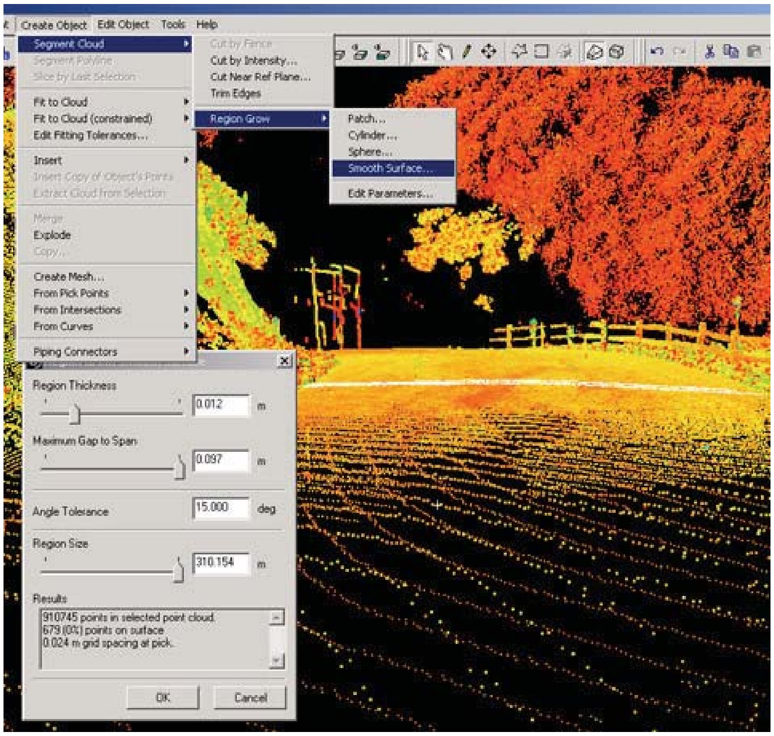
CHAPTER 3 - PROJECT STUDY APPLICATION: LASER SCANNING

A primary emphasis of this study is the emergence of ground-based Light Detection and Ranging (LiDAR) systems, known as “Laser Scanning”. Laser scanning instruments emit a pulsed laser signal with enough intensity to be uniquely detected by the instrument on its return signal from most reflective surfaces. Time travel of the light beam provides distance from the instrument to the reflected surface, and the pulsed signal is rapid enough that thousands of points can be recorded in seconds. Each point is recorded as a discrete three-dimensional coordinate relative to the instrument axis, with an attribute relating to intensity of the returning signal. Collectively a scan of points, known as a “Point Cloud” contains tens of thousands of points depicting rich detail of the scene as viewed from the instrument. In addition to the ground, the scene includes trees, brush, cars, people, and anything else that can be “seen” from the instrument-viewing angle. It does not include “shadows”, or those features that are behind something else. Herein begins to show the limitations of this technology as it is applied to conventional topographic mapping assignments. With heavily-obscured terrain, such as forested or brush-covered areas, extracting the ground points from the noise, in a data set that can reach well over a million points, can be extremely challenging. Software is making great advances in solving these problems. Advanced statistical algorithms are able to analyze blocks of data points and “grow” surfaces based upon anticipated geometric conditions. Nothing can be done; however, in shadows where data doesn’t exist. And at some point, noise becomes so dominant that no amount of computer processing can extract the good from the bad. Scenes can be accurately merged together, and the data set fit to project coordinates and elevations, by common feature objects and unique targets placed in the scene. This process is very similar to analytical aerotriangulation in photogrammetric mapping, and likewise demands preplanning and conventional control surveying to position the laser scanning targets. An experienced operator becomes key to the success of a laser scanning project. The operator must be able to position the instrument and control for the scene so as to capture the required detail, and provide for enough geometric integrity to accurately place each scene within the project control system.



Region Thickness 0.012 m

Maximum Gap to Span 0.097 m

Angle Tolerance 15.000 deg

Region Size 310.154 m

Results

910745 points in selected point cloud
679 (0%) points on surface
0.024 m grid spacing at pick.

