AUTOMATING PLOT BASED FOREST MEASUREMENT USING GROUND BASED LASER SCANNING

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ABSTRACT

Forest inventory plays an important role as a basis for forest management decision making and as a means of meeting external reporting obligations. Ground based lidar technologies have potential to increase the efficiency of these surveys while simultaneously augmenting the current range of readily measurable parameters. The ECHIDNA® ground based lidar has been developed specifically for the purpose of forest structural measurement. The following paper describes the automated estimation of parameters important in characterising forest structure. The system has been shown to have significant potential for achieving acceptable accuracy in the measurement of standard inventory parameters, while also allowing the measurement of other more complex parameters that are currently not practically attainable in operational surveys. However, efficiency gains in an operational setting will rely heavily on further hardware development in order to increase the portability of the current instrument.

1. INTRODUCTION

The benefits of accurate resource information are recognised throughout the forestry industry as a basis for planning and management decisions which ultimately influence gross margins. There is also an increasing need for such information to assist in fulfilling reporting obligations to stake holders and government agencies. Forest measurement takes many forms depending on the specific objectives of managers and the physical characteristics of the resource being measured. Specific aims of the measurement may include:

- Assessing volume or biomass;
- Measuring and monitoring growth;
- Determining merchantable value of the timber;

all of which rely heavily on the characterisation of the physical structure of the forests in question. In many commercial forestry organisations, significant investment is made in these plot based structural measurements. Consequently, there is an ever present interest in technologies that may increase forest structural measurement efficiency while maintaining the accuracy inherent in current manual measurements. Ground based lidar, often referred to as ground based laser scanning, has been identified by the industry as one potential technology that could deliver such measurement efficiency gains.
A number of studies have used lidar instruments to characterise aspects of forest structure such as stem diameter and location (Theis and Spiecker, 2004), stem form (Theis et al., 2004, Pfeifer et al., 2004), tree heights (Parker et al., 2004, Hopkinson et al., 2004), canopy cover and leaf area index (Henning and Radtke, 2006). In all but the case of Parker et al. (2004), commercially available instruments optimised for engineering applications were employed. Such instruments return only a single distance for every direction sampled within the scan. This may not be ideal in forest structural assessment where there are a large number of surfaces and complex shapes, distributed in a spatially complex manner. These instruments also generally only scan within a limited angular range which restricts the amount of information available for a given instrument setup, decreasing possible data capture efficiency gains. The custom instrument employed by Parker et al (2004) is a non-scanning instrument and consequently has limitations in the quantity and unity of data captured.

2. THE ECHIDNA® INSTRUMENT

The ECHIDNA® Validation Instrument (EVI) was developed and built by the CSIRO Division of Marine and Atmospheric Research and Ensis, and is based on the patented ECHIDNA® concept which specifically targets efficient forest structural measurement. Two specific features set the ECHIDNA® instrument concept and the EVI apart from other commercially available ground based lidar: the recording of the full waveform of the return laser signal and scanning across the entire upper hemisphere above the instrument.

For a single direction within a scan, conventional ground based lidar instruments return the distance to the nearest surface in that direction, given a significant interception of the beam. Significance in this case is measured by the return of energy relative to detector noise. For the EVI, all energy returned to the instrument is recorded leading to a time trace of returns as shown in Figure 2.1. In the case of hard targets like stems and branches, the return is characterised by a short intense pulse, while crowns are usually characterised by broader and less intense pulses due to multiple partial interceptions by distributed foliage elements.

![Figure 2.1: Typical waveform associated with the interception of the laser beam by a hard target such as a trunk.](image-url)
The EVI is also a full hemispherical scanning instrument which allows it to capture the maximum amount of forest structural information from a single setup location within the forest. The instrument also scans to approximately 30 degrees below the horizon in order to capture local topography so that tree height can be more easily established.

![Figure 2.2: Two dimensional projection of the hemisphere of EVI data in a mature Pinus radiata plantation.](image)

Given the range and intensity of returns inherent in each waveform within the scan, data can be readily transformed into discrete points with given Cartesian coordinates and intensity. An example of this reprojection of the data is shown in Figure 2.3. The combination of both the waveform characteristics and the spatial arrangement of returns produce a powerful dataset from which many attributes of forest structure can be derived.

![Figure 2.3: Cartesian projection of the EVI data with shading performed on the basis of the return intensity. Data collected in mature P. radiata plantation.](image)

The EVI was developed as a scientific validation instrument and was deliberately over-engineered to ensure that all aspects of the ECHIDNA® patents could be
adequately tested and validated. However, this has necessitated some compromising of practical considerations such as instrument simplicity and portability. However, for the purpose of prototype testing, the EVI has provided much of the data required to demonstrate its utility in an operational forestry environment. These data and applications are discussed in the following sections.

3. AUTOMATED INVENTORY MEASUREMENTS

Standard inventory measurements are readily retrieved using ground based lidar instruments. Hopkinson et al. (2006) showed that the distribution of both stem diameters and tree heights can be retrieved with high precision ($r^2 = 0.85$). They also showed that in the case of stem diameters, high accuracy could also be achieved.

