STUDYING CANOPY STRUCTURE THROUGH 3-D RECONSTRUCTION OF POINT CLOUDS FROM FULL-WAVEFORM TERRESTRIAL LIDAR

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ABSTRACT

This study presents a three-dimensional (3-D) forest reconstruction methodology using the new and emerging science of terrestrial full-waveform lidar scanning, which can provide rapid and efficient measurements of canopy structure. A 3-D forest reconstruction provides a new pathway to estimate forest structural parameters such as tree diameter at breast height, tree height, crown diameter, and stem count density (trees per hectare). It enables the study of the detailed structure study with respect to the canopy (foliage or branch/trunk), as well as the generation of a digital elevation model (DEM) and a canopy height model (CHM) at the stand level. Leaf area index (LAI) and Foliage area volume density profile directly estimated from voxelized 3-D reconstruction agree with measurements from field and airborne instrument. A 3-D forest reconstruction allows virtual direct representation of forest structure, and provides consistent and reliable validation data sources for airborne or spaceborne data.

Index Terms— Terrestrial lidar, full waveform lidar, 3-D reconstruction, canopy structure parameter, leaf area index, digital elevation model, canopy height model

1. INTRODUCTION

Canopy structure includes information about the state of the canopy and the interaction between vegetation and its environment through photosynthesis and transpiration. Measuring and monitoring canopy structure parameters provide a baseline for carbon flux studies related to natural and anthropogenic processes. Lidar has emerged in recent years as an important tool for studying canopy structure due to its high measurement accuracy and efficiency. Although regional coverage (such as possible from airborne lidars) is impractical, terrestrial lidar scanning (TLS) systems have a number of advantages where site-based information is desired and reliable validation data sources for airborne or spaceborne data are required. The Echidna® Validation Instrument (EVI), a terrestrial full-waveform lidar, provides rapid, accurate, and automated retrieval of forest structural parameters, as demonstrated in a series of validation experiments carried out in California, New England, and New South Wales, Australia with varying forest density and species [1-4]. Strahler et al. [2] and Yang et al. [5] have established a paradigm for the 3-D reconstruction of forest stands by merging point clouds constructed from overlapping EVI scans, voxelizing the reconstructions, and thereby allowing virtual direct representation of forest structure. These efforts will continue with data from the Dual Wavelength Echidna Lidar (DWEL), a successor to the EVI now in final phases of testing [6].

2. 3-D FOREST RECONSTRUCTION

EVI is a terrestrial scanning lidar instrument equipped with a 1064 nm Nd:YAG laser. Unlike most of the terrestrial lidar systems that record a single range for each laser return, the return sensor system of the EVI digitizes and records the intensity of the pulse reflected from targets along the entire transmission path. Point clouds are generated from EVI scans with information including 3-D coordinates (x, y, z) and physical attributes, such as peak intensity of the return, the corresponding apparent reflectance, and the relative width of the returned pulse. Supported by field geolocation devices, point clouds from nearby locations are merged together to reconstruct the study site in 3-D space. The resulting forest reconstruction integrates individual EVI scans observed from different angles to greatly reduce the occlusion effect, allowing more accurate and detailed characterization of the forest structure.

Classification algorithms [5] based on laser pulse shape process the points into different categories (Figure 1). These reconstructions not only provide more accurate measures of biomass than usually accomplished with allometric relationships, they can also provide estimates of fallen trees and branches on the ground, thus providing better estimates of the volume of biomass undergoing direct decay [7].