Figure 1. Screen Shot. Laser scanning software provides sophisticated algorithms for computing geometric objects and surfaces from point cloud data.

Some laser scanning equipment provides options for interactive data collection, and others operate in a point-and-shoot mode. Operator identification of targets and detail scanning of specific regions are examples of possible operator intervention during the scanning collection. Other variations in the instruments include the range or distance the laser can operate at, and the horizontal and vertical viewing angle within an individual scene. All surveying type laser scanners collect a digital picture of the scene in addition to the data points. The following table lists the most common laser scanning instruments and a few characteristic features.

Table 3. Characteristics of most common scanning instruments.

MANUFACTURE	3rdTech	Cyra Technologies	MENSI	Optech, Inc.	Riegl USA	Trimble
PRODUCT	DeltaSphere-3000	Cyrax 2500	GS100	ILRIS 3D	LMS Z420	Callidus
FDA Laser Class	IIIa	2	2	1	2	1
Accuracy at Specified Distance	0.4 in at 40 ft	6mm from 0-50m	6mm at 100m	10mm at 100m	20mm at 1000m	5m at 30m
Maximum Range	40 ft	100m	100m	1500m	1000m	80m
Field of View Vertical	145	40	60	40	90	140
Field of View Horizontal	360	40	360	40	360	360
Scanner Weight	22 lbs	20.5 kg	13.6 kg	12 kg	14.5 kg	13 kg
Computer Control Requirements	PC Laptop	PC Laptop	Pocket PC or Laptop	PCMCI Card	Laptop	Incl. Field Laptop
Battery Life	8 Hrs	8 Hrs	4 Hrs	2.5 Hrs	8 Hrs	?

As described above, application software for laser scanning is easily as important as the instrument its self. For one, the massive amounts of DTM data that must be processed would overwhelm any conventional CADD software. Point cloud data must be accessed and manipulated in a rigorous database application specifically focused on manipulating and analyzing points and surfaces. CloudWorks from Cyra Technologies includes numerous features targeted to the surveying and mapping market. In addition to being able to efficiently handle millions of data points and providing sophisticated filtering and analysis tools, CloudWorks allows the analyst to "survey" within the virtual environment represented by the point cloud. Just as a rodman on a topographic survey would locate specific objects in the field and identify them with feature codes, the analyst is able to mark points and establish break lines, then identify them with the same feature code list that is used to process conventional topographic surveys. All laser scanning application software includes tools to clean the point cloud data as this is the single biggest challenge for any LiDAR task. Finding and identifying the ground amid thousands upon thousands of points defines the success or failure of LiDAR derived topography.

LASER SCANNING FIELD DEMONSTRATIONS

The Bautista Canyon Road project (CA PFH 224) in Riverside County, California was selected as a demonstration site for two laser scanning instruments. The project was chosen because it had been recently mapped with conventional photogrammetry, and because there were different areas of terrain that ranged from ideally suited for laser scanning solution to areas that were almost certain to fail. Bautista Canyon Road is very typical of

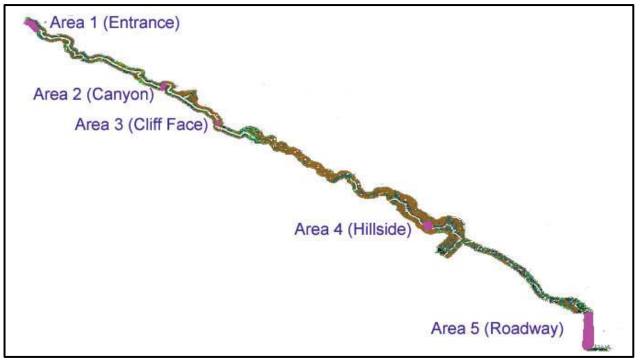


Figure 2. Map. Bautista Canyon Road Demonstration Sites.

