# THE ALLURE AND PITFALLS OF USING LIDAR TOPOGRAPHY IN HARVEST AND ROAD DESIGN

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## ABSTRACT

Airborne laser altimetry (Lidar) can produce topographic maps of amazing detail and accuracy, even where the ground is obscured by forest canopy. Detailed Lidar topography can identify possible landing locations, difficult stream crossings, unstable soils, difficult side-slopes, and useful benches. This detail can reduce field time, guide road designs towards better options, and improve confidence in our cost estimates. Lidar mapping can occasionally fail however, and how these failures are represented will determine Lidar's reliability and value for road design. We discuss first experiences with an operational Lidar mapping of the Tahoma State Forest, south of Mt. Rainier. This detailed topographic mapping was used in forest operations design such as landing and road locations as part of a watershed-based harvest and transportation plan. Lidar-based in-office designs were subsequently field-verified. Critical to the success of such DEM's for forest engineering design was the ability (or lack thereof) to distinguish between areas of adequate or marginal ground point coverage leading to excellent or erroneous mapping detail. We discuss various methodologies that would identify areas of marginal Lidar ground point coverage leading to a first set of Lidar data collection requirements mapping contractors should adhere to.

## SEEING UNDER THE CANOPY

A recurring problem in timber harvest and road planning is that the trees that intended for harvest can hide the ground over which logs must be yarded and roads must be built. The topographic maps that are commonly used in planning are based on aerial photographs in which the stands that we now want to harvest have obscured the ground over which we must plan. The resulting topography is thus a map of the top canopy, with an offset for the assumed tree height. Unfortunately, the canopy does not follow the ground exactly, and the minor topographic variations that can be crucial in harvest and road planning are not reflected in the top of the resulting canopy. The topography often includes areas of soil instability, rock outcrops, and uneven topography that can present difficulties in harvest and roading. The canopy can also obscure natural mounds and benches that can serve as convenient landing and road locations. As a result, these topographic maps can only serve as a general guide for design, and critical elements of the operation will need to be based on field verification.

Recent developments in airborne laser topographic scanning (Lidar) allow for detailed topographic mapping even under forest canopy. Lidar works by shooting millions of laser range-finding pulses (Figure 1) from an aircraft whose location is precisely determined by global positioning satellite and inertial navigation. In unforested regions the resulting points can be converted directly into a topographic map, using methods and software well developed for surveying (Haugerud and Harding, 2001). In forested areas, most of the laser pulses will be intercepted by the forest canopy, but if these can be identified and removed, the few that penetrate the canopy can be used to map the forest floor. The processes by which these ground points are identified and turned into a map determine the nature of the resulting map, and its utility in harvest and road design.

