Alaska Department of Transportation & Public Facilities

LiDAR Testing Under Heavy Tree Canopy and in Steep Terrain

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Abstract

The objective of this project was to evaluate the accuracy of light detection and ranging (LiDAR) for topographic information in support of a transportation project for the Alaska Department of Transportation & Public Facilities (Department). In particular, accuracy in steep terrain and varied vegetative cover was evaluated. LiDAR acquisitions in Southeast Alaska were compared to RTK GPS survey acquisition. Comparison of the LiDAR to ground survey showed significant differences for the Ketchikan to Shelter Cove project evaluated, this may be due to vertical datum issues, improper geoid model selection, post-processing methods that were not sensitive enough, inaccurate GPS readings, improperly located GPS base stations, calibration report inaccuracy, and extremely thick vegetation canopy. By comparison, areas with less steep terrain, less dense vegetation, and better controlled LiDAR compared more favorably to the ground survey points.

Statement of Problem

LiDAR can be an extremely accurate mapping method when the surface being measured is unobstructed. However, when foliage and trees are a factor, obstructing direct light contact with the surface intended to be mapped, the vertical accuracy of the measurements degrade despite techniques to "filter out" and correct for the obstructions. Vertical accuracy of LiDAR data is generally twice as good as the horizontal accuracy, so steep terrain also adversely affects the accuracy of the data. LiDAR has not, however, been thoroughly tested in the dense vegetation and extreme terrain of southeast Alaska.

Problem Background

We need to analyze the quality of LiDAR data collected in Alaska. The data at Alaska's northern location can be affected by poor geoid definitions, solar weather, and poor satellite geometry. The better the initial topographic data, the more defined and thorough the design of a preliminary route will be, allowing for alignment changes, bridge site location adjustments, computing cut and fill quantities and catch points, determination of soil types and determination of areas of clearing and grubbing. Better initial topographic data means fewer requirements of follow-up field surveys that would equate to repeated mobilization costs, travel time, per diem compensation and expenses. In addition, this project has the potential to identify areas of good LiDAR coverage versus those of poor coverage. This in turn will aid in our confidence level in the LiDAR mapping product, resulting in maximum usage of this economical and effective survey method.

Objectives and Scope of Work

The objective of this research project is to determine LiDAR accuracy in a variety of terrain and vegetative canopy. As LiDAR is becoming more mainstream in today's large scale mapping efforts, it is important for the department to know what kind of accuracies can be expected in varying terrain and vegetation.

Disparity between LiDAR data and actual, "real" ground elevations can be checked, correlated and adjusted by means of "ground truthing," where a land survey field crew conducts topographic mapping of the ground using conventional survey tools (theodolite) or global positioning system (GPS) measuring units. These ground measured points can be compared to the LiDAR derived elevations to build a statistical model of the comparison of the two. This statistical model can then be used to evaluate the LiDAR mapping product in relationship to National Map Accuracy Standards. This standard states that 90% of all check shots must fall within one half the contour interval of the product. Typical LiDAR contour interval is 2 feet, so our test would evaluate if 90% of ground measured check shots fall with 1 foot of the LiDAR derived elevation.

The department proposes allocating a three person survey crew for ten days of data collection on the project site during the spring of 2009. Following the data collection effort, comparisons of LiDAR elevations versus ground surveyed elevations will be logged to a spreadsheet for statistical analysis. A report will follow describing the accuracy of the data in relation to National Map Accuracy Standards, as well as performance of the product in differing areas of tree cover and steepness.

Several ground-reference control points have already been established as photopanels along the project's corridor. These points have been measured using survey-grade GPS units, processed as static data through Leica Geomatics Office, and thus have very accurate coordinates and elevations assigned to them. The field crew will use these points as reference (base) for conducting further GPS Real Time Kinematic (RTK) mapping of the surrounding terrain, or measure directly from the control points using conventional survey theodolites. Where additional control is needed, the crew will establish permanent points similar to those already in existence.

Ideally, GPS control pairs will be established in open terrain and conventional theodolites employed from there. To fully evaluate the project area a random traverse into vegetation and up steeper terrain will be conducted while simultaneously collecting random topo shots from each set up. These traverses will close back to the original GPS control pair and adjusted to minimize accumulated error in the traverse. In addition to collecting topographic shots for comparison, the field crew will characterize both the terrain and vegetation cover for the particular series of shots. Terrain will be rated on a scale of 3. A 1 representing flat and uniform, a 2 would indicate moderately steep and or inconsistent, and a 3 would be indicative of very steep terrain. Likewise, vegetation cover will be described on a similar scale where 1 represents open and unobstructed cover. A 2 would describe mixed forest containing some deciduous trees. A 3 would indicate very large trees with a very dense canopy. Understory will be noted as well for it's type, height, and density. The goal here is to collect as much data as possible in the allotted time, and in a wide variety of conditions. Every effort will be made to collect similar amounts of data in each of the distinct types of terrain and vegetation in order to limit any statistical bias.

Previous Ground Truthing

The Juneau Access project was the Department's first experience with LiDAR data. Aeromap US (now Aerometric, Inc.) flew the project in late 2002 with a 25 kHz Optech 2025 LiDAR acquisition system. By late 2004 our survey crews had performed topographic mapping at over 30 sites for bridges or other structures thereby giving us ample ground points to compare with the LiDAR. Using the brute force method of comparison, an intern used Land Development Desktop with a LiDAR terrain model active while hovering over survey points. The intern then logged both the survey point elevation and the LiDAR surface elevation to a spreadsheet for statistical analysis. The sample set contained 1,090 conventionally surveyed points compared to the LiDAR surface model. See Figure 1.

