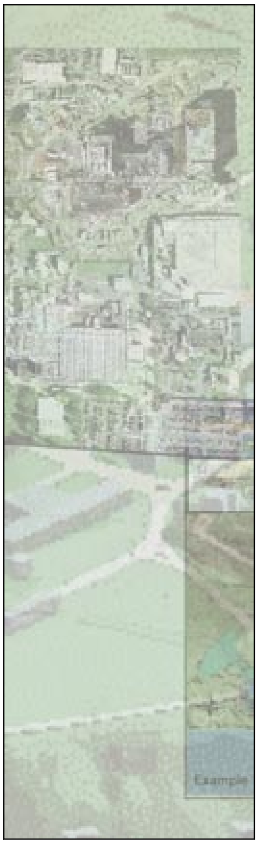

LIDAR GUIDEBOOK: CONCEPTS, PROJECT DESIGN, AND PRACTICAL APPLICATIONS

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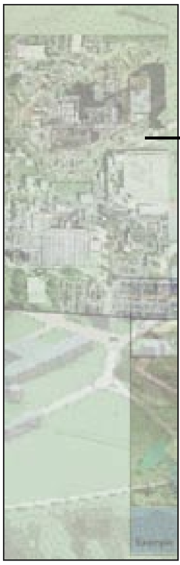

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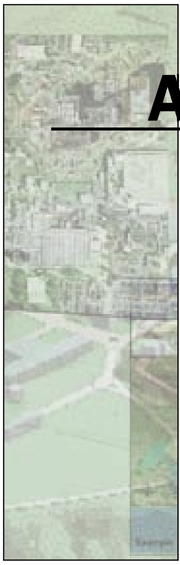
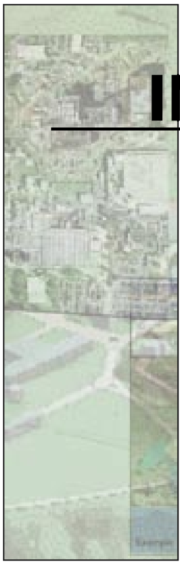


ABSTRACT

Light detection and ranging (LIDAR) over recent years has become widely accepted as an input tool for generating extremely accurate terrain models that are used in a variety of Geographic Information Systems (GIS) applications. This publication first provides an overview of LIDAR technology. It additionally addresses the advances in LIDAR over the years, how it can be used to meet different map accuracy standards, and how conventional photogrammetry still plays a role in the development of terrain modeling, and it outlines quality control measures used to verify this data set. This Quick Study Guide also describes potential applications and provides examples and case studies of how this data has been used by various agencies throughout the United States.

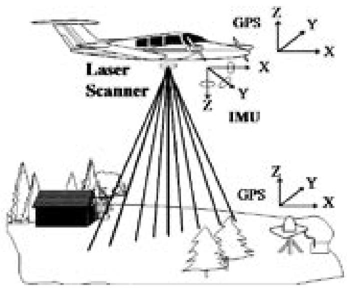


INTRODUCTION

LIDAR has become a widely accepted tool for generating extremely accurate terrain models that are used in a variety of GIS applications. The following topics are addressed in this publication:

- An overview of LIDAR technology
- The advances in LIDAR over the years
- How LIDAR can be used to meet different map accuracy standards
- How conventional photogrammetry still plays a role in the development of terrain models
- An outline of the quality control measures used to verify LIDAR data
- Descriptions of potential applications
- Examples and case studies of how LIDAR data has been used by various agencies throughout the United States

Concepts



A LIDAR collection system uses a powerful laser sensor comprised of a transmitter and a receiver, a geodetic-quality Global Positioning System (GPS) receiver, and an Inertial Navigation System (INS) unit. The technology resembles that used by radar sensors by which a device emits energy (focused light) and then measures the time it takes to travel to a target and return to a collector and at the same time compensates for the movement of the aircraft and the sensor. The laser sensor is precision-mounted to the underside of an aircraft (helicopter or airplane) similar to the mounting of a precision aerial mapping camera. Once airborne, the sensor emits rapid pulses of infrared (IR) laser light that are used to determine ranges to points on the terrain below as shown in the accompanying illustration.

Most LIDAR systems use a scanning mirror to generate a swath of light pulses. The swath width depends on the mirror's angle of oscillation and the ground-point density depends on such factors as aircraft speed, system capability for emitting pulses of light, and mirror oscillation rate. Ranges are determined by computing the amount of time it takes light to leave its source, travel to the ground, and return to the sensor. The sensing unit's precise position and attitude, instantaneous mirror angle, and the collected ranges are used to calculate 3-D positions of terrain points. As many as 50,000 positions, or "mass points," can be captured every second.

Although features such as buildings and automobiles are included in the accompanying figures, these can be removed from Digital Surface Models (DSMs) through postprocessing filtering techniques. In addition, the ground can be modeled as a "bare-earth" Digital Elevation Model (DEM).

Most of the first LIDAR systems were custom-developed sensors. Within the past five years, the availability of off-the-shelf (commercial) sensors has increased and, in turn, the number of firms that provide commercial LIDAR data-acquisition services has also increased. As the technology has advanced, and users have become more familiar with the advantages and benefits of the data for geospatial applications, use of this technology has grown tremendously. And as the geospatial industry progresses, it is expected that LIDAR data or LIDAR-derived products will become standard components of a state or local government geospatial database in much the same manner that digital orthophotos became integral components of most integrated geospatial databases during the 1900s.

History

Studies and tests concerned with using laser systems to obtain altimetry information have been ongoing since the 1960s. Since the 1980s, the technology has been used for atmospheric studies, volumetric analysis, and materials-composition analysis. Not until the late 1990s, however, did the technology begin to be adopted by the remote sensing and photogrammetric community and applied to geospatial database development projects. Some of the early LIDAR pilot projects for GIS-related mapping applications were conducted in the late 1990s. These initial projects focused on elevation information to support photogrammetric projects that involved using a Digital Terrain Model (DTM) to support the production of orthophotos or the generation of contours.

The introduction of LIDAR to the mapping science and photogrammetry industry came about because of the increased availability of reasonably priced yet highly accurate Inertial Measurement Units (IMUs) that could be mounted in an aircraft, and by advanced GPS ambiguity resolution procedures, which combined with onboard computers and LIDAR sensors, could produce highly accurate and dense elevation information.

Definitions*

Several key definitions applicable to acquiring, processing, and utilizing LIDAR data are described as follows.

Airborne Global Positioning System (AGPS) Technology that computes the x, y, and z coordinate information from the air in relation to one or more base stations on the ground. AGPS sensors are used for photogrammetric and LIDAR data-acquisition activities.

Bare earth Digital elevation data of the terrain, free from vegetation, buildings, and other man-made structures. Elevations on the ground. Bare earth data may be modeled as a DEM or a DTM.

Breakline A linear feature that describes a change in smoothness or continuity of a surface. Breaklines are typically captured along road edges and along hydrographic features to assist with the accurate depiction of contours.

Digital Elevation Model (DEM) An acronym used as a generic term for digital topographic data.

Often referred to as bare-earth elevations at regularly spaced intervals.

Digital Surface Model (DSM) Elevation data set containing accurate x, y, and z coordinates of all the LIDAR system returns. A DSM contains all the topographic, planimetric, and vegetative information of the area. A DSM typically also contains surface features such as cars and trucks present when the laser scanning took place.

Digital Terrain Model (DTM) Similar to a DEM but incorporates significant topographic features on the land as well as mass points and breaklines that are irregularly spaced to better characterize the shape of the terrain.

Inertial Measurement Unit (IMU) Technology that computes the roll, pitch, and heading of a moving object, for example, a LIDAR sensor or an aerial camera.

Light Detection and Ranging (LIDAR) A technology that employs an airborne scanning laser range finder to produce accurate topographic surveys. Also known as Airborne Laser Swath Mapping (ALSM).

LIDAR Intensity The strength of the light pulse being observed. Intensity readings can be used to produce raster image files that serve as image maps or that can be stored as intensity values for each point being measured.

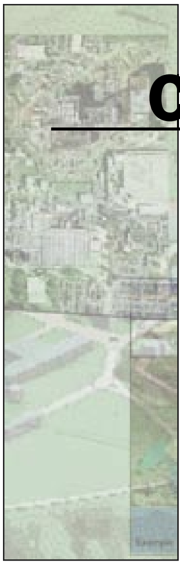
LIDAR Pulse Rate Typically referred to as the number of light pulses emitted per second in a scanning array. Pulse rates for various sensors typically range from 5,000 to 50,000 pulses per second.

LIDAR Returns The number of signals received per pulse. Some LIDAR sensors are capable of receiving up to five returns per pulse. Typically, the first and last returns are most commonly used for mapping applications. The first return measures the first object observed. The later returns usually measure the ground unless an obstruction (tree, car) obscures penetration to the ground.

Triangulated Irregular Network (TIN) A set of adjacent, nonoverlapping triangles computed from irregularly spaced points with x, y, and z coordinate values. A TIN model is used to create a surface and may be preferable to a DEM or DTM when it is critical to preserve the location of narrow or small surface features such as a stream channel or ridgeline.

Voids Portions of a digital elevation data set where no elevation data are available.

*Selected definitions derived from *Digital Elevation Model Technologies and Applications: The DEM Users Manual, Appendixes A and B,* by the American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 2001.



CHAPTER 1

LIDAR DATA ACQUISITION

The LIDAR data-acquisition process is similar to that used for aerial photography acquisition. Extensive preplanning is required before beginning the data-acquisition process. As with aerial photography acquisition, a detailed understanding of the uses and applications the data needs to support will determine the flying parameters.

The major steps of a typical LIDAR data-acquisition process, shown in Figure 1.1, are described in the following text.

Flight Planning

The key parameters addressed in flight planning are the accuracy requirements and the area of coverage. Flight planning parameters also include flying height, amount of overlap, and planning for cross strips to verify accuracy. Other parameters include aircraft speed and swath width. As part of the flight-planning process, all necessary flight clearances (and security waivers if flying in restricted airspace) are obtained. A sample LIDAR flight plan for acquiring LIDAR data in Maryland is provided in Figure 1.2.

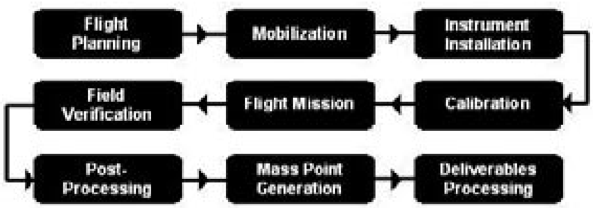


Figure 1.1 Major steps of a typical LIDAR data-acquisition process.

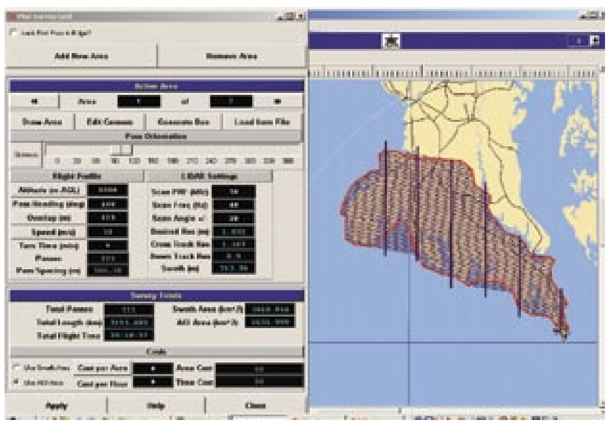


Figure 1.2 Sample LIDAR flight plan.

Mobilization

This includes mobilization of aircraft, sensor, and field operations staff to the project site. Typically, two or three persons are necessary to support the data collection effort. This includes a pilot, a system operator, and ground support staff. Mobilization usually begins at an airport in close proximity to the project area. Other mobilization activities include establishing AGPS base stations and checkpoints, and surveying a data-validation test or calibration site.

Instrument Installation

This involves installing the LIDAR system in the aircraft, which may be undertaken before or after mobilization to the project site.

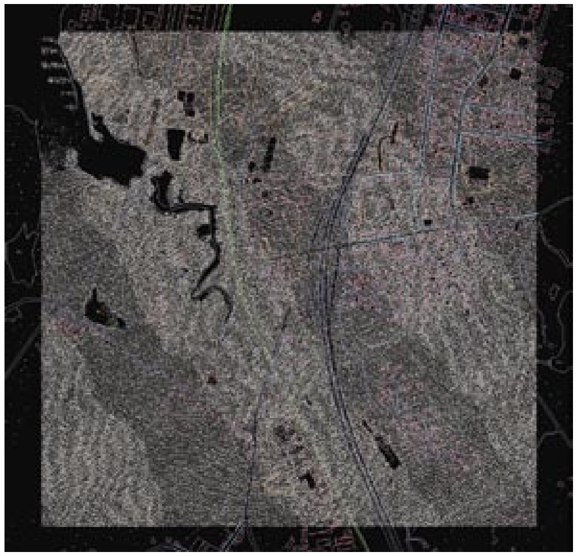


Figure 1.3. LIDAR strips.