CFLHD surveying assignments with a linear, mostly dirt-surfaced route, and including many areas of steep terrain and dense brush, and some areas with oak trees, in character with the forests so often encountered on CFLHD projects.

Six days of field data collection were completed in June of 2002 over five different target sites. Scanning work used equally a Cyrax 2500 instrument and an Optech instrument. It should be noted that both instruments experienced equipment breakdowns during the field schedule. This experience illustrates the complicated nature of these first-generation instruments for use in field environments. All equipment performed to manufactures specifications outside of the noted breakdowns.

Site Number 1, Bautista Honor Camp Entrance

Figure 3. Photo. Cyrax 2500 Laser Looking Towards Entrance.

The first target area, Site number 1, was at the entrance to Bautista Honor Camp along Bautista Canyon Road. Mapping the detail found in the Honor Camp entrance area provided the best location to demonstrate the strengths of laser scanning technology. Trees, walls, signs and park benches were revealed in clear and precise detail. Even the raised lettering on the entrance sign showed clearly in the point cloud scenes. Both scanners were able to collect the data necessary to map the site's topography to at least the accuracy provided from the original photogrammetry (i.e. plotting scale of 1:500 with 0.5 meter interval contours). Site number 1, of approximately 4,000 square meters, took each system four to five hours to collect the multiple scenes needed to depict the entire ground area without extensive shadowing. Processing the point cloud data into a typical topographic mapping CADD file required approximately four hours of analyst's time. Adding to that an hour of conventional

Figure 4. Photos. Point cloud data was able to reveal rich detail of the texture on the camp entrance sign

control surveying to position targets linking the scenes to the project control system, and the laser scanning project consumed twelve or more man-hours with perhaps three different experience levels required. The same topographic mapping project, completed by conventional total station survey methods would have consumed three or four hours of crew time, and three or four hours of an analyst. Two different experience levels and a total of twelve man-hours would have been needed for a similar conventional topographic survey. Due to trees, hillsides and other line-of-sight obstructions, the longer range of the Optech scanner (300 meters vs. 50 meters) did not provide any distinct advantage over the Cyrax scanner for this experiment.

The laser scans provide additional information that typically would not have be collected by field survey methods, and simply would not have be seen at all by aerial photogrammetry. The entrance sign and supporting wall structure are one example of this additional information. Heights and widths of walls, accurate tree trunk diameters, and the bolt pattern on the gate can be accurately picked out of the point cloud data for Bautista Canyon Road. Here then in this extremely rich detail depiction begins to emerge the most significant advantage of laser scanning over other mapping technologies.

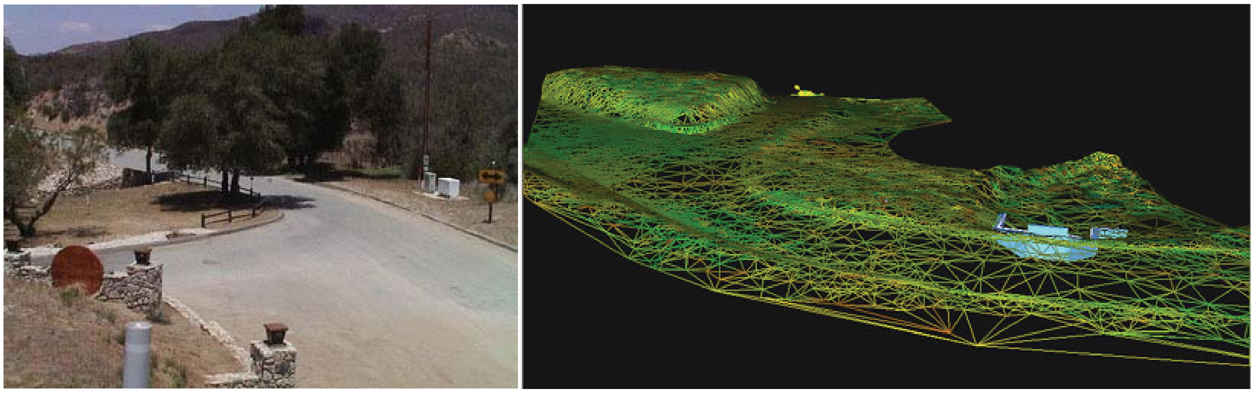


Figure 5. Photos. Rich detail of information.

