DIRECT MEASUREMENT OF INDIVIDUAL TREE CHARACTERISTICS FROM LIDAR DATA

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ABSTRACT

LIDAR data collected at high density over a forested area provide accurate measurements of ground surface details and a large volume of point data reflected off trees and other vegetation. These data are useful for characterizing both the ground surface and vegetation. A data exploration and visualization software system has been developed to allow exploration and measurement within large LIDAR datasets. This system, known as FUSION, was used to measure individual tree characteristics (location, height, height to crown base, and crown diameter) using LIDAR data obtained over a conifer forest located in western Washington. Measurements were compared to measurements collected in the field. The average difference in tree location was 3.18 feet (0.97 m) and the average difference in tree height (field height – LIDAR-measured height) was -0.96 feet (-0.29 m). This paper describes the FUSION system, highlights specific software features that facilitate the measurement of tree characteristics, and discusses the processes used to make detailed measurements within LIDAR point clouds.

INTRODUCTION

The Silviculture and Forest Models Team of the USDA Forest Service, Pacific Northwest Research Station based in Olympia, Washington and the Precision Forestry Cooperative located at the University of Washington in Seattle, Washington are evaluating the accuracy of LIDAR data and developing tools to describe vegetation characteristics such as tree density, tree size, canopy volume, and crown bulk density using LIDAR data. Efforts to date include the comparison of LIDAR-derived terrain models with models produced by the USGS in both 10- and 30-meter resolutions, accuracy assessments of LIDAR-derived terrain models using surveyed control points (Reutebuch and others, 2003), development of algorithms to locate individual trees and characterize their size and overall crown shape using raw LIDAR returns (Andersen and others, 2001), comparison of LIDAR-derived terrain and canopy models with photogrammetric measurements collected from 1:3000 color photography, and the comparison of terrain and canopy surface models derived from LIDAR data with models developed using interferometric synthetic aperture radar (IFSAR) data (Andersen and others, 2003). These efforts have all included extensive data analyses and some type of data visualization to support analysis activities and help communicate the wealth of information contained in the LIDAR datasets. Visualizations are commonly hill-shaded or perspective renderings of surface models or renderings of large point clouds using various color schemes to enhance particular attributes of the return data.

McGaughey, R.J., W.W. Carson, S.E. Reutebuch, and H.-E. Andersen. 2004. Direct measurement of individual tree characteristics from LIDAR data. *Proceedings of the Annual ASPRS Conference, Denver, May 23-28, 2004.* American Society of Photogrammetry and Remote Sensing, Bethesda, MD.

In general, project scientists have experienced frustration with the difficulty inherent in manipulating the large datasets common in LIDAR analysis. We have found that geographic information systems (GIS) are incapable of processing files containing several million features each consisting of a few points or at least suffer severe performance degradation when drawing or searching through such files. We have used programming products such as the Interactive Data Language* (IDL) from Research Systems, Inc. to provide a more general solution for analysis and visualization of LIDAR data but generally used such tools for task-specific analysis and visualization.

To support our current and future analysis activities, we developed a data management and visualization system that provides easy access to a variety of spatial data layers and large LIDAR datasets (McGaughey and Carson, 2003). Our visualization system also supports direct measurement of features evident in LIDAR data such as transmission tower and line locations, building locations and dimensions, and individual tree characteristics.

This paper focuses on testing the feasibility of measuring individual tree characteristics using LIDAR data. We seek answers to the following questions:

How easily can individual trees be isolated and measured within a LIDAR point cloud?

How do such measurements compare to the same measurements collected in the field?

VISUALIZATION SYSTEM OVERVIEW

The visualization system consists of two main programs, FUSION and LDV (LIDAR data viewer), implemented as Microsoft Windows applications coded in C++ using the Microsoft Foundation Classes. The primary interface, provided by FUSION, consists of a graphics display window and a control window. The FUSION display presents all project data using a 2D display typical of geographic information systems. It supports a variety of data types and formats but requires that all data be geo-referenced using the same projection system and units of measurement. LDV provides the 3D visualization environment, based on OpenGL, for the examination of spatially-explicit data subsets.

In FUSION, data layers are classified into five categories: images, raw data, points of interest, hotspots, and surface models. Images can be any geo-referenced image but they are typically orthophotos, images developed using intensity values from LIDAR return data, or other images that depict spatially explicit analysis results. Raw data include LIDAR return data and simple XYZ point files. Points of interest (POI) can be any point, line, or polygon layer that provides useful visual information or sample point locations. Hotspots are spatially explicit markers linked to external references such as images, web sites, or pre-sampled data subsets. Surface models are expected in a gridded format that represents either a ground surface or other surfaces of interest such as the top of a forest canopy. The current FUSION implementation limits the user to a single image and a single surface model, however, multiple raw data, POI, and hotspot layers can be specified.

The FUSION interface provides users with an easily understood display of all project data. Users can specify display attributes for all data and can toggle the display of the five data types. The entire raw data layer can be rendered, however, it generally requires excessive time and is often left as a hidden layer.

FUSION allows users to quickly and easily select and display subsets of large LIDAR data. Users specify the subset size, shape, and the rules used to assign colors to individual raw data points and then select sample locations in the graphical display. LDV presents the subset for the user to examine. Subsets include not only raw data but also the related portion of the image and surface model for the area sampled. LDV provides the following data subset types:

- Fixed-size square,
- Fixed-size circle,
- Variable-size square,
- Variable-size circle,
- Variable-width corridor.