System Calibration

System calibration should be performed each time a LIDAR system has been removed from and reinstalled in an aircraft. This essentially involves calibrating the sensor using survey techniques to define the geometric relationship between the sensor, aircraft with AGPS, and inertial measurement system components.

Flight Mission

A flight mission includes actual flying and initialization of the LIDAR and AGPS sensors. Data is typically flown in strips (or swaths), with each strip or group of strips making up a flight mission. Figure 1.3 shows several LIDAR strips.

Flight missions typically include premission and postmission flights over the data validation test site, thus bracketing each mission with test data.

Field Verification

A test strip or test field should be surveyed using conventional GPS or surveying techniques to validate and serve as a check of the data collected. This field verification should be integrated into the collection process and should supplement any independent checks completed after the LIDAR data is processed.

Postprocessing

Postprocessing involves processing the LIDAR data along with the AGPS information and IMU data to derive the surface model.

Mass Point Generation

Mass points and other supplemental products are derived from the processed imagery.

Deliverables Processing

Additional Information about Flying Parameters

In addition to the flying parameters described previously, other flying considerations should be addressed; briefly, they are:

Cloud cover. Cloud cover may affect LIDAR collection if the flying height is higher than the cloud base. LIDAR data acquisition is typically completed at a flying height lower than the cloud base.

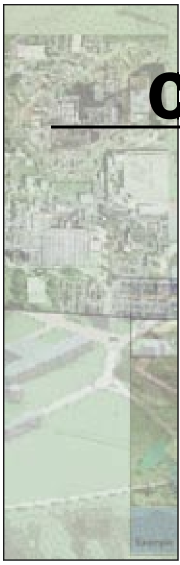
Flight clearance issues. As with aerial photography acquisition, flight plans need to be submitted to the Federal Aviation Administration (FAA) for approval and the appropriate flight clearances must be obtained. Flying in restricted airspace (for example, over military bases, airports, downtown areas of major cities) may require special waivers to obtain flight clearance.

Safety issues. Safety issues associated with using LIDAR sensors are usually not an issue for most projects. For the class of sensors involved in most GIS mapping projects, there is a safety threshold of 430 meters (1,410 feet) above the mean terrain. Most LIDAR projects are flown at flight altitudes ranging from 800 meters (2,624 feet) to 1,500 meters (4,921 feet) above the mean terrain. If LIDAR data collection is to be completed at a lower flight altitude, safety considerations must be addressed.

Tidal conditions. Many coastal areas restrict flying to certain tidal windows. Generally, it is preferable to fly tidal areas as close as possible to the mean low tide. Some organizations specify that tidal area data collection must be completed within ± two hours of the mean low tide.

Time of day. LIDAR data acquisition projects can be flown in daylight or darkness. They are often flown at night because it is easier to obtain flight clearances and because fewer cars are on the road during nighttime hours.

Weather conditions. LIDAR data is operationally considered an "all-weather sensor." The practical reality for most projects is that LIDAR data is collected during good weather conditions that are suitable for flying at lower flight altitudes.



CHAPTER 2

DATA CLASSIFICATION AND PROCESSING

When LIDAR data is collected, it essentially consists of timing data (often in a binary format) that needs to be correlated with navigation information (x, y, and z, and attitude information). This data must be processed to generate usable elevation products such as DSMs, DTMs, regularly gridded DEMs, and TIN. Further processing is required to generate contours and to produce intensity images. LIDAR data must also be processed to generate a listing of x, y, and z coordinates in American Standard Code for Information Interchange (ASCII) format.

The processing work typically involves the following:

- GPS/INS processing that correlates the timing information from the laser
- Classification and filtering activities that involve classification of vegetation and aboveground features as well as activities to compute x, y, and z coordinates for each LIDAR return (see Figure 2.1)
- Generation of surface products that includes creating various elevation products such as the bare earth surface model and intensity images in the required topographic model format (DEM, DTM, TIN, etc.) as shown in Figure 2.2

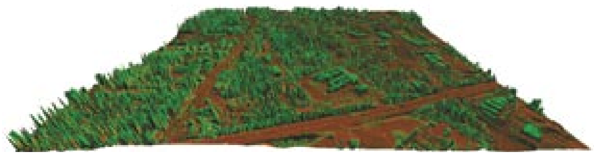


Figure 2.1. Vegetation, buildings, and other artifacts shown in green. ***Courtesy of Gwinnett County, Georgia***

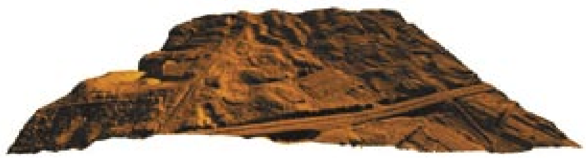


Figure 2.2. Bare earth. ***Courtesy of Gwinnett County, Georgia***

Descriptions of the major processing-related activities follow.

GPS/INS Processing

Processing activities occur during the flight mission and after the data acquisition has been completed. As part of the flight mission, processing activities include initializating the GPS system and flights over the data validation test sites.

This also involves preprocessing the data while in the field to make sure full coverage (no gaps) is obtained and that the quality of the data is sufficient. After each day's work, the data is typically downloaded and postprocessing commences. GPS data from the aircraft and multiple ground stations are processed together using sophisticated kinematic GPS postprocessing software.

Subsequent to GPS processing, INS data and GPS trajectory are combined using advanced filtering techniques. The outcome is a complete set of orientation information (x, y, z, and altitude) for sensor origin and output. Mass points (first and last return positions) are then computed using a combination of measured ranges, mirror-scan angles, and orientation information. Various calibration parameters are input at this stage, depending on the project requirements.

As part of the processing phase, additional adjustment activities may be performed. Adjustment techniques vary in sophistication depending on the application and size of the project. Techniques range from simple vertical translations of mass points to removing vertical bias to complex "block" adjustments that involve ties among strips, ground control, and modeling systematic errors on a time-varying basis.

Classification and Filtering: Surface Estimation

The large volume of data points generated by a LIDAR system poses a significant challenge in terms of data management and raw processing power. For example, 2 million to 500 million points typically are captured for a medium-sized county, depending on the final density.

With these large data sets, simply displaying or extracting information from LIDAR data sets can be demanding. Processing activities such as generating a TIN from a point file typically need to be performed using a subset of data. Data is typically partioned into tiles to facilitate the processing work. Tiles often correspond to 10,000' x 10,000' grids or may be based on United States Geologic Survey (USGS) 7.5-minute or 3.75-minute quadrangle subsections.

Classifying and filtering raw LIDAR data identifies and removes elevation points reflecting off vegetation, bodies of water, and man-made structures. Ground clutter, associated with features such as cars, is also removed as part of the classification process.

This processing work also includes interpolating points falling in void areas created by removing aboveground strikes.

Generation of Surface Products

Once the surface is created, a variety of products can be derived. Surface products may include the following:

- Gridded DEMs (regularly spaced, gridded DEM (e.g., one- or two-meter DEM)
- Mass-point files of bare earth
- Point files of elevated features (buildings, vegetation, etc.)
- Intensity images
- LIDAR-generated contours

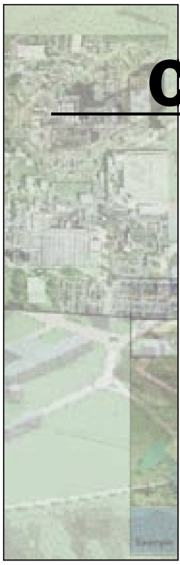
The products can be provided in a variety of GIS formats, in addition to the first and last return information.

Several types of surface generation, filtering tools, and methodologies are available. They include:

- Morphological filters
- Slope-based filters
- Direct (stereoscopic) editing of raw, classified, or filtered data (more time-consuming and costly)
- Hybrid approaches that combine various approaches

The exact methodology is a function of the accuracy required and the product to be produced. The direct or stereoscopic method of refining the surface model based on aerial photography is often the most time-consuming and costly approach unless it is also being produced for other purposes such as generating new orthophotos or updating planimetric information. Most of the local government GIS projects involve using slope-based filters that are combined with some form of surface estimation based on aerial photography or other photogrammetric sources.

Generation of surface products includes the creation of various elevation products such as the bare-earth surface model and intensity images in the required topographic model format (DEM, DTM, TIN, etc.).



CHAPTER 3

SUPPLEMENTING LIDAR DATA WITH BREAKLINES

Introduction

Breaklines are very important components of the DSM. A breakline is a linear line string that has elevation values attached to each vertex. Breakline line strings are different from contour line strings because each vertex may have a different elevation. Common breaklines include road crowns, tops of riverbanks, bottoms of drainage ditches, edges of pavement, ridgelines, tops and toes of retaining walls, building footprints, and lake shorelines. There are two types of breaklines. Hard breaks are abrupt changes in the surface (i.e., buildings, lake or ocean shorelines, dams, and culverts). Soft breaks are linear features that generally produce a rounded appearance to the contours during the interpolation process (i.e., road crowns and drainage centerlines). The frequency, type, compilation procedure, and complexity of the breaklines depend on the desired accuracy of the standard and data products. Figure 3.1 illustrates the general process of creating elevation data using photogrammetry.

Depending on the accuracy requirements, a specification may use a combination of 3-D and/or 2-D breakline technologies to supplement the LIDAR DSM. Because LIDAR point placement is random, elevation points do not always model steep slopes, retaining walls, culverts, roadside ditches, or hydrographic features. Therefore, breaklines are a necessary part of the process to achieve accurate contour results. Figure 3.2 shows a typical breakline line file in an urban environment. Notice how the raw contours are shaped around the breaklines. The brown lines are road crowns, the white lines are road edges, the

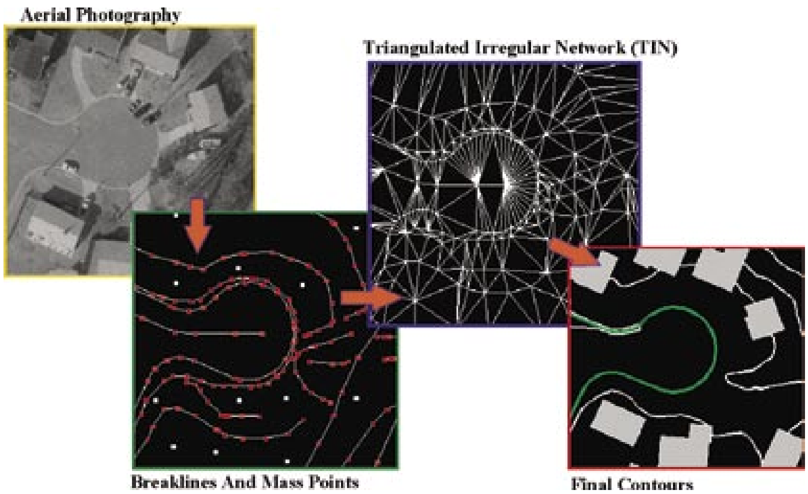


Figure 3.1. How a DSM is created using a photogrammetric process.

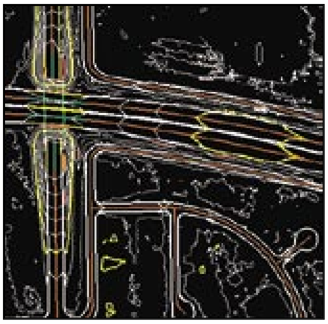


Figure 3.2. Breaklines and raw LIDAR contours in a typical urban environment.

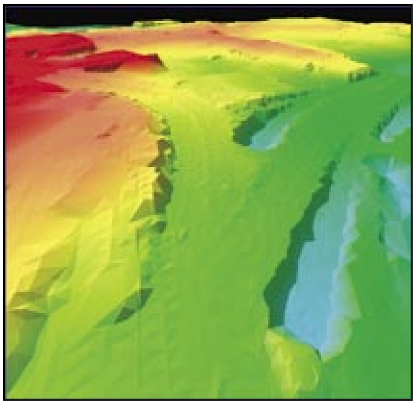


Figure 3.3. LIDAR without breaklines.

red lines are retaining walls, and the green lines are bridge features.