Site Number 2, Brushy Canyon

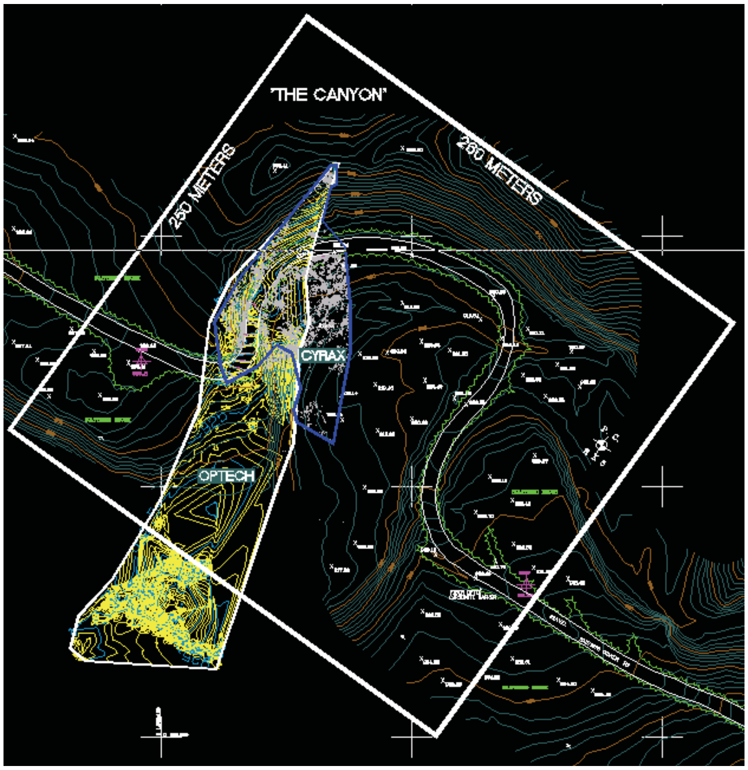


Figure 6. Plot. Very limited visibility through thick brush prevented accurate collection of the ground surface.

The second site location included in the study was a 400-meter "S" turn in Bautista Canyon Road where it crosses a small canyon. The canyon is filled with scrub oak and chaparral making any type of survey work difficult at best. Other than the visible sections of roadway, neither scanner was able to collect enough points through the dense brush to accurately reveal the bald earth topography. This site also demonstrated the difficulty using bulky equipment with cables and batteries and complicated components in typical field terrain. The preferred set-up vantage for the second site was on a small hill overlooking the canyon. Getting the Cyrax scanner and its associated laptop computer, Ethernet communications network, and power supply up even this short hike was something none of the crewmembers wanted to do more than once. It should be noted that aerial photogrammetry is also challenged by visibility though brush as was found on this site. No attempt was made to check the accuracy of the original photogrammetric mapping in this area.

Site Number 3, Cliff Face

Site number 3 was selected to demonstrate the ability of laser scanning to collect topographic detail on a near vertical cliff face. The selected roadway segment included a four-meter-high cut slope on the uphill side, and a very deep brush covered canyon on the downhill side. Both scanners were able to collect sufficient point cloud data for the roadway surface and the cut slope face. Neither was able to map into the canyon and through the brush. The point cloud data depicted the cut slope face in far greater detail than was shown in the photogrammetric data. It was even superior to typical topographic mapping from conventional total station surveying. A reflectorless total station could have been used to individually locate each of the rock faces and rivulets making up the texture of the slope. The labor required to collect and analyze conventional topography of that detail would be extensive. Site #3 provided the most successful demonstration of laser scanning applicable to CFLHD mapping assignments. Where accuracy and detail of a visible surface are of utmost importance, laser scanning could provide an ideal solution.