In order to assess the ability of the EVI to measure tree diameter at breast height (DBH), EVI scans were recorded at six plot locations within a mature *Pinus radiata* plantation in Mt Gambier, South Australia, managed by ForestrySA. Manual measurements of DBH were recorded within their standard 0.1 hectare rectangular plot boundaries. DBH was also estimated for every unobscured tree using the EVI data, recorded from the centre of each plot. Manual measurements produced an average of 20 DBH measurements while the EVI scans showed an efficiency gain being able to record the diameters of 38 trees on average; effectively extending the sampling area outside the plot boundary. The mean and standard deviation in DBH for both manual and EVI based measurements were used to produce log-normal distributions for each plot. These are shown in Figure 3.1. In general, DBH was estimated well with an average underestimation in diameter of 0.5cm.
Ten trees within three of the plots were harvested by ForestrySA in order to determine the taper of each tree. Manual measurements of the upper stem diameters were performed using callipers at approximately three metre intervals along the fallen logs. These measurements were compared with upper stem diameter measurements estimated pre-harvest using automated processing of the EVI scans.

Difficulties were experienced with interference from branching along the stem. In general this caused an erroneous dilation of the diameter estimate that can clearly be seen above 20m on Tree 16 in Figure 3.2. Although this is a significant factor in characterising taper, these errors are easily detectable due to their rapid departure from the relatively consistent shape of the stem.

Accuracy of the derived diameter profilers varied depending on a number of factors. The distance of the tree from the instrument had a significant effect on the diameter measurement precision (Tree 22 in Figure 3.2). This is likely due to the beam interception density which is inversely proportional to distance from the instrument. Despite the drop in precision for individual diameter estimates, fitting of taper curves for distant trees still produced strong correlations with the manual measurement recorded post harvest.
A natural extension of the taper estimation process is the characterisation of stem sweep and lean, which is important in determining volume by product class. In the case of taper, each successive diameter measurement is performed through a process of circle fitting. Since the centre of the circle is returned as part of the same fitting process, the movement of the stem centre in the horizontal plane can also be tracked. An example of this measure of stem form is shown in Figure 3.3. Due to the difficulty in manual characterisation of sweep and lean, no validation of sweep and lean estimates was performed in this study.
The measurement of tree height is also an important component of standard forest inventory. Conventional tree height measurements are usually based on distance and angle based approaches such as that employed by the Vertex Hypsometer. Hopkinson et al. (2006) showed that height estimation using ground based lidar was prone to underestimation relative to manual methods. In their study, this error was of the order of 8% underestimation and is likely due to both the low intercepting area of the crown apex and the high probability of obscuration of the apex by other plant elements.

For the EVI, returns emanating from the highest points in the canopy can be easily established within the data. Comparisons were made between plot means for Vertex Hypsometer heights and EVI based heights for a range of forest age classes in both hardwood and softwood. Results showed a systematic underestimation in the EVI estimates of the order of 10% (Figure 3.4). This is consistent with the findings of Hopkinson et al. (2006). However, this offset should not reduce the utility of the height information produced in an operational setting if suitable adjustment is made in allometric equations within which the metric is used.

Increasingly, foliage area index is becoming an important metric in commercial forestry due to its direct relationship with photosynthetic capacity. Measurements of foliage area are traditionally performed using canopy gap fraction estimates derived from hemispherical photography. There are two major limitations with this approach. First, the estimation of gap fraction in hemispherical photographs is highly dependent on consistent sky illumination (ideally uniformly overcast skies), which are not always present during convenient times for data collection. Second, there is no easy way to make distinction between interception due to foliage and interception due to other plant elements such as branches and stems. Both these factors lead to uncertainty in the final foliage area estimate.
Estimation of foliage area index using EVI data is performed using the knowledge of beam interception (and its complement, the gap fraction) and the degree of interception (as indicated by the return intensity) and the range from the instrument for each of these interceptions. This effectively allows classification of woody and non-woody returns and a method of estimating the foliage area index without interference from other plant elements. In addition, since the measurement is independent of natural illumination, data can be recorded at any time and under varying illumination conditions.

Validation of foliage area index estimates was performed using hemispherical photography at sites within a number of hardwood and softwood plantations. This showed a strong relationship between the two techniques with a slight bias toward lower values for the EVI based estimates. This is consistent with the assumption that woody components of the vegetation may increase the apparent foliage area index when hemispherical photography is used.

![Figure 3.5: Relationship between foliage area index derived from hemispherical photography and those derived from the EVI data.](image)

4. CONCLUSIONS

Work using the EVI research instrument has shown that estimates of inventory parameters can be derived from ground based lidar data. The EVI provides a permanent three-dimensional record of forest structure that can be interrogated at any time to derive estimates of additional inventory parameters. Given the digital nature of the data, the extraction of these parameters can also be highly automated, increasing the efficiency of inventory data analysis.

The accuracy of the derived estimates has been shown to vary depending on the parameters being considered. In some cases (such as the measurement of DBH) it is unlikely that ground based lidar estimation will be able to achieve the accuracy of manual measurement. However, there may be significant efficiency gains to be
achieved over manual inventory surveys given further development of the instrument in terms of portability. Such accuracy limitations may also be negated by the fact that the instrument is able to measure a large number of trees from a single location, thus characterising the variance in forest structure with greater confidence.

Further development of the ECHIDNA® concept by the CSIRO and Ensis will be focussed in two areas. First, in the development of new versions of the ECHIDNA® instrument hardware that will allow more practical deployment in the field. Second, in the further refinement of data processing algorithms to increase parameter estimation accuracy and the range of structural parameter that can be retrieved.

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