Subset locations can be "snapped" to a specific sample location, defined by POI points) to generate subsets centered on or defined by specific locations. The elevation values for LIDAR returns can be made relative to a local surface model prior to display in LDV. This feature is especially useful when viewing data of forested regions in steep terrain as it is much easier to examine returns from vegetation after subtracting the ground elevation.

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* Use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

LDV strives to make effective use of color, lighting, glyph shape, motion, and stereoscopic rendering to help users understand and evaluate LIDAR data. Color is used to convey one or more attributes of the LIDAR data or attributes derived from other data layers. For example, individual returns can be colored using values sampled from an orthophoto of the project area to produce semi-photorealistic visual simulations. LDV uses a variety of shading and lighting methods to enhance its renderings. LDV provides point glyphs that range from single pixels, to simple geometric objects, to complex superquadric objects. LDV operates in monoscopic, stereoscopic*, and anaglyph display modes. To enhance the 3D effect on monoscopic display systems, LDV provides a simple rotation feature that moves the data subset continuously through a simple pattern (usually circular). We have dubbed this technique "wiggle vision", and feel it provides a much better sense of the 3D spatial arrangement of points than provided by a static, fixed display. To further help with understanding LIDAR data, LDV can also map orthographic images onto a horizontal plane that can be positioned vertically within the cloud of raw data. Surface models including "bare-earth" and canopy models are rendered as a shaded 3D surface and can be textured-mapped using an orthographic image.

FUSION and LDV have several features that facilitate direct measurement of LIDAR data. FUSION provides a "plot mode" that defines a buffer around the sample area and includes data from the buffer in a data subset. This option, available only with fixed-size plots, makes it easy to create LIDAR data subsets that correspond to field plots. In the context of this paper, "plot mode" lets us measure tree attributes for trees whose stem is within the plot area using all returns for the tree including those outside the plot area but within the plot buffer. The size of the plot buffer is usually set to include the crown of the largest trees expected for a site. When in "plot mode", FUSION includes a description of the fixed-area portion of the subset so LDV can display the plot boundary as a wire frame cylinder or cube.

LDV provides several functions to help users place the measurement marker and make measurements within the data cloud. The following "snap functions" are available to help position the measurement marker:

- Set marker to the elevation of the lowest point in the current measurement area (don't move XY position of marker)
- Set marker to the elevation of the highest point in the current measurement area (don't move XY position of marker)
- Set marker to the elevation of the point closest to the marker (don't move XY position of marker)
- Move marker to the lowest point in the current measurement area
- Move marker to the highest point in the current measurement area
- Move marker to point closest to the marker
- Set marker to the elevation of the surface model (usually the ground surface)

The measurement marker in LDV can be elliptical or circular to compensate for tree crowns that are not perfectly round. The measurement area can be rotated to better align with an individual tree crown. Once an individual tree has been isolated and measured, the points within the measurement area can be "turned off" to indicate that they have been considered during the measurement process. This ability makes it much easier to isolate individual trees in stands with dense canopies.

LDV provides a simple function that "shrink-wraps" points within the measurement area using a wire frame mesh. After isolating an individual crown, activating the "shrink-wrap" can help users confirm that the bounding volume represented by the points does not include more than one tree crown.

As part of this project, a special interface was added to LDV to support individual tree measurements. This interface, shown in figure 1, guides the user through the measurement process and automates the storage of measurements in spreadsheet compatible files. The interface also displays the vertical distribution of LIDAR returns for the entire sample plot (black histogram in figure 1) and for those returns located within the measurement area (yellow histogram in figure 1).

STUDY SITE

Our measurement project uses data for a small project area located in western Washington State. We have used the same area for a variety of LIDAR-related projects including the evaluation of LIDAR accuracy for ground surface measurements, determination of stand-level vegetation characteristics using LIDAR data, and general

* Stereoscopic display requires a graphics adapter that supports OpenGL quad-buffered stereo and display hardware such as active and passive systems available from StereoGraphics Corporation.

exploration of the utility of LIDAR data for detecting terrain and vegetation features. The area is part of Capitol State Forest and is managed by the Washington State Department of Natural Resources. The site is mountainous with elevations varying from 500-1300 feet (150-400 meters) and ground slopes from 0-45 degrees. Forest canopy within the study area is primarily coniferous and highly variable. It includes recent clearcuts, areas thinned to varying tree densities, and forest plantations ranging in age from recently planted to 70-year-old mature forests. As part of a forest management study (Curtis and others, 1996), the canopy of the 70-year-old forest stand was partially harvested in 1998, resulting in four different residual canopy density classes. In clearcut areas, the number of residual trees per hectare (TPH) is zero; in the heavily thinned areas, approximately 16 trees per acre (TPA) (40 TPH) remain; in lightly thinned areas, 70 TPA (175 TPH) remain; in the uncut area, 113 TPA (280 TPH) remain. The dominant tree height in the harvest area was approximately 164 feet (50 m). Figure 2 is a screenshot of FUSION showing a 1999 orthophotograph of the study area (outlined) taken 4 months prior to the LIDAR flight, contour lines generated from the digital terrain model, and the location of the field plots used for this study.

For this project, all horizontal data are referenced to the State Plane projection system, Washington south zone (4602), NAD 83, U.S. survey feet. Vertical data are referenced to NAVD88, U.S. survey feet.

