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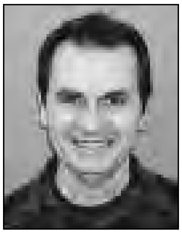
LIDAR: An Emerging Tool for Multiple Resource Measurement, Planning and Monitoring

BY STEVE REUTEBUCH AND BOB McGAUGHEY



Steve Reutebuch

Bob McGaughey

Over the last decade, a revolution in active remote sensing technology has occurred, providing new tools for measuring and monitoring forests over the landscape at unprecedented resolution and accuracy. The basis of this revolution is the ability to directly measure the three-dimensional structure (i.e., terrain, vegetation and infrastructure) of forests and to separate measurements of above-ground vegetation from measurements of the terrain surface. Of these new remote-sensing technologies, airborne laser scanning, a type of light detection and ranging (LIDAR), is the most commonly available (see sidebar: Airborne LIDAR in a Nutshell).

Nationally, at least 30 remote sensing companies have LIDAR sensors and are providing LIDAR for a wide range of applications. Several eastern states have embarked on, or completed statewide LIDAR acquisitions primarily for natural hazards mapping, particularly updating of flood zone maps.

In Oregon and Washington, two public LIDAR acquisition consortiums were formed, initially focused on the heavily forested areas west of the Cascades (see sidebar: How to Get LIDAR Data). As in other states, mapping of natural hazards (earthquake faults in the Puget Sound trough and landslides in western Oregon) has been the main justification for these efforts. However, participating consortium partners have recognized and are encouraging the use of these publicly available LIDAR datasets for other uses, particularly forest management.

Much research is underway to develop more precise measures from LIDAR; however, the following simple LIDAR-derived products are easily generated and quite useful to resource managers.

High-resolution ground surface models. Traditional digital terrain models (DTMs) were compiled from aerial photos that required map makers to make their best guess about where the ground surface was in heavily forested areas. LIDAR can provide much more accurate ground models for slope mapping, stream delineation, and road and harvest system planning and design. The Oregon and Puget Sound LIDAR Consortiums are producing DTMs with one- to two-meter grid resolution, a vast improvement over the standard USGS 10-meter DTMs.

Canopy height models. By subtracting the LIDAR-derived ground surface DTM from a LIDAR-derived canopy surface model, a canopy height model (CHM) is produced. CHMs provide spatially-explicit stand structure data over the landscape for estimation of growing stock, input for habitat and fire models, and any other resource planning activities where spatial arrangement and tree height are important considerations.

Percent canopy cover models. These models provide a direct measurement of cover by height above ground.

LIDAR intensity images. These high-resolution images can be matched with existing orthophotographs and other digital imagery for change detection and monitoring over time. Intensity data from leaf-off acquisitions can be used to separate hardwood from conifer canopy areas; intensity data from leaf-on data can be used to separate live trees from dead trees.

All Returns Datasets. This archive of the LIDAR point cloud (including all returns for each pulse) provides baseline data on current terrain and vegetation structure that is valuable for future change detection and monitoring (e.g., crown expansion or dieback). These files can also be used when checking the quality of other derived LIDAR products. For instance, the point cloud can be superimposed on the LIDAR ground surface model to assess how well the ground fits the raw LIDAR scan.

Most LIDAR vendors can easily provide these simple products along with the raw LIDAR point data. Also, public domain software is available from the U.S. Forest Service that can be used to process, visualize and perform basic measurements with LIDAR data (see

(CONTINUED ON PAGE 2)

JOB OPPORTUNITY
CLACKAMAS COUNTY FORESTER

The Clackamas County Parks & Forest Department wishes to hire a forester to manage 4,000 acres of county forestland. The position reports to the Department Manager and includes: timber sale design and on-the-ground preparation, road and plantation establishment, monitoring and maintenance; timber sale contract administration and accounting; determination of appropriate measures to protect resources; conducting surveys to determine the best silvicultural treatments for forest stands; managing public involvement with timber sale proposals; analyzing natural resource legislation and preparing reports for the Board of County Commissioners; communicating with the public regarding tree and forestry related questions, identification and resolution of hazard tree problems in county parks and other county properties.

A degree in forestry or related field is required. Monthly salary range: $4,200-$5,000 depending on qualifications. Benefits package includes health and dental insurance, retirement pension, vacation, sick leave and holidays. For more information, contact Chris Van Duzer at 503-353-4663.

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LIDAR: An Emerging Tool

(CONTINUED FROM FRONT PAGE)

sidebar: Fusion LIDAR Software).

Over the last decade numerous projects have demonstrated that LIDAR data can provide high-resolution, spatially-explicit information for multi-resource management and planning. Simultaneously, LIDAR has emerged as the leading technology for high-resolution terrain mapping needed to better identify natural hazards such as flood- and landslide-prone areas. As LIDAR sensors and vendor capabilities continue to grow, LIDAR data will become as indispensable to tomorrow's foresters as the aerial photograph has been to today's foresters! ◆

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Golden Years

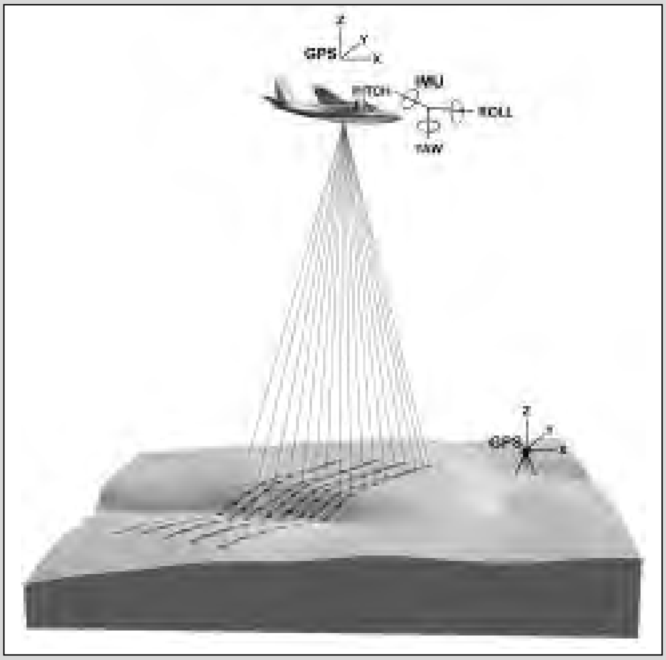
John Grey Wittmeyer was presented with his 2007 Golden Award on January 8 by Darren Mahr. The Coos Chapter member is a World War II veteran and long-time employee with the BLM, and still enjoys "carefully" cutting his own firewood.

