Proceedings of the 7th International Conference on Functional-Structural Plant Models, Saariselkä, Finland, 9 - 14 June 2013. Eds. Risto Sievänen, Eero Nikinmaa, Christophe Godin, Anna Lintunen & Pekka Nygren. http://www.metla.fi/fspm2013/proceedings. ISBN 978-951-651-408-9.

tLiDAR methodologies can overcome limitations in estimating forest canopy LAI from conventional hemispherical photograph analyses

Eric Casella[1], Mat Disney[2], James Morison[1] & Helen McKay[1]
[1]Centre for Sustainable Forestry and Climate Change, Forest Research, Farnham, Surrey, GU10 4LH, UK
[2]Department of Geography, University College London, London, WC1E 6BT, UK
Correspondence: Eric.Casella@forestry.gsi.gov.uk

Highlights: The hemispherical photography technique has been widely used to assess the three-dimensional reconstruction quality of virtual plant canopy architectures (Casella & Sinoquet 2003). High-resolution terrestrial Light Detection And Ranging (tLiDAR) has recently been applied for measuring the 3-D characteristics of forest vegetation (Omasa et al. 2006.) and specifically the extraction of canopy directional gap fraction (Danson et al. 2007). In contrast with the digital hemispherical photography method, sky conditions appear to have little influence on the quality of the data collected by the tLiDAR technique. This study considers the resolution used during both point cloud data acquisition and the computation of equiangular hemispherical images, which may influence the resolving power of this technique in estimating gaps in a forest environment.

Keywords: TLS, laser, point cloud, gap fraction, equiangular projection, composite hemispherical picture, resolution

INTRODUCTION

Leaf area index (LAI) is defined as the one-sided leaf blade area per unit ground area. It is a key parameter in ecophysiology for scaling-up from leaf to canopy level gas exchange and energy fluxes between the vegetation and the atmosphere. LAI is one of the most difficult parameter to quantify *in situ* although many non-destructive methods have been proposed (Bréda 2003). The upward-looking hemispherical photography technique has been used extensively to map and quantify canopy gaps for LAI computation. However, photographs must be taken under uniform overcast sky conditions and image analyses involve complex and critical steps for pixel classification between sky and canopy components despite recent increases in the resolution of digital cameras.

Terrestrial laser scanners (TLS) have the potential to provide detailed information about forest canopy architecture by collecting 3-D point clouds of several million data points (Tab. 1) that can be transformed into hemispherical images by an equiangular projection procedure (Steyn 1980). However, the resolving power of this technique in estimating gaps in a forest environment may be affected by the resolution used during both point cloud data acquisition and the computation of hemispherical images as shown in Figure 1.

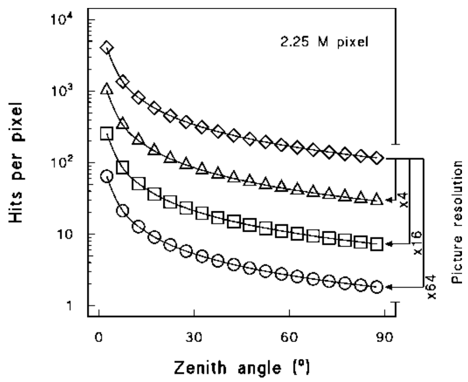

Fig. 1. Modelled mean number of laser return hits per pixel in each 5° zenith band from hemispherical images generated by an equiangular transform projection procedure (Fig. 2.) of a *x*, *y*, *z* coordinate data set computed from an opaque hemisphere for the Low (○), Medium (□), High (△) and Ultra-high (◇) TLS resolution levels (Tab.1).

METHODS

The TLS used was the pulsed time-of-flight HDS 6100 (Leica Geosystems Ltd.) which has a rotating mirror system that covers a 360° (horizontal) x 310° (vertical) field of view with a range of about 79 m at 90% albedo (Tab. 1). The laser beam wavelength is 670 nm with a 3 mm spot size at its source and a 0.22 mrad beam divergence. Hemispherical photographs were taken using a Nikon Coolpix 995 camera (2.25 M pixel) with the Nikon FC-E8 hemispherical lens.

Spatially and temporally coincident point-cloud data and digital hemispherical photographs were collected in a six-year-old stand of *Eucalyptus spp.* in southeast England. The stem density was 700 trees ha^{-1}, with an average tree height of 11±3 m. For each position (*n*=8) and for scan zenith angles of 0-90°, one point-cloud was recorded at each of the four predefined resolution levels of the TLS (Tab. 1).

Tab. 1. Characteristics of the Leica HDS-6100 TLS used in this study for point cloud acquisitions.