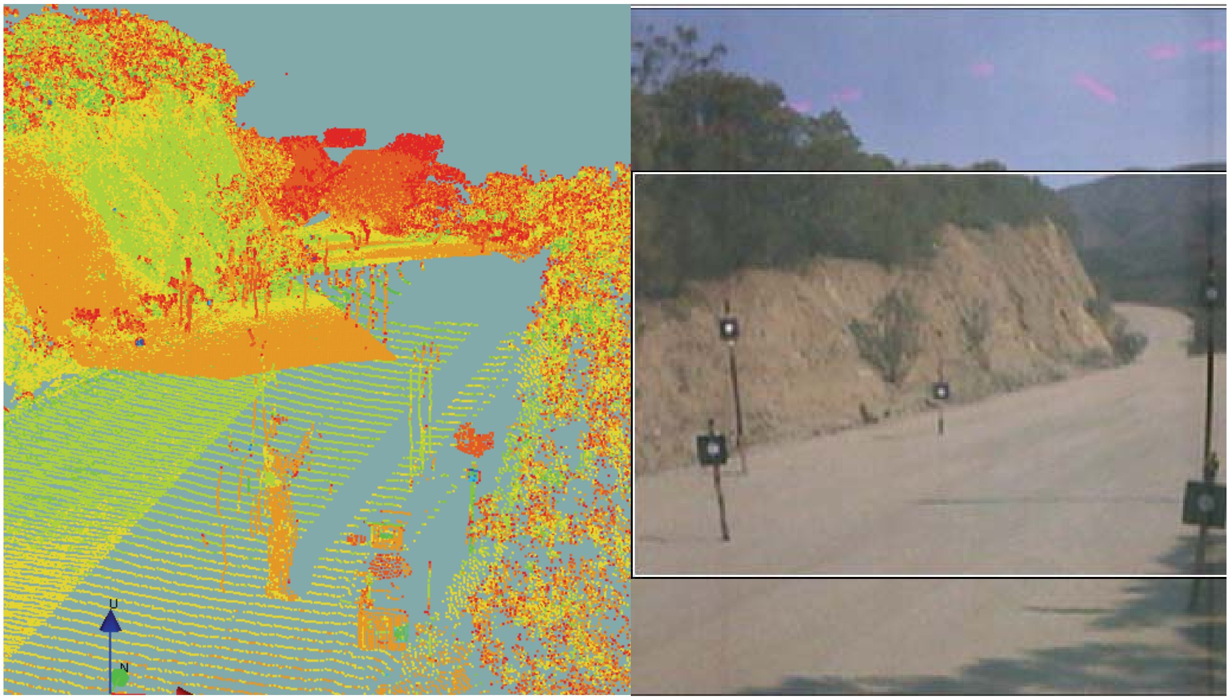


Figure 7. Photos. Targets placed in the scene are surveyed to register scans to the project coordinate system.

Site Number 4, Brushy Hillside

The fourth site also included an area of brush along Bautista Canyon Road. This 200-meter section looked more open than the canyon (Site #2) and was predominantly a hillside directly facing the scanner's viewing angle. This perspective was more favorable for laser scanning in that the instrument was able to look directly into the brush rather than crossing through it at an angle.

Site #4 was only mapped with the Cyrax instrument since the power supply on the Optech instrument broke for a second time and a replacement could not be shipped in time from the manufacture in Canada. The scanner was able to penetrate the brush and collect topographic point data for some of the ground surface. For approximately half of the hillside, the brush was too dense preventing sufficient data points to develop an accurate ground surface. The entire hillside in Site #4 was sufficiently visible from the air to compile design level topography using conventional photogrammetric methods.

Figure 8. Photo. Bulky equipment, cables and batteries present challenges to the field environment.

Figure 9. Photo. The brushy hillside directly facing the scanner provided limited success seeing to the ground surface.