PHOTO COURTESY OF DARREN MAHR

Next Issue: Tribal Forestry

Airborne LIDAR in a Nutshell

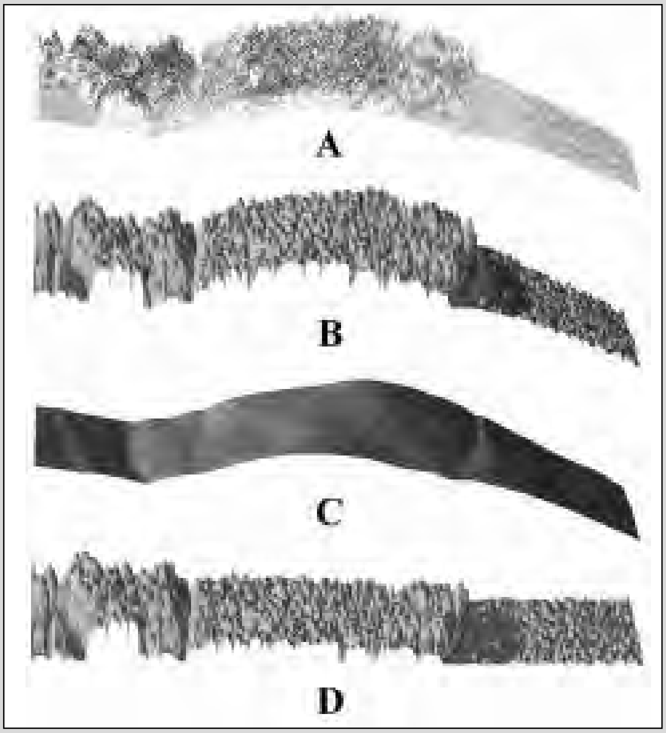
There are many different types of airborne LIDAR systems, but the most common for terrain mapping is discrete-return, small-footprint LIDAR. These laser-scanning systems have four major hardware components: 1) a laser emitter-receiver scanning unit; 2) GPS [aircraft and ground units]; 3) a highly sensitive inertial measurement unit (IMU) attached to the scanning unit; and 4) a computer to control the system and store data from the first three components. Large areas are surveyed with a series of swaths that often overlap one another by 50 percent or more.



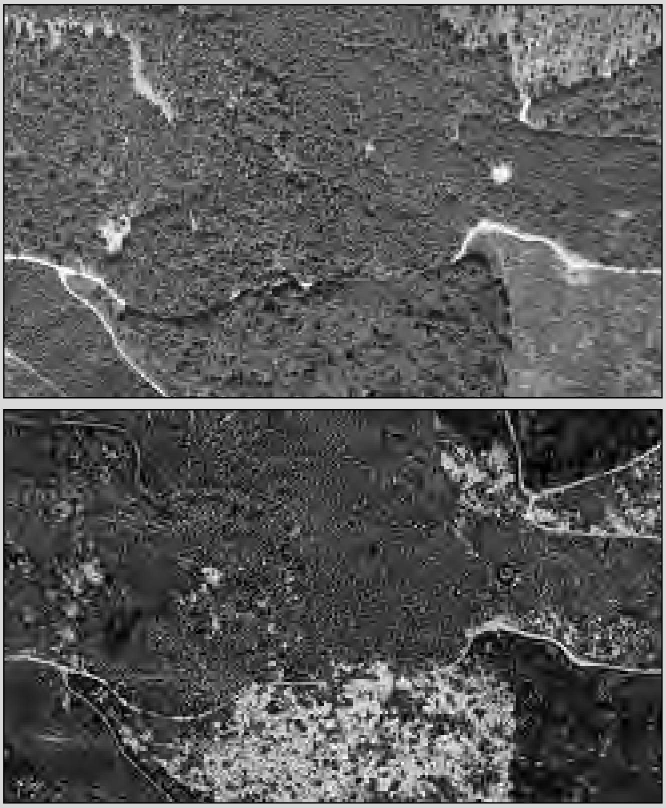
Schematic of a typical airborne LIDAR system.

State-of-the-art LIDAR scanners designed for terrain mapping emit near-infrared laser pulses at a high frequency (typically 50,000 to 200,000 per second). For each emitted pulse, most LIDAR sensors can record one to seven reflections from foliage, branches and sometimes the ground as the pulse passes from the top of the canopy down through canopy gaps. Using the distance from the sensor to each reflection or "return," the GPS aircraft position and the IMU aircraft altitude data, a 3D coordinate is computed for each object that reflected a pulse, resulting in a raw LIDAR data cloud. In a properly executed mission, the accuracy of points is typically 15 centimeters vertically and 25-50 centimeters horizontally. The density of points collected varies with mission specifications. In forested areas, one pulse per square meter has been commonly collected in the past; however, many newer surveys have collected five-plus pulses per square meter.

This data cloud (A) is then processed into different products such as canopy surface models (B), ground surface models (C), and canopy height models (D). In addition, a series of LIDAR point cloud metrics can be computed that have been shown to be strongly correlated with stand mean height, diameter, basal area, volume, biomass, cover and canopy fuel variables. Most LIDAR systems also record the level of near-infrared energy that was reflected. These return "intensity" values can be used to create near-infrared images of the forest and to separate leaf-off hardwoods from conifers or dead from live trees. Because the point cloud is in real-world coordinates, all LIDAR-derived products can be imported directly into GIS for use with existing orthophotos and resource data layers such as stand polygons and road coverages.



A: LIDAR Point Cloud (4 points/m^2); B: Canopy Surface Model; C: Ground Surface Model; D: Canopy Height Model (created by subtracting C from B)



Top: Aerial photograph. Bottom: LIDAR near-infrared intensity image. Dark areas are conifers; light gray areas are leaf-off hardwoods and dead trees (and roads).

How to Get LIDAR Data

There are dozens of remote sensing vendors that fly airborne LIDAR systems and can provide a range of LIDAR products with costs ranging from less than $1 to several hundred dollars per acre, depending on mission requirements and desired products. Costs for large blocks over 10,000 acres are generally $1 to $3 per acre for typical LIDAR deliverables. So, before a landowner requests a bid, it is important that they understand what products and specifications will work for their project. Additionally, LIDAR missions require mobilization of personnel and aircraft, often from other states. Therefore, it is advantageous to spread this mobilization cost over a large area to hold down the cost per acre. To do this, landowners may want to see if their lands can be flown as part of a larger, coordinated acquisition.

In Oregon and Washington, consortiums have formed to coordinate large-area LIDAR mapping projects. Both the Oregon LIDAR Consortium (oregongeology.com/sub/projects/olc/) and the Puget Sound LIDAR Consortium (pugetsoundLiDAR.ess.washington.edu) have maps of completed and planned LIDAR project areas. They invite other federal, state, local and private owners to pool resources for more cost-effective LIDAR acquisitions.

The Oregon consortium's initial goal is to collect LIDAR over the nominally inhabited areas in western Oregon, with the ultimate goal of covering the entire state. In 2007, the Oregon consortium was funded by the state legislature to collect LIDAR over 2,000-3,000 square miles in 2008. In addition, the Bureau of Land Management and tribal partners are flying an additional 1,000-1,500 square miles in Oregon as consortium partners. The Puget Sound Consortium has collected over 12,000 square miles and hopes to eventually fly all of western Washington. The consortium has also flown smaller areas in eastern Washington with state and federal partners. Like Oregon, the ultimate goal is to fly the entire state of Washington.