Figures 3.3 and 3.4 illustrate a 3-D representation of a LIDAR data set without and with breaklines. Figure 3.3 clearly shows the rough edges that are caused by the randomness of the LIDAR collection pattern. Notice that features such as the river channel and retaining walls are very jagged. Figure 3.4 shows that after breaklines were added, linear features such as retaining walls and river channels now have well-defined edges.

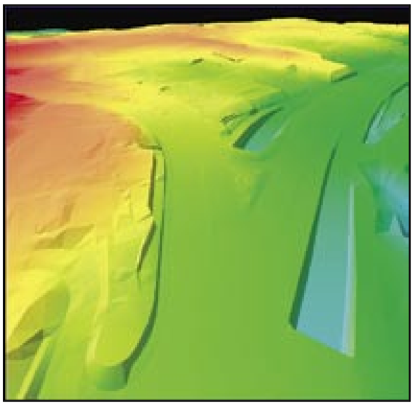


Figure 3.4. LIDAR with supplemental breaklines.

Moreover, the addition of breaklines dramatically improves the aesthetic appearance of contours. Without the presence of breaklines, contours may not correctly represent linear features such as road crowns and riverbanks. Figure 3.5 is a graphic of a LIDAR data set where breaklines were omitted during the contour interpolation process. Figure 3.6 illustrates the same LIDAR data set with breaklines used in the contour interpolation process. Notice how the hard breakline was used to define the water edge. This breakline was also used as a polygon to eliminate extraneous LIDAR returns within the surface of the lake.

The actual number and density of breaklines added to a DSM is significantly less, when compared to a traditional photogrammetric DTM, because the number of LIDAR points is hundreds of times denser. In the near future, as higher LIDAR pulse rates allow more points to be output on the ground, the number of breaklines may become even fewer than are needed today. However, discrete edges of some linear features will not be defined unless breaklines are added.

A final note: Breaklines can actually introduce errors into a LIDAR DSM, that is, breaklines incorrectly compiled in obscured areas or too close to a LIDAR point, etc., will cause major inconsistencies in the final surface.

Aerial Imagery Sources for Breakline Compilation

Breaklines can be compiled using either conventional film aerial photography or fully digital aerial collection systems. In some cases, satellite imagery sources may also be appropriate. The film and digital imagery should be captured in stereo for use in a photogram-

Figure 3.5. LIDAR contours without breaklines and smoothing. ***Courtesy of Marion County, Florida; Space Imaging; and Jones Edmunds & Associates***

Figure 3.6. LIDAR contours with breaklines and smoothing. ***Courtesy of Marion County, Florida; Space Imaging; and Jones Edmunds & Associates***

metric collection work flow of planimetric, ortho, and breakline databases.

The photo scale that is used is directly related to the accuracy of the final elevation product. Additionally, with the use of LIDAR, other factors found in the LIDAR flight plan (i.e., pulse rate, side overlap, field of view, etc.) will affect the final Ground Sample Distance (GSD). Specifications that desire a dense GSD may allow the photography scale to be higher than traditional photogrammetric specifications. In general, the denser the GSD (more points on the ground) and greater vertical accuracy of the DSM, the smaller the photography scale (higher flight altitude) that may be required.

Types of Aerial Film and Imagery

Aerial film comes in a variety of types. Depending on the application, a specification may require using a given type of film. For example, using color infrared (IR) is common when interpreting the condition of vegetation. The primary film types include panchromatic (black and white), natural color, color IR, and panchromatic IR. Figure 3.7 shows the same geographic area with all four types of film mosaicked.

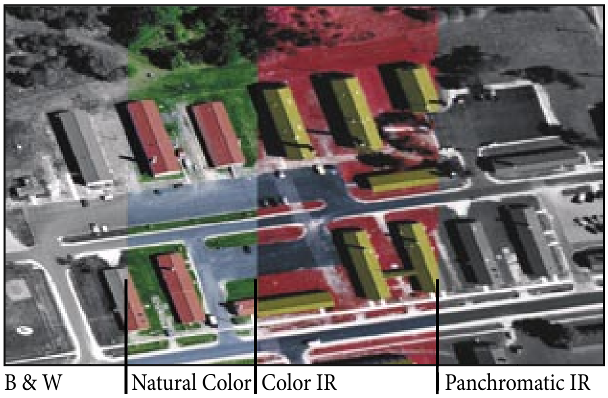


Figure 3.7. Types of aerial film.

Digital Imagery Sources

A rapidly increasing number of digital imagery options are becoming available. The advantages of using a digital source (compared to film) are many. For example, a digital aerial source allows quicker breakline compilation because the project area is collected in a digital format. That is, no scanning is required after collection of the target area. Several disadvantages of digital sources remain, however, such as lower resolution and loss of natural continuous tone progression (i.e., digital imagery already generalizes the photograph because the data is in a pixel format).

The following briefly highlights the major technologies presently available to the user community. This technology is constantly being upgraded, therefore, it is imperative that the user work closely with professional photogrammetric firms to determine an imagery solution that is best for a given project.

Leica Airborne Digital Sensor Imagery. The ADS40 is a digital linear array that collects panchromatic, color (RGB), and IR imagery simultaneously. ADS40 imagery can be used for both 2-D and 3-D breakline compilation. Digital ortho imagery produced from this technology reduces building displacement because the linear array collecting image data is almost at nadir. Recent advancements in this platform allow for 0.5' pixel resolution and sub 1' horizontal accuracy. Details concerning the ADS40 can be found at http://www.gis.leica-geosystems.com.

Zeiss Intergraph DMC® (Digital Mapping Camera). Similar to a film camera, the DMC® is a digital frame system. In fact, most flight parameters are very similar to a traditional film-based plan (i.e., side/forward overlap, altitude, etc.). Because most systems do not have onboard IMU, imagery taken from this system still requires traditional photo control and aerotriangulation methods for its orientation parameters. At this point, photogrammetric firms like this technology because it more closely matches their current "frame" work flow. Information concerning the Z/I DMC® can be found at http://www.ziimaging.com.

Vexcel UltraCam™. This is a large-format digital frame camera system, that is, the number of pixels involved is greater than with the other small-medium format systems currently on the market. With the addition of a high-accuracy Position and Orientation System, the UltraCam™ may become a cost-effective alternative to the more expensive digital camera/sensor solutions. UltraCam™ digital camera systems feature 12-bit per pixel dynamic range for panchromatic, color, and false color IR imagery. Product information concerning the UltraCam™ can be found at http://www.vexcel.com.

Small-Format Digital Cameras. The Emerge DSS™ and the Merrick DACS™ (Digital Aerial Camera System) are two examples of small-format (4k x 4k pixels) digital-imaging systems. In the past, these systems were cost-effective solutions for smaller project areas. Previous drawbacks to these systems have been that the "footprint" or area covered by a single frame is four or five times smaller than that of traditional film negatives. Because of advancements in image postprocessing, however, handling the large number of frames taken from a small-format system is no longer an issue. Because of their small physical size, these systems can be installed in the same aircraft as the LIDAR unit. Therefore, imagery can be collected simultaneously with the LIDAR mission, which is beneficial for flight economics, and provides cohesive image and LIDAR data sets. Product information concerning the DSS™ and DACS™ systems can be found at http://www.gis.leica-geosystems.com or at http://www.merrick.com/servicelines/gis/lidar.aspx, respectfully.

USGS Digital Ortho Quarter Quad (DOQQ) Imagery. The USGS DOQQ program offers one-meter pixel resolution throughout most of the United States. Using this source of imagery is limited to 2-D breakline collection. The advantages of this imagery source are that archive coverage is readily available and the imagery is relatively inexpensive. The major disadvantage of using the DOQQ for 2-D breaklines is the imagery is not taken at the same time as the newer LIDAR elevations. Furthermore, most imagery is two to five years old. This causes a major problem with water elevations, geometry of rivers, and newer planimetric features. Information on the national DOQQ program can be found at http://geography.wr.usgs.gov/doq.

Satellite Imagery. Satellite imagery can be a very cost-effective source for lower-accuracy breakline compilation and digital orthos, especially over extremely large areas (i.e., entire countries). DigitalGlobe, OrbImage, and Space Imaging are a few of the major providers of satellite imagery. Satellite companies have archive data sets available for immediate purchase, or project areas can be scheduled for new acquisition. Breaklines can be compiled mostly in 2-D using satellite imagery; however, some companies are releasing their sensor models to photogrammetric firms so that satellite imagery can be viewed in stereo at a softcopy workstation.

LIDAR Intensity Imagery. In certain cases, digital or film aerial photography may not be practical for a given project. In these cases, a photogrammetrist may use the intensity returns from the LIDAR as the source for breakline compilation. The intensity is a grayscale image that measures the reflectivity of objects on the ground. Intensity images have the same positional accuracy characteristics as the LIDAR data. Each LIDAR "shot" has an attribute stored as a grayscale value between 0 and 255. For example, objects such as white sand and tin roofs exhibit high reflectivity. Techniques and automated extraction processes for using intensity returns are still in development; however, once perfected, this will become a viable source for breaklines and ancillary data. Figure 3.8 is a LIDAR intensity image. Notice how the edges of pavement, paint stripes, and building footprints are well defined.

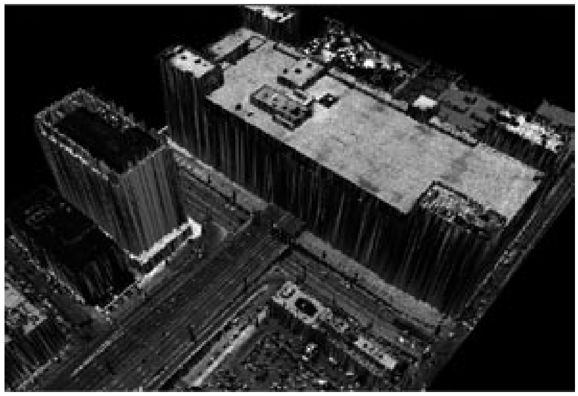


Figure 3.8. 3-D perspective image of a LIDAR intensity scene in downtown Denver, Colorado.

Breakline Collection

Supplemental breaklines can be compiled using a variety of techniques, software, and equipment. This Guidebook does not support any method, vendor, or software. URISA's objective is simply to inform the user community of some of the more popular and proven methods currently being used by photogrammetric firms. Because advances in procedures and software are occurring rapidly, a qualified photogrammetric consultant should be contacted for current procedures and technologies.

Depending on the accuracy requirements, any combination of 3-D and/or 2-D breakline technologies can be used to supplement the edited LIDAR DSM. In general, when a 2-D compilation method is used, the photogrammetrist is digitizing breaklines from a digital orthophoto. Elevation attributes for the 2-D breaklines will be added to the breaklines using the densified LIDAR surface in a process called draping. Conversely, the 3-D approach takes advantage of the photogrammetric stereo work flow to compile the breaklines in conjunction with the DSM. Features that are "elevation sensitive," such as retaining walls and bridges, are typically compiled using traditional stereo photogrammetry (3-D). More frequently, however, in both 2-D and 3-D methods, the breaklines are being integrated to create the final LIDAR surface. Independently captured breaklines will cause many instances of conflicting and erroneous contour data. The following is a summary of the 2-D and 3-D breakline compilation concepts. Additionally, depending on the specifications, each compilation procedure can be used to create hard and soft breakline types.

2-D Breaklines from Orthophoto Imagery

Supplemental LIDAR breaklines can be effectively and economically compiled using a 2-D approach. The process begins by using a digital ortho of suitable resolution and horizontal accuracy to be able to interpret the breaklines. Skilled photogrammetrists next determine where breaklines are required by "reading" raw contours created from the edited LIDAR DSM. That is, if the DSM adequately defined a given feature, the photogrammetrist may not add a breakline. Adding breaklines to only those areas needing more definition takes advantage of the LIDAR accuracy and dense GSD, and is more economical. Some specifications, however, may require that breaklines be added on all traditional breakline features regardless of whether the DSM adequately defined them. This approach is obviously more expensive; however, some clients are more comfortable with more breaklines. If this is the case, an additional step is required to eliminate conflicting LIDAR and breakline points that are too close together. If this is not accomplished, the TIN will exhibit many small and erroneous triangles.

A key part of the 2-D process is transferring the LIDAR elevations to the newly compiled breakline. This draping process begins with the LIDAR DSM "normalized or densified" to a grid size appropriate to the accuracy specification of the given project. For example, a DSM that was collected at a nominal spacing of 6 feet may be normalized to a 2-foot posting. This will allow LIDAR elevations to be transferred to the 2-D breakline at a much higher frequency along the breakline.

As previously stated, the source imagery for the breaklines needs to be of a similar vintage to the LIDAR data so that compiled breaklines and LIDAR elevations match. The surface elevation of water bodies and shoreline geometry are examples of problems that occur if the LIDAR and image source are not taken in a close time frame.

