TWO-DIMENSIONAL FOREST CANOPY ARCHITECTURE FROM TERRESTRIAL LASER SCANNING

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ABSTRACT:

Terrestrial laser scanners (TLS) are now capable of collecting 3d data clouds consisting of the x,y,z coordinates of several million laser hits, plus information on return intensity and, in some cases, target colour. TLS collect data at sub-centimetre resolution at a range of zenith view angles. This paper describes the results of a series of experiments in which a TLS was used to measure the two-dimensional structure of a broadleaf deciduous woodland canopy at a range of dates with different leaf cover. The TLS was mounted on a tripod and oriented to measure canopy gap fraction over a near-complete hemisphere. The laser data were compared with near-simultaneous hemispherical photographs of the canopy taken at the same location. Comparison of the hemispherical photography and TLS data showed that, in contrast to our earlier work in needle-leaf canopies, the TLS underestimated canopy directional gap fraction. The explanation of this difference is explored and alternative approaches to measure gap fraction from laser scanner data are suggested.

1. INTRODUCTION

Data on the three-dimensional structure of vegetation canopies are required to validate and test models of vegetation canopy reflectance and to better understand the role of multiple scattering at various scales (leaf/needle, shoot, branch, and crown) in determining canopy spectral signatures. Direct methods to measure canopy structure normally involve destructive sampling of canopy elements but in complex forest or woodland canopies it may be impossible to collect sufficient samples to accurately characterize canopy architecture. Indirect methods of measuring canopy structure (light interception instruments and hemispherical photography) are faster but require assumptions to be made about the clumping of foliage and the proportions of woody and non-woody material (Weiss et al., 2004). Hemispherical photographs may be used to capture images of the two dimensional hemispherical projection of a forest or woodland canopy, but they do not contain information about the three-dimensional structure (Jonckheere et al., 2004). This paper describes the results of an experiment to the application of Terrestrial Laser Scanners (TLS) and hemispherical photographs to measure gap fraction in woodland canopies.

Although there is now a large body of research on the interaction of airborne LIDAR pulses with forest canopies, there are only a few studies that have used TLS to examine forest structure. Most of these have been concerned with the measurement of stand variables, including tree height, stem taper, diameter at breast height and planting density (e.g., Hopkinson et al., 2004; Thies et al., 2004; Watt and Donghue, 2005). However, recent research has tested the potential of TLS to measure forest canopy directional gap fraction, defined as one minus the probability of a beam of light intercepting a canopy element in a given direction. Lovell et al. (2003) used a laser scanner to determine directional gap fraction in stands of different species and found close correlation with data from hemispherical photography. Danson et al. (2007) measured gap fraction in conifer forest stands and found a maximum difference of 11% compared with gap fraction measured using hemispherical photography. This paper extends this earlier work and tests the potential of TLS for measuring directional gap fraction in broadleaf canopies with very different structure to the conifers in our earlier experiments. This work is the first stage of an exploration of TLS to measure the three dimensional structure of forest canopies noting here that forest canopy directional gap fraction is in fact a two dimensional parameter.

2. METHODS

TLS data were collected in a small stand of deciduous trees composed of birch and sycamore, located on the campus of the University of Salford, UK. The trees had an average height of approximately 15m. A Riegl LMZ 210i laser scanner was used to measure two orthogonal scans each covering a zenith range of 180 x 80 degrees. A scanner step resolution of 0.108 deg was used resulting in 1.2 million points in each scan. The scanner had a fixed beam divergence of 3mrad so that the beam had a diameter of 15mm at 5m, 30mm at 10m and 45mm at 15m. Data were collected on three dates 30th October, 17th November 2006 and 23rd February 2007. On the first date leaf cover was high, in November there were leaves still present in parts of the canopy and in February there were no leaves on the trees. At each date a hemispherical photograph of the canopy was taken with a six mega pixel Canon digital SLR camera equipped with a full frame hemispherical lens. Directional gap fraction was computed from the photographs using the Gap Light Analyzer software (Frazer et al., 2000). To determine directional gap fraction from the TLS data the coordinates of the laser hits were converted to spherical coordinates and the number of hits in 5 degree zenith angle bands, from 0-80 degrees, compared with the total number of shots in that direction, computed from the model of Danson et al. (2007).

The ratio of 'hits' to 'shots' gives an estimate of the gap fraction in a given direction.

30th October   17th November   23rd February

Figure 1. Hemispherical photographs of canopy in October (top), November (middle) and February (bottom)

3. RESULTS

Comparison between the directional gap fraction derived from the TLS and photography showed that the TLS estimates of gap fraction were significantly lower at all zenith angles up to 65 degrees (Figure 2). Visual inspection of the hemispherical photography and comparison with the TLS data suggested that the laser scanner was not able to detect small gaps in the canopy, even in regions where there was sparse cover of leaf or woody material.

This hypothesis was confirmed by visual inspection of the TLS intensity data displayed in a cylindrical projection (Figure 3). The intensity data showed that there were laser hits, often with intermediate to high intensity values, in regions of the canopy where leaf or woody cover was low. It also appeared that the laser data at far range values (15-20m) showed the largest discrepancy between the TLS and hemispherical photographs. It was observed that there was in an increase in laser return intensity with range caused by the bi-axial configuration of the laser scanner which meant that at close range the transmitted beam and the field of view of the detector did not completely overlap and return intensity was lower than expected (Figure 3). This measurement-related characteristic of the data prevented correction of the range-intensity relationship using the radar equation described in Wagner et al. (2004) which shows that laser intensity should decrease by a factor related to range to the power four.