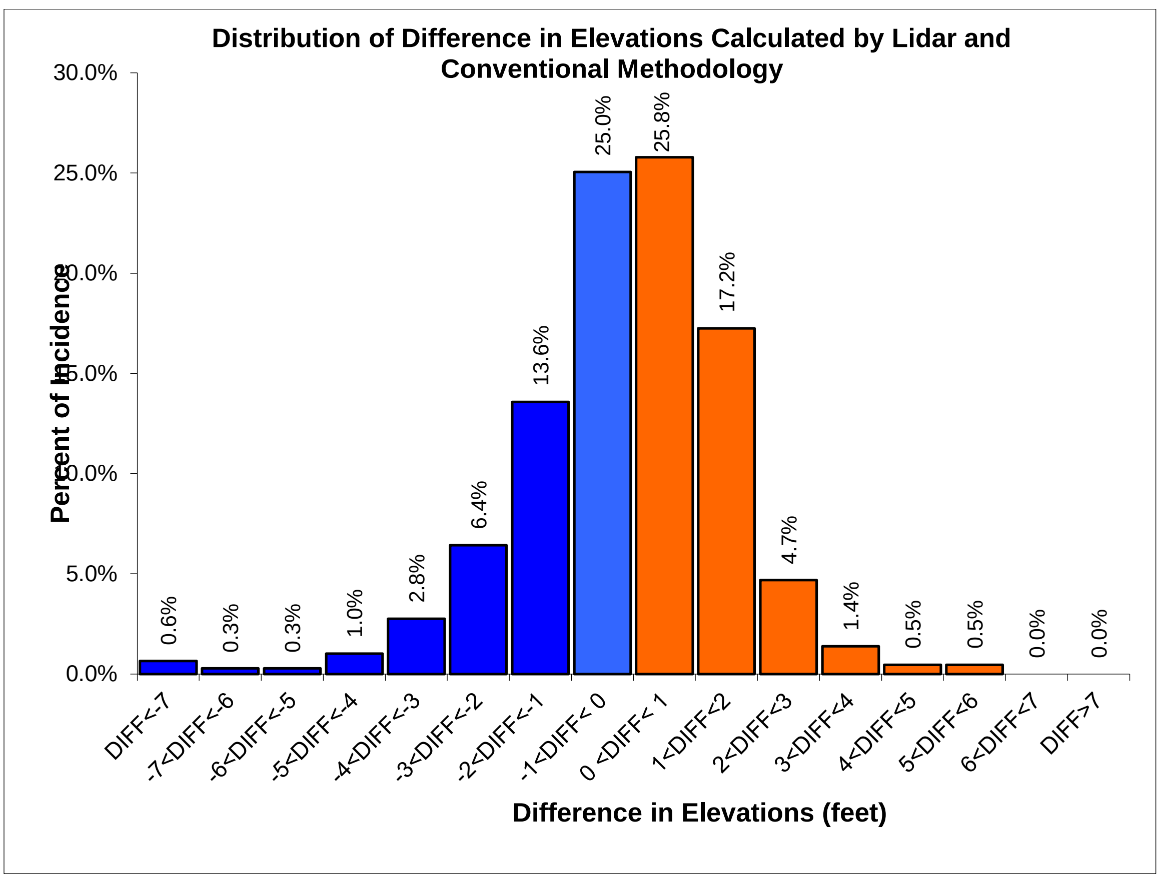

Figure 1. Percent of incidence for difference (DIFF) between elevations surveyed conventionally and using LiDAR. Elevation points were measured conventionally at several locations along the Juneau Access alignment (Proj. #71100). The elevation at each point was subtracted from the corresponding LiDAR elevation at the same point.

The difference in elevation between the two data sets (conventional and LiDAR) was tabulated into sixteen categories and the Percent of Incidence was calculated by dividing the number of sampled points in each category by the total sample (n=1090). 81.6% of the points were within the target range of + - 2 feet. The LiDAR elevations were higher than the conventional elevations 50% of the time and lower than the conventional elevations 50% of the time, however the histogram is skewed slightly to the left (i.e. LiDAR elevations slightly lower than conventional).

The majority of these survey points were stream site surveys located in steep terrain characterized by deep gorges and valleys. Vegetation was moderately tall and somewhat thick, typical of Northern Lynn Canal. It should be noted that timber in this region has very little marketable value due to high winds and salt spray creating scrubby and somewhat scraggly trees. Because this sample data set was biased towards steeper terrain the results are not completely indicative of the project as a whole. One of the 30 sites was makedly different and of the 145 survey points that came from the area known as "Antler Flats" 96.6% of these shots fell within the +/- 2 foot target range. Antler Flats is located in a very flat area between the Antler River and the Lace River in Berners Bay. Aside from being flat, the area is mostly covered in cotton wood and alder trees that were in leaf-off condition at the time of LiDAR acquisition. The graph in Figure 1 illustrates that a large percentage of ground surveyed points agree well with the LiDAR produced elevations. The graph also shows good symmetry in that roughly half of the time the LiDAR elevations were low while half the time they were high.