Partial List of LIDAR Project Specifications in Forested Areas*

Pulse density per sq. meter	Minimum 1 for stand level canopy models and medium resolution ground models (2-m grid) 4+ for individual tree canopy measurements and high-resolution ground models (1 m grid)
Returns per pulse	Minimum 2 for canopy and ground surface measurements. 4+ for improved mid- and lower-canopy structure measurements
Laser beam divergence	Narrow beam settings have been shown to provide better tree heights and higher percentage of ground returns in limited studies. Narrow beam allows higher flight altitudes.
Scan angle	+/- 15 degrees or less increases ground returns in heavy forest cover, but narrower scan angles increase number of flightlines required and costs.
Swath overlap	Usually 50% or more sidelap on adjoining swaths, i.e., survey is designed for 100% double coverage at planned aircraft height above ground.
Season of survey	Leaf-off in areas of significant hardwood cover and no significant snow cover. Results in better ground measurements, but can be difficult to achieve in higher elevations. Leaf-off flight window can be very constrained by weather in the Northwest, resulting in lower probability of on-time mission success. Leaf-off also allows separation of hardwoods from conifers, but dead trees are difficult to separate from leaf-off hardwoods. Leaf-on for separation of live from dead trees. Conifer areas can be flown leaf-on, but poor separation of hardwoods from conifers. Leaf-on flight window is often larger, resulting in higher probability of on-time mission success.
Absolute LIDAR measurement accuracy	Horizontal: typically +/-0.5 to 1 m depending on survey objectives. Vertically: typically +/-0.15 to 0.5 m depending on survey objectives
Swath to swath LIDAR relative accuracy	Horizontal. +/-0.25 to 0.5 m depending on survey objectives. Vertically: +/-0.10 to 0.5 m depending on survey objectives.

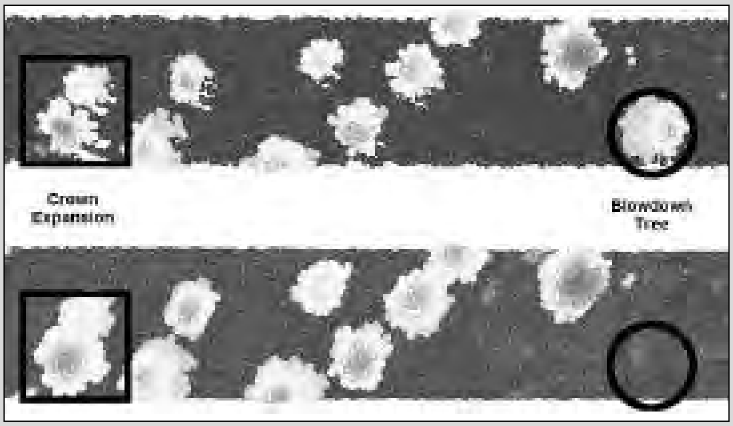
*Adopted from the Puget Sound LIDAR Consortium. Refer to article by Ralph Haugerud elsewhere in this publication for more information on model specifications.

If a landowner decides to contract for LIDAR data directly with a vendor, rather than partnering with one of the regional consortiums, review of the consortium specifications will help them better understand important choices that must be made regarding mission specifications, required accuracy standards and options for deliverables.

Above is a table of some of the major mission variables and typical specifications that should be considered when contracting for LIDAR projects.

As with any remote sensing contract, the purchaser should also address who owns the collected data, for what purposes, and for what timeframe after the project is completed. Some vendors retain ownership of the raw data and only license use of delivered products to purchasers.

This highlights another advantage of partnering with the consortiums—all data from their projects are put in the public domain and are carefully archived. This long-term warehousing of LIDAR missions will become particularly important as areas are re-flown over time (e.g., after large flood events, landslides or wind storms) and earlier LIDAR data are combined with data from later flights for change detection and monitoring purposes, such as tree growth, mortality and wind-throw.



Top: Overhead view of LIDAR points flown in 1999. Dark areas are ground.
Bottom: LIDAR for same area flown in 2003. Notice the crown expansion for most trees and the missing tree on the right side of the 2003 image. This tree was blown down between the 1999 and 2003 LIDAR flights.

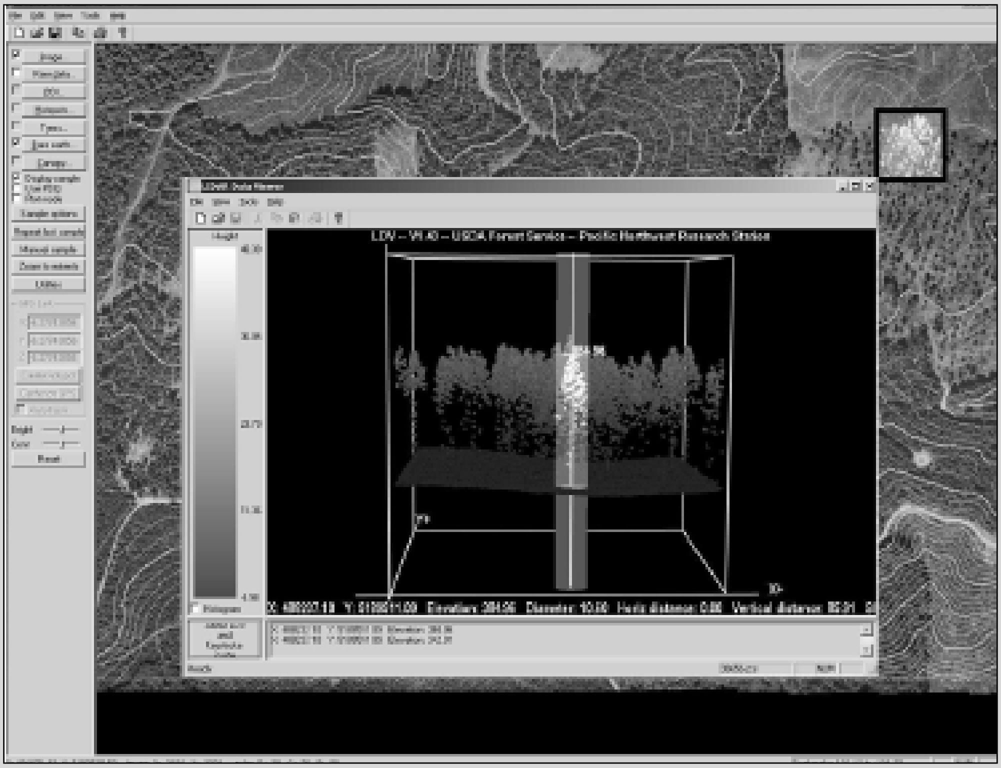
Fusion LIDAR Software

The PNW Research Station has developed a suite of software tools called “Fusion” that can be used to combine LIDAR point clouds with existing orthophotos, maps and GIS layers.

Fusion also includes utilities to process point clouds into canopy and ground surface models, canopy metrics (heights, cover, etc.) that can be imported into GIS for further analysis.

The Fusion package, along with an online tutorial, manual and sample dataset is available from the USFS Remote Sensing Applications Center’s website at www.fs.fed.us/eng/rsac/fusion.

GRAPHICS COURTESY OF STEVE REUTEBUCH



Background: LIDAR contour lines super-imposed on an orthophoto. Foreground: Sample (from area shown in the black square) of LIDAR point cloud with individual tree measurement.