The limitations of a 2-D approach are as follows. The 2-D elevation product will not yield a National Map Accuracy Standard (NMAS) or American Society for Photogrammetry and Remote Sensing (ASPRS) contour accuracy without supplemental DTM (spot elevations and breaklines) development using a traditional photogrammetric 3-D compilation approach. The three major problem features are individual spot height (i.e., at road intersections), breakline features obscured by building displacement, and large retaining walls (because the top and toe of a vertical wall cannot be measured in 2-D). Supplementing collection of these features using the 3-D photogrammetry approach typically mitigates these limitations.

While not a true large-scale map accuracy contour product, the advantage of the 2-D breakline approach is that it yields elevation data that is sufficient for hydrologic analysis. If performed correctly, the 2-D approach offers proper connectivity and flow for significant hydrographic surface features such as rivers, lakes, drainage ditches, etc. Additionally, hybrid accuracy standards can be developed for contours that use this approach. In most cases, contours derived using the 2-D methods conform to accuracy standards except for the previously mentioned limitations. However, if a hybrid contour accuracy is being used, detailed metadata attributes must accompany the data.

One example of a 2-D breakline approach is the Marion County, Florida project. The LIDAR work was a portion of a countywide asset management project being completed by Space Imaging and Jones Edmunds & Associates. An ALS40/50 LIDAR sensor was utilized by Merrick & Company to collect elevation data over a 1,600-square-mile project area. The GSD for the project was less than 6 feet. The flight altitude for this project was 1,400 meters; the side overlap was 30 percent; and the scan field of view was 15 degrees each side of the nadir. These collection specifications allowed the individual elevation points to be suitable for 1-foot contour accuracy. The

Figure 3.9. The 2-D breaklines in the Marion County, Florida project mosaicked on digital orthophotography created using an ADS40 digital camera. ***Courtesy of Marion County, Florida; Space Imaging; and Jones Edmunds & Associates***

LIDAR point accuracy will be 0.25 foot Root Mean Squared Error (RMSE) to a 90 percent confidence level when compared to unobscured, hard-surface surveyed checkpoints.

The 2-D breaklines were compiled using an ADS40 digital camera and color digital orthos. The pixel resolution of the digital orthos used for breaklines was 1'. The horizontal accuracy of the digital orthos was ±1.75'. The Marion County, Florida project LIDAR collection parameters, 2-D breakline approach, and postprocessing methods allowed the hybrid 1' contour accuracy to be met. Figure 3.9 illustrates an example of breaklines being added using the 2-D approach.

3-D Photogrammetrically Derived Breaklines

Breaklines can also be added to a LIDAR DSM using softcopy stereoplotters. This process views aerial photography in stereo (3-D) with the edited LIDAR data superimposed. The biggest difference between the 2-D and the 3-D approach is that the collection of some highly elevation-sensitive breakline features can only be mapped when viewing in stereo. The primary features include large retaining walls, buildings with a large amount of displacement (lean), culverts, and bridges.

Because it is virtually impossible to view all the individual LIDAR points, most photogrammetrists superimpose preliminary contours created from the DSM. As with the 2-D approach, a skilled photogrammetrist interprets the preliminary contours then determines where breaklines need to be compiled.

Additionally, when compiling linear features such as stream edges, most LIDAR compilation software will maintain a "positive flow" and snap to the underlying LIDAR DSM. This procedure takes advantage of the accuracy of the densified LIDAR points and guarantees stream flow in a downhill direction. For ponds or lakes, a fixed elevation is placed on the breakline polygon with removal of LIDAR points inside the polygon (so the pond or lake has one elevation attribute). This process should be used in both 3-D and 2-D compilation approaches.

Breaklines must not be compiled independently of the DSM. If this occurs, the contours and DTM that are created, once the two data sets are merged, will contain many conflicts. Photogrammetrists who are new to LIDAR make this typical mistake. Figure 3.10 is an example in Florida where an unskilled photogrammetrist merged an independently compiled 3-D breakline with a DSM. Notice how the data disagrees throughout the tile.

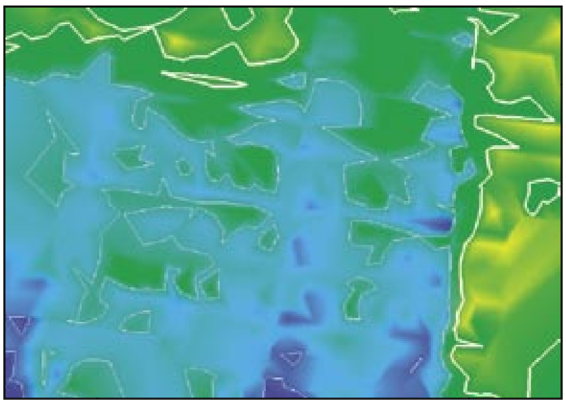


Figure 3.10. Clearly shows how 3-D breaklines independently merged with a LIDAR DSM cause erroneous TINs and incorrect contours.

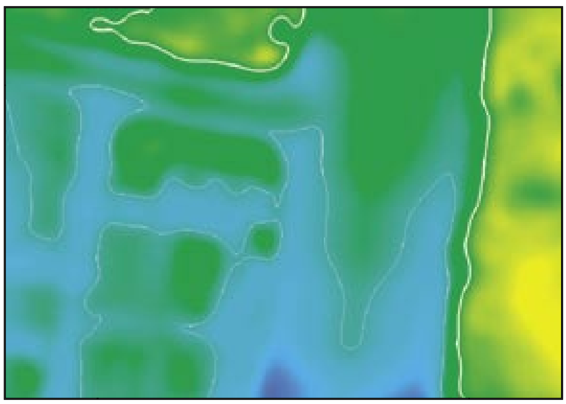


Figure 3.11. Contours and DSM developed using an integrated 2-D breakline approach, which uses the LIDAR elevations during compilation. This is the same area as in Figure 3.10.

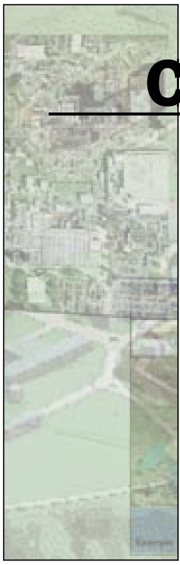
Breaklines from Existing GIS Data Draped Over LIDAR Data

In some cases, existing 2-D planimetric and/or 3-D breakline databases may already exist and can be incorporated into the LIDAR DSM. This process can produce accurate and aesthetic results if the existing data was created at a compatible specification with the desired LIDAR and contour expectations.

The first step to integrate existing data into a LIDAR DSM is to update this information. This is accomplished by acquiring new aerial photography (either digital or film). It is preferable that the new photography is acquired in a time frame that is close to the LIDAR acquisition. The photogrammetrist then completes the change detection to determine which features have changed since the time the existing data was compiled. After the change detection takes place, the photogrammetrist then makes the physical changes to the planimetry and breaklines so that these databases represent what is present on the new aerial photography. Using either 2-D, 3-D, or a combination of both methods can accomplish this process.

Following the update compilation, LIDAR elevations are added to these new breakline features using a draping method. Even though the breaklines where collected independently, the draping process assigns LIDAR elevations to the breaklines (see Figure 3.11). Additionally, some LIDAR data that is too close to the breakline is removed, thus eliminating any conflicting data. Now that the breaklines have LIDAR elevation attributes, they can be used for either modeling and/or contour applications.

An example of this approach being successfully deployed can be found in the Cook County, Illinois project. The previously mentioned breakline compilation process was used to create a two-contour DTM from LIDAR. This process saved the County a considerable amount of money by taking advantage of its existing planimetric data resources. The existing data used the most was the numerous buildings and roads in the Chicago portion of the project. Updated features included rivers, creeks, lakes, and some roads.



CHAPTER 4

TYPICAL DELIVERABLE PRODUCTS AND FORMATS

Introduction

LIDAR data can be delivered in a variety of products and formats that can be imported into most engineering, modeling, planning, and GIS software. LIDAR data may contain one or more classifications of data. Raw LIDAR data is a single class that typically represents all the returns for each laser shot. Classifications are created during the filtering process mentioned in Chapter 2, *Data Classification and Processing.* Most projects will contain a minimum of two classes: ground and canopy. Other classifications include intensity, breakline points, building points, transmission line points, etc. These classifications can be considered as attributes for a given point.

This chapter will briefly review a few of the major formats and products currently being provided. These products are expanding rapidly as more and more software companies take advantage of the full capability of LIDAR data.

Examples of Classified Data

LIDAR data can be interpreted and attributed into a large number of classifications. Some of the reclassification of the original LIDAR points can be accomplished automatically. Most final classifications, however, involve either supervised automation or manual interpretation. Figures 4.1 through 4.5 illustrate applications using classified LIDAR data.

Delivery Formats

LIDAR data can be delivered in a variety of formats, including .las, TIN, Grid, ASCII, Shapefile, and contours. Other formats are available; however, these are the primary ones that can be readily used with most applications.

.las. The .las format is an industry-accepted standard for storing all applicable LIDAR attributes. At this point, most of the larger LIDAR sensor manufacturers have embraced this data format. This format efficiently stores LIDAR attributes in a binary format. In general, these attributes include GPS coordinates, IMU orientation data, and a host of data that allows the x, y, and z to be computed (scale factors, projection, offsets, etc.). An advantage of the .las format is that all the final classified attributes are stored in one database table, thus allowing users to possess a single file with many views and analysis possibilities.

An ASPRS LIDAR subcommittee has created a more detailed description of the characteristics of the .las

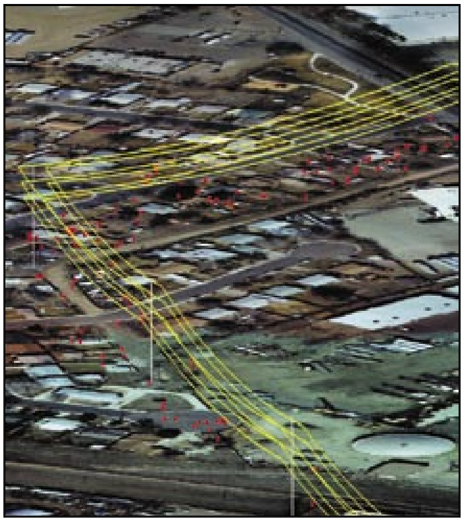


Figure 4.1. LIDAR data that has been reclassified to power lines, power poles, and potential intrusion zones. ***Courtesy of Xcel Energy***

Figure 4.2. A LIDAR intensity data set.

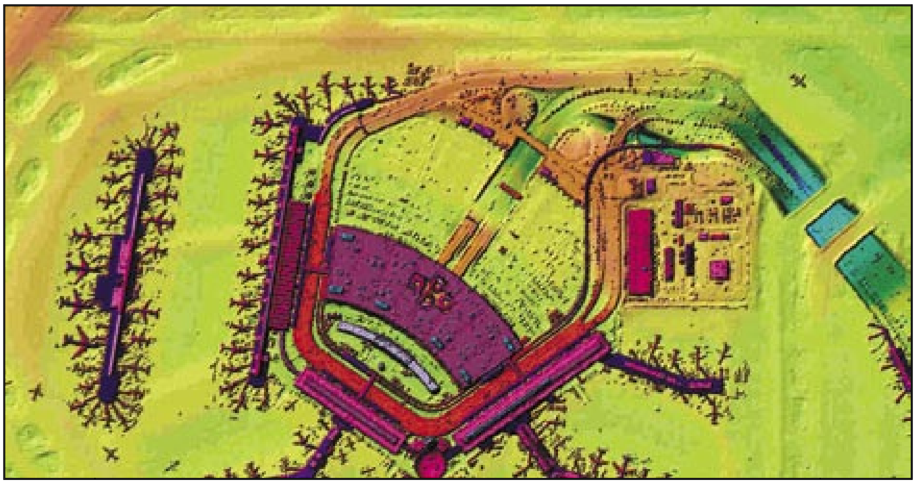


Figure 4.3. Illustration of final bare earth and aboveground classifications at Chicago's O'Hare Airport.
Courtesy of the Cook County Office of Technology

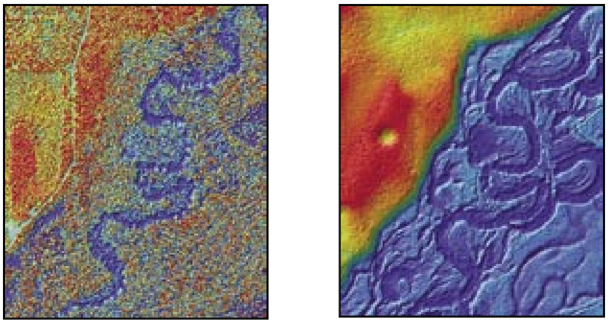


Figure 4.4. Illustration of the all-returns data is on the left. Notice that the tree cover prevents interpretation of the drainage systems. The final bare-earth model is illustrated on the right. Notice the amount of detail in the drainage systems that the LIDAR and advanced filtering processes were able to create. This example is located in Tallahassee/Leon County, Florida. *Courtesy of the TLC GIS Consortium*

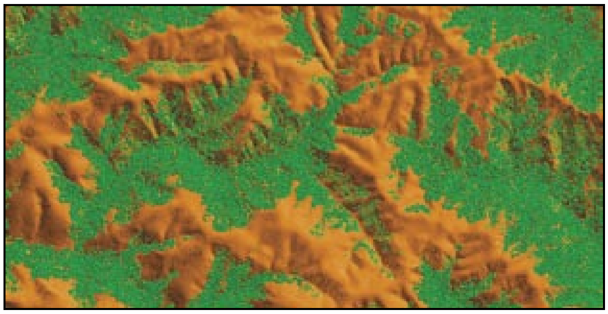


Figure 4.5. Bare earth (brown) and tree canopy (green) LIDAR data. This example is located within the Southern Alameda County Water District, California. *Courtesy of the Southern Alameda County GIS Consortium*

format. A downloadable document can be found at http://www.asprs.org.