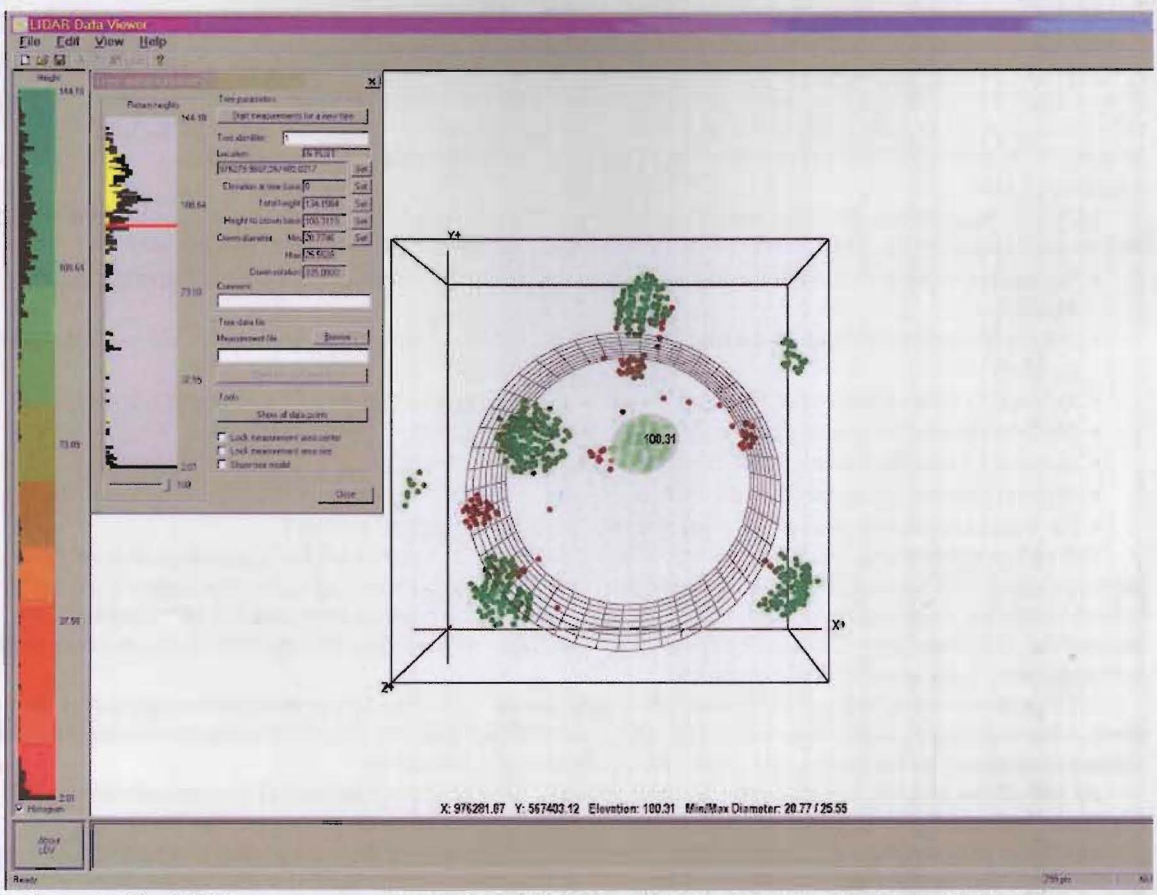

Figure 1. The LDV tree measurement interface facilitates collecting measurements for individual trees.

Digital Orthophoto

The Washington Department of Natural Resources, Resource Mapping Section produced a digital orthophoto for the study area using a softcopy system (Socet Set). The source imagery was 1:12,000 color aerial photography. Orthorectification was accomplished using a canopy surface model developed using autocorrelation techniques. The final image used a 1 foot (0.3m) pixel.

LIDAR Data

A small footprint, discrete return LIDAR system was used to map approximately 1,235 acres (5.25 $km^{2)}$ of the study area in the spring of 1999. The contractor used a Saab TopEye LIDAR system mounted on a helicopter to collect data over the study site. Table 1 presents the flight parameters and instrument settings for the data acquisition. LIDAR data were supplied in 15 separate files each containing 600,000 to 3,000,000 returns. To simplify interaction with the data, the files were combined into a single file containing 37,077,317 LIDAR returns. Each return included the pulse number, return number for the pulse (up to four returns were recorded per pulse), X, Y, elevation, scan angle and intensity.

Table 1. Flight parameters and scanning system settings.

Flying height	200 m
Flying speed	25 m/sec
Scanning swath width	70 m
Forward tilt	8 degrees
Laser pulse density	4 pulses/m^2
Laser pulse rate	7,000 points/sec
Maximum returns per pulse	4
Footprint diameter	40 cm