A Model Specification for LIDAR Surveys in the Pacific Northwest

BY RALPH HAUGERUD

An increasing number of vendors offer LIDAR surveying services to a client community that includes local, state, federal and tribal governments, private landowners large and small, engineering and land management firms, and a handful of researchers. With time, LIDAR survey data should become a well-understood commodity. But we are not there yet! Many purchasers of LIDAR survey data still find that, on occasion, they do not receive a product that meets their expectations. To avoid this, it is helpful to have a specification that communicates to the vendor what the client desires, and that if met, guarantees that a data set will be fit for use and provides a framework for resolving disputes over data quality.

Recently, Susan Nelson (Bureau of Land Management), Diana Martinez (Puget Sound Regional Council) and I, with advice from several colleagues, wrote a model specification for LIDAR data to be purchased by public agencies in the Pacific Northwest. The complete specification is available online at http://pugetsoundLIDAR.ess. washington.edu/proposed_PNW_LIDAR_specification-1.0.pdf. The specification is based on prior experience with several vendors and multiple acquisition contracts. While it is informed by the experience some of us have with the Puget Sound LIDAR Consortium, it is not based solely on this experience. Use of this specification should ease data interoperability, reduce contracting costs, and facilitate development of a shared set of tools for manipulating LIDAR data.

The model specification is designed for the Pacific Northwest. It reflects the prevalence of young, angular landscapes, the regional importance of forests and fish habitat, and the need to intelligently guide ongoing urbanization. It may, perhaps with adjustments, be useful elsewhere. The specification reflects our perception of LIDAR technology and market conditions as of 2007. It should evolve with increasing experience and changing technology. We know that in at least one aspect (classification of LIDAR returns) the specification needs to be improved.

Writing a LIDAR survey specification presents a challenge. A good specification is such that: (1) conformance to the specification can be readily evaluated; and (2) if data conform to the specification, the data are assured of being suitable for the task at hand. Absolute vertical accuracy, typically the foundation of topographic surveys, fails this challenge on both counts. LIDAR data should be accurate, complete and usable. We wrote a specification that describes these qualities and for which conformance can, with a few exceptions, be easily measured. In general, the specification focuses on LIDAR data, not the procedures employed to collect the data. An exception is GPS practice, as we have found that it is very expensive to adequately judge the quality of absolute spatial positioning; for this reason, we specify some aspects of GPS procedures.

In addition, the specification prescribes some aspects of GPS procedures, prescribes a data-tiling scheme and file names, discusses the negotiation of point-classification procedures, and provides instructions for formal metadata. Perhaps the most important feature of the specification is not the particular set of choices for point density, absolute accuracy, maximum scan angle, swath overlap and the like, but the recognition that these things should be specified.

Constraints in survey design

There are tradeoffs between survey design, cost, accuracy and resolution of a LIDAR survey. To a first approximation, cost is the sum of mobilization expenses (including establishing GPS ground control), aircraft and crew time, and processing time. Accuracy is controlled by GPS base-line length, inertial measurement unit (IMU) quality, care and experience in calibration, and flying height. Resolution is mostly a function of on-ground spot spacing, which is governed by instrument pulse rate, flying height and airspeed. In forested areas, ground resolution is significantly decreased as most laser pulses do not produce returns from the ground surface.

At a given pulse density, single-swath (no overlap) data generally provide better relative accuracy, and thus better feature recognition, but may require a higher pulse-rate instrument to achieve the desired pulse density. However, multiple, overlapping swaths make it easier to achieve high pulse densities and generally have multiple look angles, both desirable characteristics for increasing the probability of ground returns in dense forest canopy, but at a cost of poorer feature recognition

Summary of the specification

Acquisition procedures	Instrument shall be capable of detecting and recording at least 3 returns per pulse, 10-40 cm on-ground spot diameter, maximum permissible scan angle ≤ ±20 degrees, at least 4 pulses/m^2 nominal 50% sidelap survey in leaf-off conditions
Accuracy	≤15 cm root mean square error (RMSE) vertical absolute accuracy as measured by contractor, ≤10 cm RMSE vertical and ≤50 cm RMSE horizontal intra-survey reproducibility for project as a whole, ≤5 cm RMSE reproducibility of range measurements.
Completeness	No voids between swaths, no voids because of cloud cover or instrument failure, ≤20% no overlap area per project, ≥85% design pulse density for project as a whole.
Usability	Consistent file names, consistent file formats. Minimum deliverables are Report of Survey, aircraft trajectory files, all-return point cloud bare-earth surface model (DEM), and formal metadata. Optional deliverables include first-return surface ground point list, intensity image and contours.
Intellectual property considerations	Unrestricted rights to all delivered reports and data.

because of swath-to-swath errors. Leaf-off acquisition gives much better ground penetration, but at the cost of a shorter acquisition season that generally has poor weather. Leaf-on acquisition is likely to be cheaper because of better instrument availability and generally better weather.

Since 2000, there has been a six-fold increase in instrument pulse rate. Faster computers, better codes and more experience have allowed handling of greater data volumes at the same cost. Rather than moving toward lower-cost surveys at the same resolution, the Puget Sound LIDAR Consortium has chosen to acquire surveys with a higher pulse density. There are several reasons for this.

First, and best documented, is that higher-density surveys allow much better characterization of the forest canopy. Second, we observe that with a six-fold increase in pulse density, we have not seen a corresponding increase in the number of identified ground points, but we see fewer vegetation returns misidentified as ground and fewer landscape corners misidentified as vegetation. We suspect that with a smaller fraction of returns identified as ground, the confidence that these are indeed ground points increases and the fraction of errors decreases. The resulting bare-earth surface models are more detailed and more informative (see Figure 1). Third, closer pulse spacing probably results in better survey calibration, as (a) the data set has better XY resolution (a limiting factor in some pointing calibration procedures); and (b) interpolation errors associated with tying quasi-regularly spaced LIDAR returns to arbitrary ground control points are smaller. Fourth, reducing cost by increasing the instrument pulse rate and flying higher and faster significantly reduces survey accuracy, as the dominant error in most LIDAR surveys is mis-positioning because of pointing error and this effect is linear with instrument height.

Why not save money by purchasing lower quality data?

LIDAR data are expensive and we believe that community support for continued data acquisition is more likely if we meet the needs of most potential users. Angular landforms, dense forest cover, and significant land and habitat values dictate that in the wet Pacific Northwest we need dense, accurate surveys.