The second project that the Department had employed LiDAR on was the Hoonah to Tenakee corridor study. The project was to connect existing logging roads with a four mile extension to connect the two towns. In late 2007, prior to the LiDAR being flown, the survey crew ran a traverse from GPS control on the Hoonah side to GPS control on the Tenakee side. During the traverse they conducted topographic mapping of an approximately 200' wide corridor. Aerometric flew this project November 7, 2007 with their Optech Gemini LiDAR system operating at 100 kHz. This particular project area was generally flat with some rolling hills and small drainages. Vegetation consisted of some stands of timber broken up by several muskeg meadows. The crew collected 611 topo points to compare with LiDAR. See Figure 2.

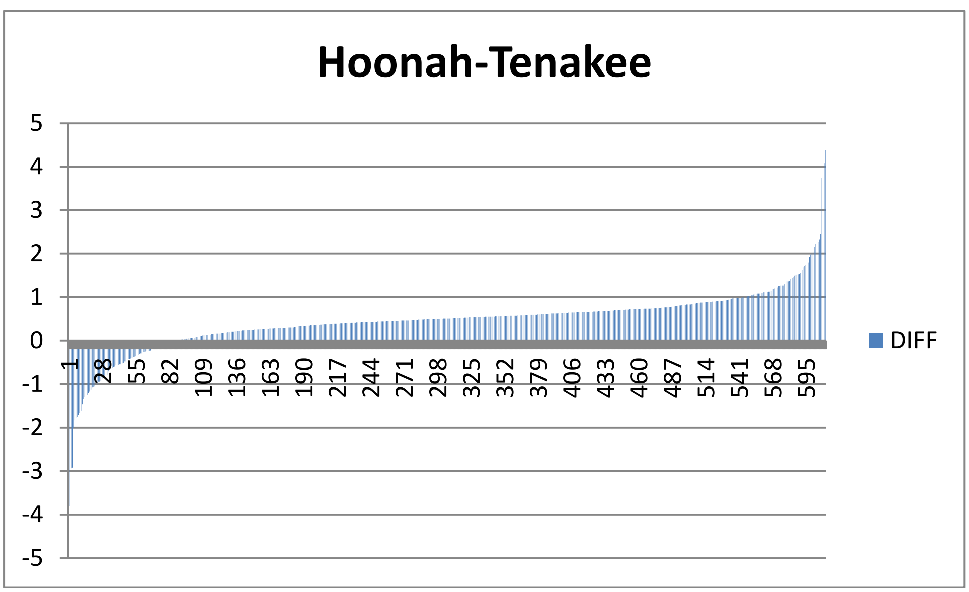

Figure 2. This graph does show a slight vertical bias in the LiDAR surface elevations at approximately 0.5'. It also shows a fairly good match between the datasets with over 85% of the ground shots falling within one foot vertically, and 97% within two feet of the LiDAR data.