Triangulated Irregular Network (TIN). TINs are a set of triangles that are created when connecting points in a DTM. Depending on the type of DTM point (i.e., breakline or mass point), the "legs" of each triangle must conform to very rigid rules. For example, no triangle will ever overlap and some legs of the triangle have "more important relationships with the adjacent triangle" (i.e., at breaklines). The TIN process is used during the contour procedure termed contour interpolation (CIP). TINs can be automatically generated and exported by most LIDAR-processing software. Once the TIN is created, all the primary mapping software, including Autodesk, ESRI, and Intergraph, can incorporate this type of elevation data in their work flows.

Grids. Grids are regularly spaced sets of elevation cells that have an elevation attribute stored at the centroid of each cell. The resolution of the cell size (or grid) depends on the application or accuracy standards that are required. LIDAR data is often put into a grid to "smooth" the data; however, precautions must be taken not to generalize the inherent quality or accuracy of the original randomly spaced points.

American Standard Code for Information Interchange (ASCII). This format is a method of delivering LIDAR elevations that typically stores a unique point ID, x, y, and z that are separated with a common delimiter. Several limitations and problems are associated with using this format. Because each LIDAR elevation point has multiple attributes associated with a single point, there are several ways to export into ASCII. The first method is to have multiple ASCII files created for each classification (i.e., bare earth, canopy, etc.). The second option would be to take advantage of the attribute field that could store LIDAR classifications.

Shapefile. Shapefile, an ESRI ArcInfo format, is useful for storing several types of data. The shapefile is constructed to draw relatively fast and is easy to edit. Shapefiles are good ways to store and deliver breakline, mass point, and classified LIDAR data. A shapefile has an attribute field that can easily store each classification of LIDAR data.

Contours. Contours can be interpolated from LIDAR elevation data following the compilation of breaklines. Contours created from LIDAR data represent a very accurate but somewhat different graphic appearance (when compared to those generated using string or DTM methods.) That is, because the number of elevation points is 10 to 20 times denser, contour interpolation software has more information available to create a representation of the surface. Contours interpolated from LIDAR tend to be more "jagged" in appearance unless appropriate smoothing routines are applied.

GIS Database Designs for LIDAR Data. Most GIS software companies are creating database models that accommodate the complex LIDAR attributes. Development by the major companies will intensify as LIDAR becomes the most popular method for creating elevation databases.

Personal Geodatabase Design. Personal geodatabases can be provided in proprietary or other custom database formats. These database structures are somewhat generic in format and may provide the client maximum flexibility with the comprehensive LIDAR data sets provided with the capability to export to numerous other database designs. The following is an example of how topographic data can be stored in a GIS system. This example comes from the Cook County, Illinois LIDAR project:

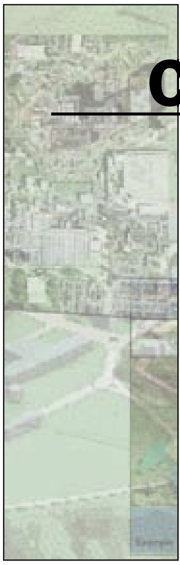
- DTM—Feature data set containing the digital surface data compiled from the 2003 LIDAR mission
- Breakline—This line feature class contains breaklines classified into one type, i.e., TYPE = 1. The type determines how they will be used in creating a TIN surface. This feature class is Z-enabled.

Fields:

- OBJECTID—internal record identifier
- SHAPE—geometry. Line
- SHAPE_Length—internal feature length value. Double
- ModelKeyPoint—This point feature class contains all mass and thinned LIDAR points defining the ground surface. This feature class is Z-enabled.

Fields:

- OBJECTID—internal record identifier
- SHAPE —geometry. Point
- X_COORD—x-coordinate. Double
- Y_COORD—y-coordinate. Double
- ELEVATION—z-coordinate. Double



CHAPTER 5

QUALITY CONTROL

Introduction

Because LIDAR data can be influenced and rendered less accurate in numerous ways, it is important to understand where error is likely to be introduced and how various types of error can be identified. The purpose of this section is to briefly summarize the major types of LIDAR error sources. Once a potential error source is identified, a variety of methods can be used to test if an error has occurred. The LIDAR professional and the client must be aware of the many error sources and must have a plan to validate that the data conforms to client specifications.

Also discussed in this chapter are several surveying procedures that can be used to assess the positional accuracy of LIDAR data sets. A summary of validation techniques used to check the overall quality of the data set as well as quantify accuracy in heavily vegetated areas of a project can also be found in this chapter under the headings "Keys to a Successful LIDAR Project" and "Current Industry Accuracy Standards."

Potential Sources of Error

Because a LIDAR project involves the synchronization of many technologies, it is important to be aware of the stages of a project where error can occur. Every stage from planning to delivery has potential error opportunities. Error at any stage of the process can adversely affect the overall accuracy of the LIDAR data. The following is a list of the primary areas of a LIDAR project where error can be introduced:

Planning:

- Incorrect project boundary
- Wrong horizontal or vertical datum
- Conversion and translations
- Ground sample distance inadequate to meet accuracy expectations
- Flight line breaks because of extreme elevation change
- Beam width too small or too large
- Pulse rate and/or scan rate not correct for desired flying altitude and vertical accuracy
- Field of view too wide for adequate penetration in vegetation
- Lack of adjacent overlap could cause data "holiday" (missing data)
- Inadequate project procedures and documentation
- Poor communication with internal and external clients

- No field and office data management plan
- No quality control and ground-truth plan
- No eye safety plan

Ground Support:

- Erroneous reference station (horizontal or vertical)
- GPS baseline distance too long
- No redundant GPS receivers in case a receiver malfunctions
- GPS base station problems (not enough satellites, incorrect antenna-height measurement, battery failure, vandalism, etc.)
- Postprocessing error (poor constraint network, lack of local control knowledge, datum transformation, etc.)
- Operator error

Airborne LIDAR Acquisition:

- Wrong navigation input (incorrect coordinate system)
- Laser malfunction
- IMU malfunction
- AGPS problem (onboard antenna offset or system failure)
- Premission and/or postmission calibration not performed
- Aircraft electrical problem
- Operator error

LIDAR Postprocessing:

- Incorrect office boresiting
- Application of wrong horizontal and vertical survey adjustments
- Incorrect Calibration of each flight line to adjacent lines
- Breaklines not referencing the LIDAR data during compilation

Validation Methods

After each flight line and mission day is fully calibrated, several methods can be employed to validate that the LIDAR data is going to meet the predefined specifications. A few of the more common approaches will be summarized in this chapter. These include individual checkpoints, cross sections, ground-truth surveying, and existing data.

The location and number of survey checkpoints, as well as the methodology, will vary for each project. Survey points should be strategically located in the overlap area of each LIDAR flight line and in different mission days. This procedure places the independent checkpoints where there is a greater chance of systematic error occurring.

Individual Checkpoints. Individual checkpoints are single locations with valid horizontal and vertical locations. A variety of methods can be used to create an individual checkpoint. The most common method is GPS. Because GPS requires an open horizon to the sky, the locations of individual checkpoints must be in areas void of large trees or buildings. Individual checkpoints are relatively inexpensive if Real Time Kinematic (RTK) GPS is used because the procedure is fast and accurate.

Individual checkpoints can also be marked before the LIDAR mission so they may be visible in the intensity data. This procedure is useful to check horizontal accuracy. The reflectance property of the premarking material must be high enough to obtain suitable results. Additionally, the GSD and physical size of the premark need to be examined, that is, the premark has to be large enough so the random LIDAR collection has a chance of actually "hitting" the premark. Premarks that are large squares offer good potential for obtaining reflectance values.

If Fully Analytical Aerotriangulation (FAAT) was completed for the photogrammetry portion of the project, individual "pug" and "pass" points may be used to make a cursory inspection of the DSM. An advantage of using the FAAT results is that an extremely large number of points are regularly spaced throughout the project because of the triangulation process. This approach cannot be used to accept or reject the DSM because the triangulation results will most likely be less accurate than the DSM results. Another advantage of this approach is that it offers a blunder validation procedure for both the LIDAR and aerotriangulation.

Cross-Sections or Survey Breaklines. Cross-sections, which are created using vertical survey level technology, are strings of elevation points. This method is typically used in heavily vegetated areas to test the behavior of the LIDAR under vegetation. Cross-section surveys are more expensive than GPS surveys because the leveling procedure is more time-consuming and the locations are typically in hard-to-access places. Although their cost is expensive, cross-section quality-control methods should be included in every LIDAR project.

Area Surveys. Area surveys allow verification over a larger area. Two examples of area surveys are engineering as-built drawings and construction design surveys. The advantage of this approach is that engineering surveys are typically performed to a high level of horizontal and vertical accuracy. They are usually very comprehensive because they include many ground features (i.e., walls, culverts, and curbs). Additionally, the elevation data is generally surveyed to a higher standard than is any LIDAR project. A disadvantage could be that the area survey is on a different datum or the LIDAR data may have been flown after construction occurred.

Ground-Truth Surveying. Ground-truth surveying is usually performed during or following the LIDAR mission. The primary purpose of this type of validation surveying is to assist the user in determining how accurate the contour and elevation data are in obscured areas. This step is very important, for the LIDAR data sets are typically held to a higher standard than is a traditional photogrammetrically compiled DTM. That is, the photogrammetric DTM in obscured areas (heavily vegetated where elevations cannot be compiled) is generally held to an accuracy standard of ±½ the height of the vegetation creating the obscured situation. Therefore, in a dense forest where the tree height is 80 feet, the contour accuracy for a photogrammetric DTM would have to meet a ±40-foot accuracy standard.

In general, two approaches can be employed for using this survey information. The first is to simply quantify the vertical accuracy of the DSM before and after filtering. The second is to actually utilize the ground-truth survey points in an adjustment of the DSM before interpolating contours. The first approach is more common; however, as LIDAR postprocessing techniques advance, the second approach (in combination with the first) will also be used.

The technique for a ground-truth accuracy assessment typically includes surveying individual points and cross-sections in a wide range of land-use and land-cover classifications (under trees, marsh, low ground cover, urban areas, etc.). Because the surveying is conducted in heavily vegetated areas, digital levels are commonly used to collect the ground-truth elevations.

An example of ground-truth surveying took place during the Tallahassee/Leon County (TLC), Florida LIDAR project. The TLC stakeholders knew that LIDAR would produce more accurate elevation data when compared to their traditional photogrammetric DTMs. However, they needed a method to quantify this increased accuracy obtained from using LIDAR. TLC worked very closely with its photogrammetric consultant to create the ground-truth plan.

The plan consisted of analyzing more than 12 land-use and vegetation classification categories to demonstrate laser and filtering performance. Table 5.1 shows the results of a ground-truth survey by primary vegetation classification. These results clearly indicate that the conservative LIDAR collection and postprocessing procedures yielded excellent results in each vegetation class that was tested in the ground-truth study. Moreover, the ground-truth study gave the TLC users quantifiable accuracy statistics that could be used when working with the data.

	Grass	Hardwood	Live Oak Hammock	Mixed Pine/ Hardwood	Open Pine	Pine	Sand Pine	Sand	Shrub
RMSE	0.69’	0.63’	0.41’	0.81’	0.58’	0.58’	0.68’	0.92’	0.69’
Ground-Truth Points	262	31	25	171	64	89	25	31	119

Table 5.1. Results of the TLC ground-truth survey.