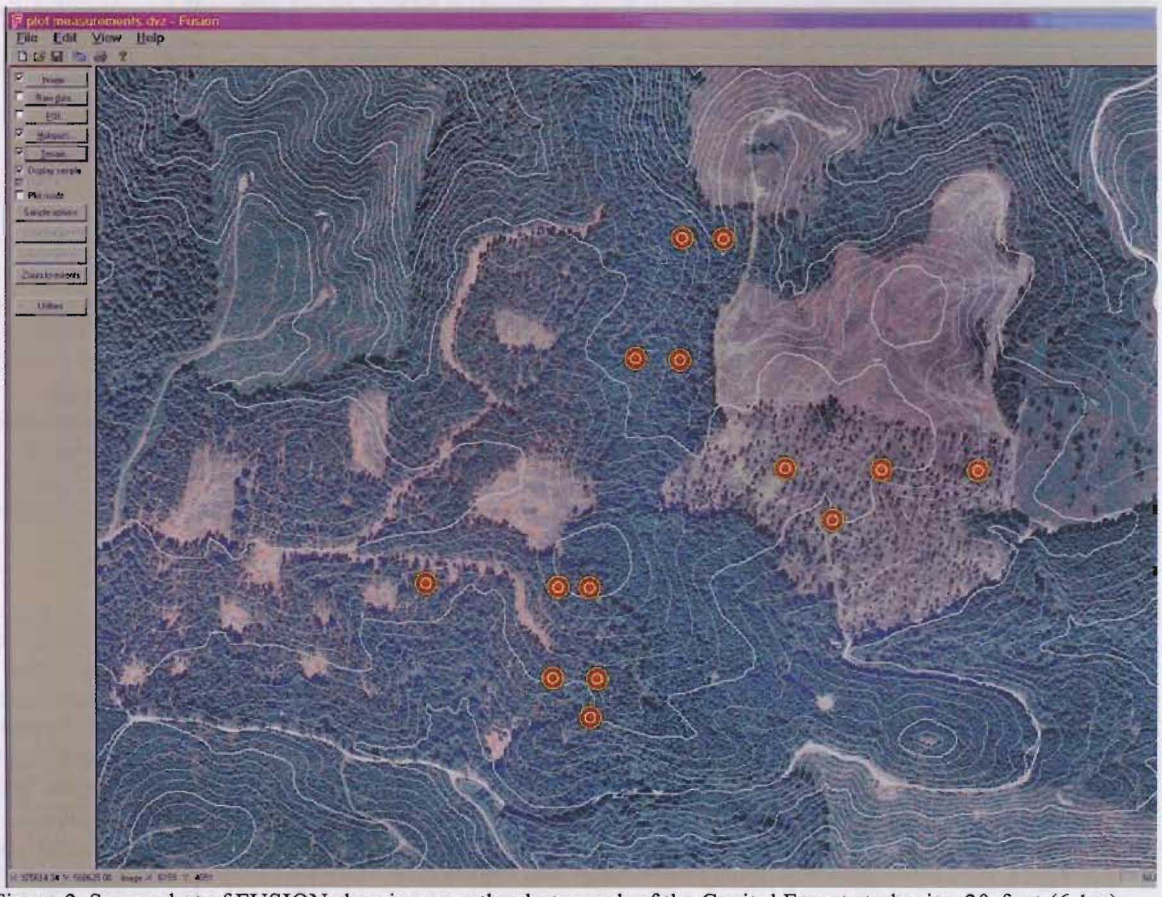

Figure 2. Screenshot of FUSION showing an orthophotograph of the Capitol Forest study site, 20-foot (6.1m) contours created from the digital terrain model, and the location of field plots used in this study.

Digital Terrain Model

For this project, the contractor sorted the data into "last returns"--approximately 6.5 million candidate ground-points. They then used a proprietary routine to further filter the data down to approximately 4 million points assumed to be on the ground. We used these filtered ground points to create a ground-surface digital terrain model (DTM) using a 5- by 5- foot (1.524- by 1.524-meter) grid resolution. The final filtering of last returns for the purpose of generating a "ground surface" is a commercially important and, thereby, inherently proprietary activity. Some discussions have been published in the open literature (Elmqvist, 2002; Haugerud and Harding, 2001), however, it is common for the consumer of LIDAR data to order the "bare-earth" coordinate data or a "bare-earth" surface model and accept it as a commercial product. In this case, we worked with the filtered last returns or "ground surface" coordinate dataset as delivered by the contractor. In their evaluation of this LIDAR-derived terrain model, Reutebuch and others (2003) found an average LIDAR elevation error of 8.6 inches (22 cm) when the model was compared to 347 checkpoint locations surveyed with a Topcon ITS-1 total station.

Field Measurements

Field data were collected on several fixed-radius plots (0.2 acre, 52.66 foot radius; 0.081 hectare, 16.05 meter radius) distributed over the study area during the summer of 2002. Heights, distances, and angles were measured using an Impulse laser rangefinder with a MapStar compass module. Plot locations were obtained using differentially-corrected GPS. Plots located in open stands were measured directly. For plots located under dense canopy, the plot center was located using traverse shots from points located in openings where reliable GPS points could be obtained. Measurements including diameter at breast height DBH), total height, and height to the base of the live crown were obtained for all trees with a DBH of 5 inches (12.7 cm) or greater. The distance from the plot center to the center of each tree and the azimuth angle for each tree were measured and later used to compute the location of each tree.

MAKING MEASUREMENTS IN THE LIDAR POINT CLOUD

Before we could compare measurements made directly from LIDAR data with field measurements, we had to create a FUSION project and specify the LIDAR data and other layers for the project. In FUSION, the orthophoto and "bare-earth" surface model provide a visual frame of reference to assist with locating plots and exploring the LIDAR data. Field plot locations were used as a "points of interest" layer to help us match LIDAR data samples to field plot locations (figure 2). While it was entirely feasible to work with the entire 37,077,317 million point LIDAR dataset, we chose to create data subsets for each field plot and store the subsets for later use while collecting measurements. For the FUSION project used to do the actual measurements, the plot locations were used as hotspots to link the stored subsets to their correct spatial location. This process dramatically reduced the overall storage requirement for this project since we now had only the LIDAR subsets to store and move from one computer to another. Individual trees were identified and measured in LDV with the results saved to a file suitable for import into a spreadsheet program for subsequent analysis.

Creating LIDAR Subsets

Data subsets included all LIDAR returns located within the sample plot plus returns located within the buffer area around the plot. In FUSION, we activated the layer containing the plot locations and used the "snap to POI point" feature, to create data subsets for each field plot. FUSION sampling options were specified to create fixed-size circular subsets that matched the size of our field plots. A 25 foot (7.62m) buffer was added around the plot to allow more accurate measurements for trees located near the edge of the plot. LIDAR returns were color-coded by height above ground and the return elevations were normalized using the elevation values sampled from the "bare-earth" surface model. Returns less than 2 feet (0.61m) above the ground surface were omitted from the subsets. FUSION included the plot locations and an object representing the plot boundary (wire frame cylinder) as part of the subset. Figure 3 shows a subset from the heavily thinned area. Data subsets contained from 800 to 10,000 data points.