Site Number 5, Open Roadway

The final site, number 5, was selected to demonstrate the ability of laser scanning to rapidly collect topographic mapping data in an open environment. The target area covers a strip of mostly open roadway for approximately one kilometer. A few visibility obstructions, such as signs, buildings, and cut-bank for the roadway presented some challenges for optimum scanning angles.

Both instruments were run collecting data sufficient point cloud data to derive design level topography. In eight (8) hours the Cyrax instrument collected a 440-meter segment of point cloud data. The Optech instrument with its longer range was able to collect 740 meters of point cloud data in four and a half (4.5) hours. An additional one and a half (1.5) hours of conventional control surveying was necessary to support each laser scanning demonstration. It was estimated that a conventional survey crew would have completed the one-kilometer segment in approximately eight (8) hours. Processing time for the topographic data was not considered in this demonstration, but is typically much less for conventional surveying as opposed to laser scanning. Again, the level of detail revealed by laser scanning could provide significant benefits on certain applications, but was not considered in this demonstration.

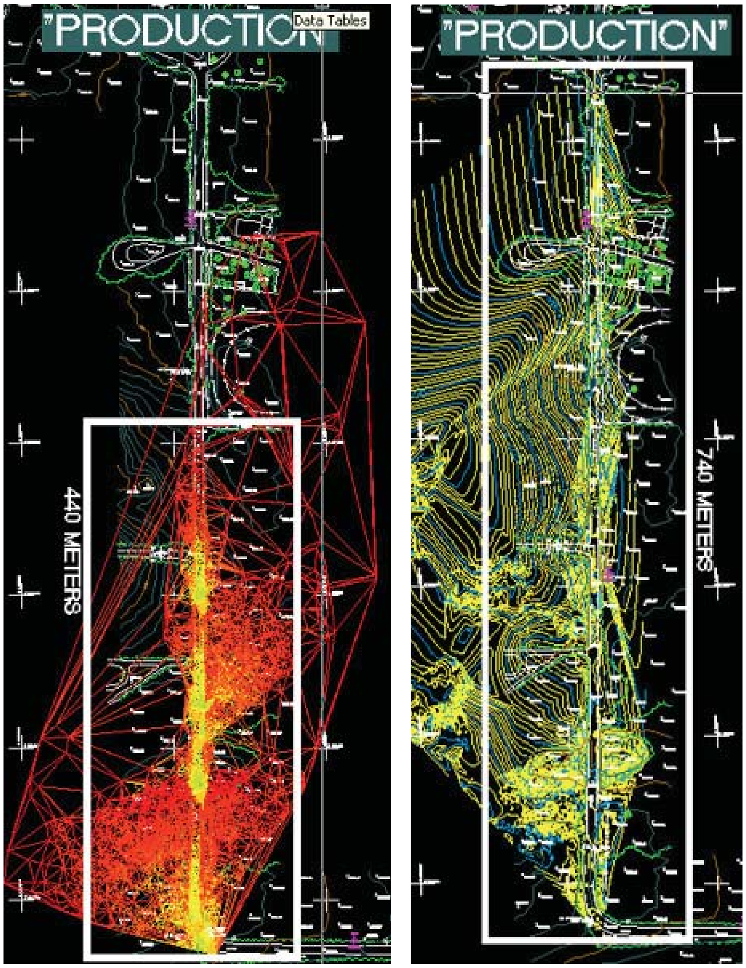


Figure 10. Plots. The longer range of the Optech scanner was able to collect 60% more data.

AIRBORNE LIGHT DETECTION AND RANGINE (LiDAR)

Similar to ground-based laser scanning, airborne LiDAR relies upon a high-speed, reflectorless, laser distance meter instrument to collect point cloud data from an airborne platform. The laser ranging instrument is matched to kinematic GPS point positioning, and an inertial measurement unit (IMU) to record angular velocity (yaw, pitch and roll) of the aerial platform. All three data measurement streams are time-tagged through the GPS time signature to facilitate simultaneous solution of position, angular attitude, and distance, to determine coordinates and elevations for discrete data points. The LiDAR system may be mounted in fixed-wing or rotary aircraft, from which design-level topographic data is possible. Typical point posting for current LiDAR is one meter, with an accuracy of 0.1 meter horizontal and vertical. These figures vary greatly depending upon the particular sensor and the altitude of the flight.

