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Detecting pruning of individual stems using Airborne Laser Scanning data captured from an Unmanned Aerial Vehicle

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ABSTRACT

Modern forest management involves implementing optimal pruning regimes. These regimes aim to achieve the highest quality timber in the shortest possible rotation period. Although a valuable addition to forest management activities, tracking the application of these treatments in the field to ensure best practice management is not economically viable. This paper describes the use of Airborne Laser Scanner (ALS) data to track the rate of pruning in a *Eucalyptus globulus* stand. Data is obtained from an Unmanned Aerial Vehicle (UAV) and we describe automated processing routines that provide a cost-effective alternative to field sampling. We manually prune a 500 m^2 plot to 2.5 m above the ground at rates of between 160 and 660 stems/ha. Utilising the high density ALS data, we first derived crown base height (CBH) with an RMSE of 0.60 m at each stage of pruning. Variability in the measurement of CBH resulted in both false positive (mean rate of 11%) and false negative detection (3.5%), however, detected rates of pruning of between 96% and 125% of the actual rate of pruning were achieved. The successful automated detection of pruning within this study highlights the suitability of UAV laser scanning as a cost-effective tool for monitoring forest management activities.

1. Introduction

The application of treatments such as thinning, to increase volume, and pruning, to ensure timber quality have become essential activities in modern forest management. The optimal timing and level of treatment for many plantation species have been widely studied resulting in the design of best practice treatment regimes (Pinkard, 2002; Montagu et al., 2003; Wills et al., 2004; Alcorn et al., 2008). In *Eucalyptus* plantations for instance, the rate (stems/ha) of pruning needs to be targeted to match the desired harvest rate and the timing of pruning needs to coincide with canopy closure (Pinkard, 2002). The height of pruning is also critical in order to prevent a significant reduction in growth (Pinkard, 2002). In the forest industry, the application of these treatments is often performed by contractors, with very little if any checking to ensure that the treatment has been applied correctly. One reason for limited quality assurance is that post treatment inventories are currently not economically viable. Detailed tree-level inventory data, however, would be valuable for optimal decision-making on pruning.

Airborne Laser Scanning (ALS) has become a key tool for gathering information on the 3D structure of forested environments (Wulder et al., 2012). The information derived from ALS point clouds allows detailed estimates of the characteristics of the forest to be collected over wide areas at relatively low cost (Hilker et al., 2013). Recently, the high geometric accuracy and precision of the data collected by modern ALS sensors has led to individual tree crowns being increasingly used as the object of analysis (Yao et al., 2012; Ørka et al., 2012; Maltamo et al., 2012; Korhonen et al., 2013). Key metrics such as tree count, species, location, height, and crown properties can be accurately measured with high resolution ALS data (Maltamo et al., 2012).

In order to monitor silvicultural activities with this technology, the ability to accurately track individual tree-level changes on demand is essential. Although ALS data can be used to monitor forest change at the plot-level, with for example forest growth (Næsset and Gobakken, 2005; Hopkinson, 2008), changes in canopy closure (Vepakomma et al., 2008), defoliation and damage (Solberg et al., 2006b; Vastaranta et al., 2013; Nyström et al., 2013) and variation in biomass (Bollandsås, 2013; Næsset et al., 2013) all shown to be quantifiable, individual tree-level change has been less comprehensively studied. The precision of individual tree-level metrics demonstrated in several studies, such as Holmgren and Persson (2004) and Vastaranta et al. (2011), imply there is potential for repeat acquisition ALS data to be used to monitor and detect change. Yu et al. (2008), for instance, demonstrated that it is possible to track growth at the individual tree-level.

Although previous research shows potential for monitoring growth and dramatic change such as thinning, little emphasis has

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been placed on the detection of change occurring in the lower part of the crown, where pruning occurs. Several properties of individual tree crowns have, however, been shown to be measurable from ALS data. Pyysalo and Hyyppä (2002), for instance, developed polygon models for extracting these attributes from ALS data with a point density of 10 points/m^2. Although this method readily described the upper parts of the crown, there were greater errors in the estimation of the properties of lower parts of the crown. Holmgren and Persson (2004), Solberg et al. (2006a), Popescu and Zhao (2008) and Maltamo et al. (2010) all used techniques based on vertical binning of the ALS returns to estimate crown base height (CBH). The errors in these estimates were, however, typically greater than 1 m. In order to track changes in the lower part of canopy, CBH (or a similar variable) would be required to be made with greater precision. To achieve this Vauhkonen (2010) suggested that collecting data at increased point densities may allow a more accurate representation of the actual discontinuities in the crown.