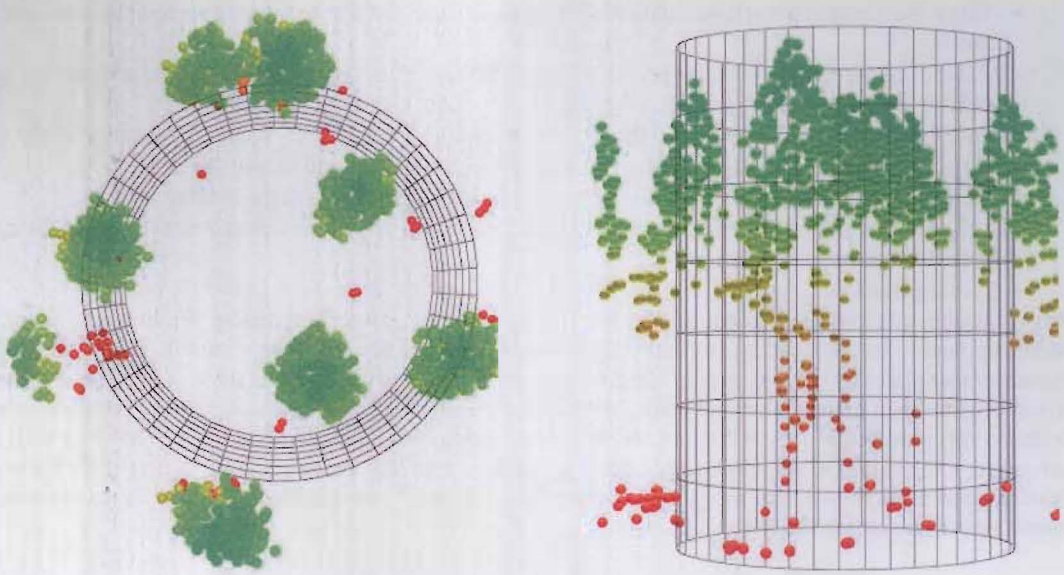

Figure 3. LDV visualization showing an overhead view and a side view of the LIDAR data and plot boundary for a 0.2-acre (0.081 ha) sample plot.

Individual Tree Measurement

Tree measurements were collected using only the LIDAR returns and the plot area boundaries. FUSION produces a georeferenced image, clipped from the orthophoto, covering the plot area as part of the data subset (see figure 5 for an example). However, we did not use this image while collecting tree measurements. We felt that using the image would be "cheating" since one of the objectives of the project was to determine how well individual trees could be isolated and measured given a LIDAR point cloud. In addition, the project orthophoto was not perfect. It was created using a canopy surface model developed using autocorrelation methods in a softcopy photogrammetry system. We have identified several areas where scattered, individual trees are not represented in the surface model. In these areas, tree crowns are displaced from their true location and could lead to confusion when trying to identify and isolate individual trees. All tree measurement were collected using monoscopic rendering mode in LDV. Measurement accuracy would not have been improved by using stereoscopic mode in LDV. However, measurements might have been collected more quickly because it is easier to isolate individual trees when working in stereoscopic mode. The following attributes were recorded for each tree that could be isolated and measured within the plot boundary:

- Tree identifier (sequential tree number for the plot),
- Planimetric location,
- Elevation at the base of the tree (0.0 since return elevations were normalized using the "bare-earth" surface model),
- Total tree height,
- Height to the base of the live crown (defined as the height to the lowest branch that appeared to have foliage),
- Crown diameters (defined by the diameters of the elliptical measure ment area),
- User comment.

All measurements were collected by the same individual. LDV does not force the user to follow a specific procedure when collecting tree measurements. It simply provides a set of tools and an interface to help the user isolate individual trees and collect measurements. Different individuals will likely develop their own method for isolating and measuring trees. For this project, the following procedure was followed:

- Load a data subset into LDV then activate measurement mode and the tree measurement interface,
- Starting with the lowest trees in the plot, move the measurement marker to cover a portion of the data cloud that might be a tree,
- Snap the measurement marker to the highest point in the measurement area,

- Adjust the dimensions and orientation of the measurement marker to roughly surround the returns for the tree crown,
- Manipulate the view to look for possible LIDAR returns from the tree stem to assist with determining the location of the tree and to further refine the measurement area dimensions,
- Once satisfied that you positioned the measurement area around a tree, record the location of the tree,
- Adjust the height of the measurement plate to the top of the tree and record the tree height,
- Adjust the measurement plate to the base of the live crown and record the height,
- Adjust the location and size of the measurement marker to bound the tree crown and record the dimensions and orientation,
- Save the tree to the data file.

All of the above activities are facilitated by buttons on the tree measurement dialog. While it may sound like a tedious process, isolation and measurement of an individual tree takes less than a minute. During the process, the measurement plate can be used to help identify the upper portion of tree crowns since points above the plate appear much brighter than points below the plate. LDV also provides a vertical clipping capability (display only points within a specified height range) that can assist in locating and isolating individual trees. When tree measurements are saved to the data file, all points within the measurement area that are below the tree height are turned off. This feature helps users follow their progress across a plot but it may make it difficult to make measurements in dense stands where tree crowns overlap significantly.