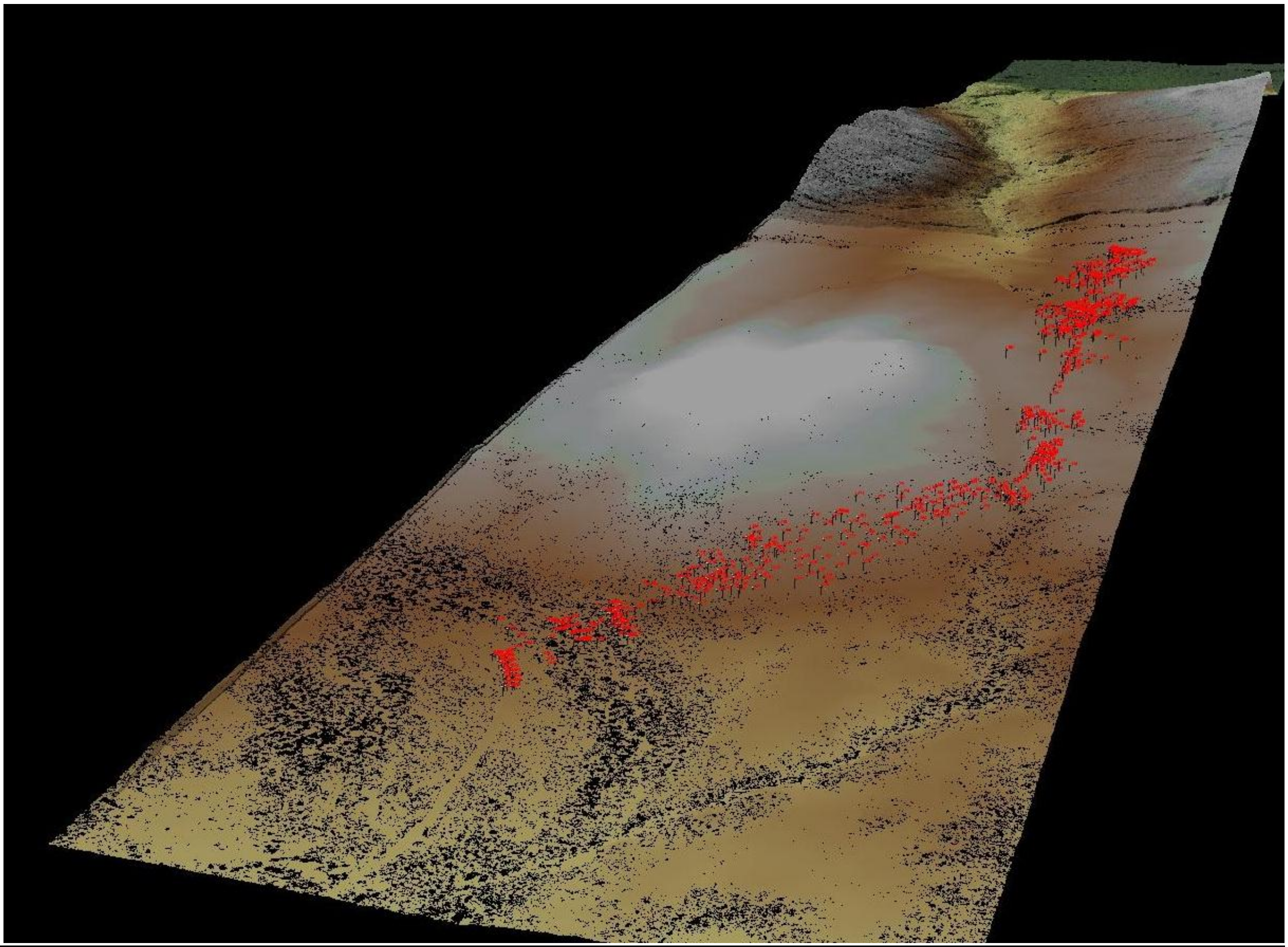

Figure 3. General layout of Hoonah to Tenakee project. Notice the relatively flat nature of the terrain.

The Department recently acquired the software QT modeler from the Applied Physics Lab at Johns Hopkins University. QT modeler's "Point Query" tool was invaluable for conducting this ground truthing. Instead of relying on the brute force approach to comparing elevations manually, an entire ground survey file can be imported to a LiDAR model and subsequently write out a report of the comparison point by point. It can pass through such information as point number and point description to the report file making it easy to further analyze problem points. Such things as bad rod heights or shots in the center of streams can be readily discovered and eliminated from the analysis report.

New Project

The Department began a study of connecting existing logging roads between Lake Harriet Hunt and Shelter Cove in the Ketchikan area in 2007. Aerometric flew the main portion of the project in June 2007 with a follow-up mission in December 2008 using an Optech Gemini LiDAR system operating at 100 kHz. This system is capable of four times more data than the system used on Juneau Access. Similar scan angles (14°) were used on both projects as well as similar flying height (1100m above mean terrain). The department provided Aerometric with 9 control points and they collected 378 survey points of their own for initial quality control. The Department reserved an additional 51 topo points for our own internal quality control.

For this research project, the department's survey crew conducted an additional ten days of topographic surveying at various places within the LiDAR footprint during May, 2009. The crew was composed of crew chief Jay Johnson, crew chief Paul Maggard, and instrument man George Cottrell. Using the criteria outlined above for grading of terrain and vegetation every survey area was classified into the categories of Terrain = 1,2, or 3 and Vegetation = 1,2, or 3. One area in particular was very unique in that it was completely forested during LiDAR acquisition, but had been clear cut by May, 2009. The ground may have changed slightly during the logging operation due to equipment and log hauling, but photos show very little disturbance to the old forest floor. This area was steep and was classified as Terrain = 3, and Vegetation = 3 (as it was during LiDAR acquisition). Not all combinations of terrain & vegetation were observed during this survey. 915 survey points were collected with the following distribution:

T1 V1 = 137
T1 V2 = 0
T1 V3 = 2
T2 V1 = 0
T2 V2 = 54
T2 V3 = 259
T3 V1 = 0
T3 V2 = 13
T3 V3 = 450

Results

Unfortunately the LiDAR dataset for Ketchikan to Shelter Cove does not compare well to the ground survey. In addition to a possible datum issue, there seems to be inconsistencies between data collected in different areas at different times. For all areas except the T3V3 section, the LiDAR data is almost always higher in elevation than the ground surveyed points. This could indicate a particular bias to the LiDAR dataset, or it could indicate that forest understory is being picked up by LiDAR rather than actual ground. The T3V3 section does not show any particular bias as sometimes the LiDAR is higher than ground topo while sometimes being lower. There are however significant elevation differences in this T3V3 area on some points in the magnitude of 25’. This T3V3 area will be discussed in detail below.

Initial results of quality control were based on 60 survey control points and general topo conducted during photopanel control work. See Figure 4.

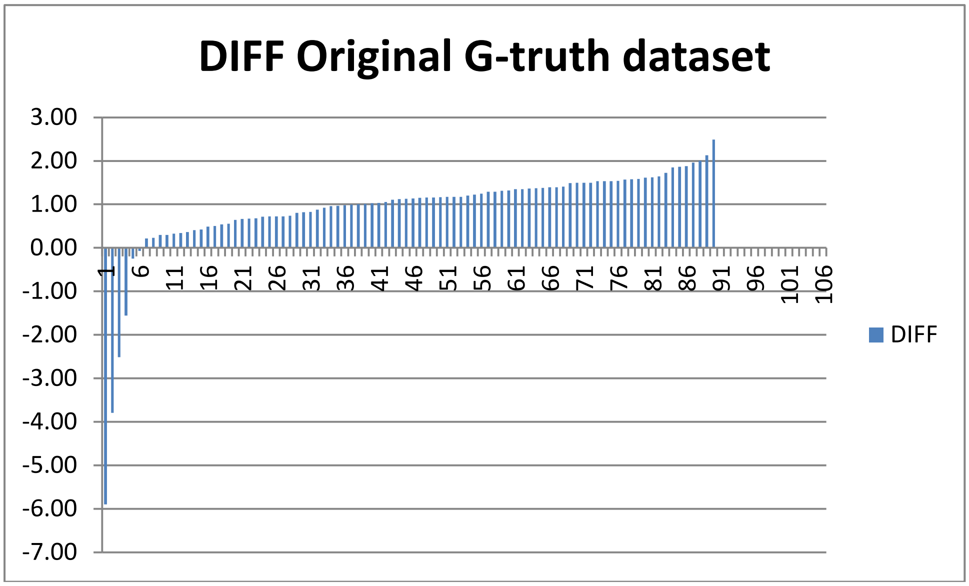

Figure 4. This graph shows a slight vertical bias in the data, and shows fairly good agreement between the datasets with 93% of the data falling within 2 feet of the LiDAR elevations.

