Statistical analysis of LiDAR-derived structure and intensity variables for tree species identification

Zhenyu Zhang[1], Xiaoye Liu[1] & Wendy Wright[2]

[1]School of Civil Engineering and Surveying, and Australian Centre for Sustainable Catchments
University of Southern Queensland, Toowoomba, Queensland 4350, Australia
Phone: +61 7 46311980 Fax: +61 7 46312526
Email: zhenyu.zhang@usq.edu.au

[2]School of Applied Science and Engineering
Monash University, Churchill, Victoria 3842, Australia

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1.0 INTRODUCTION

Tree species identification is part of decision support for sustainable forest management and native forest conservation (Brandtberg 2007; Koch et al. 2006). The traditional methods for tree species identification were based either on an interpretation of large-scale aerial photographs or a field inventory work. These methods are labour intensive and time consuming (Franklin 2001). Although remotely sensed data have been widely explored for forest applications, passive remote sensing techniques still fall short of capturing three-dimensional forest structures, particularly in uneven-aged, mixed species forests with multiple canopy layers (Lovell et al. 2003). Fortunately, it has been shown that active remote sensing via airborne LiDAR (light detection and ranging) with capability of canopy penetration yields such high density sampling from the top and interior of the canopy and understorey vegetation that detailed description of the forest structure in three-dimensions can be obtained (Zhang et al. 2011).

Species classification at individual tree level using LiDAR-derived variables has been attempted for coniferous forests, deciduous forest, and mixed coniferous, deciduous and other forests. All these studies were performed using either: a) LiDAR derived structure variables, or b) intensity variables or c) both structure and intensity variables. In contrast to the present study, most of the above studies were carried out in open, conifer or deciduous forests of even-aged of relatively homogenous structures. Accordingly, priority can now be given to test the suitability of LiDAR data for delineating the structure of complex forest types, particularly for cool temperate rainforest and neighbouring uneven-aged mixed forests in severely disturbed landscapes.

The overall objective of this study is to use the statistical analysis of both structure and intensity variables derived from airborne LiDAR data for the classification of the cool temperate rainforest (the Myrtle Beech) and the Silver Wattle forests at individual tree level in the Strzelecki Ranges, Victoria, Australia. Specific objectives include the normality test of LiDAR-derived variables, tree species classification by linear discriminant analysis, examining of the contribution of the LiDAR intensity variables to the classification results and accuracy assessment using the error matrix.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study area is in the eastern Strzelecki Ranges, southeast Victoria, Australia. Prior to European settlement the Strzelecki Ranges were densely vegetated by wet forest (also referred to as wet sclerophyll forest) and cool temperate rainforest. The Ranges have experienced widespread land clearing since European settlement. Subsequent agricultural abandonment and a frequent wildfire history have resulted in severely disturbed landscape in the Strzelecki Ranges. The landscape has undergone further significant changes with the establishment of large scale plantations in the area since the mid-twentieth century (Noble 1978). Currently, areas bordering cool temperate rainforest in the Eastern Strzeleckis are a mosaic of different land use histories involving both natural and human disturbances, and so a very complex forest structure in the remnant patches of cool temperate rainforest and adjacent forests including wet sclerophyll and plantation forests prevails. This study focuses on an area with cool temperate rainforest distribution in the Eastern Strzeleckis, which covers an area of 1.82 km^2 with elevations ranging between 322 m and 448 m.

2.2 Data

LiDAR data were collected using an Optech ALTM Gemini LiDAR system at a flying height of 1,100 m above ground between the 11th and 23rd of October 2009. The laser pulse repetition frequency is 70 kHz. The laser scanner was configured to record up to 4 returns for one laser pulse. The average point density was 4 points per square metre, and the laser footprint diameter was 0.3 m. The LiDAR data used for this project was documented as 0.20 m for vertical accuracy and 0.25 m for horizontal accuracy. The LiDAR data were classified into ground and non-ground points by the vendor and were delivered in binary LAS 1.2 file format (ASPRS 2008).

Ecological Vegetation Classes (EVCs), which describe the spatial extent of vegetation types, are the basic regional scale mapping unit used for forest ecosystem assessments, biodiversity planning and conservation management in Victoria. The EVC mapping was undertaken first by the interpretation of aerial photographs and the process was designed to outline native vegetation patches and any obviously related patterns. The range of aerial photograph patterns was then field checked and lists of plant species were recorded (Davies et al. 2002; Boyle and Lowe 2004). The EVC data were used as reference data in this study.