ANALYSIS AND RESULTS

A total of 112 trees on 10 plots (6 plots in the lightly thinned treatment area and 4 plots in the heavily thinned area) were measured. We could not measure tree heights in the field in the control unit plots due to the dense canopy and difficulty seeing the top of trees. To check our overall ability to identify and isolate individual trees, each LIDAR-measured tree was matched to the closest field-measured tree. The data subsets and objects representing the trees measured in the field and using the LIDAR data were examined to judge the overall results. LDV displays such as those shown in figure 4, provide a quick visual check to see if the field-measured and LIDAR-measured trees were paired correctly and whether or not trees were missed. As an additional visual check, the orthophoto image containing the plot center and the locations of all field-measured trees was turned on as shown in figure 5. During this preliminary check, 12 trees were removed from our sample because of obvious blunders in measurement. In some cases, the dense canopy prevented field measurements of tree height and in others we identified a tree in the LIDAR data that did not exist in the field. In one case, we measured a tree in the LIDAR data (captured in 1999) that subsequently broke in half and was not measured in the field. We also identified several cases where field data had been entered incorrectly resulting in incorrect heights or incorrect tree locations. By comparing the field-measured object to the LIDAR-measured objects, we were able to identify 42 small trees that were measured in the field but not in the LIDAR data. In some cases, closer examination of the LIDAR point data revealed that the small trees were simply overlooked but in most cases, there were insufficient returns to adequately characterize the relatively short trees with sparse crowns located beneath large tree crowns.

Descriptive statistics were computed to compare the LIDAR-measured and field-measured tree locations, total heights, and heights to the base of the live crown. The average difference in the tree locations was 3.18 feet (0.97 m) with a standard deviation of 1.85 feet (0.56 m). The maximum location difference was 9.09 feet (2.77 m). For tree heights, the average difference was -0.96 feet (-0.29 m) and the standard deviation was 7.31 feet (2.23 m). The negative difference indicates that the height measured from the LIDAR data was lower than that measured in the field. Height differences ranged from -27.46 to 20.85 feet (-8.37 to 6.36 m). Figure 6 shows a scatter plot of the height measurements. For height to the base of the live crown, the average difference was -10.58 feet (-3.22 m)and the standard deviation was 13.02 feet (3.97 m). Crown base height differences ranged from -46.43 to 26.06 feet (-14.15 to 7.94 m). Figure 7 shows a scatter plot of the crown base height measurements. Crown dimensions (diameters and orientation) were not measured in the field.

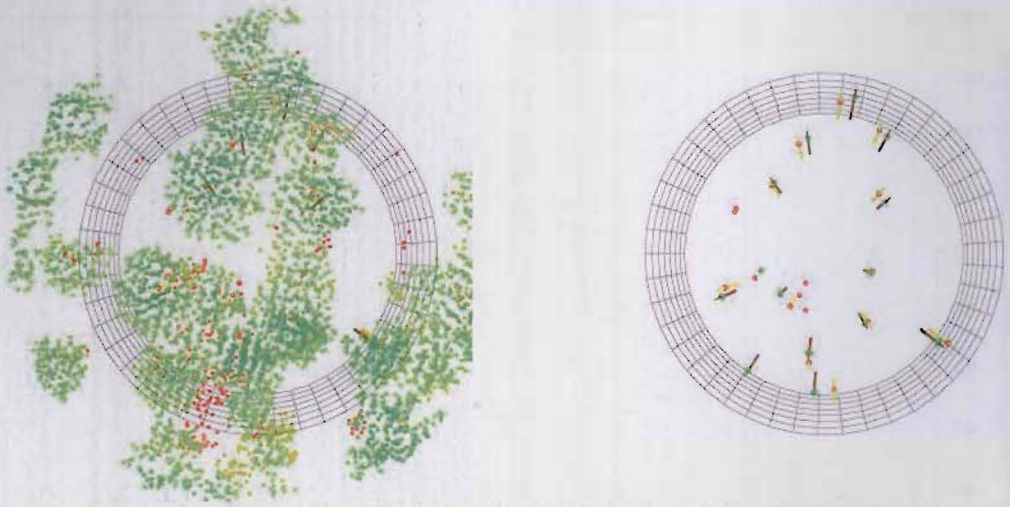

Figure 4. Overhead view of the LIDAR data subset for a plot located in the lightly thinned treatment and the same view without the LIDAR data points showing the tree stems measured on field plots (yellow) and from the LIDAR data (brown). Red and green markers along the stems show the measured location of the base of the live crown.

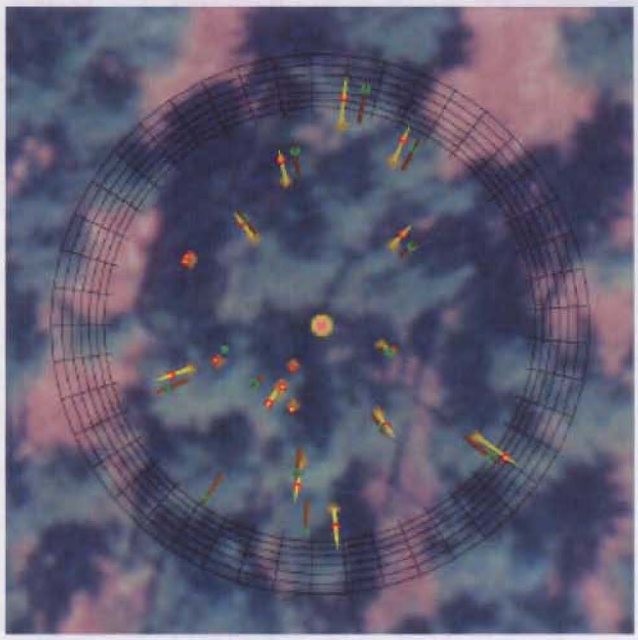

Figure 5. The same view shown in figure 4 but with the addition of the orthophoto that corresponds to the LIDAR data subset created in FUSION. The large dot in the center of the image is the plot center. Small dots under the yellow stems are the locations of the trees measured on the plot.