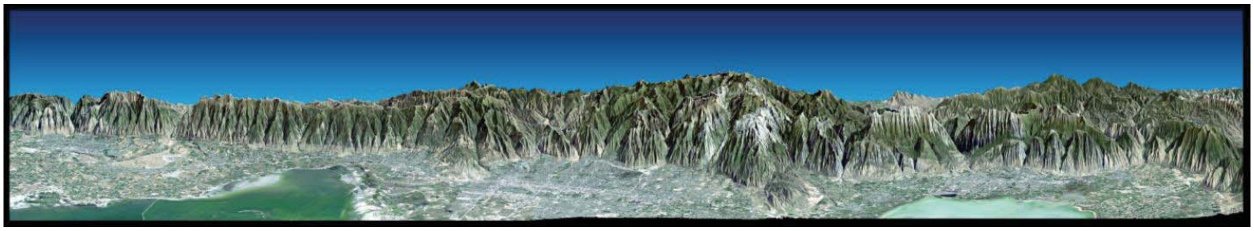


Figure 11. Photo. Colored relief image of Wasatch Range from Shuttle Radar Topography mission.

A similar system, using radio waves, or RADAR, as the sensor flown on either high-altitude aircraft or satellites, has been used to collect digital terrain data. Interferometric Synthetic Aperture RADAR (InSAR) uses two passes of RADAR imagery over the same ground area to develop a stereo image similar to conventional photogrammetry. It has most often been applied to planning-level mapping assignments, and also for land deformation monitoring projects, such as landslides, subsidence, and earthquakes. In February of 2000, the Space Shuttle Endeavour, equipped with InSAR, collected enough data in ten days to map 80% of the earth's surface to an accuracy of 20 meters horizontal and 16 meters vertical (90% probable error). The potential for topographic mapping from InSAR is significant, particularly for developing extremely large data sets for off-the-shelf digital terrain data, and mapping in areas where ground penetration of light waves is very limited (i.e. cloud cover and certain vegetation). The ability to use InSAR for design-level topographic mapping, while not impossible, appears unlikely in the immediate future. A separate study at CFLHD is being conducted to investigate the application of InSAR data for deformation monitoring on geotechnical projects.

Figure 12. Photo. Dual GPS antenna and LiDAR system mounted on helicopter.

Airborne LiDAR has proven to be a useful tool for topographic mapping work on typical FHWA assignments. Field demonstrations have been completed on projects including Guenella Pass, Beartooth Highway, and Lava Beds National Monument. Testing against conventional surveying and photogrammetric mapping shows favorable agreement at National Map Accuracy Standards. The following histogram was developed from conventional survey data points compared to LiDAR data compiled for a project in Oxnard, California. The imagery was flown by Airborne1at an average flying height of 800 meters using an Optech ALTM sensor.