A faster instrument allows one to fly higher and faster and cover the same area at the same pulse density in less time—but in most cases such cheaper data will be significantly less accurate. For earthquake and landslide hazards mapping where public safety is an issue, we are concerned to deflect liability issues by using the best-available data. In the long run, change detection and analysis is likely to be a major use of LIDAR data and the ability to detect and describe change is closely related to data resolution and accuracy. ◆

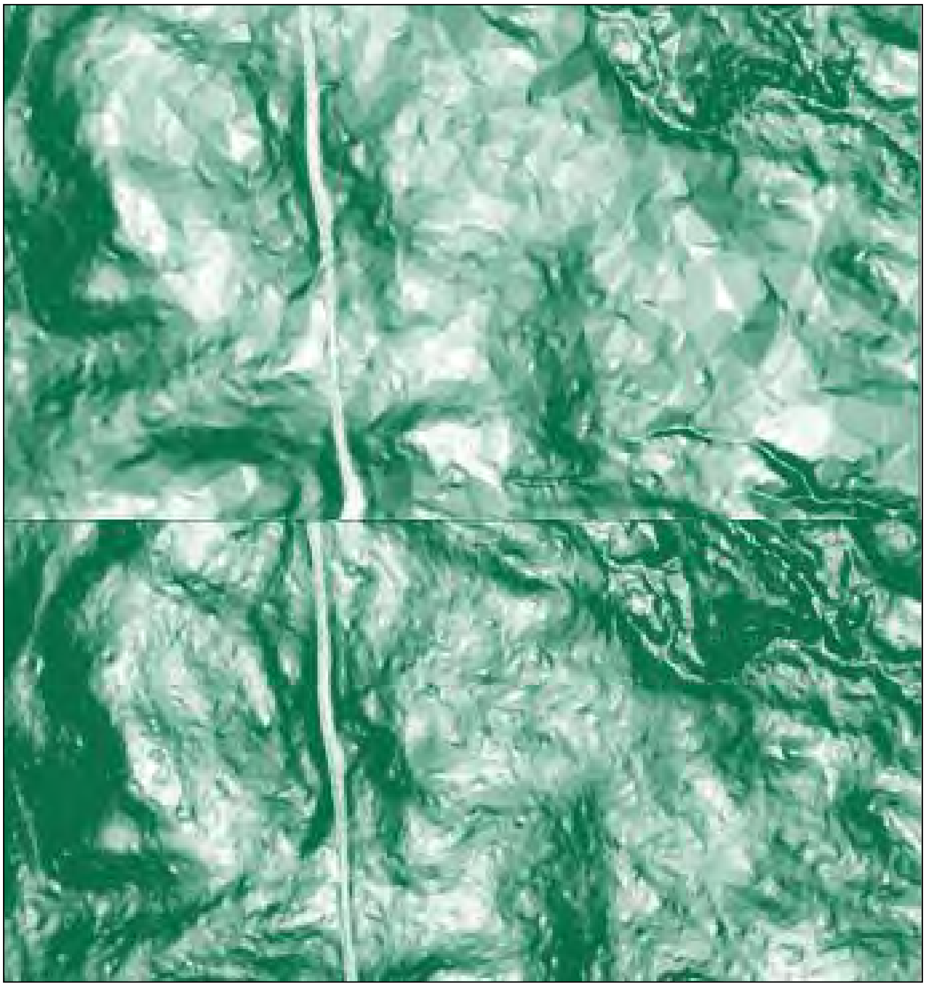


IMAGE COURTESY OF IAN MADIN, OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

Figure 1. Bare-earth images showing effects of pulse density in forested areas. Top, 2005 survey at ~2 pulses/m². "Crystal forest" is indicative of too-few ground returns. Bottom, 2007 survey of same area at ~8 pulses/m². Note North-South forest road for scale.

Ralph Haugerud is a research geologist with the U.S. Geological Survey, stationed at the University of Washington in Seattle. He can be reached at 206-553-5542 or rhaugerud@usgs.gov.

Developing a Stand-Level Inventory Using LIDAR

BY GEORGE McFADDEN

Remote-sensed data collected using Light Detection and Radar (LIDAR), when combined with additional data in a two-stage sampling procedure can provide stand-level inventory information with sampling errors that are equivalent to ground sampling techniques. The use of remote-sensed data has the potential to reduce field costs and quickly complete large inventory programs. These savings are possible because of the economies of scale that are achieved when computing capacity is substituted for labor costs.

The first stage in the two-stage process is to acquire the raw LIDAR data. Organizations such as the Puget Sound LIDAR consortium and the Oregon LIDAR consortium can assist in this process by coordinating the efforts of multiple landowners to acquire LIDAR data. The savings can be substantial between large and small projects.

LIDAR acquisition in the 5,700-acre Panther Creek watershed approached $5.00 per acre, whereas the cost of data acquisition in the 1,500,000-acre Coos Bay project coordinated by the Oregon LIDAR consortium is expected to be less than $0.70 per acre. In addition to coordinating large acquisition projects, the consortiums can establish technical specifications for resource-grade LIDAR acquisitions that will ensure the compatibility of current and future LIDAR collection projects.

Raw LIDAR data can be used to model the surface of the earth and individual tree canopies (ITC). The information from the bare-earth models can be used to produce several products, such as digital elevation models, without the need to acquire additional data. The ITC models can be used to locate individual tree canopies and estimate canopy height, area, shape and return intensity, but in order to produce a stand-level inventory, additional information is required.

The second stage of the data acquisition process involves acquiring information that can be used to identify tree species and to estimate individual tree diameters and the number of ITC polygons that contain more than one tree. The key to creating a stand-level inventory from LIDAR data is establishing an unbiased link between remotely sensed ITC data and ground measurements of identifiable trees. This link enables the integration of additional remote-sensed data and the establishment of a statistical correlation between the ITC data and ground measurements.

Digital color infrared (CIR) photography is used to identify the species of individual trees through a process that requires the digital CIR photography to be intersected with the ITC polygon layer. This produces a layer where the spectral characteristics of individual tree canopies can be identified and species identified based upon the spectral characteristics, provided there is a good match between the location of the ITC polygons and the CIR photography.

The correlation process to identify individual tree metrics requires the boundaries of individual stands in the inventory area be identified as well as stratifying the stands based upon their LIDAR derived metrics. A statistical analysis is conducted to determine the number of plots and stands where correlation plots are to be established. It is important that the ground measurements are accurate and unbiased at the stand level. This requires that the trees on the correlation plots be located with survey-level accuracy in order to achieve as near to a one-to-one relationship between the ITC location and the ground-based tree location. Tests of this process by ImageTree Corporation in the southeast United States have yielded root mean square errors for basal area and volume estimates at the stand level of 9.7 and 12.8 percent.

Once the correlation is established in the sample stands, this information along with the CIR photography and the ITC map is used to develop stand tables for all of the stands in the inventory project. If there is a good correlation between the modeled stand boundaries and the actual stand boundaries, then the stand table information derived from the remote sensed data is expected to be similar in accuracy to ground-based inventories.

The knowledge base necessary to complete stand level inventories using remote-sensed data is expanding. Several organizations are developing and validating the computer algorithms necessary to adapt this sampling process to the forests of the Pacific Northwest.

Developing a stand-level inventory using remote-sensed data is a computer-intense process. The raw LIDAR data for the Coos Bay project alone is expected to approach 2.5 terabytes. A limited number of organizations have the knowledge and computer capacity necessary to work with multi-terabyte files. The use of a computer-intensive inventory process to replace a labor-intensive process provides economies of scale that reduces the cost per acre for large inventory projects.

In the 5,700-acre Panther Creek, the cost for a stand-level inventory based upon remote sensing would approach $20.00 or more per acre. The Washington State DNR is currently completing a 200,000-acre inventory project using remote-sensed data and the cost is approximately $4.00 per acre, including the $1.50 per acre for acquisition of the raw LIDAR data.

The $4.00 per acre cost of remote-sensed inventories compares favorably with the $7.00 to $10.00 per acre that a typical ground-based inventory costs to complete. In the future, the cost of an inventory based upon remote-sensed data should decrease as computer processing and storage become cheaper and the algorithms necessary to produce the inventory become more refined. The cost of a ground-based inventory will likely increase in the future in relation to labor cost. The result is that stand-level inventories using remote-sensed data will become more cost competitive in the future.