Pre-set scanner resolution levels	Low (L)	Medium (M)	High (H)	Ultra-high (U)
Angular sampling resolution (°)	0.072	0.036	0.018	0.009
Point spacing at 50 m (m)	0.063	0.032	0.016	0.008
Maximum point cloud size (M points)	6.255	25.01	100.02	400.04
Acquisition time (minute)	3.6	6.8	13.4	25.2

An equiangular projection procedure (Fig. 2) was used to transform each point cloud into 2.25, 9, 36 or 144 M pixel hemispherical images. Hemispherical photographs and images were processed with the HemiView program. Lens correction factors were applied after classifying the photographs using the CANEYE software. For each image, sky-maps were constructed by dividing the sky into an array of 18 annuli of equal zenith angle.

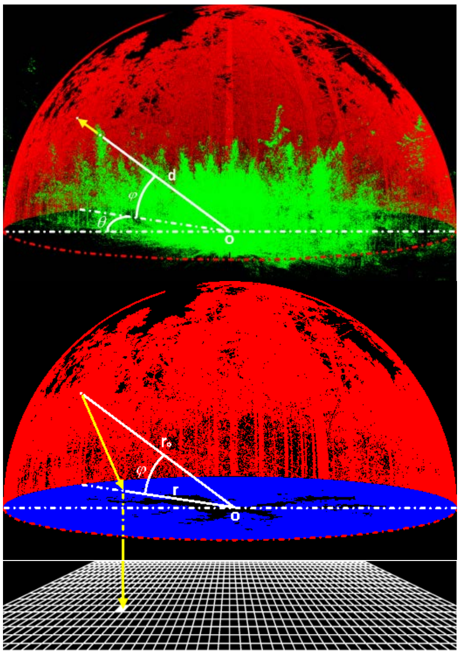

Fig. 2. Illustration of the Cartesian-spherical (top) and spherical-planar (bottom) equiangular transform projection procedures used to generate hemispherical images from the *x*, *y*, *z* coordinate TLS data. *O* is the TLS location and *d* is the distances from the laser beam source to a plant component hit. φ is the elevation angle and $r = 2r_o(90-\varphi)/\pi$.

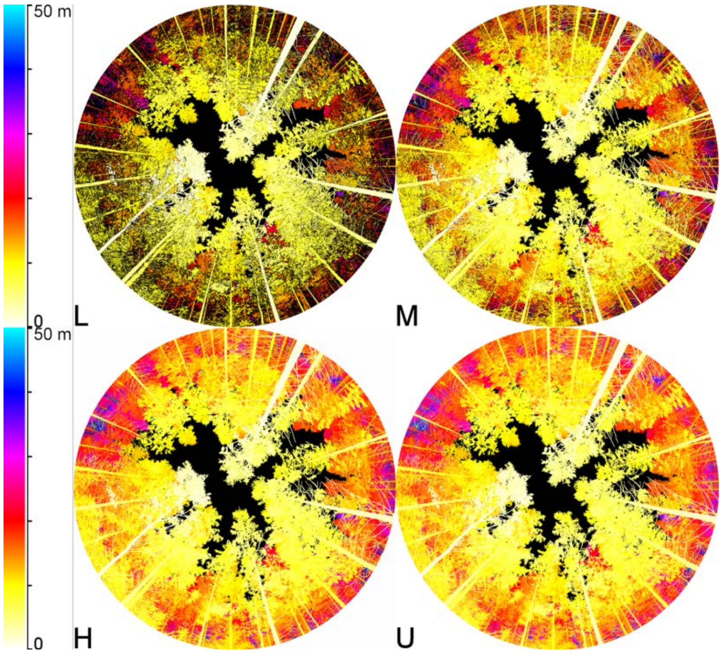

Fig. 3. Examples of computer-generated hemispherical images at 2.25 M pixel from the *x*, *y*, *z* coordinate TLS data (position #1) for the Low (L), Medium (M), High (H) and Ultra-high (U) TLS resolution levels. Colours represent the distance from the laser source to a plant component hit.

RESULTS AND DISCUSSION

Neither the range of the TLS, nor the sky conditions have any influence on the quality of the data collected (results not shown), but the quality of the reconstructed hemispherical images was gradually improved with: i) increasing levels in TLS resolution (Figs. 3 & 4); ii) increasing the resolution of the hemispherical image (Fig. 4). Alterations in the shape of the gap fraction distributions were explained by gradual increases in levels of non-return signal from the vegetation with increases in zenith angle values (Fig. 5). This loss of return signal was mainly explained by the effect of laser beam scattering around the edges of plant components (results not shown).

Therefore, the reconstruction method of the hemispherical images has been modified by taking into account this limitation in the resolving power of the technique as presented in Fig. 1. As a result, composite hemispherical images have been recomputed from the Ultra-high *x*, *y*, *z* coordinate data, showing gradual decreases in their resolution i.e., from 144 M pixel at the zenith to 2.25 M pixel at the horizon (Fig. 6).