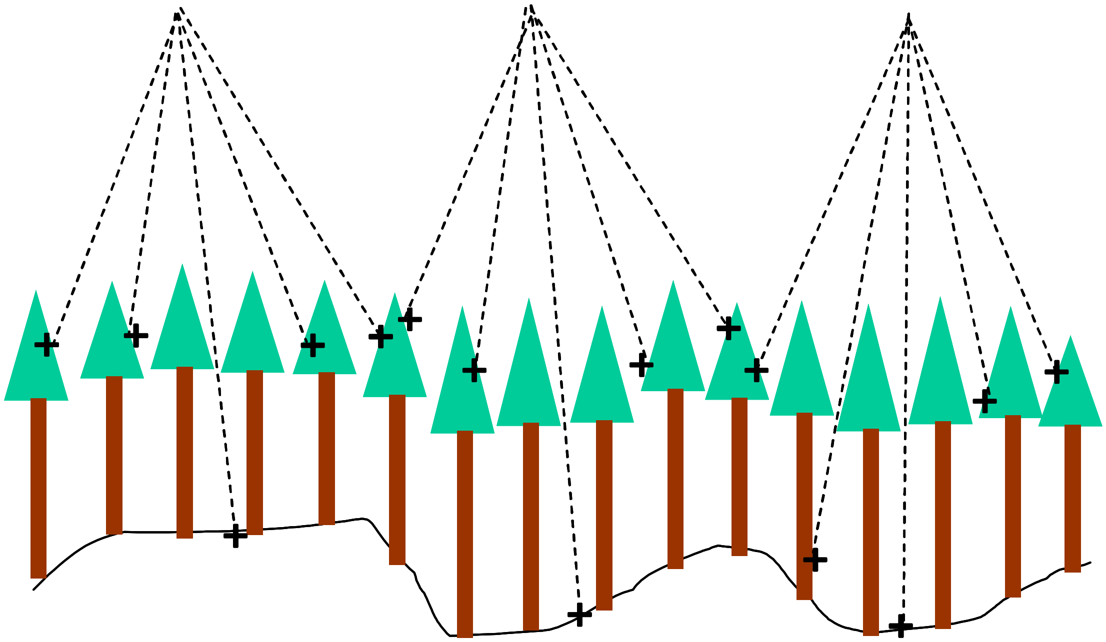

Figure 1: Lidar maps the ground topography through forest canopy by shooting millions of laser pulses at the ground, identifying the returns that are on the ground, and interpolating between them.

## TOPOGRAPHIC DETAIL

Another benefit of this automation in data collection and map generation is that it allows a previously unattainable level of detail. Both surveying and photogrammetric mapping required extensive human labor, making it costly to map at a high level of detail. Lidar mapping, being highly automated, can shoot many laser pulses a second. A high pulse density is needed in stands with a dense canopy to guarantee that some Lidar pulses will reach the ground. In stands with a lower crown density however, this point density allows an amazing level of detail.

This detail can be seen in the computer generated hillshaded image (Figure 2). 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 appear to correspond with stumps and slash piles.

Lidar's ability to 'see through' the canopy is demonstrated by the fact that the upper right portion has been clearcut, while the rest is covered by a dense Western Washington conifer stand. The topography in the clearcut area is more realistic and believable than in the rest of the image, but even this less realistic looking topography in the forested portion however provides confidence that it approximates the true ground surface, and can reliably be used in harvest and road planning.

Figure 2: Lidar topography provides great detail, including streams, roads, ditches and slash piles. The upper right portion of the image has been harvested, while the rest is dense mature second growth.

## LIDAR IN ROAD AND HARVEST DESIGN

One of the issues/problems for forest engineers in designing transportation systems (roads, harvest units, landing locations) has been the quality of maps that is, the lack of necessary details to carry out adequate or appropriate design. Forest engineers, for that reason 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, identifying the critical areas for field verification. Field reconnaissance always has been time consuming and therefore expensive. Due to the often times long 'walk-in' times to get to the necessary planning locations substantial times had to be allowed for, or limited field verification was done to stay "on budget".

This issue has also been one of the reason why some land owners like the Washington State Department of Natural Resources (DNR) invested in additional mapping resources to have better planning tools than the standard USGS 7.5’ DEM. Carson and Reutebuch (1997) showed the limits of planning for cable yarding using USGS DEM’s. DNR developed their own mapping products from aerial stereo photos, usually from a 1:12,000 scale and then remapped at 1:4800. Those maps were a significant improvement over the USGS mapping product, particularly for road location and skyline cable profile analysis (Schiess, 1999; Schiess and Rogers, 2000; Schiess and Arntzen, 2001). Field reconnaissance still was required, although uncertainties of initial paper road locations and landing locations based on cable profile analysis could be reduced (but not eliminated).

Recent experiences with the use of Lidar-generated maps as part of the University of Washington Forest Engineering (FE) Senior projects in collaboration with 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 Forests the FE seniors developed paper plans with resulting field work. DNR had one timber sale designed with corresponding field work such as field-verified skyline profiles (despite the availability of 1:4800 DEM’) to assure the technical feasibility (Figure 3).