The use of LIDAR as part of an inventory program will not completely replace the need for ground-based inventories. Stand cruises will still be necessary in small-scale projects, in high-value projects that require low standard errors, and in any stand type were LIDAR cannot produce equivalent estimate errors. ◆

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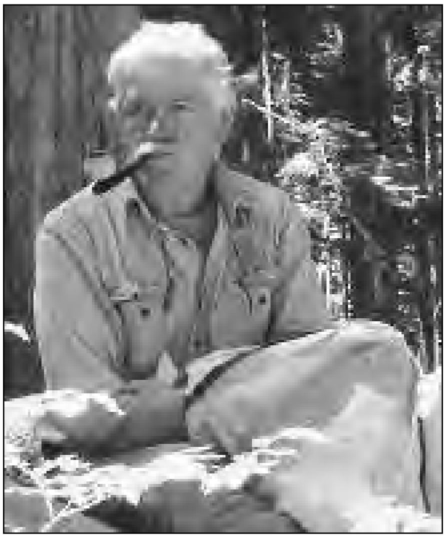
The Impact of LIDAR Technology on Transportation System Design: Moving from Coarse Topographic Maps to Detailed Digital Elevation Models

BY PETER SCHIESS

Recent advances in remote sensing and data collections are creating an environment where forest operation designs result in a high level of agreement between paper designs and



Peter Schiess

their corresponding field locations. In fact, we see a change in paradigm in that discrepancies between map-based locations and field-located conditions are not the result of poor map material, but rather a reflection of no longer appropriate (or needed) measuring and referencing procedures during the field verification process. This article discusses the impact of the increased quality of data collection on road and skyline profiles.

Maps have been one of the critical data requirements for forest engineering application, ranging from topographic to forest stand maps. In the past, ground-based and photogrammetric mapping has been the most cost effective way to build topographic and other maps of forested areas. At the turn of the last century, during the railroad logging days, the necessary detailed maps were created using staff compass and steel tapes. Those maps did have the necessary level of detail, usually with 0.5 meter contour interval, unencumbered by tree coverage. In later years, the advent of aerial photography led to the creation of photogrammetric maps. These maps provide good preliminary guidance for laying out roads and harvest units; unfortunately, the trees that draw us to these areas also obscure the underlying topography. In difficult topography, planned skyline profiles and road

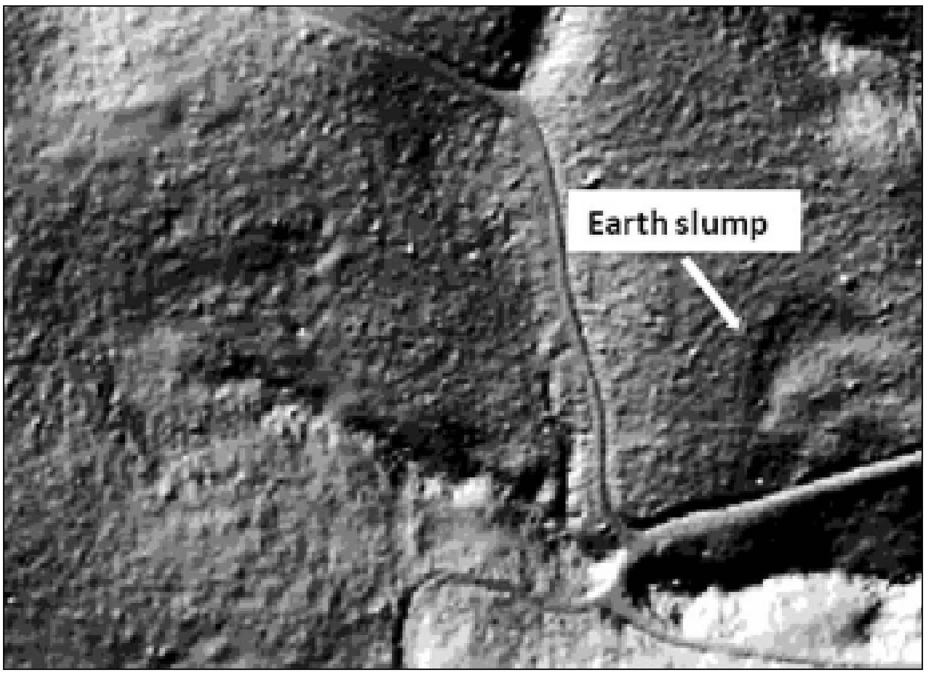


Figure 1. LIDAR topography provides detail from road beds, individual slash piles, ditches and earth slumps. Note the earth slump encroaching on an existing road with the headwall clearly noticeable. Walking the ground, field engineers were not even aware of the headwall.

alignments are frequently rendered unworkable by topographic “details” that are not represented in the photogrammetric topography that is used to plan them.

For that reason, forest engineers always emphasized the importance of field verification. Initial planning in the office was certainly recognized as important, but its primary function was to focus field reconnaissance. Field reconnaissance always has been time consuming and therefore expensive. Due to the often long “walk-in” times to get to the necessary planning locations, substantial time had to be allowed for, or limited field verification was done to stay “on budget.”

Recent technological advances led to a rapid spread in airborne laser altimetry (LIDAR) mapping of the earth’s surface. Just as in photogrammetry, forest canopies can intercept most of the laser pulses, but any stand in which sky can be seen from the ground will allow LIDAR penetration to the ground. Wherever the LIDAR pulse density can overcome canopy density, the resulting ground points can be interpolated into a topographic map.

The detail of the new LIDAR-generated maps can be seen in the computer-generated hill-shaded image (Figure 1). In addition to roads and streams, roadside ditches are clearly evident, as is a subtle earth slumping along the eastern edge. The minor mounds scattered across the area in the upper half of Figure 1 appear to correspond with stumps and slash piles. This new mapping shows considerable promise in a range of designs from skyline corridor profiles to road location and design activities.

Recent experiences with the use of LIDAR-generated maps as part of the University of Washington Forest Engineering (FE) Senior projects, in collaboration with Washington State Department of Natural Resources (DNR) has led to a significant shift in how to approach paper planning and subsequent field reconnaissance. As part of the planning for the Tahoma State Forest, the FE seniors developed LIDAR-based paper plans that were subsequently field verified. For a particular timber sale DNR had field-measured skyline profiles to assure

