed through leaf area and leaf colouration, and to the variable shadowing in the canopy resulting from variations in tree spacing and height. This has enabled remote sensing to be used for inventory of boreal forests, based on correlations between image intensity and wood volume. The technique has been applied to the Finnish National Forest Inventory through the development of a “multi-source” inventory method by the Finnish Forest Research Institute (Tomppo, 1996). Multi-source inventory combines the data from a large number of inventory plots, stand maps, records and Landsat imagery to predict volumes, heights, species composition and other parameters of interest. A GIS is used to display maps of the results which are increasingly being used as a source of operational data for stand management (Tomppo, 1988).

In recent collaborative work with the Finnish Forest Research Institute, we investigated the application of the multi-source inventory method to New Zealand’s plantation forests. A trial was conducted on a block of 1000 hectares of radiata pine in Kaingaroa Forest, consisting of stands ranging in age from new plantings through to mature 28 year old stands. The objective was to compare predicted log products with the estimates of log product volumes derived from the MARVL inventory method for a subset of stands in the 20 to 28 year age range.

The basis of the technique is that if the forest can be stratified into areas of similar silvicultural history, then within-area differences in log product volumes should be related to stand density, which can be predicted from image intensity values (Tomppo et al., 1999). The former Forestry Corporation of NZ supplied data from 188 of their inventory plots in the block. The locations of these plots were mapped, and for each plot the corresponding intensity values were extracted from the six spectral bands of a Landsat TM satellite image.

The correlation relationship developed between inventory data and the variables of image intensity, stand age, and years since last thinning was then used to predict the total standing and merchantable volumes of pruned-, saw- and pulp-logs at the spatial scale of the image-one pixel representing 25 metres square (Tomppo et al., 1996, Trotter et al., 1997). An example of the type of information that can be produced is shown in Figure 2.

Although the variation in intensity values in an image of radiata pine plantations is much less than for that of boreal forests, the research confirmed that the method is sound over larger areas in New Zealand plantations. Care was required in the selection of the analysis method. The original approach produced biased results at the stand level for the Kaingaroa study (Tomppo et al., 1996, Trotter et al., 1997). An alternative approach that used the satellite and inventory plot data averaged by standing volume-increment produced unbiased predictions and achieved a precision of 50 m³/ha for standing volume in stands of 40 ha or larger (Trotter et al., 1997).

For optimisation of harvest planning, the real interest lies in using the above techniques for producing forecasts at the logging setting or coupe scale. As stand size decreases much below 40 ha the accuracy of the predictions falls significantly (Trotter et al., 1997). It therefore seems unlikely that a multi-source approach that incorporates satellite data will prove suitable for coupe-scale, precise estimates of forest products, even using data from more advanced satellites available in the future (Trotter et al., 1997, Holmgren and Thuresson, 1998).

However, although the estimates for individual small areas have reasonably wide confidence limits, the additional information on the pattern of spatial variation of standing volume is still useful. Areas of damage due to windthrow or severe disease are often clearly visible, as are larger areas of higher and lower volumes within a stand. These are features which cannot be determined from plot data alone when it is acquired at standard sampling intensities.

Automatic Delineation of Individual Trees

An alternate method of determining the spatial distribution of product volumes is based on the
automatic identification of the location of each individual tree within a stand or coupe using image processing of aerial photography.

The number of trees can then be counted and the count combined with measurements from cruising a sample of individual trees. While such an approach currently still has associated difficulties, such as the dependence of growth projections on stand parameters which may not be easily determined remotely, the advantage of the approach is the improved accuracy of stocking data. Variation in stocking is a major contributor to the variability in total recoverable volume, and thus log products also. If stocking can be determined more accurately, the amount of field assessment could be reduced, resulting in reduced costs and improved quality of information. The analysis of a stand’s spatial distribution (irregular spacing, clumping, etc.) may also be useful for the stratification of log products.

Where plantation boundaries are indistinct and the total area known only approximately, per hectare volume estimates from plots can be poor and better accuracy could be achieved by multiplying average tree parameters by the total number of trees present. The absolute accuracy of each tree location need not be high. The problem reduces to one of correctly distinguishing an individual tree from its neighbours, separating one tree from another.

In the last six years, methods of automatically delineating tree crowns from aerial photography have been reported in the literature. Large scale photographs are scanned, and the reflectance values of each sub-metre pixel analysed. For example, in mature plantations of Douglas fir, British Columbia, Daley et al. (1998) used a method of counting local maxima in varying window sizes. They reported being able to locate trees with errors of about 20%.

For Norway spruce in Denmark, Dralle and Rudemo (1996) carried out a method of kernel smoothing then counting maxima above a threshold level. They reported being able to locate trees in stockings varying from 367 to 1257 per hectare in a thinning experiment, with tree count errors of less than seven percent.

Radiata pine does not have the regular, narrow, conical crowns found in the species that have been the focus of some of the international research. The branches in the upper half of the crown grow upwards and although height growth is vigorous, apical dominance can easily be lost if the main shoot is damaged. Double or multiple leaders can occur. From above, the tips of branches of the topmost branch cluster could easily be mistaken for individual trees under some circumstances. The crown shape is ragged and seldom circular, as branches grow into gaps or areas of less crown competition where they quickly become large.