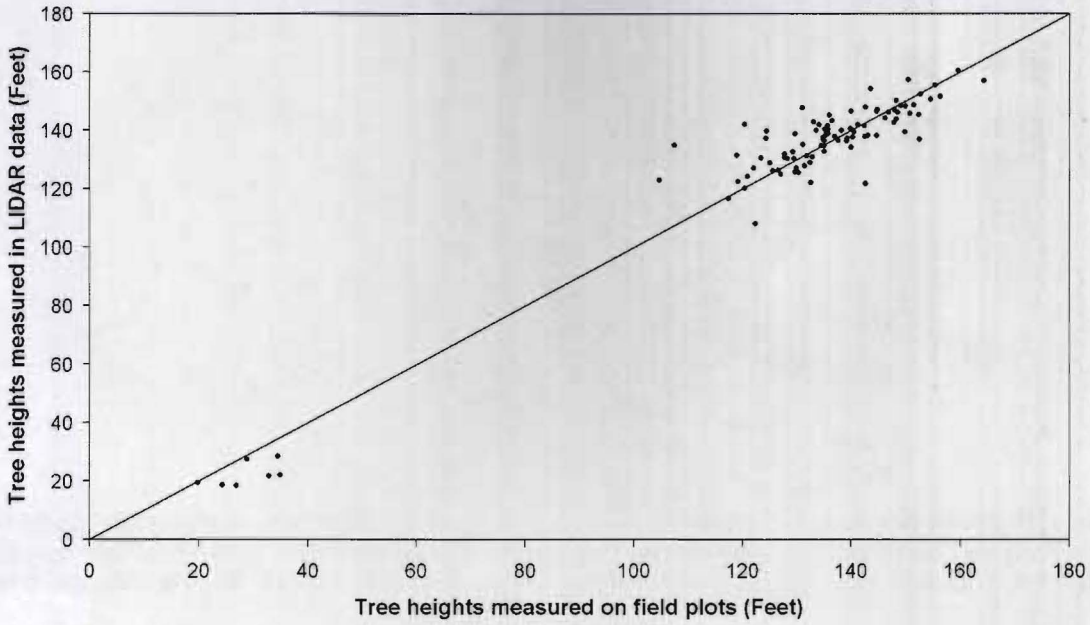

Figure 6. Scatter plot of the tree heights measured on field plots and those measured in the LIDAR data. The line shows a 1:1 relationship.

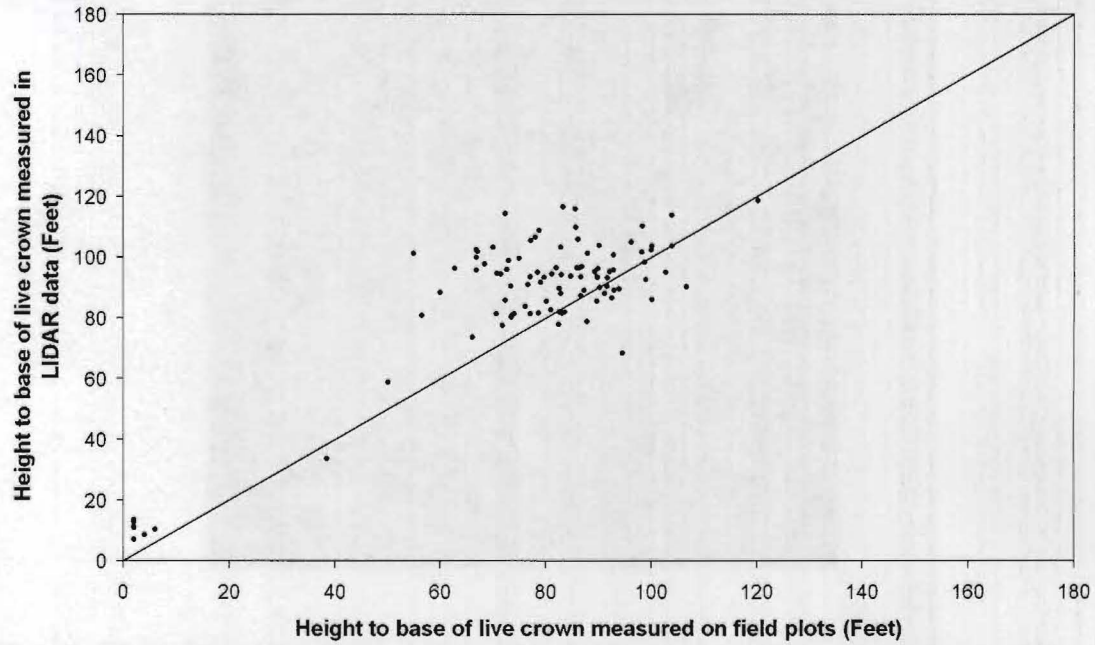

Figure 7. Scatter plot of the height to the base of the live crown measured on field plots and those measured in the LIDAR data. The line shows a 1:1 relationship.