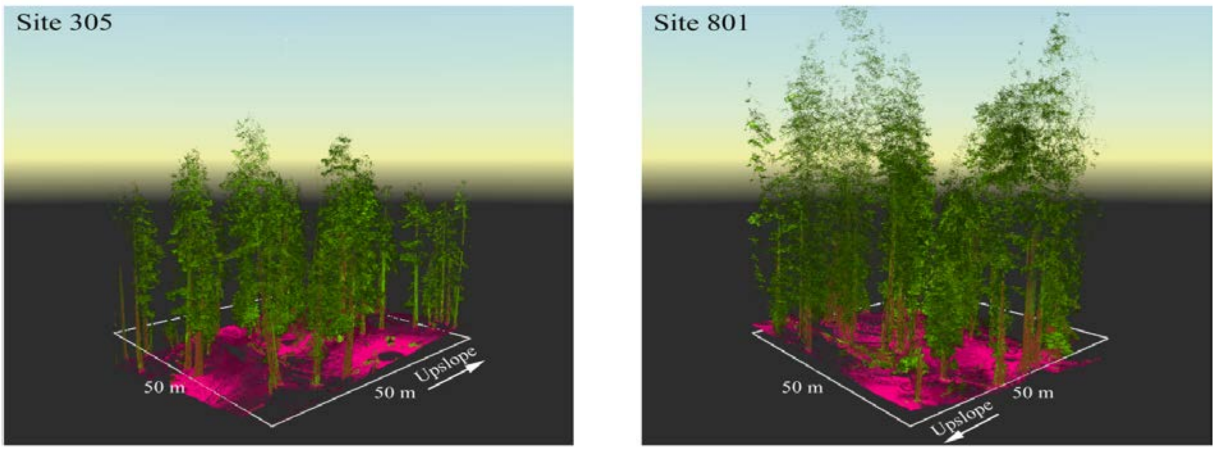

Figure 1. Registered and classified point clouds for sites 305 (red fir) and 801 (giant sequoia), each constructed from five registered point clouds. (Green: foliage; brown: trunk or branch; magenta: ground.)

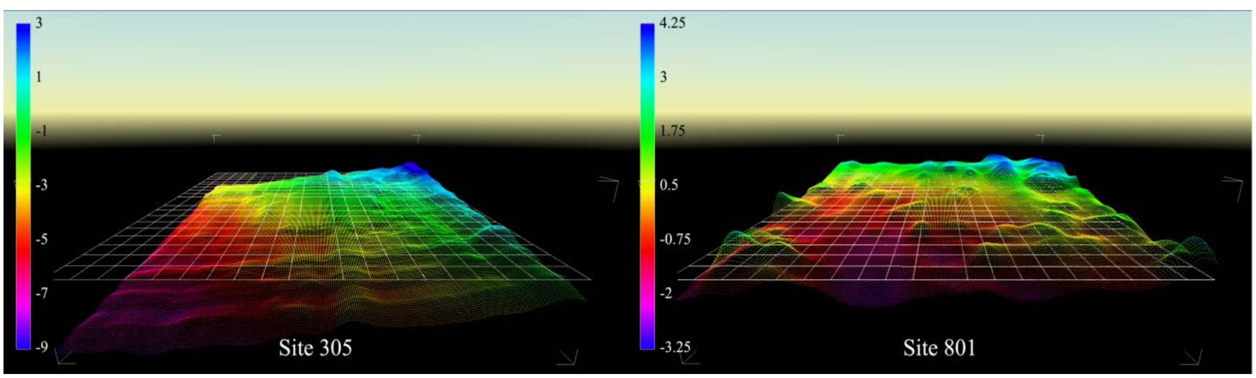

Figure 2. DEMs generated from 3-D forest reconstruction of site 305 and 801.

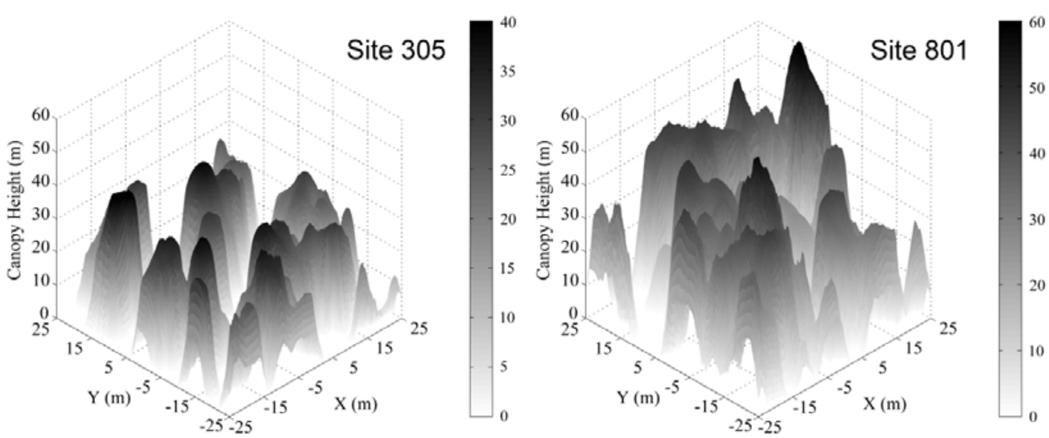

Figure 3. CHMs generated from 3-D forest reconstruction of site 305 and 801.