The T1V1 section surveyed consisted mainly of existing road bed with mostly open skies. 137 survey points were collected using Real Time Kinematic GPS in this classification. This is an area that we would expect the best agreement between datasets as well as the most density of LiDAR points making it to the ground. See Figure 5.

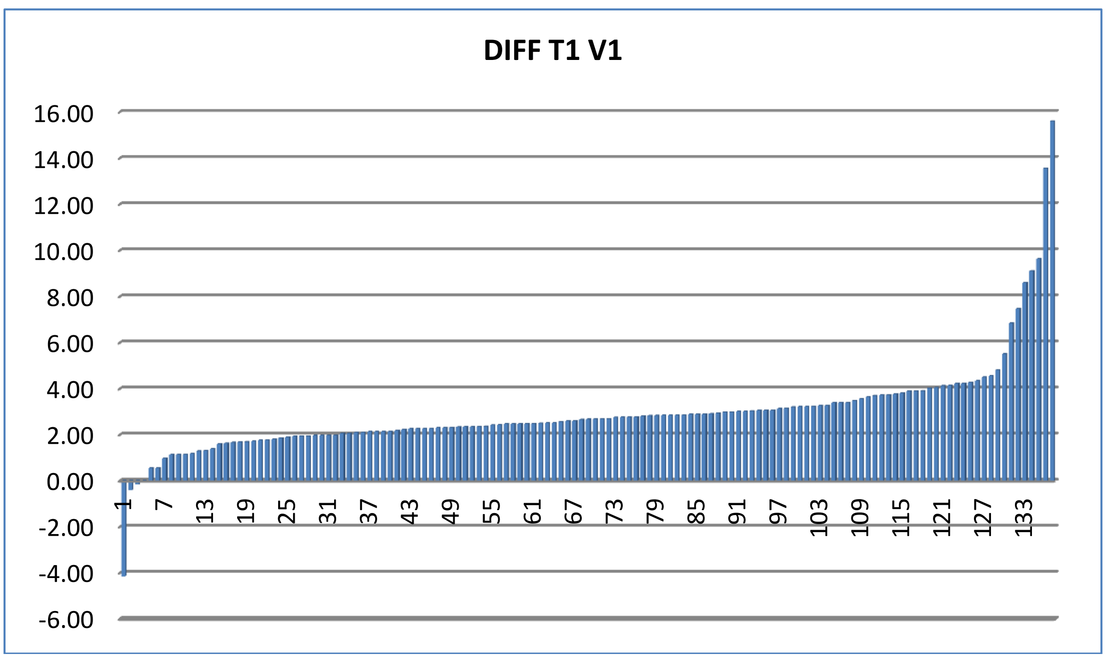

Figure 5. This graph shows a significant elevation bias in the LiDAR data in the neighborhood of three feet. The LiDAR on average was three feet higher than the ground surveyed points. Antenna heights were triple checked during the ground survey, and all base station setups were verified by check shots into existing control on a daily basis.

No T1V2, T2V1, or T3V1 sections were observed during this survey, and only two shots were classified as T1V3. The LiDAR elevations corresponding to those two shots were 3.8’ and 4.5’ higher than ground survey.

The T2V2 section was surveyed by total station. Beginning on GPS control points, the crew traversed through roughly half of a mile of moderately dense forest before closing into additional GPS control. During the traverse, random topography was collected for a total of 54 points. See Figure 6.

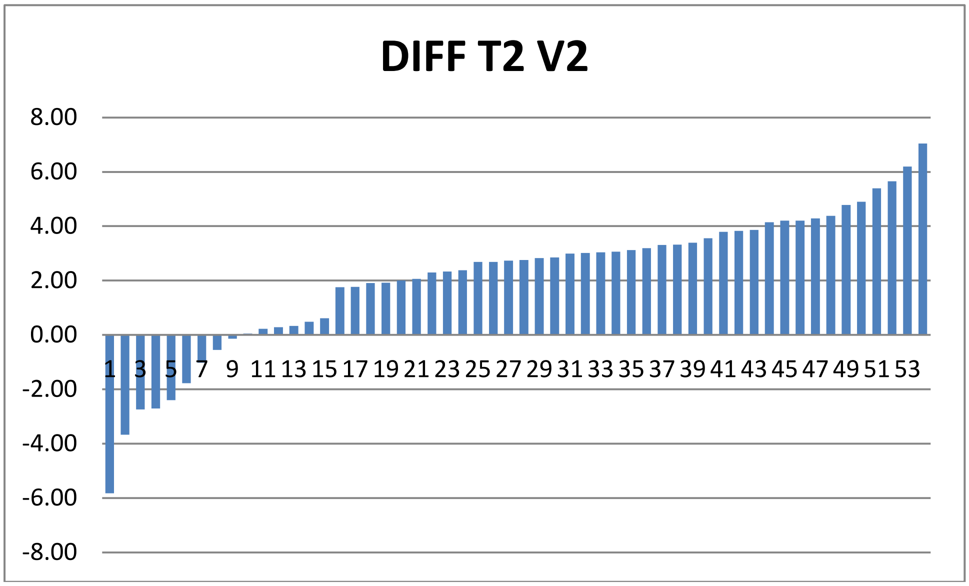

Figure 6. Much like the T1V1 section, this graph shows an elevation bias in the LiDAR data of about two feet. There were some significant differences in the other direction however where LiDAR elevations compared as much as six feet too low.