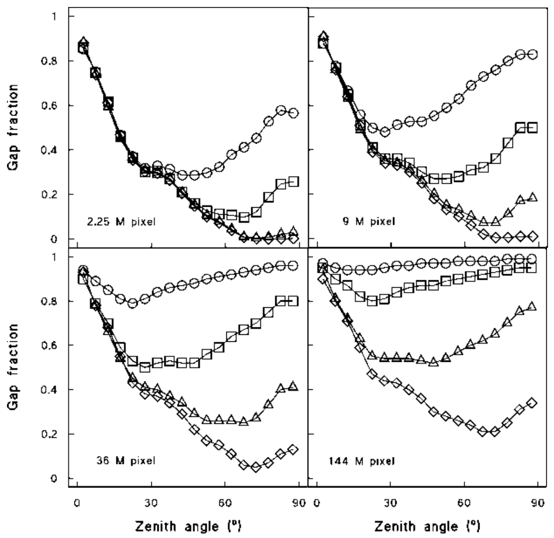

Fig. 4. Estimated gap fraction values in each 5° zenith band from hemispherical images (2.25, 9, 36 or 144 M pixel) generated by the equiangular transform projection procedures of the *x*, *y*, *z* coordinate TLS data for position #1. Same symbols as in Fig. 1.

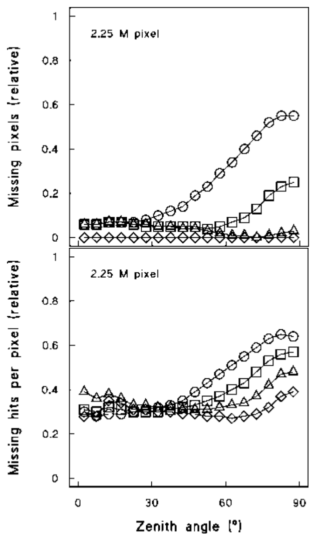

Fig. 5. Mean relative numbers of missing pixels per image and missing laser return hits per pixel in each 5° zenith band.

Fig. 6. Example of a composite hemispherical image computer-generated from the *x*, *y*, *z* coordinate TLS data for position #1.

Computed at the entire sky-map level, estimated gap fraction and plant area index (PAI) values from the hemispherical photographs were close to those estimated from the images (Fig. 7), especially when using the composite method (Fig. 6).

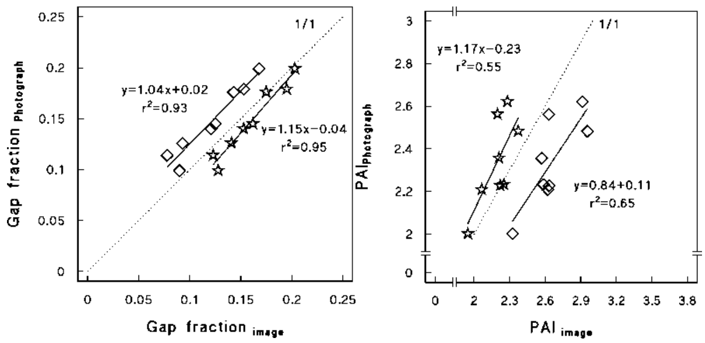

Fig. 7. Comparison between gap fraction values and plant area index (PAI) estimated from the hemispherical images (◇, 2.25 M pixel for the Ultra-high TLS resolution level; ✧, using the composite method) and the photographs over the entire sky-map. Each data point represents a different location within the stand.

CONCLUSION

The tLiDAR technique will be central to developments in acquiring canopy geometric characteristics in the future, especially for computations of solar radiation indices. Avoiding the problem of loss of return signal, the technique explained here shows promise in overcoming the discrepancies in cross-validation between direct and indirect methods for assessing canopy LAI (Bréda 2003). No effects of laser beam divergence on gap detection have been detected in this study, but further experimentation will be required to assess the influence of wind on the quality of the data collected as high scanning resolutions take longer.

Casella E, Sinoquet H. 2003. A method for describing the canopy architecture of coppice poplar with allometric relationships. *Tree Physiology* **23**:1153-1170.

Omasa K, Hosoi F, Konishi A. 2006. 3D lidar imaging for detecting and understanding plant responses and canopy structure. *Journal of Experimental Botany* **58**:881-898.

Danson FM, Hetherington D, Morsdorf F, Koetz B, Allgöwer B. 2007. Forest canopy gap fraction from terrestrial laser scanning. *IEEE Geosciences and Remote Sensing Letters* **4**.

Bréda NJJ. 2003. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. *Journal of Experimental Botany* **54**:2403-2417.

Steyn DG. 1980. The calculation of view factors from fisheye-lens photographs: Research note. *Atmosphere-Ocean* **18**:254-258.