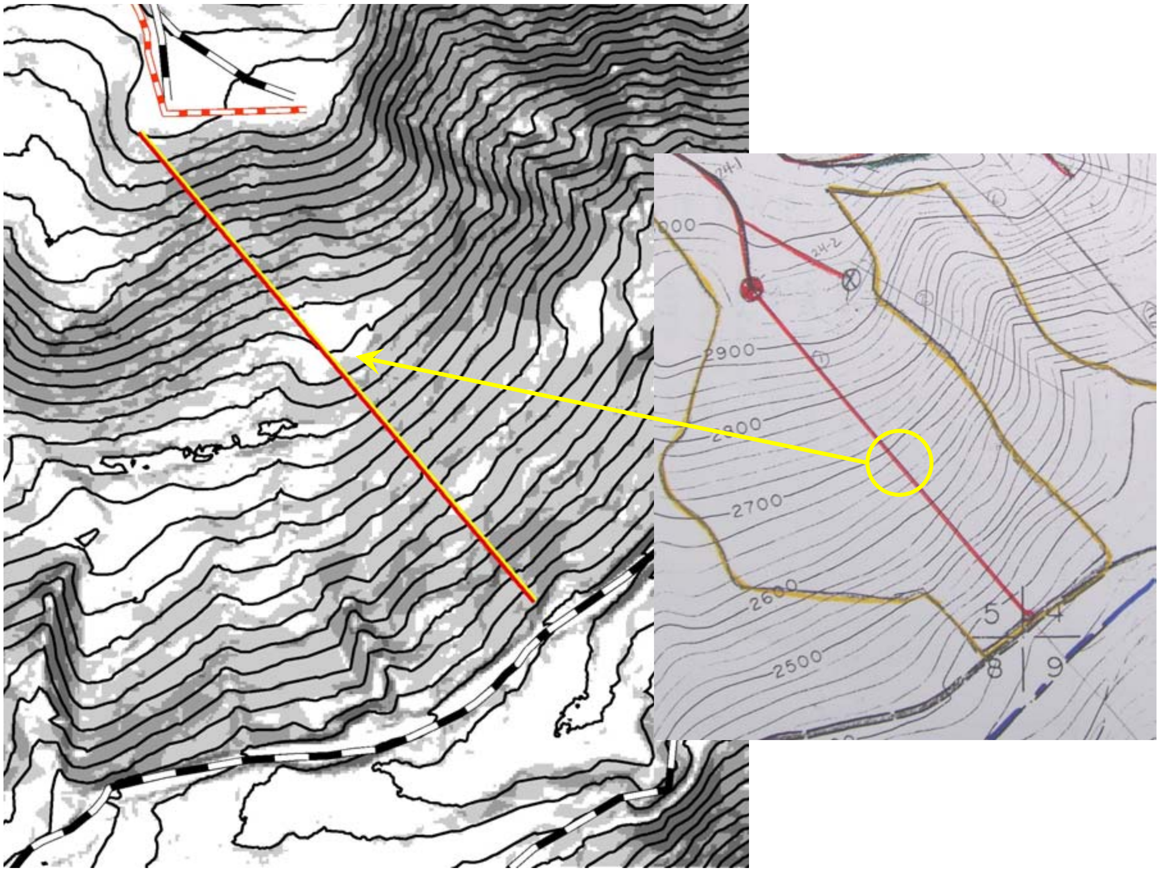

Figure 3: A Lidar-generated contour map (left) and a standard DNR 1:4800 contour map (right) with a field-verified profile marked (Figure 4). The Lidar map clearly identifies a

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

Field work required to acquire the profile data amounted to 5 person-days given the difficulty of terrain, brush conditions, etc. (personal communications Keith Yonaka, Regions Engineer, South Puget Sound, DNR). We had some difficulties in establishing the correct beginning and ending points of the field profile and mapping those corresponding start and end points on the maps (Figure 4).  They explain the differences in starting elevations between the Lidar/1:4800 paper map and the field profile (Lidar and DNR map have the same beginning elevation).  In any case, the trends of the field profile and Lidar profile are almost identical.  Both profiles clearly identify a bench, missed by the DNR 1:4800 map.  We also note that the ending elevations of the field and Lidar profile do not agree.  (nor do Lidar and DNR map profile ending points).

We speculate that the Lidar profile provides the best approximation of true ground conditions given the precision of the instruments used (clinometer, hand-compass, string-box).  Other researchers established high correlations between Lidar–derived topography and true topography based on terrestrial mapping (Reutebuch et al., 2003).  The Lidar profile could be generated in something like 5 minutes, compared to the 5 person day to generate the field profile.