In an attempt to filter the TLS data to eliminate hits in directions where the canopy gap fraction was low, a rule-based algorithm was applied to the data which retained only points with intensity values was less than a given threshold value. Empirically adjusting this threshold and re-computing the TLS gap fraction allowed identification of the best-fit gap fraction distribution. A filter with the threshold set to an intensity value of 0.45 produced the closest fit to the gap fraction derived for the November data (Figure 4).
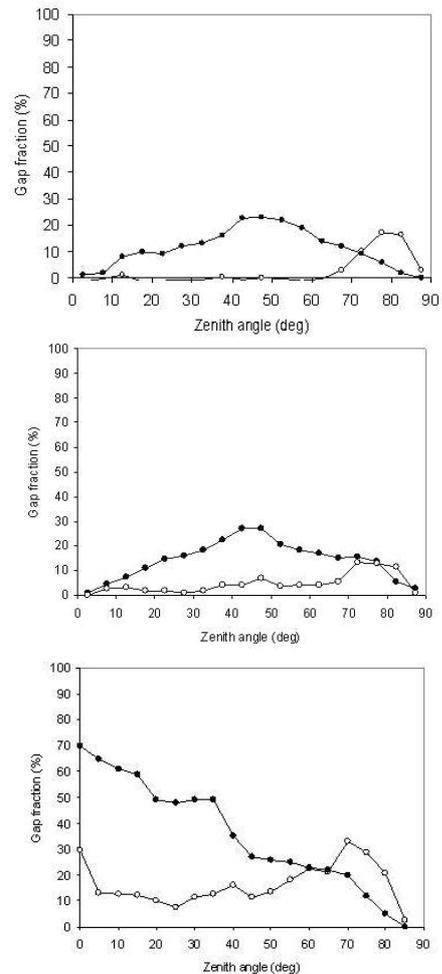

Figure 2. Comparison between gap fraction derived from TLS (open circles) and hemispherical photography (closed circles. Top: 30th October, Middle: 17th November, Bottom: 23rd February
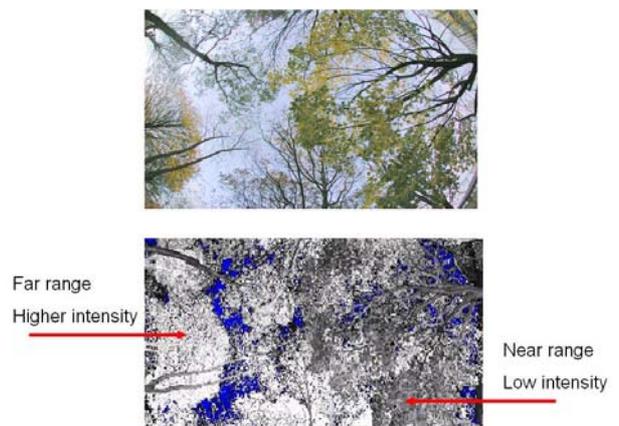

Figure 3. November hemispherical photograph and corresponding laser scanner data in cylindrical projection showing variation intensity of laser returns.
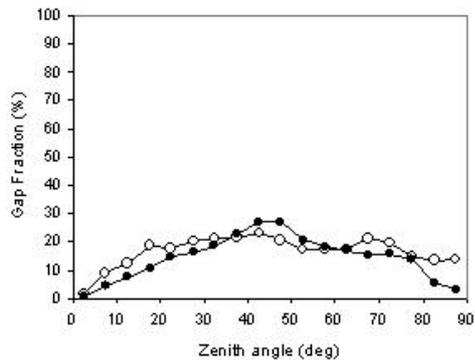
Figure 4. Directional gap fraction derived from TLS data with intensity <0.45 (open circles) and hemispherical photography 17th November.

4. DISCUSSION AND CONCLUSIONS

Terrestrial laser scanners have the potential to revolutionise the measurement of vegetation canopy structure with their rapid measurement time, repeatability and accuracy. For highly clumped conifer forest canopies it appears that TLS can accurately measure canopy directional gap fraction as gaps tend to be large. In the deciduous woodland canopy chosen for this study gaps were smaller a more evenly distributed across the hemisphere and this, coupled with the relatively wide laser beam, meant that only the largest gaps were detected by the scanner, resulting in underestimation of gap fraction compared with hemispherical photography. In effect the TLS was too sensitive to canopy elements within the laser beam so that even if the fractional cover within the beam was, say, 10%, a laser return was recorded. It would be ideal if the sensitivity of the instrument could be modified so that a laser return was only triggered if the gap was greater than fifty percent. However most commercially available systems do not have such a capability. Another alternative would to record and interpret the complete 'wave-form' of the returned energy, but this technology has only very recently been developed in a ground based instruments and this requires further testing. Finally it may be possible to use the laser return intensity data to capture additional information about the objects within the laser beam. However return intensity depends not only on the objects within the beam, but also their reflectivity, scattering characteristics and their range distribution and so that such an interpretation will not be straightforward.

This paper has shown the strengths and weaknesses of terrestrial laser scanner data for measuring directional gap fraction in deciduous woodland canopies. Further work will explore the issues of gap detection outlined above and will go to explore the application of TLS to measure the size shape and three -dimensional distribution of canopy gaps.

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