For the New Zealand situation the most appropriate tree-counting technique appears to be that described by Gougeon (1995, 1998). Gougeon’s method uses two steps: a “valley following” algorithm in which shadowed areas around and between trees are delineated, followed by a rule-based algorithm to split the clumps of trees that remain undifferentiated. The valley-following algorithm proceeds by extracting the darker areas, shadows or background vegetation, using a thresholding operation, and finding the local
minima (dark pixel surrounded by lighter pixels) within the remaining areas. From these local minima, irregular lines are grown along ‘dark valleys’ within the image until they reach another local minima, or until no further valley-following is possible. This process partially separates crowns but further processing is required to complete the separation. The second step, the rule-based algorithm, outlines the boundaries of each crown. The program uses several rules to move from pixel to pixel around one crown boundary at a time attempting to delineate the separate crowns.

To implement the method, some modifications specific for radiata pine were made. Colour photographs were tried initially, but infra-red photographs show promise and are likely to be very suitable, because the loss of resolution of the outer periphery of the crown makes the central, tallest portion more readily distinguishable in the pine plantations.

Mathematical filters were used to pre-process the original image to reduce the raggedness of the crown shape. Gougeon’s method was applied with modifications to the rules to allow for shapes that were more ragged than those of the Northern hemisphere trees.

The results of these procedures applied to a stand in Kaingaroa forest are shown in Figure 3a. Figure 3b shows the final output of the method, with the edges of the delineated crowns overlayed on the original image.

Conclusions
Defining the most appropriate markets, and then improving the allocation of log-products to current market commitments, offers the potential to greatly improve the profitability of plantation forests. To achieve this profitability requires good information on the geographic distribution of potential log products. The value of pre-harvest inventory information has increased significantly over the last decade and this increase has generated an even greater demand for more precise and spatially accurate information about the potential yield of log products. Remote sensing and geostatistical techniques now offer the means to provide a picture of within-stand variability in log product distribution, when used in combination with existing inventory data.

Of the newer techniques being developed, those based on locating the positions of individual trees appear to show the most promise. Using these techniques, more detailed and precise quantitative information on the availability of log products and on their spatial distribution within a stand or a coupe should be available for input to log allocation and wood-flow decision support systems. The concept of just in time harvesting from the forest as a warehouse should be achievable.

Acknowledgements
This research was funded by the Foundation for Research, Science and Technology.

References

Deadman, M.W., and C.J. Goulding

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Figure 3a. Output of the rule-based algorithm from the modified Gougeon method applied to a colour infra-red aerial photo in order to identify tree crowns.

Figure 3b. Edges of the crowns delineated by the modified Gougeon method overlayed on the original colour photograph.

Comparisons with the original aerial photographs showed that the automatic tree counting method delineated the same potential crown areas as a subjective classification of the photograph. Future work will involve a more rigorous testing over a range of conditions and on data sets with known truth sets, in order to determine validated measurements of the accuracy of the method. We also want to investigate the merit of adding further intelligence to the rules. For example, the expected crown size could be approximated based on the known age. It may also be possible to detect the pattern of the original planting rows, even if they are not straight lines. This, combined with information on initial stocking and thinning operations, could indicate where to expect the next tree.

While the inventory immediately prior to harvesting is important for harvest planning, the automatic delineation of mature trees may prove to be too difficult to solve sufficiently accurately. An option may be to analyse photography acquired after the final thinning, if necessary allowing enough time to lapse after the thinning operation for the waste needles to have turned brown. Trees identified on this image could then be searched for on a second image acquired shortly before harvesting. Given even radiata pine's inability for its leader to move far from its original position, we believe the individual tree location problem is solvable at an economic cost.
A method for assessment of recoverable volume by log types.

Dralle, K. and M. Rudemo (1996)
Stem number estimation by kernel smoothing of aerial photos.
Canadian Journal of Forest Research, 26:1228-1236.


A crown following approach to the automatic delineation of individual tree crowns in high spatial resolution aerial images.


On the potential of kriging for forest management planning.

Höck, B.K., T.W. Payn and J.W. Shirley (1993)
Using a geographic information system and geostatistics to estimate site index of Pinus radiata for Kaingaroa forest.

Höck, B.K., T.W. Payn and A. Dunningham (1998)
Research on spatial analytical tools for New Zealand plantation forests. Proceedings of the 10th Annual Colloquium of the Spatial Information Research Centre (SIRC'98), University of Otago, Dunedin, November 1998.

Holmgren, P. and T. Thuresson (1998)
Satellite remote sensing for forestry planning - a review.

Oliver, M.A., and R. Webster (1991)
How geostatistics can help you.

Tomppo, E. (1988)
Standwise forest variate estimation by means of satellite images.
IUFRO S.4.02.05 Meeting, Aug. 29 - Sept. 2, 1988.
Forest Station Hyytiala, Finland, Proceedings University of Helsinki, Department of Forest Mensuration and Management, Research Notes No.21, pp 102-111. ISBN 951-45-4820-5.

Tomppo, E. (1996)

Tomppo, E., M. Katila and C.J. Goulding (1996)

Tomppo, E., C.J. Goulding and M. Katila (1999)
Adapting Finnish Multi-Source Inventory Techniques to the New Zealand Preharvest Inventory.