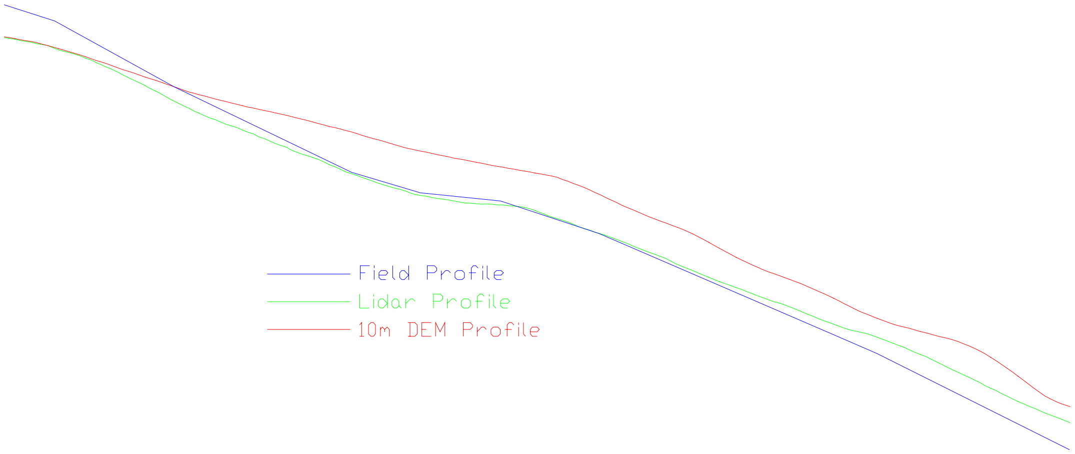

Figure 4:  Skyline profiles from 1:4800 map (top), Lidar-generated profile and field data profile (both bottom). The Lidar profile

Traditionally, field data, generated with typical instruments of the trade (hand compass, clinometer, string box/cloth tape) are better than data derived from the standard 1:4800 maps and certainly superior to the 1:24,000 USGS maps.  However, when we compare those traditional field-generated data with Lidar maps we conclude that we may actually derive the same if not more reliable information from the Lidar maps in the office than field-derived measurements.

This point was also demonstrated with extensive road locations, where roads were initially pegged in on Lidar –derived contour maps. Resulting field verification ("running grade line") typically resulted in very high agreement between map-derived roads and field verified roads. For example, critical areas such as switch back locations or stream crossings could be identified on the map (using desirable terrain features) and indeed be found on the "ground" (Figure 5). Where Lidar-map road locations and field-verified road location did differ was usually the result of not being able to follow the exact locations/dimensions as derived in the office due to the inaccuracies of the field measuring tools.