Please note that these results are unique to the TLC project because of the LIDAR flight plan used, that is, the specific collection techniques such as flying altitude, very narrow field of view, side overlap, high pulse rate, as well as postprocessing procedures, all affected the accuracy results. However, the photogrammetric firm that completed the TLC ground-truth analysis is creating a database of ground-truth results for all its LIDAR projects. The firm’s goal is to be able to model the behavior of LIDAR and filtering techniques in specific vegetation and land-use types. These types of advanced databases, in conjunction with research being performed by universities and manufacturers, will ultimately provide the user community with valuable information concerning the performance of LIDAR in heavy vegetation.

Cook County, Illinois was the site of another project where ground-truth surveying was used. Prior to beginning the survey, the project team consulted many sources to determine the locations of various land-use and land-cover classes. (This is an important step in the ground-truth process.) In Cook County, one of the sources was an existing study called the *2000 Atlas of Biodiversity*. Although the data and maps were generalized, this gave the project team a place to begin to select specific locations for the accuracy-assessment survey. If there is limited land-use and land-cover data available for a specific project, several national databases can be used. One common database is the National Land Cover Dataset (NLCD) published in 1992. This land-cover classification system is available online at http://www.epa.gov/mrlc/definitions.html.

Existing Control and Contour Databases. An economic way to obtain data to validate a LIDAR data set is to conduct “data mining” within the project area. In most cases, one can find existing data to perform some level of validation. Issues associated with this approach are many; however, the characteristics of the existing data are completely understood. This is an inexpensive source of data for checking LIDAR data. This data can be individual points, area surveys, photogrammetric mapping, or cross-section surveys.

Items to review before using the existing data include the following (most of this data should be in the metadata files of the existing databases):

- Area coverage
- Vertical datum
- Horizontal datum
- Special horizontal or vertical adjustments
- Elimination of lower accuracy data in obscured areas (if photogrammetric)
- Obtaining compilation or field-survey collection procedures documentation

Keys to a Successful LIDAR Project

Important points to consider when attempting to conduct a successful LIDAR project include:

- Understand the mapping requirements and the purpose for completing a LIDAR project. If the project has a clear set of objectives, its outcome will be measurable and successful—for example, when a GIS manager in local government knows who the internal clients are and how LIDAR data will enhance their business operations.
- All LIDAR companies and equipment are not created equal. Utilize a Qualification-Based Selection (QBS) process to select a LIDAR consultant. Price-based selection has caused some firms to cut corners to lower cost. When this hap-

pens, offshore labor is typically employed, critical procedures are excluded, and older equipment is used. All these shortcuts add risk to a successful LIDAR project.

- Hire a photogrammetric firm that owns a LIDAR sensor. Subcontracting LIDAR services can be risky because a user has little control over the planning, collection, and validation of the databases.
- Include a detailed quality control and acceptance plan in every project. This plan allows the user to understand how he or she will receive the data, schedule the review, inspection processes, and issue notification, and establish the data-acceptance criteria.
- Dedicate the appropriate amount of management and technical resources to the project.
- Know exactly how the quality control is going to be performed by the consultant. This includes the procedures performed during acquisition, surveying, postprocessing, data delivery, etc.
- Understand the differences in LIDAR technology. The age of the sensor, pulse rate, roll compensation, and field of view are unique to each system. Each of these sensor characteristics could add or detract from meeting a project's objective.
- Determine (and be very clear on) which accuracy specification is going to be adhered to (i.e., ASPRS, NMAS, National Standard for Spatial Data Accuracy (NSSDA), etc.). Do not "mix and match" accuracy standards and terminology. Hybrid accuracy standards should be used only as long as extremely detailed metadata and documentation are available to clearly explain the accuracy results.
- Do not exclude ground-truth surveying from a project for it is very important for a user community to know the accuracy of the LIDAR databases in areas where dense vegetation and/or tall buildings may influence the accuracy results.
- Request a LIDAR flight plan in the Request for Qualifications (RFQ) that clearly demonstrates the consultant's understanding of the acquisition issues. The plan should address covering the project area, side overlap percentages, eye-safety requirements, flight line breaks caused by extreme elevation change, multiple-pass areas over very tall buildings, etc.

Current Industry Accuracy Standards

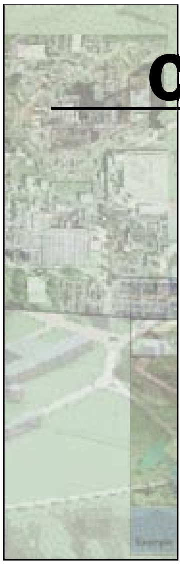
Several accuracy standards are available for users as reference when planning a LIDAR project. The problem is that most of these standards do not specifically address LIDAR. Following are several documents and professional organizations that address LIDAR accuracy. The ASPRS document specifies the vertical accuracy reporting requirements when analyzing elevation data generated using LIDAR; however, if conflicts exist between documents, the NSSDA document takes precedence.

ASPRS Guidelines Vertical Accuracy Reporting for LIDAR Data. These ASPRS guidelines are available online at http://www.asprs.org/asprs/society/committees/lidar/lidar_frame.html.

Guidelines for Digital Elevation Data (Version 1.0) released by the National Digital Elevation Program (NDEP). The NDEP guidelines are available online at http://www.ndep.gov.

The Federal Geographic Data Committee (FGDC) is an interagency committee that created the NSSDA. This set of guidelines is available online at http://www.fgdc.gov/standards/standards.html.

The United States Geologic Survey (USGS) publishes an accuracy standard called the NMAS, which is available online at http://rockyweb.cr.usgs.gov/nmpstds/nmas.html.



CHAPTER 6

LIDAR APPLICATIONS

LIDAR data is being used for a wide variety of environmental, transportation, and land-planning and analysis applications. Virtually any application that involves using terrain information can be enhanced with LIDAR data. Typical applications are briefly described in the following sections.

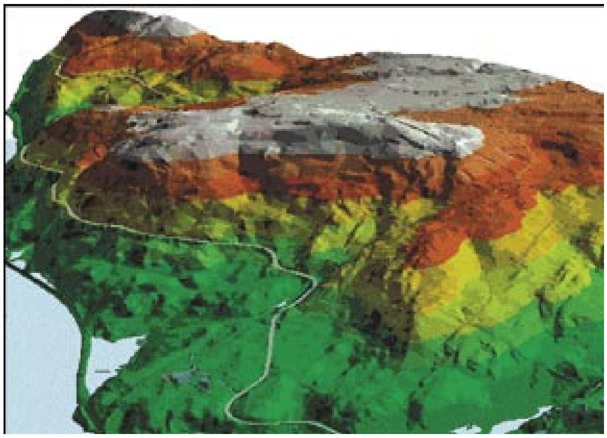


Figure 6.1. Planimetric features draped over LIDAR data and DTM. ***Courtesy of Westchester County, New York***

Contour Mapping

LIDAR data can be used to create a DSM upon which contours are generated. Contour generations at the 2-foot, 4-foot, and one-meter intervals are commonly produced using LIDAR data. Depending on the accuracy standards, cartographic requirements, and the final applications, breaklines should be added to the LIDAR data to support the contour generation process. See Chapter 3, “Supplementing LIDAR Data with Breaklines,” for an in-depth discussion.

3-D Perspective Analysis

Planimetric features can be draped over the LIDAR data and DTM (see Figure 6.1) to provide tools for 3-D analysis and display application.

Floodplain Mapping

Accurate, high-resolution LIDAR data is being used to support floodplain mapping and enhancement applications. The detailed elevation information is used throughout the floodplain modeling process. Major floodplain mapping programs such as the one under way in the State of North Carolina (see Figure 6.2) rely extensively on LIDAR data as input to support the floodplain delineation process.

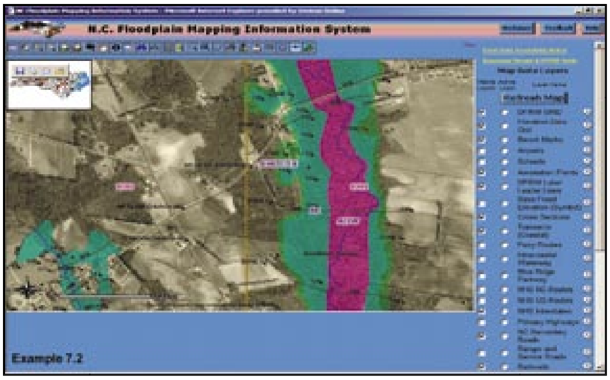


Figure 6.2. Floodplain mapping. ***Courtesy of N.C. Floodplain Mapping Program; www.floodmaps.com***

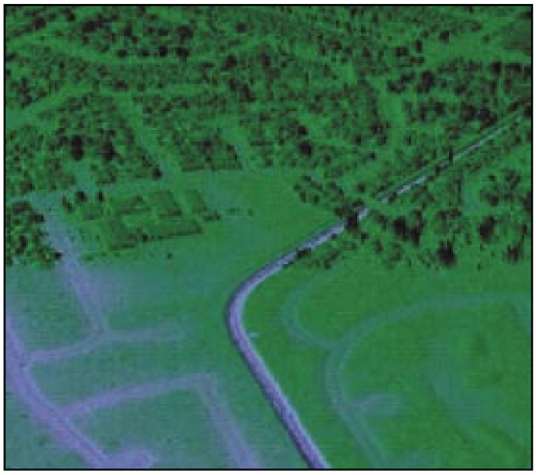


Figure 6.3. Vegetation mapping. ***Courtesy of Airborne1***

Vegetation Mapping

LIDAR data can be used to determine vegetated and nonvegetated areas. Increasingly, LIDAR data is being employed to measure tree-canopy coverage and to estimate timber volumes for forested areas. Once LIDAR vegetation point clouds are classified, they can be converted to a vector format. Instead of photogrammetrically compiling tree canopy, the LIDAR data combined with image-processing tools can be used to map vegetated areas as shown in Figure 6.3.

Shoreline Analysis

LIDAR data is being used for shoreline analysis along coastal areas and to support environmental analyses related to coastal erosion, sediment transport, and vegetation areas. LIDAR is also being employed to define shoreline effects associated with sea-level change, for example, determining the impact areas associated with a rise in sea level along the Chesapeake Bay in Maryland. Coastal mapping in tidal zones may require specialized flying requirements (e.g., flying at low tide or a window around low tide). LIDAR data is particularly suitable for coastal areas because coastal channels are often difficult to access and map otherwise. Figure 6.4 shows a 3-D LIDAR model of a coastal area.

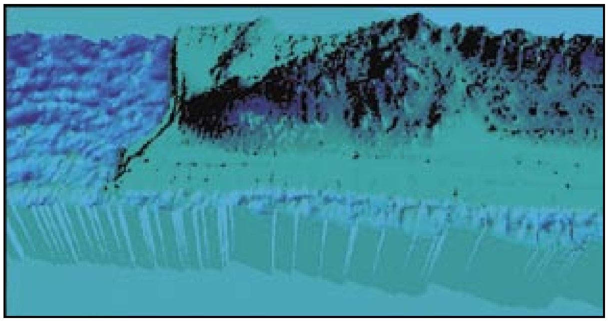


Figure 6.4. 3-D LIDAR model of a coastal area. ***Courtesy of Optech***

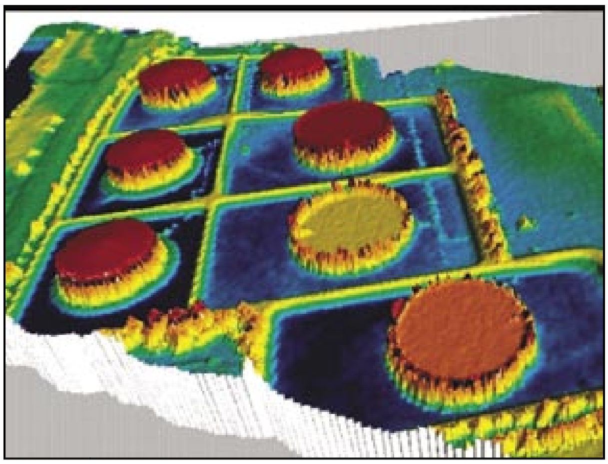


Figure 6.5. LIDAR data can be used for volumetric analysis. ***Courtesy of Airborne1***

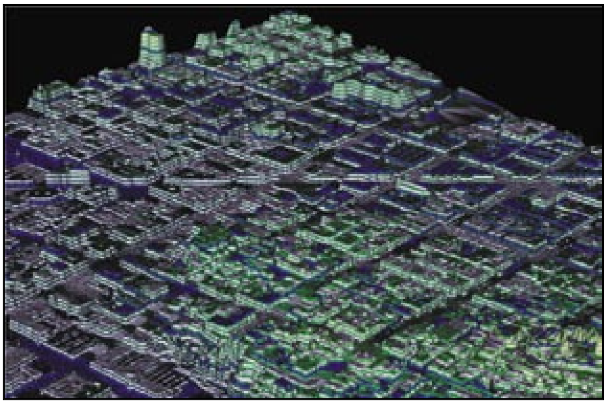


Figure 6.6. LIDAR data can be used to determine line-of-sight and development areas. ***Courtesy of Airborne1***

Volumetric Studies

Volumetric studies are often performed for landfills on an annual basis to determine the available life span of sites. Volumetric calculations are also performed on material piles (sand, gravel, coal pilings, etc.). LIDAR data can provide a readily available tool to perform the necessary volumetric calculations. Land subsidence can also be precisely measured and monitored using LIDAR, which is significant for mining and landfill sites. Figure 6.5 illustrates LIDAR data being used for volumetric analysis.

