The Salford Advanced Laser Canopy Analyser (SALCA): A multispectral full waveform LiDAR for improved vegetation characterisation.

Gaulton, R.[1], Danson, F.M.[1], Pearson, G.[2], Lewis, P.E.[3] and Disney, M.[3]

[1] *Centre for Environmental Systems Research, School of Environment and Life Sciences, Peel Building, University of Salford, Salford, Greater Manchester, M5 4WT. email:R.Gaulton@salford.ac.uk*

[2] *Halo Photonics Ltd, Unit 2, Bank Farm, Brockamin, Leigh, Worcestershire, WR6 5LA*

[3] *Department of Geography, University College London, Gower Street, London, WC1E 6BT*

Abstract

Vegetation canopy structure influences key physiological and ecological processes, such as photosynthesis and net primary production. Accurate measurement of canopy parameters such as leaf area index and canopy cover via direct methods is time-consuming. Indirect methods are limited by an inability to distinguish woody material and foliage, assumptions relating to canopy leaf angle distribution and clumping and the lack of a permanent record of canopy structure (except for hemispherical photography).

Terrestrial laser scanning can provide a permanent, three-dimensional record and allow the extraction of more detailed and accurate information on the distribution of canopy components. Most laser scanners apply commercially sensitive echo detection algorithms to detect ranges to a limited number of targets, and as this may include returns triggered by objects only partially occupying the laser beam, errors can result in estimating gap fraction. The Salford Advanced Laser Canopy Analyser (SALCA) is the first multispectral full waveform terrestrial laser scanner for characterising forest canopies. The instrument records the full waveform of backscattered energy at two wavelengths in the near- and middle-infrared (1040 and 1550nm), designed to allow the separation of foliage and woody material. The first results are presented from laboratory-based trials of the instrument to examine the return from a range of targets.

Keywords: *Terrestrial laser scanning, leaf area index, canopy density, forest structure.*

1. Introduction

Vegetation canopy structure determines light interception, evapotranspiration, aerodynamic roughness and gaseous fluxes between the atmosphere and the surface, influencing key physiological and ecological processes, such as photosynthesis and net primary production. Variables characterising canopy structure (including leaf area index (LAI), canopy cover, directional gap fraction, canopy clumping and vertical foliage distribution) are therefore key inputs to vegetation growth, carbon cycle, hydrological and radiative transfer models. Detailed measurements of vegetation structure are also critical for validation of larger-scale remote sensing products. Accurate measurement of parameters such as LAI via direct methods, such as clipping of leaf material or litter fall collection, is extremely time-consuming. Canopy structure is therefore typically measured based on indirect non-contact methods, measuring canopy gap fraction or gap size distribution using instruments recording light interception (for example the LAI-2000 (Licor Inc.)) or through hemispherical photography. However, such methods are limited by an inability to distinguish woody material and photosynthetically active foliage (without manual intervention), assumptions relating to canopy leaf angle distribution and clumping and, with the exception of hemispherical photography, the lack of a permanent record of canopy structure (Jonkheere *et al*. 2004). The development of terrestrial laser scanning (TLS) has potential to provide a permanent, three-dimensional record of vegetation structure and allow the extraction of more detailed and accurate information on the distribution of foliage and woody material.

A number of recent studies have demonstrated the potential of TLS for characterising vertical foliage profile, directional gap fraction and LAI (e.g. Tanaka *et al*. 1998, Radtke and Borstad 2001, Lovell *et al*. 2003, Tanaka *et al*. 2004, Henning and Radtke 2006, Danson *et al*. 2007, Danson *et al*. 2008, Moorthy *et al*. 2008). However, separation of foliage and woody material remains a challenge. Most laser scanners operate using a short pulsed time-of-flight measurement to determine the range of objects within the laser beam and digitize the time-dependent backscattered energy for each pulse, providing a 'full waveform'. However, commercially sensitive and unknown echo detection algorithms are usually applied to this waveform to detect ranges to a limited number of targets, and as this may include returns triggered by objects only partially occupying the laser beam, errors can result in estimating gap fraction. Danson *et al*. (2008) found a consistent under-estimation of gap fraction likely to result from this effect in TLS measurements from a UK mixed woodland stand. Without knowledge of the echo detection algorithm applied, correcting for such errors is difficult. Full waveform scanners can record the range to multiple targets and allow the application of alternative echo detection algorithms and varying sensitivity thresholds. As foliage and woody canopy elements have very different spectral reflectance properties, by combining multiple wavelengths of laser the different components can potentially be separated, allowing improved estimation of LAI and other structural attributes.