The T2V3 was also surveyed by total station on the same traverse as the T2V2 section. It was located on the northern end of the traverse on a south facing slope with noticeably more dense vegetation. See Figure 7.

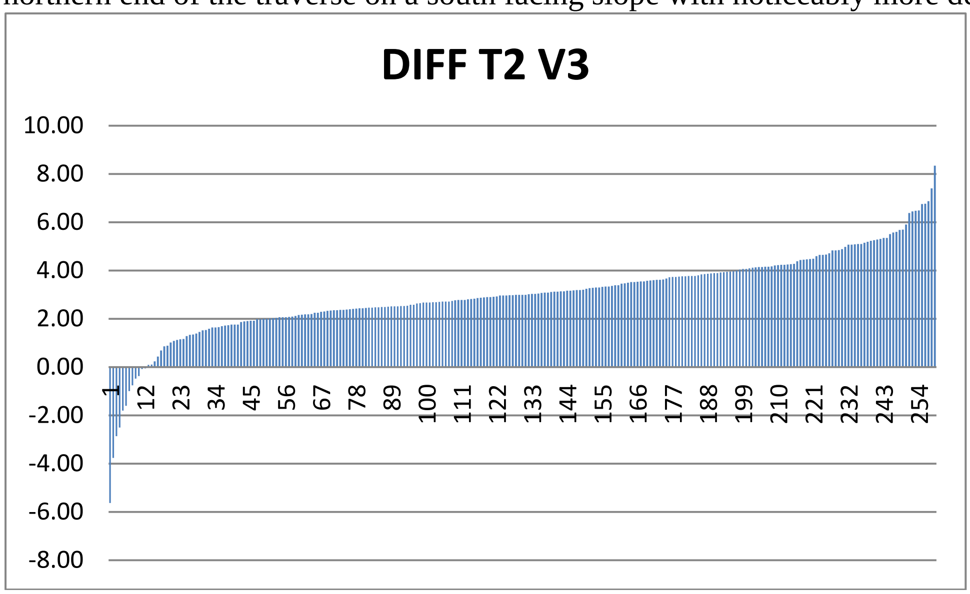

Figure 7. Again this graph points to an elevation bias in the LiDAR data of roughly three feet too high.

The T3V2 section was conducted from the same traverse as the other sections but was located near the middle of the traverse at a ravine crossing. Only 13 shots were classified as T3V2. See Figure 8.

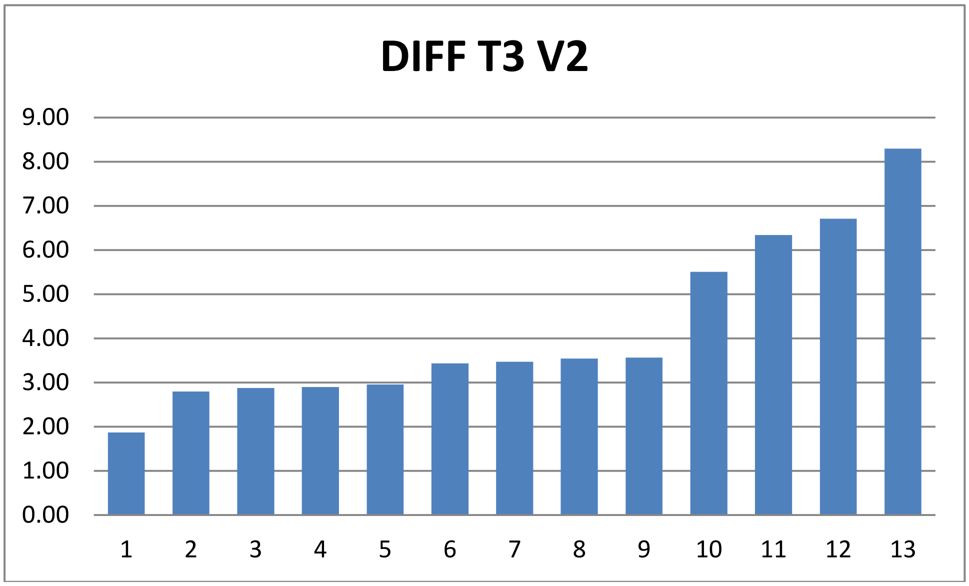

Figure 8. All shots in this section show a LiDAR bias of approximately four feet too high.

The T3V3 section was very unique in that it was forested when LiDAR was acquired but had been clear cut by the time the survey crew arrived for this ground truthing project. This area is very steep and is bordered by a deep gorge on the eastern side. The crew utilized RTK GPS for the entirety of the 450 shots in this section. See Figure 9.