2.3 Methods

The LiDAR ground data were used to create a DEM (digital elevation model) with one metre horizontal resolution (grid size) while the first returns of non-ground LiDAR data representing the laser returns from tree canopy were used to generate a DSM (digital surface model) for the study area. A canopy height model (CHM) was computed by subtracting the DEM from the DSM. The TreeVaW software developed by Popescu and Wynne (2003) was used to identify the location and crown size of individual trees from the CHM in the study area. Extracted LiDAR points for each of the individual trees were used to create tree height profiles representing the spatial distribution of the vertical structure of individual trees. The *k*-means clustering algorithm was performed on the height profile to determine the crown base height of each individual tree. It is the LiDAR point data from above the crown base that are used in deriving canopy variables. The variable names and descriptions derived from heights and intensity values of laser returns within tree crowns are listed in Table 1.

Table 1 LiDAR-derived structure and intensity variables and description

Variable	Description
MaxH	Maximum crown height
Depth	Depth (or extent) of tree crown
MeanH	Mean crown height
StdDev	Standard deviation of heights of laser returns within a crown
Density	Ratio of the number of laser returns in the crown to the total number of laser returns within the area defined by a crown diameter
MeanI	Mean intensity value of laser returns within a crown
StdDevI	Standard deviation of intensity value of laser returns within a crown
MeanIF	Mean intensity value of first laser returns within a crown
StdDevIF	Standard deviation of intensity value of first laser returns within a crown

If passed the normality assessment, the one-way ANOVA was performed on these variables to see if each of these variables can be used to distinguish one tree species from the other. Linear discriminant analysis with cross-validation was performed to classify the tree species and assess the classification accuracy. The cross-validation, often termed a jack-knife classification (Burns and Burns 2008), successively classifies all individual trees but one to develop a discriminant function and then categorizes the tree that was left out. This process was repeated with each tree left out in turn (Burns and Burns 2008).

3.0 RESULTS AND DISCUSSION

The results show that using LiDAR-derived structure variables, 83.2% of the individual trees of the Myrtle Beech and Silver Wattle were correctly classified using linear discriminant analysis with cross-validation. If using only the intensity variables, an overall classification accuracy of 74.6% was achieved. An overall accuracy of 86.4% was achieved by using both structure and intensity variables in the discriminant analysis with the cross-validation. The overall classification accuracy increased from 83.2% (using only structure variables) to 86.4% (using both structure and intensity variables). With the inclusion of the intensity variables, both producer's accuracy and the user's accuracy for the Myrtle Beech and the Silver Wattle increased. For example, the producer's accuracy increased from 87.6% to 91.2% and the user's accuracy increased from 69.1% to 73.4% for the Myrtle Beech. It is seen that the approach in which the LiDAR-derived canopy structure variables are analysed together with the related intensity variables produced accurate classification results: 84.0% of the Silver Wattle trees and 91.2% of the Myrtle Beech trees were correctly classified; and the likelihood of misclassification is reduced in terms of the omission error and the commission error.

This study showed the successful identification of tree species (the Myrtle Beech and the Silver Wattle) at individual tree level in our study area. The results of this study demonstrated the contribution of LiDAR-derived intensity variables to the identification of the Myrtle Beech and the Silver Wattle tree species at individual tree level. Although relatively low classification accuracy was obtained when only using LiDAR-derived intensity variables, the combination of both the structure and intensity variables in the discriminant analysis allowed individual Myrtle Beech and the Silver Wattle trees to be identified with high accuracy. The outcome of this study is such as to encourage further tests of the extent to which the LiDAR data may be applied in vegetation community mapping, particularly for rainforest and neighbouring forests in a severely disturbed landscape. Studies such as this one will also serve to increase the understanding of the value of the LiDAR intensity data to improve the accuracy of forest type classification and tree species identifications.

4.0 CONCLUSIONS

This study demonstrated the applicability of LiDAR-derived variables referring to canopy structure and laser return pulse intensity for the identification of the Myrtle Beech (the dominant species of the Australian cool temperate rainforest in the study area) and adjacent tree species – notably, the Silver Wattle at individual tree level. The results show that an overall classification accuracy of 86.4% can be achieved when both structure and intensity variables were included in the discriminant analysis with the cross-validation in the study area. The overall classification results are only 74.6% when just using the intensity variables in the analysis, but combination of the structure and intensity variables in the discriminant analysis did improve the accuracy of classification results, indicating the contribution of the LiDAR intensity variables to the classification results. It is expected that calibrated LiDAR intensity values will improve the application of LiDAR data in forest classification and tree species identification.

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