Landslide Analysis

LIDAR data can be used to monitor and predict slope failure by quickly obtaining highly accurate and dense elevation data and determining slope information. In postslide conditions, rapid damage assessment and mapping can be performed using LIDAR.

Transmission Line Studies

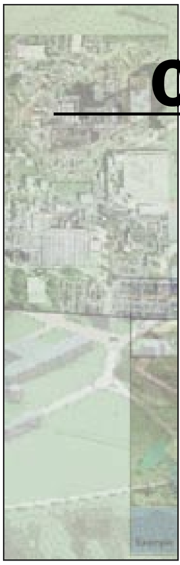
LIDAR data can be used to monitor transmission lines. Linear stretches of transmission lines can be mapped relatively quickly to determine the locations of transmission towers, to accurately map the topography of the corridor, and to determine the encroachment by vegetation for maintenance purposes. (See Figure 4.1 in Chapter 4.)

Route Mapping

Dense LIDAR can be used to differentiate objects such as railroad tracks, damage to road surfaces, accident sites, traffic density, and subtle changes in slope or grade on roadways and railways without interrupting the services.

Cellular Networks

Planning and managing cellular networks requires terrain elevation, ground-cover information, and building outlines. To ensure a clear line of sight and locate areas for development, accurate and detailed data sets containing information about natural and man-made obstructions are critical. Because LIDAR data is suitable for this purpose, an increasing number of communication companies are relying on it (see Figure 6.6).



CHAPTER 7

FUTURE TRENDS

Although the application of LIDAR data to the geospatial industry is relatively new, its use and potential is very extensive. Advances have been rapid as technological innovations occur and as the experience of users and vendors grows. In the past five years, LIDAR usage in the GIS user community has evolved from a few experimental projects where the focus was to reduce the cost of a DTM for contour mapping applications to being an integral component of state and local government geospatial databases.

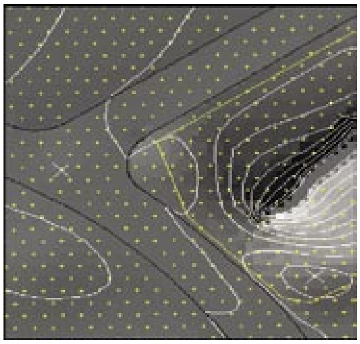


Figure 7.1. One-meter point data density on a road.

Technical Trends

Several technical trends that will influence the availability of data and the ability to acquire and process LIDAR information more rapidly include:

- Larger sensor arrays that allow broader spatial swaths with faster and less expensive coverage
- Faster and larger data-handling capacities that allow more data elements (spectral and spatial) to be recorded and processed
- Fusion of data with other imaging sensors, for example, fusing LIDAR data with orthoimages
- High-speed data transmission, allowing processing and analysis to take place at a central location with faster turnarounds and higher efficiencies

Increased Pulse Rates. Pulse rates are increasing from 10 kHz and 25 kHz-based systems to 50 kHz and 100 kHz-based systems. This allows for a tremendous increase in point density or, alternatively, provides an opportunity to fly over an area in less time and at a higher altitude.

Increased Point Density. In addition to the increased pulse rates, users will be requiring data at an increased point density. There is a trend toward increased point spacing from three to five meters a few years ago to one to two meters today. Figure 7.1 shows the density of point data along a roadway intersection at approximately one-meter spacing

Figure 7.2. Fused imagery.

Figure 7.3. LIDAR intensity data.

With this increased point spacing, a LIDAR data set for a county could contain 200 million to 600 million elevation points. With this volume of data, questions related to visualization, storage, processing, and how to perform analysis will ensue. Currently, most users are not dealing with surface elevation data on such a comprehensive basis but are having the data tiled or "subdivided" and accessing the elevation information on an area basis. One of the expected trends is an increase in user tools to assist in accessing and manipulating the elevation data on a more comprehensive basis.

Industry Trends

The LIDAR industry is also seeing an increase in the number of firms and service providers that provide LIDAR data collection services. Currently, more than 20 firms use LIDAR systems to offer data-collection services. Most of the larger photogrammetric firms are supplementing their aerial photography data-acquisition services with LIDAR data collection capability. Initially, many of the firms that provided LIDAR data collection services were LIDAR-only firms. Photogrammetric firms contracted with these LIDAR service providers. Now more full-service mapping firms are acquiring LIDAR data collection capabilities. This trend is expected to increase as the technology becomes integral to the mapping process.

Most large-area LIDAR data collection projects are currently being completed for and funded by federal, state, and local governmental agencies. The data collections are being performed for countywide GIS base mapping initiatives such as Westchester County, New York; Leon County, Florida; Lake County, Illinois; and Virginia Beach, Virginia. All have acquired LIDAR data to support their base-mapping programs. At the state level, Maryland and North Carolina are sponsoring major LIDAR data collection to support floodplain management, watershed management, and coastal management resource programs. The Federal Emergency Management Agency (FEMA) is also providing funding for many LIDAR data collection projects to support hydrologic modeling and Digital Flood Insurance Rate Map (DFIRM) production. The National Geospatial Agency (NGA) used LIDAR data collection for its "133 Cities" program.

In addition to government-sponsored LIDAR data collection programs, a number of firms are planning to offer commercial, off-the-shelf LIDAR data sets much like the satellite imagery providers currently do and selected firms also do for photogrammetric projects. Off-the-shelf LIDAR data sets, bundled with user applications or extensions, will increasingly become more available.

Automated Feature Extraction

As the density of points increases, and processing and feature extraction capabilities grow, more and more features that are currently compiled photogrammetrically will be derived from LIDAR-based data sets, particularly for areawide features such as vegetation polygons, building outlines, and street centerlines.

Image Fusion

LIDAR data can be fused with other imagery so the point clouds of data can reflect the value of a corresponding image. Figure 7.2 shows LIDAR data that has its point cloud colorized based on existing georeferenced aerial photography. Images such as this look very much like orthoimagery and provide a quick means to generate an "orthophotolike" product. As technology and user requirements progress, fused data will be incorporated into users' databases.

Intensity Images

The intensity of each pulse can be categorized and used to produce an image product that closely resembles an orthoimage. Figure 7.3 shows LIDAR intensity data. The intensity data can be provided as a point cloud or it can be exported to an image file (.tiff or .jpg) that can then be used as a backdrop for other GIS layers. The pulse rate of the sensor combined with the range of intensity in an image determines the visibility characteristics.

Change Detection

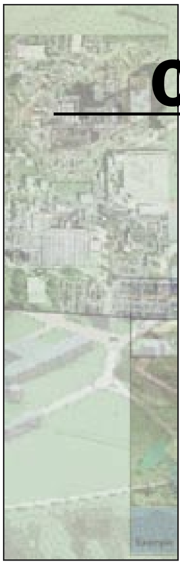
As organizations build their LIDAR data sets, as well as detailed surface and elevation models, users will be able to overlay and compare one elevation data set with another relatively easily. Once comparisons have been conducted between the two surface models, areas of change can be identified. This LIDAR-based change detection will enable users to identify new or modified buildings, new road construction, and other topographic changes.

Ground-Based LIDAR

In addition to airborne LIDAR systems, an increase in the use of ground-based LIDAR systems is expected. These ground-based systems are configured in much the same way as are airborne systems. Ground-based systems, such as those offered by Cyrax, Inc., are portable auto-scanning laser and computer systems that provide functionality for mapping and modeling large complex sites and structures. As 3-D surface points are collected and accumulate, highly accurate, detailed graphic images emerge. The 3-D models can be created in the field and can be "stitched" together. Depending on the systems, coordinates are calculated automatically or can be created with postprocessing. Ground-based systems have been used successfully by major organizations such as Chevron, Fluor Daniel, Raytheon, Disney, and the U.S. Navy and by numerous other organizations. Many departments of transportation (DOTs) are looking at ground-based systems to support their roadway engineering projects.

Figure 7.4 shows the type of imagery that can be captured with a ground-based system. The example image is from an Optech system.

Figure 7.4. Ground-based LIDAR image. ***Courtesy of Optech***



CHAPTER 8

CASE STUDIES

Case Study 1—LIDAR and Base Mapping in Puerto Rico

Background

As an island in the Caribbean, Puerto Rico is particularly susceptible to flooding during hurricanes. In November of 2003, particularly bad storms contributed to massive flooding and mudslides that affected more than 20 municipalities (see Figure 8.1) throughout the island. As a result, almost 60,000 applicants applied for federal mitigation assistance to FEMA.

Because of this and other disasters, FEMA embarked on a program to update the floodplain maps on the island. Priority areas were identified and new DFIRMS are being produced over a multiyear period.

The DFIRM Production Process

The existing Flood Insurance Rate Maps (FIRMS) for Puerto Rico were more than 20 years old. Because of development and channelization activities, the riverine environments as depicted on these maps were unrepresentative of the real work environment. As a result, FEMA and its engineering contractor undertook a detailed study to redefine the floodplain boundaries as part of the DFIRM production process. The detailed study involved the following major steps:

- Photogrammetric mapping
- LIDAR and aerial photography
- Ground survey
- River survey (cross-sections)
- Bridge and culvert surveys
- Reconnaissance
- Legal notices and prior financial information systems (FIS) studies
- Additional data acquisition
- Hydrology
- Flow calculations
- Hydraulics
- Hydraulic modeling
- HEC-RAS (backwater program)
- Floodplain mapping
- Depiction of floodplain and planimetric features
- Public notification and acceptance

Figure 8.1. Flood-affected municipalities in Puerto Rico. ***Courtesy of Medina Consultants and FEMA Region 2***

The process is providing new up-to-date DFIRM maps and accurate terrain and photogrammetric information that can be used by the municipalities for other planning and development projects.

LIDAR Data Acquisition

LIDAR data and aerial photography were determined to be the best sources for supporting base mapping requirements for the first step in the process outlined previously. LIDAR data and aerial photography were acquired for several riverine areas to cover the assumed extents of the 100-year and 500-year floodplain boundaries. Generally, this was between 20 feet and 100 feet above the river edge.

To ensure the accuracy of the dense LIDAR data, color aerial photography was flown at 1" = 600' and was used to create breaklines and generate additional mass points in areas obscured by heavy vegetation.

LIDAR data was acquired using a 50 kHz system that was designed to support one-meter point spacing. The LIDAR data was flown at an altitude of 400 meters to create the required point density. The point density was optimized to represent stream channels as accurately as possible and to account for the heavy broadleaved vegetation that is characteristic of the island.

Figure 8.2 is the LIDAR data represented as a TIN shown from a 2-D perspective. Figure 8.3 is the LIDAR data represented as a TIN shown from a 3-D perspective.

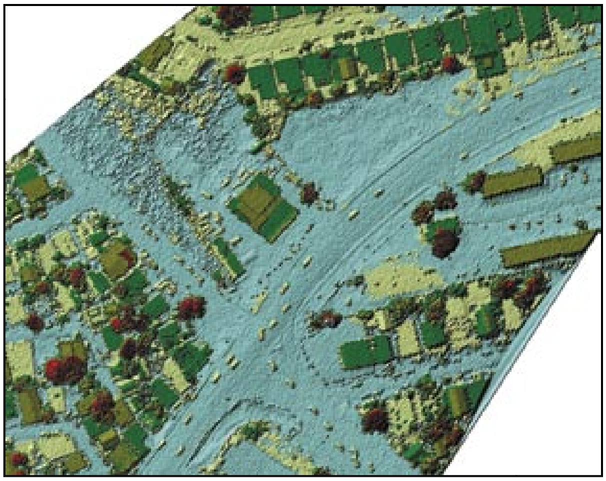


Figure 8.2 LIDAR data represented as a TIN shown from a 2-D perspective. ***Courtesy of Medina Consultants and FEMA Region 2***

The major products that resulted from the LIDAR and photogrammetric phases included the processed and edited LIDAR data and half-meter and one-meter contours, classified as intermediate, index, and depression with the usual attributes for hidden and obscured areas. Deliverables also included the following line features captured as breaklines for DTM enhancement from the color aerial photography: paved road edges, unpaved road edges, bridge outlines, stream edges (if more than six feet wide), stream centerlines (for all streams captured), mapping limit boundary, and ground control data.