Figure 1: *The Salford Advanced laser Canopy*

To the authors' knowledge, although a number of airborne systems are operational, only two previous full waveform terrestrial laser scanners have been developed. The Riegl VZ-400 performs 'online waveform analysis' to provide range, intensity, pulse width and quality information but does not allow end-user access to the full waveform. The CSIRO Echidna (Strahler *et al.* 2008) is a prototype single wavelength system recording full waveform data, but is not commercially available. Neither system includes multiple wavelengths, although a small number of prototype multispectral airborne LiDARs are also being developed for use in vegetation applications (e.g. Morsdorf *et al*. 2009).

The Salford Advanced Laser Canopy Analyser (SALCA) (Figure 1) has been developed by the University of Salford and Halo Photonics Ltd, as the first multispectral full waveform terrestrial laser scanner for characterising forest and woodland canopies. The instrument records the full waveform of backscattered energy at two synchronously emitted wavelengths in the near and middle -infrared (1040 and 1550nm). This paper describes the SALCA instrument and the first results from laboratory-based trials to examine the full waveform return from a range of targets.

2. The Salford Advanced Laser Canopy Analyser

SALCA is a field-portable hemispherical laser scanner designed to operate at dual wavelengths (1040nm and 1550nm) and to record full waveform data. Key system characteristics for the instrument are presented in Table 1. In addition to providing hemispherical scans, SALCA can operate in a 'staring' mode, recording repeated pulses at a specified fixed azimuth and zenith angle. This mode was utilized for the laboratory measurements presented below. The instrument is currently being trialled at a single wavelength (1550 nm), with the second being added during summer 2010.

Initial measurements are being taken to characterise the LiDAR response from solid objects and from vegetation. Figure 2b is an example of the waveform response from vegetation (in this case a small *Pinus mugo* specimen located at 4m from the sensor) with a white board in the background. One waveform results from the footprint being largely filled by a branch, whilst the other shows the response from partial foliage coverage, with a larger return from the board (at 6.5m). Backscattered energy the outgoing pulse can be seen at the start of the waveforms.

SALCA system specifications:	
Pulse length	1 ns
Pulse rate	5 kHz
Beam width at sensor	8 mm
Beam divergence	0.56 mrad
Detector field of view	0.84 mrad
Sampling rate	1 GHz
Range resolution	15 cm
Maximum range	105 m
Angular sampling step	1 mrad

Table 1: *System characteristics of the Salford Advanced Laser Canopy Analyser*

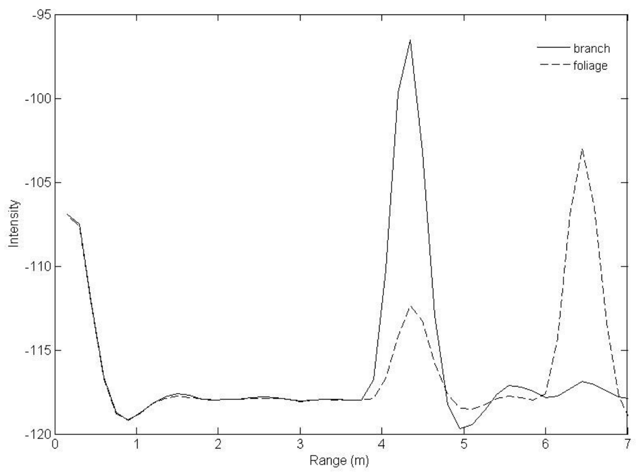

Figure 2: *Example waveforms from SALCA for pulses hitting a Pinus Mugo specimen (branch and foliage) at 4m and a solid white board at 6.5m.*