The collection of higher density ALS data requires a slower moving platform flying at lower altitudes. The low-cost (per unit area) nature of ALS surveys is made possible by the wide area data capture. As such, restricting the speed and flying height of the platform to achieve greater point densities, typically makes manned surveys prohibitively expensive. Unmanned Aerial Vehicles (UAVs) are being increasingly used as an alternative remote sensing platform. Laser Scanning data collected from UAVs (UAVLS) can be captured with significantly higher point densities and with more regular repeat visit times, due to the relatively low survey deployment costs. The ability to measure tree properties has been demonstrated by Wallace et al. (2012b) and Jaakkola et al. (2010). Jaakkola et al. (2010), for instance, demonstrated the applicability of UAVs for the detection of within canopy change by manual defoliating a single tree at several stages. The change in the number of canopy returns was found to be highly correlated to the removed biomass at each stage of defoliation.

The objectives of this paper are to determine the potential for UAVLS data to be used in the assessment of change due to pruning of a *Eucalyptus* stand. This paper is motivated by the development of UAV systems as a remote sensing platform, which can be used to collect high spatial resolution data at a relatively low deployment cost. These attributes will allow UAVLS surveys to be utilised to collect highly detailed information on-demand, allowing silvicultural treatments and other forest management activities to be monitored with greater precision.

2. Methods

2.1. Study area and field data

The study area was a 500 m^2 circular plot in a 4-year old *Eucalyptus globulus* stand located in southeast Tasmania, Australia (Fig. 1).

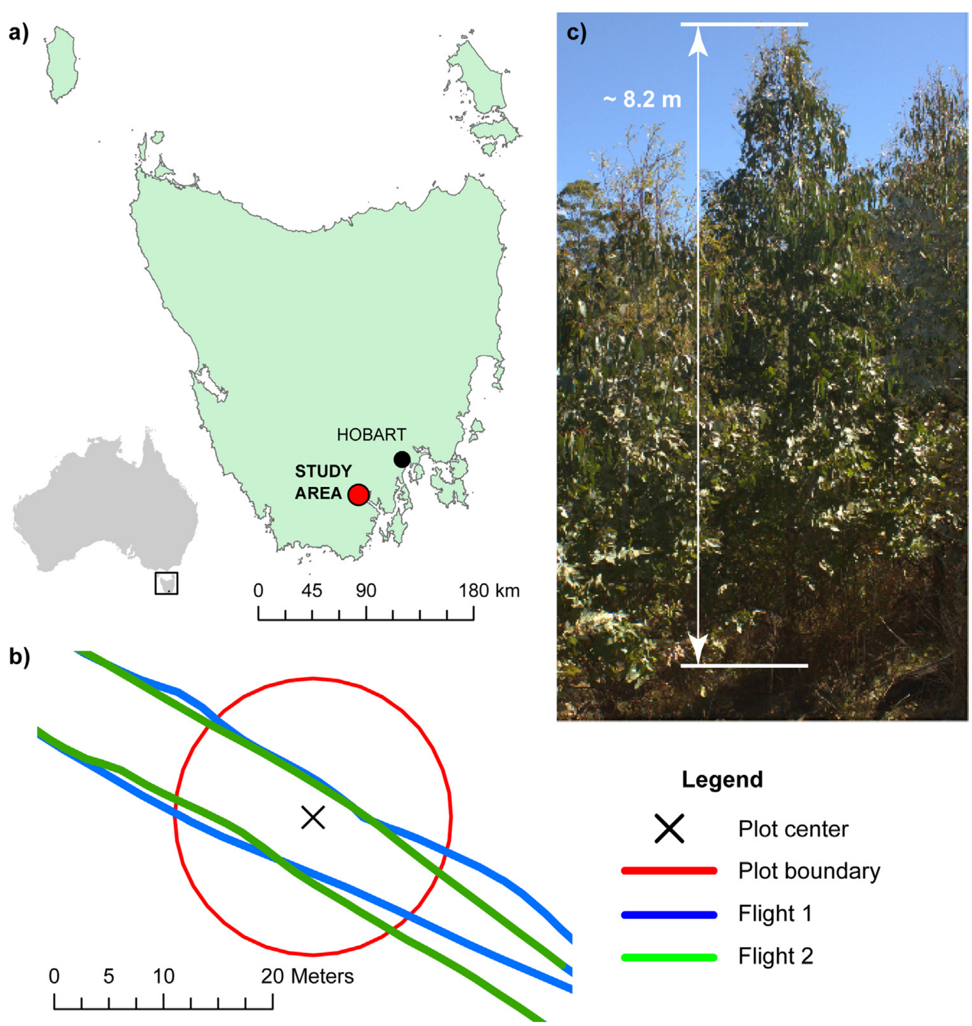

Fig. 1. Study area. *Top left*: Location of the study area in Tasmania, Australia. *Upper right*: Image of a *Eucalyptus globulus* tree within the plot. *Lower left*: Example of the repeatability of UAV flight lines over the plot.