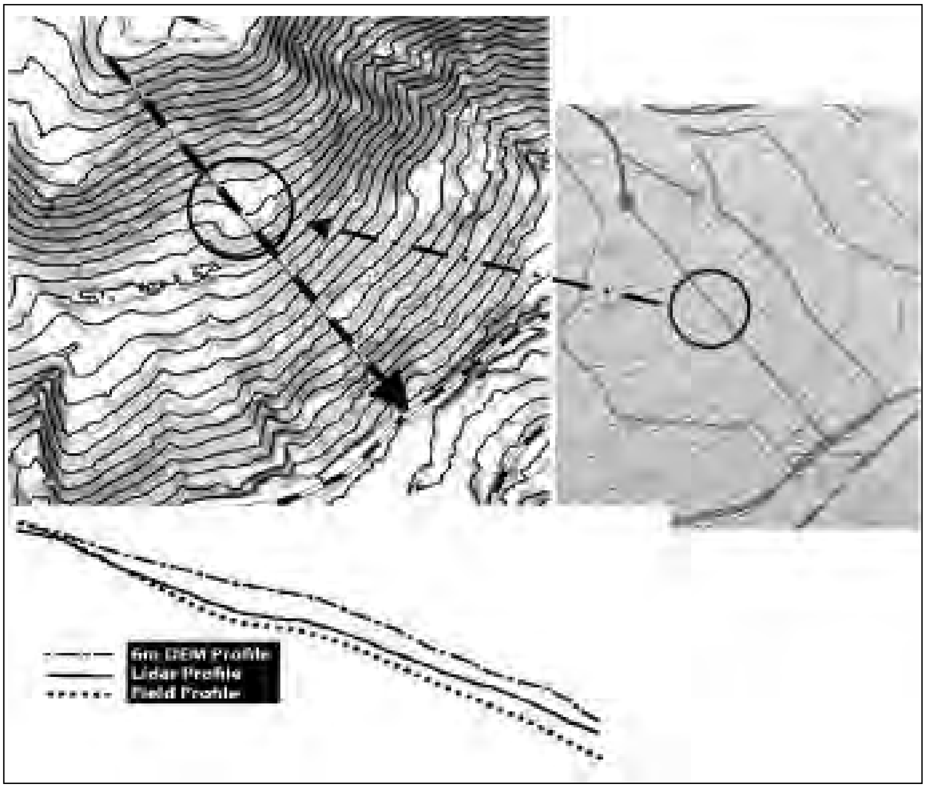


Figure 2. Shown are a LIDAR-generated contour map with a two-meter pixel size (left) and a photogrammetically-derived contour map (right, with a six-meter pixel size) showing a field-verified profile as well as profiles based on the DNR and LIDAR maps. The LIDAR map clearly identifies a bench (arrow) not shown by the DNR contour map. Also note the topographic detail of the LIDAR map elsewhere, which the DNR map does not display.

their technical feasibility. Field work took about a one-person-day given the difficulty of terrain, brush conditions, etc. The LIDAR maps provided a much more realistic assessment than the photogrammetically-derived map could (Figure 2). The LIDAR maps showed a much higher level of detail than the standard maps did. Not only that, but the LIDAR profile could be generated in less than five minutes, compared to the one-person-day to generate the field profile. The time savings are obvious.

It is speculated that the LIDAR profile provides the best approximation of true ground conditions given the precision of the field instruments used (clinometers, hand compass and string box). Other researchers established high correlations between LIDAR-derived topography and true topography based on terrestrial mapping.

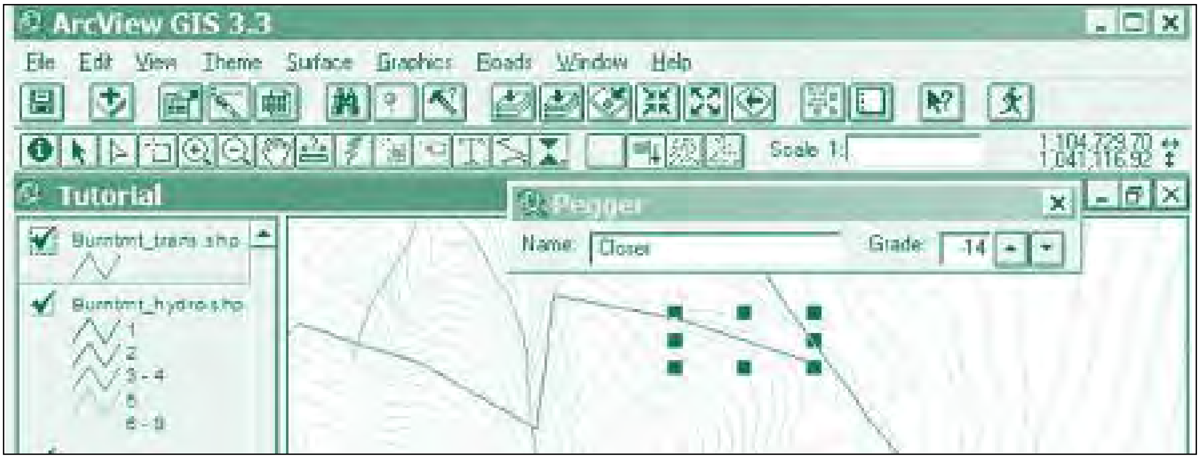


Figure 3. Locating a road with PEGGER. The tool allows for rapid road location on a digital map. LIDAR-derived maps now have such precision that map-located roads agree very well with subsequent field verification to the point that those map locations can almost be accepted as "field-verified." However, issues such as seepage and rock outcrops do not yet show up on these LIDAR maps, so some field verifications are still needed.

The nature of the map location (pegging) and grade-line location process is now beginning to change as well. Great emphasis can now be put on pegging roads on LIDAR-derived maps. A pegging tool that automates this process is available from the Rural Technology Initiative website (Figure 3, www.ruraltech.org/tools/pegger/). The pegged roads on digital LIDAR maps are the script, laid out in the office, and GPS units can be used to keep the road locators on track in the field ("following the script").

The purpose now is to "find the location on the ground" as predicted by the paper road location, rather than being guided by the simple field instruments such as cloth tape, hand compass and clinometers. Differences usually are due to the metrics used in the field for establishing grade lines. Those field instruments are far less sophisticated and less precise than the process of establishing a paper-map road from a LIDAR DEM (digital elevation model). The road location process is now moving from a field verification process to a "field tracking of map-derived (LIDAR DEMs) road locations," a basic change in road-location paradigm. Office-located roads can now be exported into RoadEng (a commercial forest road design package) for further evaluation of critical areas such as switchbacks or stream crossings (Figure 4).

LIDAR-derived maps with their high resolution also offer new ways to look at terrain features. Traditional maps utilize contour lines of varying equidistance, typically 20 feet for maps of