3. Conclusion

Early measurements suggest the full-waveform data provided by SALCA may provide important information on the properties and coverage of vegetation objects within the laser footprint, potentially improving the estimation of canopy cover, gap fraction and leaf area index. These advantages over single (or first and last) return systems should be further enhanced by the addition of a second wavelength. Work is ongoing to develop information extraction algorithms and to investigate the interaction of the laser pulses with canopy elements, through a combination of laboratory measurements and modelling.

Acknowledgements

This work is supported by NERC Technologies Proof of Concept Grant NE/H002685/1.

References

DANSON, F.M., HETHERINGTON, D., MORSDORF, F., KOETZ, B., and ALLGÖWER, B., 2007, Three-dimensional forest structure from terrestrial laser scanning. *IEEE Geoscience and Remote Sensing Letters*, **4**, 157—160.

DANSON, F.M., ARMITAGE, R.P., BANDUGULA, V., RAMIREZ, F.A, TATE, N.J., TANSEY, K. J. and TEGZES, T., 2008. Terrestrial laser scanners to measure forest canopy gap fraction, In *Proceedings of Silivlaser 2008*, Heriot Watt University, September 2008.

HENNING, J.G. and RADTKE, P.J., 2006. Ground-based laser imaging for assessing three-dimensional forest canopy structure. *Photogrammetric Engineering and Remote Sensing* **72**, 1349—1358.

JONKHEERE, I., FLECK, S., NACKAERTS, K., MUYS, B., COPPIN, P., WEISS, M. and BARET, F., 2004, Review of methods for in situ leaf area index determination – Part 1: Theories, sensors and hemispherical photography. *Agricultural and Forest Meteorology*, **121**, 19—35.

LOVELL, J.L., JUPP, D.L.B., CULVENOR, D.S., and COOPS, N.C., 2003. Using airborne and ground-based ranging lidar to measure canopy structure in Australian forests. *Canadian Journal of Remote Sensing* **29**, 607–622.

MOORTHY, I., MILLER, J.R., HU, B., CHEN, J. and LI, Q., 2008. Retrieving crown leaf area index from an individual tree using ground-based lidar data. *Canadian Journal of Remote Sensing*, **34**, 320—332.

MORSDORF, F, NICHOL, C., MALTHUS, T.J. and WOODHOUSE, I.H., 2009. Assessing forest structural and physiological information content of multi-spectral LiDAR waveforms by radiative transfer modelling. *Remote Sensing of Environment*, **113**, 2152—2163.

RADTKE, P.J., and BOLSTAD, P.V., 2001. Laser point-quadrat sampling for estimating foliage-height profiles in broad-leaved forests. *Canadian Journal of Forest Research*, **31**, 410—418.

STRAHLER, A.H., JUPP, D.L.B., WOODCOCK, C.E., SCHAAF, C.B., YAO, T., ZHAO, F., YANG, X., LOVELL, J., CULVENOR, D., NEWNHAM, G., NI-MEISTER, W. and BOYKIN-MORRIS, W., 2008. Retrieval of forest structural parameters using a ground-based lidar instrument (Echidna®). *Canadian Journal of Remote Sensing*, **34**, S426—S440.

TANAKA, T., YAMAGUCHI, J. and TAKEDA,Y., 1998. Measurement of forest canopy structure with a laser plane range-finding method - development of a measurement system and applications to real forests. *Agricultural and Forest Meteorology,* **91**, 149—160.

TANAKA, T., PARK, H., and HATTORI, S., 2004. Measurement of forest canopy structure by a laser plane range-finding method - improvement of radiative resolution and examples of its application. *Agricultural and Forest Meteorology,* **125**, 129—142.