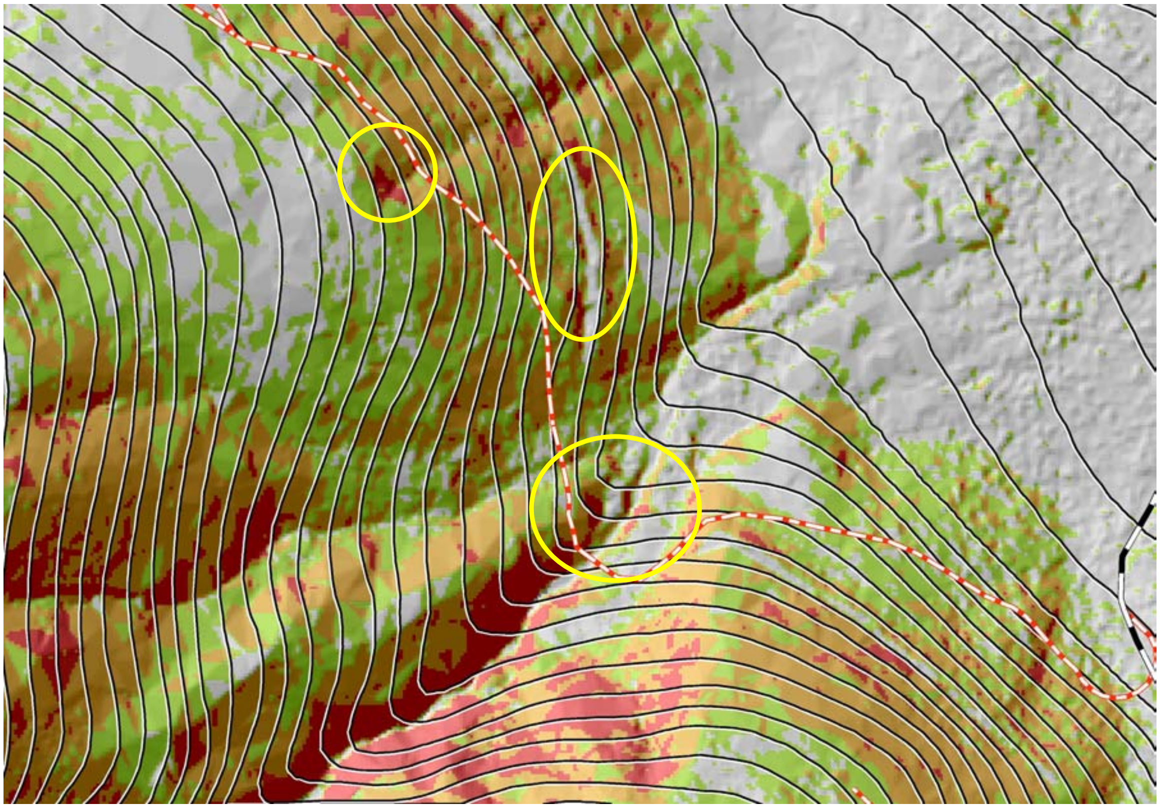

Figure 5: Photogrammetric contour lines overlain on slope classes. Contour interval is 20 ft. The underlying DEM is based on a 6 ft grid cell. Slope classes are a much better indicator of terrain features than contours alone. Note the old railroad grade (upper center and lower-right quadrant) displayed by the slope class coloring. The contours do not identify such features. Also note the headwall features displayed by slope- class coloring and missed by the contour lines. The detailed terrain features of Lidar-based DEM's can be much better displayed using slope-class coloring and shading than by traditional contours.

Another aspect relates to map representation. Typically during the field reconnaissance standard contour maps would be used, possibly with slope classes colored in. The topographic detail afforded by Lidar maps can be fully exploited by creating slope-class maps. In our experience we started to rely much more on slope-class colored maps then contours (Schiess and Tryall, 2003). They provided a much better representation of terrain features than even Lidar-derived contours could provide (Figure 5). Contours were relegated to establishing elevation but no longer as a guide to terrain shape or steepness. That information was much better transmitted visually by the slope class-colored maps then the contours.

We believe that Lidar derived maps are changing the paradigm on how we approach initial paper planning and subsequent fieldwork. In the past, paper maps were a means to establish broad design outlines, but always required intensive field verification. With the improved precision of DEM's we may actually start to think in terms of giving preference to map-derived designs. The issue in the field moves to the question "are we in the correct location (x/y)?" and as we proceed, "do our measurements indeed correspond to the detail provided by the Lidar maps?"

## PITFALLS

For all of its obvious advantages, Lidar topography does have some drawbacks when used in harvest and road planning. Some problems (subsurface and canopy issues) exist already in photogrammetric mapping technology. Lidar however can introduce new problems into road and harvest design if it suggests alevel of detail that is not maintained across the topography.

Even with existing mapping, seeing the ground topography is not the same as seeing the ground itself. There are lots of subsurface issues that are often not represented in the topography. Local soils and saturation can be crucial in road construction but are not topographic in nature. That is not to say that subsurface conditions are not represented in the topography. Where saturation and unstable soil combine to cause earth slumping, even small displacements can be observed in surface topography as shown in Figure 2. Lidar maps, which display microtopography on either side of the design path, can thus suggest problems that would not have been identified by field investigation. In such cases, Lidar topography could prove superior to field investigation.

As with existing technology, even Lidar can sometimes have problems 'seeing' the ground. Even with millions of laser pulses, it is common to find areas with few or no ground returns. It should come as no surprise that these areas with few ground returns tend to be in areas of dense canopy (Figure 6). If it is difficult to see the sky from the ground, then it will be equally difficult for a laser pulse to penetrate to the ground. Not surprisingly, it is the young dense stands that tend to produce these areas of poor canopy penetration.