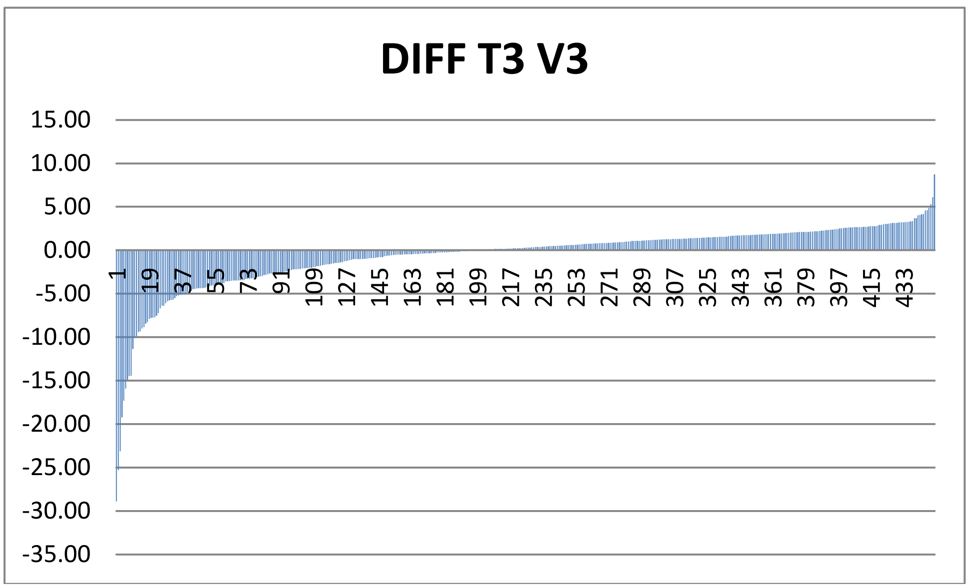

Figure 9. This graph shows very little to indicate any bias in the LiDAR. The statistics actually show the LiDAR to be slightly lower than ground elevations by approximately 0.6' too low. What is most alarming about this graph is the sheer magnitude of the differnces, some exceeding 25'.

Figure 10 is a photograph of the existing conditions of the T3V3 area. Figures 11 and 12 are screen captures from QT Modeler depicting ground shots in red overlayed on the LiDAR point cloud.

Figure 10. Photograph of T3V3 area after logging. Notice thickness of vegetation in background.

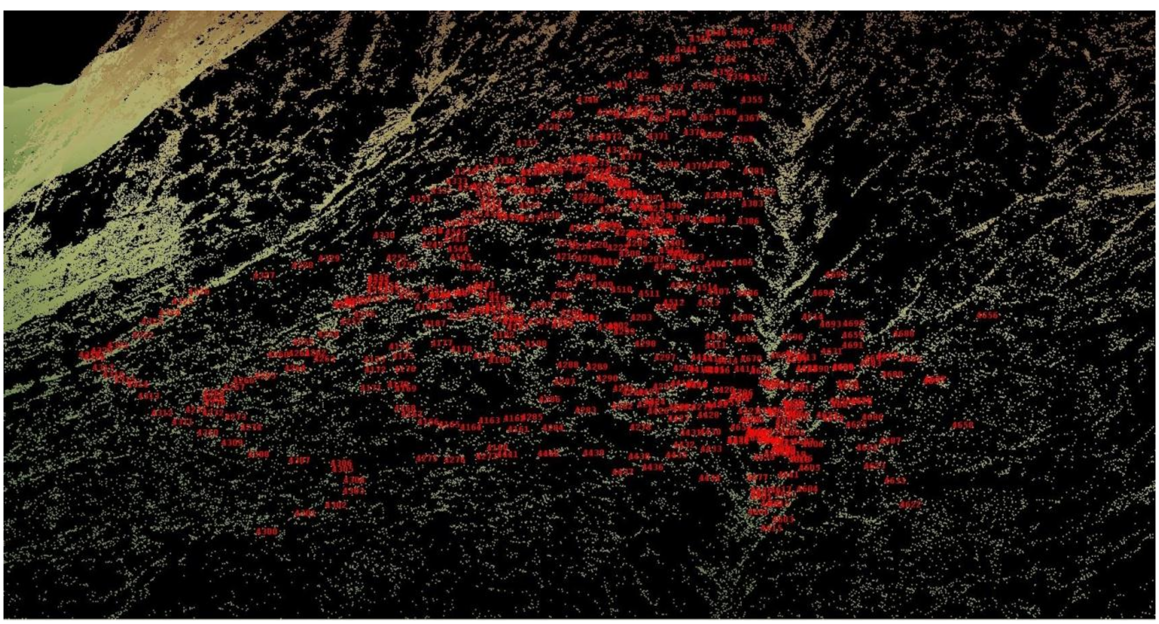

Figure 11. Overview of ground shots over LiDAR point cloud.