DISCUSSION

Overall, our results indicate that we can measure some individual tree attributes directly using a LIDAR point cloud. The major problems we encountered were identifying and isolating individual trees in areas where tree crowns overlapped, recognizing understory trees, and identifying the base of the live crown. All of the plots we measured were dominated by mature Douglas-fir trees. These trees, in general, have well defined, cone-shaped crowns (at least in the upper portion of the crown). We could easily identifying individual trees in upper canopy layers. However, trees in mid- and lower-canopy layers do not have well defined crowns making it difficult to isolate the returns for a single tree. In understory layers, there simply were not enough LIDAR returns to adequately define the crowns of individual trees. This was primarily due to the shadowing effect of overstory trees--LIDAR pulses simply do not reach the understory trees. Small trees located in openings were easily identified and measured.

We expected to find a significant overall bias in tree height measurements given the tree growth that occurred from the time the LIDAR data were acquired in March 1999 to the time the field plots were measured in the summer of 2002. While the mean difference in height measurements, -0.96 feet (-0.29 m), does not reflect the expected bias, a histogram showing the distribution of the difference values (figure 8) shows that the distribution is slightly biased, about 2.5 feet (0.76 m), in the expected direction. However, we would expect more height growth to have occurred given the time between measurements. We have compared the LIDAR data acquired in 1999 to more recent data acquired in 2003 and noticed that the heights of the residual trees in heavily thinned areas have not increased as we would expect. One theory suggests that the trees have responded to the thinning by increasing the diameter and density of their crowns rather than growing taller. However, further investigation is needed to explain the measurement differences.

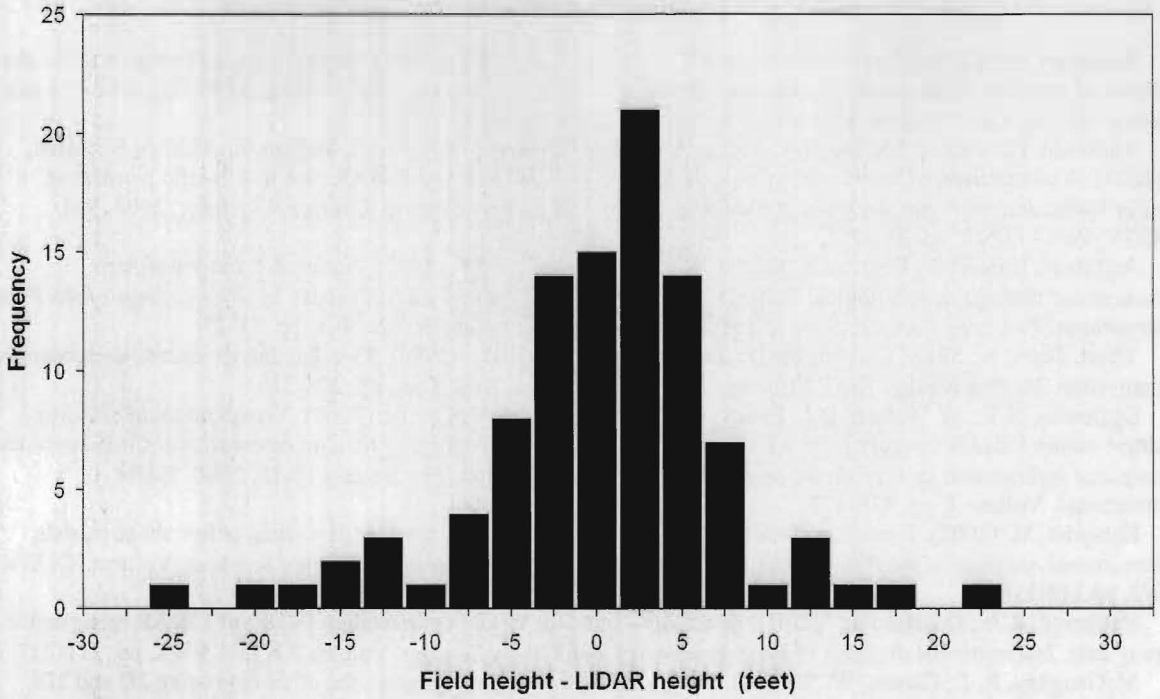

Figure 8. Histogram showing the distribution of differences between field- and LIDAR-measured tree heights.

The ability to measure the height to the base of the live crown using only the LIDAR data is not being sufficiently tested in this project. The scatter plot in figure 7 shows low correlations between field measurements and LIDAR measurements. When we consider the range of tree sizes measured for this project (mostly large trees), correlations are even lower. The height to the base of the live crown is a poorly defined metric and selection of the crown base is a subjective process in both field- and LIDAR-measurement procedures. Height to the base of the live crown can be defined as the height to the lowest green foliage associated with a tree or the height to the branch insertion point for the lowest branch with green foliage. In the field, it can be difficult to associated green foliage

with a particular tree when tree crowns overlap. When measuring in LIDAR point cloud, it is difficult (probably impossible without intensity information) to separate returns from live and dead branches so selection of the base of the crown must be based on the overall shape of the point cloud identified for an individual tree.

CONCLUSIONS AND FUTURE WORK

This project has shown us that it is possible to isolate individual trees and collect reasonable accurate measurements of tree locations and heights using only LIDAR return data. Preparations for this paper included the development of the measurement interface in LDV, the plot sampling capabilities in FUSION, and the measurement methodology. We now have a measurement system that can produce precise, accurate measurement of features within a LIDAR point cloud. However, we do not feel that this project is complete but rather that we are now ready to design and conduct a more rigorous test of the process for isolating individual trees and measuring individual tree characteristics using LIDAR data. Efforts in the near future will include a more recent LIDAR dataset acquired in the fall of 2003 and additional field measurements collected in the spring of 2004.

Interested readers are encouraged to visit the following web sites for additional information and progress updates:

http://www.fs.fed.us/pnw
http://forsys.cfr.washington.edu
http://www.cfr.washington.edu/research.pfc

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