Unlike existing aerial photographs and photogrammetric mapping, Lidar mapping does not necessarily show the areas where it was unable to see the ground. In a photograph, when the ground is obscured by a cloud or a tree canopy, you see the cloud or canopy. However, when Lidar is unable to penetrate to the ground, there may be nothing that says that it didn't. As discussed above, Lidar maps are created by filtering out the laser pulses that were intercepted by the canopy, and entering the remaining ground returns into existing interpolation software. The problem with this approach is that if there are no returns in an area, the ground surface in that area is just interpolated as a plane between the surrounding ground points. These interpolated smooth areas can be particularly dangerous in road and harvest planning precisely because Lidar topography can be useful in identifying these areas of smooth topography that are the most important for road building and harvest (Figure 7).

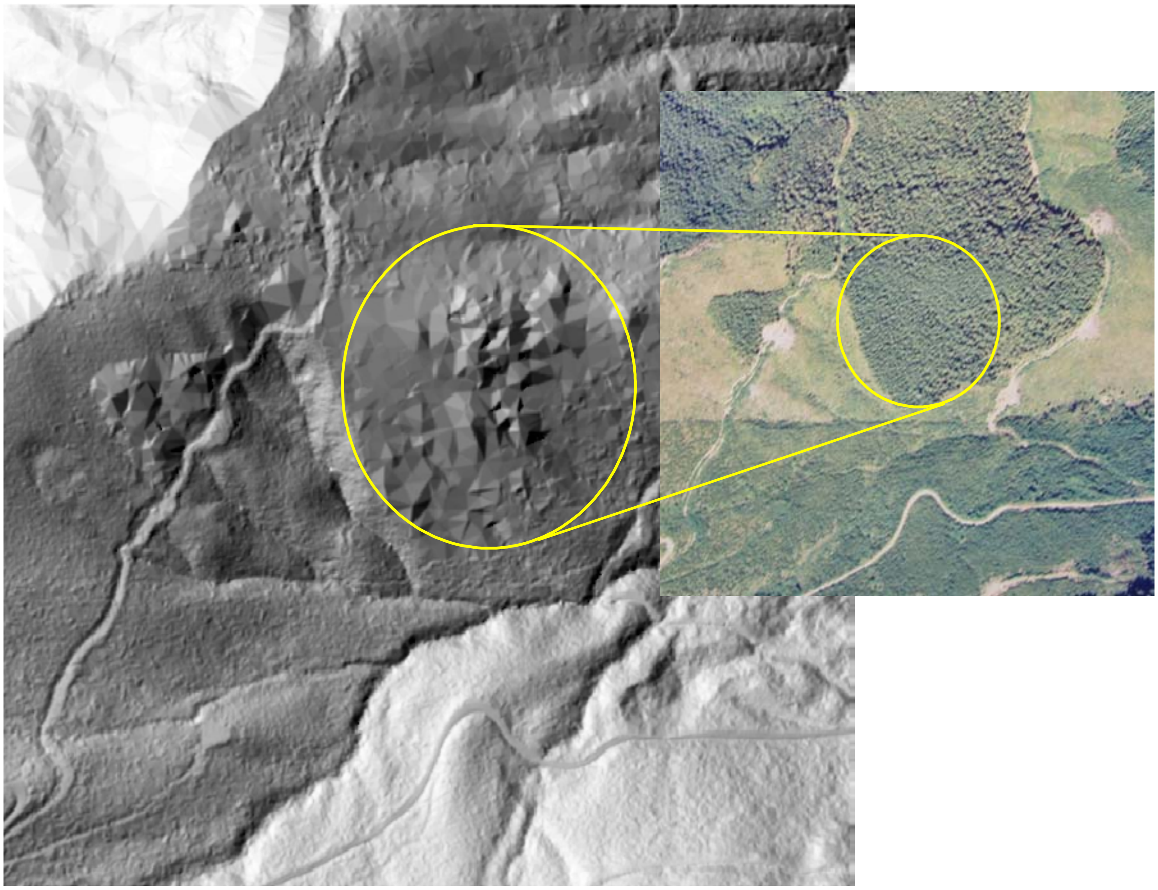

Figure 6: Lidar topography can produce good ground topography in clearcuts and mature stands, but produces poor topography in young dense stands where light (and laser pulses) can't reach the ground.

The high topographic detail in most of the map can then lead to a false confidence that we do not have with existing mapping. With existing technology, we do not expect to be able to 'see' the ground. Photogrammetric maps are generally known to represent the top of the canopy rather than the ground surface. In aerial photographs, the ground that has no tree cover can thus be seen, and in the areas that are covered with trees, the trees are seen and the engineer knows that a field investigation will be required in any areas of design interest.