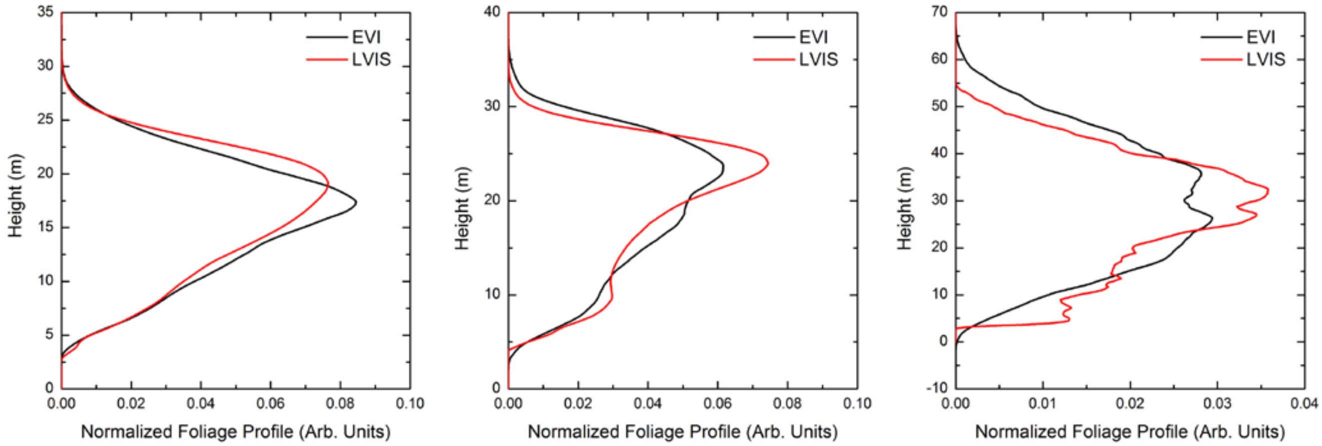

Figure 4. Comparision of foliage profile from EVI and LVIS for the Harvard Forest Hemlock site (left), the Harvard Forest EMS tower (center), and the Sierra red fir 305 site (right).

3. MEASURING CANOPY STRUCTURE IN 3-D

The 3-D forest reconstruction enables detailed structure study with respect to canopy parts (foliage or branch/trunk), as well as the generation of a digital elevation model (DEM) (Figure 2) and a canopy height model (CHM) (Figure 3) at the stand level. DEMs are particularly useful in the structural studies carried out in mountainous areas, such as in the Sierra Nevada National Forest. CHMs provide detailed horizontal distributions of the canopy for each reconstructed site, rather than a single averaged value of estimated height.

In field studies, due to the limitation of time and energy, only selected trees are measured in more detail for forest inventories. With point clouds however, it is possible to make accurate virtual measurements of all tree diameters by using the merged multi-scan point cloud. For sites 305 and 801 (a red fir site and a sequoia site in the Sierras), tree diameters and tree heights show very high correlation to the field data with R^2 values close to 1 and crown diameters and crown heights correlations in the range of 0.8 ~ 0.9 [5].

4. RETRIEVING LEAF AREA INDEX AND FOLIAGE PROFILES

LAI and foliage profile are important biophysical parameters to quantify and monitor deforestation and disturbance in forest ecosystem. Previous studies have verified that estimates of LAI and FAVD made from single EVI scans, using azimuth-averaged gap probability with zenith angle [1, 4], agree well with those of traditional hemispherical photos and LAI-2000 measurements. In this study, a new methodology is designed to estimate LAI and FAVD directly from voxelized three-dimensional forest reconstruction.

Volumetric datasets are produced by properly assigning attributes, such as gap probability, apparent reflectance, and volume associated with the laser pulse footprint at the observed range, to the foliage scattering events in the reconstructed point cloud. Leaf angle distribution is accommodated with a simple model based on gap probability with zenith angle as observed in individual scans of the stand. Clumping occurring at scales coarser than elemental volumes associated with scattering events is observed directly and therefore does not require parametric correction. For validation, comparisons are made between LAI and FAVD profiles retrieved directly from the voxelized 3-D forest reconstructions and those observed from airborne and field measurements (Figure 4). This method provides a pathway to estimate “ground truth” FAVD, LAI, and above-ground biomass without destructive sampling. These virtual measurements will be very helpful in validating retrieval algorithms for LAI and above-ground biomass using large-footprint spaceborne or airborne lidar systems.

5. DUAL WAVELENGTH ECHIDNA LIDAR

The Dual-Wavelength Echidna® Lidar (DWEL) [6], the successor instrument to the EVI, emits simultaneous laser pulses at 1064 nm and 1548 nm wavelengths. DWEL scans provide the capability to separate hits of leaves from hits of trunks and branches because of the reduced response at 1548 nm due to water absorption by leaf cellular contents. We plan to present LAI retrievals from 3-D reconstructions at Harvard Forest, Petersham, MA, USA, acquired in summer 2013, at IGARSS2013 as a demonstration of this improved capability.

6. CONCLUSIONS

Three-dimensional (3-D) reconstruction of forest stands, constructed from scans of the Echidna® full-waveform terrestrial lidar, provides a new pathway to study forest structural parameters. It enables accurate virtual measurement basic structural parameters as well as direct estimation of LAI and foliage profile. Terrestrial full waveform lidar can be combined with existing airborne and space-borne lidar systems to increase the potential to accurately measure and monitor biomass over large regions.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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