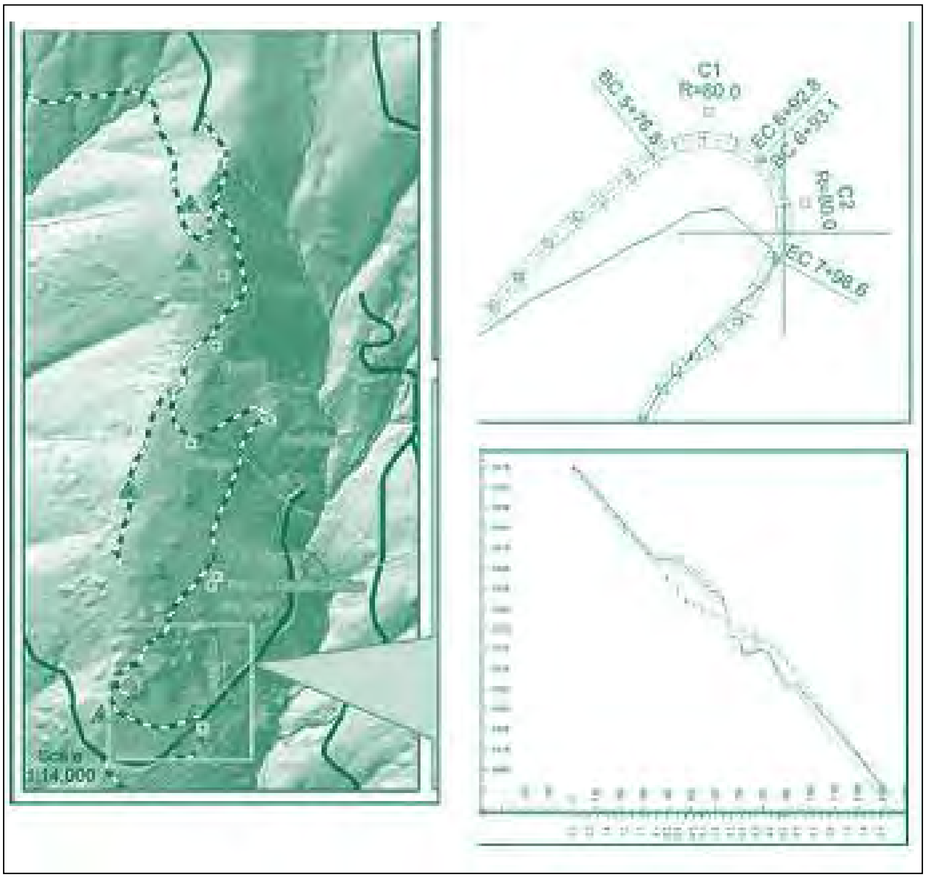


Figure 4. Road systems developed with PEGGER based on two-meter DEMs. On the left, the dashed line represents the pegged road. The circle with dot represent GPS location points collected in the field during the field reconnaissance phase. The triangles are proposed landings. The underlying DEM has a grid spacing of two meters. The enlarged area shows a plan and profile view of a critical switchback road location, initially pegged with PEGGER and further evaluated by exporting the data into RoadEng for additional evaluation, work all done in the office.

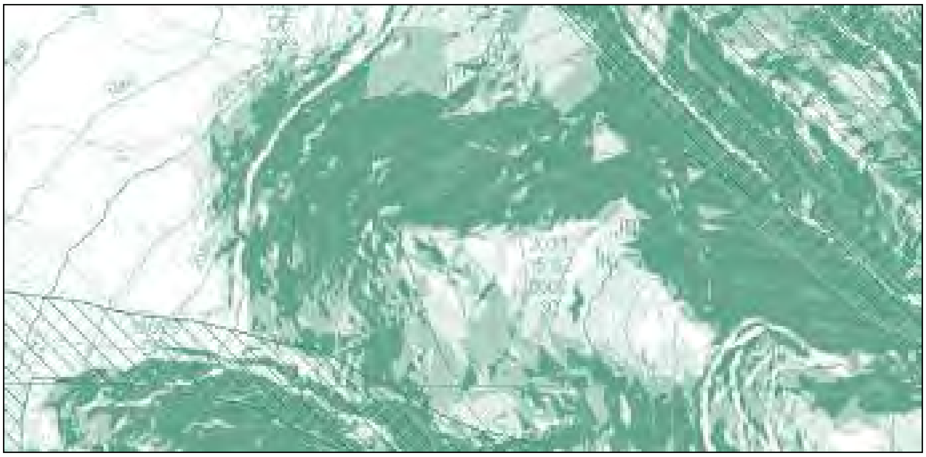


Figure 5. Slope class map derived from LIDAR DEM with two-meter grid spacing. Slope classes are in varying shades of green, the darker the steeper. Slope class depiction provides much more detail about critical terrain features than contour lines would. For example, small areas of gentle terrain (colored white or light green) within larger areas of steeper slope classes (dark green) are clearly shown. Note old skid trail locations in the lower right and roads in the left upper half.

1:4800 scale ratios. Students commented that the slope class maps provided a much better assessment of locating oneself in the field as well as finding critical topographic features such as benches, appropriate areas for switchback locations and more with LIDAR-derived maps than traditional contour maps could provide (Figure 5).

A question that still has to be answered conclusively is: Are road design data derived from LIDAR maps as reliable as road data customarily traversed in the field? Many have suggested that a LIDAR map cell size of between 1.0 and 3.0 meters is sufficient for operational route location. Extracting road design data from LIDAR maps appears feasible when considering that for forest roads, construction tolerances quite often are in the same range.

Cross section data collected from a traverse were compared with cross sections derived from LIDAR DEMs collected with typical forestry survey equipment (Figure 6). The traverse field data collected with staff compass and Laser Impulse instrument for distances and slopes were superimposed over the LIDAR DEM and the corresponding cross section extracted and compared with the cross section data collected in the field (Figure 6).

From experience, the author will accept the cross section data from LIDAR DEMs as comparable to field measurements where side shots are customarily collected with hand-held clinometers and cloth tape. In fact, it appears that LIDAR-derived cross section data are of equal if not better quality, and may provide more detail than typically recorded in the field.

It appears that we can indeed carry out a full road design based on LIDAR topography without going to the field. The issue now becomes one of being able to find and stake the coordinate value of the centerline on the ground. Currently, investigations are on-going to answer this question. Typical Global Positioning Systems (GPS) units have been unreliable, with an absolute error in the one- to five-meter range under dense canopy. So our gains of better topographic data are currently negated by our inability to accurately locate a map-derived point (coordinate) on the ground. We currently are testing some new technologies that hopefully will overcome this hurdle. ◆

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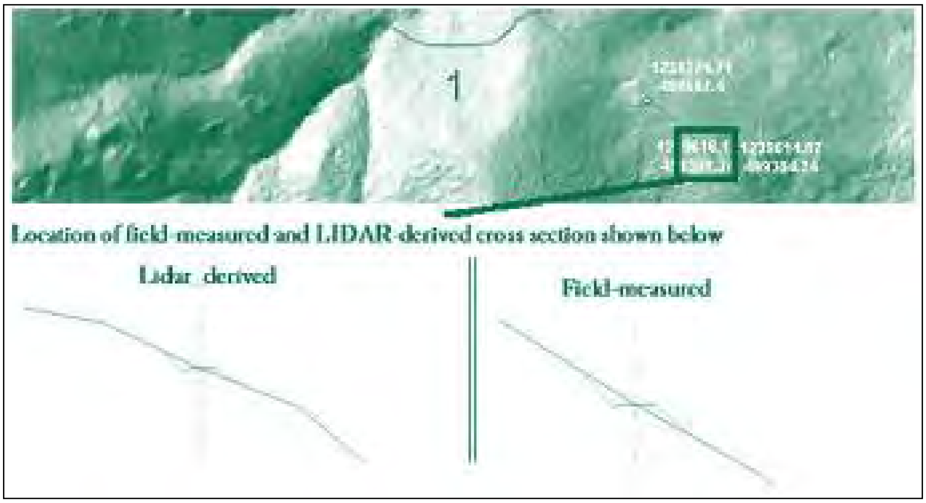

Figure 6. Road traverse superimposed on LIDAR DEM with cross section location shown. The small dots are GPS coordinates to geo-reference the field traverse. Both sets identify the slope break below the center-line stake. However, the field crew only took one "side shot" or measurement upslope from the traverse point. The LIDAR-derived cross section reveals a break above the traverse point.