## DISCUSSION

There are several possible approaches to solving this false confidence problem. The simplest approach is to shoot a higher density of Lidar pulses so as to increase the probability that some will actually penetrate to the ground. This can be accomplished by multiple aircraft flights over a given area. Unfortunately, this is also the most costly solution, since more flights requires more man-hours, aircraft time, and computation on the resulting data. And unfortunately, even a very high pulse density still does not guarantee that there will be no areas of poor Lidar penetration.

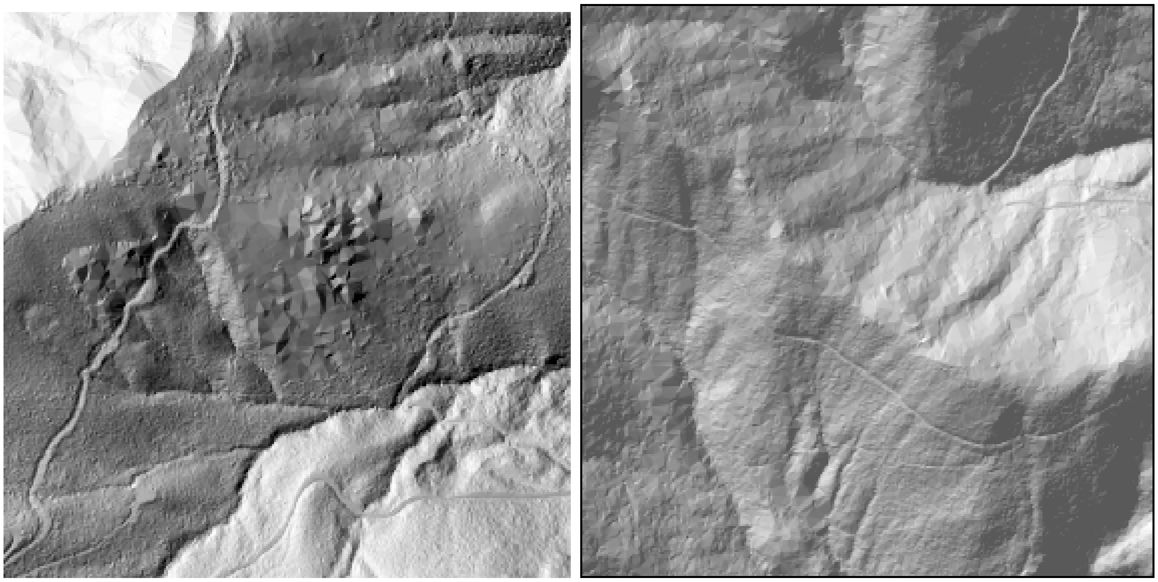

Figure 7: Two kinds of Lidar mapping error. Not filtering enough of the tree-intercepted Lidar returns produces topography (left) that is obviously incorrect. Filtering tree-intercepted returns too aggressively can eliminate real topography such as the large rock outcrops along the ridgeline (right) that were only identified by field investigation.

This process might be made more efficient by focusing extra Lidar pulsed on the areas of poor canopy penetration. These areas can be identified by trough standard data processing, and these particular areas could then be re-flown. This approach would be costly however. An alternate approach would be to use our understanding of forestry to identify likely problem areas before the area is flown. Since Lidar penetration is a function of canopy density, the more sky that can be seen from below the canopy, the more Lidar points will penetrate to ground, and the better the resulting ground topography. Since the quality of Lidar topography will vary with stand age and site potential, just about any forest professional will be able to identify these likely problem areas.

The most cost effective solution to this false confidence problem might be to ask Lidar map makers to identify the areas of minimal canopy penetration in the maps that they provide. This can be done by leaving these areas blank, or by not filtering the suspected non-ground points so vigorously and producing topography that looks silly (Figure 7).

Unfortunately, nobody likes incomplete or silly looking mapping. Clients don't like to pay for it. Providers don't like to provide it. But data gaps are a fact of life, and we need to figure out how to deal with them. If silly or incomplete topography help to avoid over-confidence and costly design errors, then we will just have to get used to them.

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