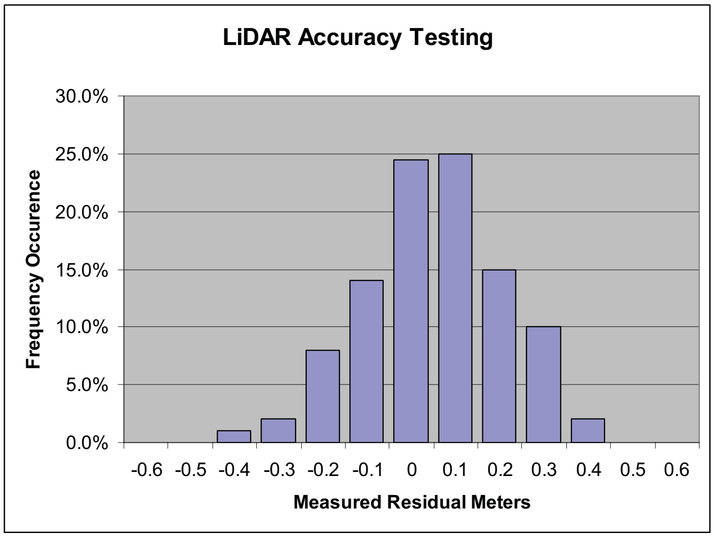


Figure 13. Chart. LiDAR accuracy histogram.

The viewing angle of airborne LiDAR is more favorable than ground-based laser scanning, to the site conditions typically found on FHWA projects. Trees and brush are much easier to see through from the vertical perspective, so more data points can be detected on the ground surface. Just as in ground-based laser scanning, filtering the point cloud data to isolate the ground points from the noise is defining of the success of the mission. Similar algorithms are used to grow surfaces from known geometric characteristics, and point attributes of signal intensity and first return/last return can also be applied to digital filters. Using different frequencies of light, LiDAR systems have been designed to capture mapping data including bathymetric mapping under shallow water, and the concentration of various gasses and chemicals in the atmosphere.

Two weaknesses stand out in LiDAR mapping technology as it is applied to topographic mapping assignments. Angular measurement from the IMU is limited to approximately 0.005 degrees using current ring-laser gyroscopes. This means that horizontal accuracy varies dependent upon flying height. Nearly 0.1 meters of angular uncertainty is incurred at a height of 1,000 meters. Since hardscape features such as curbs and buildings are less common on FLHD assignments, this limitation is not as significant as it might be for other applications. More significant is the inability of LiDAR to directly detect breaklines from the point cloud data. LiDAR points are at regular intervals along-track and across-track to the flight line. A grade break, such as a ravine, flow line, or edge of traveled way may or may not show up as points in the data set. Depending upon how many points happen to hit on the topographic breakline, an important feature may or may not be missed.

CONCLUSIONS AND RECOMMENDATIONS

Remote sensing using LiDAR technology will continue to advance its usefulness for surveying and mapping assignments. The successes achieved with airborne LiDAR at CFLHD already are providing advantages with improved mapping capability for environmentally sensitive areas, and the ability to collect and catalogue large data sets for possible expanded mapping coverage as projects change. Minimizing the location and number of aerial targets placed on a project not only saves cost, but also prevents possible damage from maintenance or brush cutting. Advances in software will certainly improve the ability to clean point cloud data for both airborne and ground based LiDAR making this data source increasingly attractive.

Currently, airborne LiDAR provides a viable option for mapping design-level digital terrain surfaces, where extensive breaklines and dense vegetation do not present significant challenges. It must be understood that the technology will not produce planimetric mapping for features such as edge of roadway or hardscape improvements. Nor will it directly provide orthophotography imagery. These typical mapping products will need to be derived by other methods, and the applicable costs factored into the work plan. Most likely this will require a separate, or simultaneous, aerial photogrammetry task. Cost savings can only be expected with LiDAR mapping on moderately large sized projects (nominally in excess of 10 Km^2), or on projects requiring only DTM data, such as floodplain studies. The limited number of these expensive systems currently in operation makes mobilization costs and timing a consideration.

Figure 14. Photo. Helicopter based LiDAR provided successfull digital terrain mapping for the Tarryall Road project.

Ground-based LiDAR, or laser scanning, is also applicable to certain surveying and mapping projects, though the range of appropriate assignments is much narrower. Generally, laser scanning shows greatest benefit in applications where great detail is desired and can be exploited. Three-dimensional modeling for historical preservation of artifacts or cultural features is one possible example. Detail of structural aspects of an existing bridge might be another. Typical topographic mapping assignments at FHWA are so limited by visibility, and generally do not demand extreme levels of detail, so that laser scanning does not find advantage.