Vegetation Structure and 3-D Reconstruction of Forest Canopies Using Echidna® Ground-based Lidar

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Overview
Our research uses a ground-based, scanning lidar instrument to retrieve forest canopy structural information, including stand height, mean tree diameter, basal area, stem count density, woody biomass, leaf area index, and foliage profile, and links this information to airborne and spaceborne lidars to provide large-area mapping of structural and biomass parameters.

The terrestrial lidar instrument, Echidna®, developed by CSIRO Australia, allows rapid acquisition of vegetation structure data that can be readily integrated with downward-looking airborne lidar, such as LViS (Laser Vegetation Imaging Sensor), and spaceborne lidar, such as GLAS (Geoscience Laser Altimeter System) on ICESat, to provide large-area maps and inventories of vegetation structure and carbon stocks.

First-generation algorithms for processing Echidna® data focus on retrieving the location, size, and spacing of tree trunks and on the foliage profile of the stand. To the right are some results for lidar scans using the Echidna® Validation Instrument (EVI), an engineering prototype. The results include comparison of stand height, LAI, biomass, DBH, and stem density derived from the EVI with contemporaneous field measurements for New England hardwood/conifer and Sierra Nevada conifer stands.

Point Cloud Processing
The peak intensity and its location within each waveform were used to create a point cloud dataset for each of the lidar scans at a site. The point cloud records each scattering event and its apparent reflectance within an x-, y-, z-coordinate space. By carefully locating the position of each scan point and then finding trees and objects viewed by multiple scans, we merged the point clouds to create a 3-D reconstruction of the stand within the 50 m by 50 m inner plot area. Scattering events were then classified into trunk, leaf and ground and used in creating the color images below.

The following text is a continuation of the above overview, focusing on the methods and results of the research.

Echidna® ground-based lidar. Lidar pulses strike a rotating mirror at an angle of 45°, providing a scan through azimuth angles of ±13° in a vertical circle. As the instrument rotates on its vertical axis, data from all azimuths are acquired.

Examples of EVI data for a hemlock stand at the Harvard Forest in Massachusetts (top image) and a giant sequoia-red fir stand at Sequoia National Forest in California (bottom image). The images are in a plane tangent projection that displays the data by azimuth angle (x-axis) and zenith angle (y-axis).

Foliage profiles (leaf area with height) retrieved from EVI scans at 6 sites, 5 scans per site. These reconstructions, based on merging multiple scans, show a stand of high-elevation red fir (left) and a stand including giant sequoias (right) in the Sequoia National Forest near Visalia, California. Using a simple classification algorithm based on the shape of the return waveform and its vertical position, each point is classified into trunk (brown), leaf (green), or ground (magenta).

Further processing of the point cloud, shown here for the red fir site, uses the ground profile to a single elevation threshold to define the 50 m plot area, which defines the sampling volume for the terrestrial lidar data. These point clouds are then projected onto a stem map, where they define locations very well (lower right), with 95% of points outside the 50 m plot area. Point clouds derived from the red fir data, were also retrieved well with R2 values of 0.98 and 0.96 respectively.

The three-dimensional forest stand reconstruction can be displayed as fly-through videos. The computer display shows the core of the two stands above as well as a decodex forest scan from the New England forests scanned in 2004.

These scans of the sequoia-red fir sites in 2007 and 2008 show that the Echidna® laser can detect small growth increments. In these two plots, the 50 m inner plot area is defined using a single elevation threshold to project the point clouds onto a stem map, where the distance between the inner and outer plots is defined by the same data. On the left, the inner plot is defined using a single elevation threshold, which is not typical. On the right, the inner plot is defined using an elevation threshold, which is typical of most lidar systems. The outer plot is defined using an elevation threshold, which is the same as that used for the inner plot.

Differences in the peak intensity and its location within each waveform were used to create a point cloud dataset for each of the lidar scans at a site. The point cloud records each scattering event and its apparent reflectance within an x-, y-, z-coordinate space. By carefully locating the position of each scan point and then finding trees and objects viewed by multiple scans, we merged the point clouds to create a 3-D reconstruction of the stand within the 50 m by 50 m inner plot area. Scattering events were then classified into trunk, leaf and ground and used in creating the color images below.

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