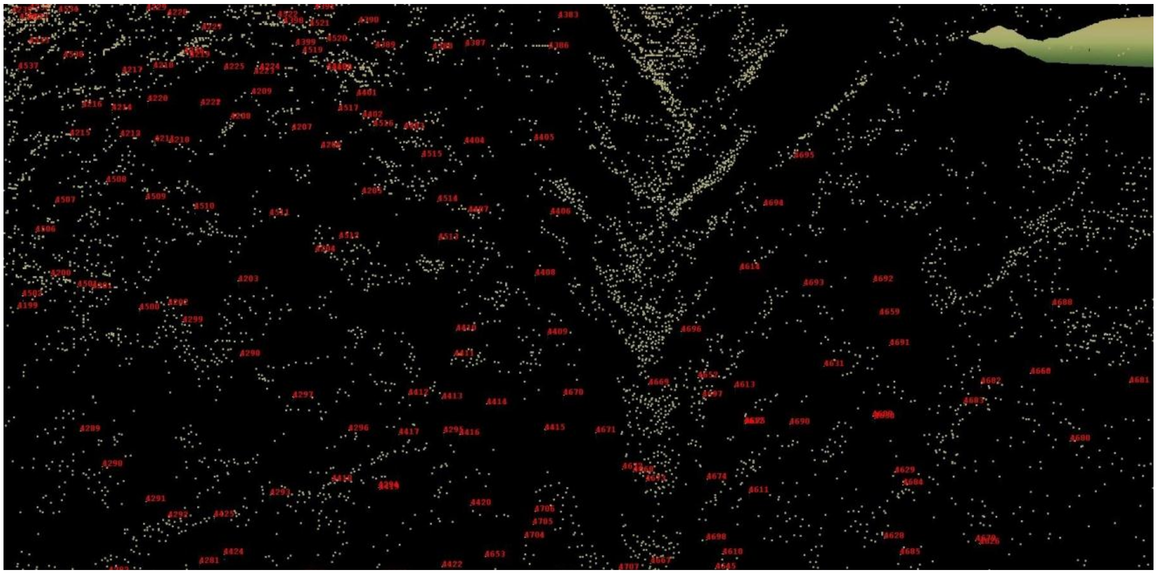

Figure 12. Close-up of ground shots over LiDAR point cloud.

The biggest source of error in this T3V3 region is due to sparsity of data. In figure 12 there are some areas showing many LiDAR points, and other areas that are void of LiDAR data. The ground shot comparisons in some of these voids are based on surface interpolation of LiDAR data points sometimes as far as 50 feet away. Where LiDAR points and ground surveyed points are close together there seems to be good correlation in their elevations. Where ground points exist in a LiDAR void the elevations can be extremely different.

Conclusions

The comparisons of ground surveyed topography versus the LiDAR derived surface model on this Ketchikan to Shelter Cove project are honestly quite poor. Going into this project we thought we would see results very similar to the Juneau Access project. We knew the comparisons wouldn't be as good as the Hoonah to Tenakee project as a whole due to the flat and relatively low vegetation observed on that project. However, we had expected to see comparable results in the sections where Terrain was classified as 1, and Vegetation was also classified as 1.

A multitude of possibilities exist as to why this LiDAR data set does not compare well to the ground surveyed points.

- Vertical datum issues as well as geoid model selection could have contributed to mismatch in elevations.
- Did the consultant use Geoid '06, AND apply the vertical offset to local Mean Lower Low Water datum of +3.62' both times they delivered data on this project?
- When the consultant merged datasets from 2007 and 2008 were the same geoid models, offsets, and coordinate conversions used prior to merging?
- Were the pre-filtering algorithms used by the consultant too aggressive? Usually LiDAR data is processed through automated routines to eliminate trees and structures. The basic premise is to remove the higher of two data points if they fall within a certain horizontal distance from one another. Could the data voids in the T3V3 area be caused by over aggressive algorithms in the pre-processing?
- Was the vegetation canopy simply too thick in some areas? The trees in this Ketchikan region were far taller than anything on Juneau Access, up to 200' tall. The survey crew as well as the geotechnical crew reported many areas of woods as "dark and scary".

- Were there any issues in processing the airborne GPS trajectory of the LiDAR aircraft? Glitches in aircraft positioning directly effects laser data from that aircraft.

- Were GPS base stations over 30km from the project site? GPS vector length can adversely affect aircraft positioning. KTN-Shelter maximum vector length was 30.6km.

- Was the calibration report delivered from the correct aircraft? The metadata delivered for KTN-Shelter indicated that a Cessna 320 and a Cessna 310 were used for LiDAR acquisition on this project, however the LiDAR system calibration report indicates that a Piper Navajo was used during calibration runs at Palmer airport.

- Was the June 2007 data affected by forest understory like devils club and berry brush?

Recommendations

- Always provide the aerial mapping consultant with solid ground surveyed points that are well distributed throughout the LiDAR footprint. Do not however give them all of your ground surveyed points so that independent quality control checks can be performed on the delivered dataset. Orthophotography is a natural product to acquire under the same contract as LiDAR, so photopanel points are a good start for ground truthing points. Conduct additional topographic mapping from those photopanels while on site.

- Never rely on LiDAR data alone for final design of any structures like bridges, retaining walls, large culverts, etc. These areas must be ground surveyed to avoid expensive redesign and/or expensive material change orders.

- Try to schedule LiDAR missions during the best “leaf off” conditions while there isn’t any snow on the ground. In Southeast Alaska that window of time generally runs from April to mid May, and again from late October through December.

- For deliverables, always request a LiDAR system calibration report. This report should detail the installation procedures of the LiDAR & Internal Motion Unit (IMU) into the aircraft as well as how well it matches a calibrated surface that was ground surveyed.

- Try to negotiate a minimum bare earth point spacing. 15’ between points is a lot better than 50’ or 100’. Consultants will be hesitant to agree to this requirement but try to at least touch on this subject and get a feel for probable point density in final dataset.

- Invest in software specifically designed to handle large datasets >100 million points. This software should be able to handle ground survey comparison. In addition, this software should prove itself valuable for cropping and gridding datasets to a manageable size for the engineering software it will ultimately be used in.

- Inspect delivered datasets with reserved topo points as soon as possible after delivery. If problems are found, notify the consultant right away. Usually engineers are over eager to get their hands on the delivered data. Do not disseminate data without first running internal checks to avoid data corruption across the server.