LIDAR deliverables included:

- Bare earth DTM with vegetation and buildings removed
- Feature-file LIDAR data set showing buildings and vegetation
- Hill-shaded LIDAR imagery with all points included
- Hill-shaded LIDAR imagery with bare earth DTM points only

Intensity images, as in Figure 8.4, were also provided in both a 2-D and a 3-D perspective to serve as secondary visualization tools.

All the LIDAR and planimetric data is being used to support modeling and hydrologic analyses to redefine the floodplain boundaries.

Case Study 2—Tallahassee/Leon County, Florida

The Tallahassee/Leon County (TLC) Interlocal Government GIS Consortium began a project to update its legacy planimetric, topographic, and orthophoto databases in January of 2001. The contract included program management, aerial photography, aerotriangulation, soft copy photogrammetric updating of digital terrain models, planimetry, contours, and aerial image rectification.

What started out to be a routine photogrammetric maintenance project quickly changed following the first delivery of data to TLC. At that time, several participants in the consortium began to question, "Why were we updating the contour layer that nobody liked?" Apparently, many problems were evident with the existing topographic data. This prompted several discussions and ultimately a consulting task to evaluate the issues that participants had raised with the existing topographic databases.

As a result of the 2002 consulting effort, an investigation was undertaken to determine if LIDAR technology could produce more accurate and complete topographic databases. If the demonstration LIDAR databases were successful, the county would produce a LIDAR database over the entire county.

Creating the Topographic Data Partnering Committee

The City of Tallahassee and Leon County have jointly funded the cost of producing a GIS for the past 12 years. Over that period, several topographic databases were created. Different technologies, procedures, accuracies, and data, however, plagued the reliability of all these data sets. Although for the most part these topographic databases met the specifications that they were created under, the interlocal user community held differing opinions about them.

Merrick & Commpany was asked to study all the existing topographic databases. After Merrick independently reviewed and evaluated each database, a meeting was held to discuss the findings. The workshop was called the Topographic Data Partnering Meeting. All the participants were asked to consider themselves as both partners and stakeholders in this

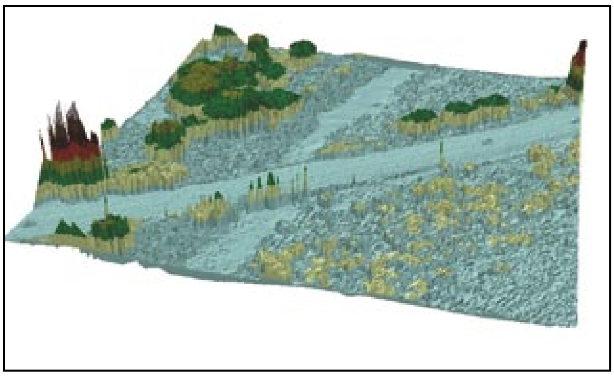


Figure 8.3. LIDAR data represented as a TIN shown from a 3-D perspective. ***Courtesy of Medina Consultants and FEMA Region 2***

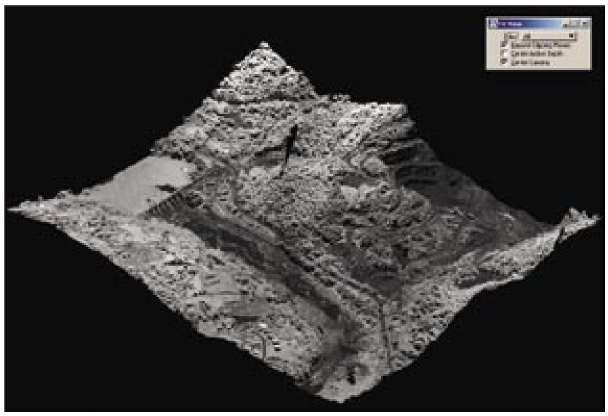


Figure 8.4. Intensity image shown from a 3-D perspective. ***Courtesy of Medina Consultants and FEMA Region 2***

consulting effort. This extremely important concept enabled everyone to devise joint solutions that met the needs of all affected.

After careful review of all the facts about the existing topographic databases, the Topographic Partnership stakeholders determined the following:

- The partnering consulting philosophy was valid because it independently evaluated TLC's existing contour data. Therefore, no biases were added because of one agency's interest taking precedence over another.
- The 1996 DTM/contour and 1988 contour data did not meet the current and future demands of all the partners.
- The primary problem with the older data sets was that photogrammetric operators were not able to identify the ground because of the heavy tree and vegetation cover throughout the county.
- Inaccuracies caused inconsistent interpretation and/or not following procedures dramatically decreased the usability of some of the data.
- Creating a new topographic database from scratch was recommended because of the increased demands to analyze the terrain for engineering, planning, and drainage projects.
- Having a current topographic database that is created to a known level of standards can be more easily maintained. This will allow the data to appreciate rather than depreciate over time as change (i.e., development) occurs within the city and county.
- A hybrid LIDAR and photogrammetry technical approach was recommended as the most appropriate technology. This approach took advantage of the new LIDAR technology that allowed millions of elevation triplets (x, y, and z) measured by the laser to penetrate the forest canopy that covers more than 60 percent of the county.
- Figure 8.5 demonstrates that the existing topographic data disagree dramatically. The black contours were derived from DTM and the brown contours were derived from contour line methodology.

Figure 8.5. Conflicts between existing contours.

LIDAR Enhanced with Photogrammetry

From a system located in an aircraft, LIDAR technology rapidly transmits pulses of light that reflect off the terrain and other objects that it touches (i.e., trees, buildings, power poles, etc.). The return pulse is converted from photons to electrical impulses and collected by a high-speed data recorder that is located in the aircraft. Because the formula for the speed of light is well known, time intervals from transmission to collection are easily derived.

LIDAR is often called a "blind" data collection. Although the density and the spacing of the elevation points can be controlled, there is absolutely no way to determine the ground location of these points. Therefore, the placement of the LIDAR elevations was extremely random. During the prototype, Merrick's innovation combined the photogrammetric breaklines with the LIDAR elevations.

LIDAR Prototype Project to Validate the Technology

The limits of the prototype projects were defined so that laser accuracy could be validated in a variety of physical and cultural landscapes. Four areas were included in the prototype:

Figure 8.6. Actual photography of dense tree canopy in Tallahassee/Leon County, Florida.

- Florida State University—urban area, dense houses, high relief with heavy vegetation
- Woodville—very small amount of relief change, heavy vegetation, some swamp
- Phase 2 North—Tall Timbers Research mature hardwood, Tallahassee-Redhills
- Phase 2 West—Okefenokee ravine, disturbed pine uplands, and mature beech magnolia

These subproject areas were well distributed in the county. This allowed the prototype data to test and validate the accuracy of the laser data in a number of diverse land-use and land-cover situations. Figure 8.6 indicates the very difficult conditions for the LIDAR mission (dense tree canopy with thick understory).

Obtaining Excellent LIDAR Elevations in Heavy Vegetation

The TLC LIDAR mission provided accurate elevation data in heavily forested areas where conventional photogrammetry could not. Although it is a misconception that LIDAR can "see through" trees, it can obtain adequate ground returns in heavily forested areas by reflecting a pulse between branches and leaves. Having a small sample distance between swath widths also contributes to LIDAR's ability to increase the number of points that make it to the ground. The swath width is controlled by the speed of the aircraft and the pulse rate of the laser.

"LIDAR far exceeded expectations for capturing elevations below the canopy," states Lee Hartsfield, GIS Manager of Tallahassee/Leon County.

Validating the LIDAR Elevation Accuracies with a Ground-Truth Survey

The ground-truth survey was conducted in unique areas such as bare earth and low grass, high grass, fully covered coniferous trees, ravine areas, fully covered deciduous trees, sandy areas, and urban land-use/land-cover subregions. This new technique allowed TLC to compare the LIDAR results in a variety of ground cover, thus improving the users' understanding and confidence in the data. Hartsfield adds, "After the prototype and the ground-truth survey, the Topographic Partners gained confidence in LIDAR."

State-of-the-Art LIDAR Equipment and Methods Made the Difference

Merrick operates an airborne laser topographic mapping system based on the LH Systems ALS40 platform. The system integrates a laser altimeter, an Applanix POS/AV IMU, GPS flight management, and other subsystems. This integrated system is capable of 52 kHz operation at a 75-degree Field of View (FOV). The system configuration includes extended altitude range up to 4,000 meters at 75-degree FOV, target signal intensity capture, and three-return capture. The laser system is mounted in a Cessna 402C twin-engine aircraft.

LIDAR Data Maintenance

A significant operational problem facing everyone in a municipality is how to protect their investment in the topographic database. In most cases, municipalities only budget for the initial collection of a topographic database and no provisions are made to keep the data current. An additional service that Merrick provided Tallahassee/Leon County GIS was a procedure to track the changes that are occurring in the database. The service included a Change Tracking software tool and procedure to input the location of areas that change the topography. These changes typically include a new subdivision, road widening, and other capital improvement projects (such as Blueprint 2000).

Now that updating only those areas that have changed lowers the cost of maintenance, TLC GIS can perform updates on a more regular basis. This aspect is important because the data will never be more than a year old.

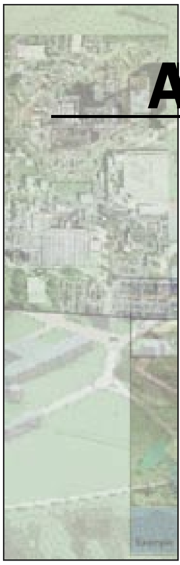
LIDAR Project Value to the Engineering and Mapping Sciences

Because of the positive feedback received from all the Topographic Partners, funding has been secured to continue with the countywide LIDAR data sets. The project will include creating a two-foot contour database and digital surface model over the entire 750 square miles of Leon County.

The Topographic Partners determined the following when comparing the LIDAR data to traditional photogrammetry:

- The approach used by Merrick was a custom and innovative use of the most modern mapping technology available.
- The value of the topographic data for future engineering projects will pay for the LIDAR cost. The LIDAR is available to engineers working on Blueprint 2000. Having the topographic data readily available decreases the overall cost and schedule of creating individual project databases. Because all the stakeholders in the Topographic Data Partnering team cooperated, the engineering work will be completed on a base map with "common" coordinates, thus eliminating any duplication of efforts.
- Planning and designing Blueprint 2000 projects will be expedited because the topography databases are already created, allowing engineering to take place without any delays caused by mapping schedule problems.

The new technical procedures used to acquire the high percentage of ground elevations in the dense tree canopy are now being used in several other projects throughout the United States.



APPENDIX

USEFUL LIDAR RESOURCES

LIDAR Hardware Manufacturers

Leica Geosystems GIS & Mapping, LLC
Worldwide Headquarters
2801 Buford Highway, N.E.
Atlanta, GA 30329-2137
USA
Phone: 877-463-7327 or 404-248-9000
Fax: 404-248-9400 (general inquiries)
Fax: 404-836-6541 (sales)
http://www.gis.leica-geosystems.com

The Leica ALS50 Airborne Laser Scanner is a laser-based system for acquiring topographical and return-signal intensity data. The most versatile and powerful LIDAR system in the industry, the ALS50 can yield details under tree cover, record data at night, and orthorectify imagery using specialized software. This is an especially efficient tool for generating accurate DTMs day or night, especially over large areas of featureless or densely covered terrain.

Measuring roughly 9.5 inches tall and weighing approximately 65 pounds, the compact ALS50 Scanner Assembly can be installed quickly and easily in helicopters and small aircraft. With scanning speeds 20 percent to 40 percent faster than competing systems, the ALS50 offers high productivity for rapid return on investment. The Leica ALS50 LIDAR System now features an 83 kHz pulse rate.

Optech Incorporated, LLC
100 Wildcat Road
Toronto, Ontario,
Canada M3J 2Z9
Phone: 416-661-5904
Fax: 416-661-4168
http://www.optech.on.ca

Optech's ALTM airborne laser terrain mappers with REALM postprocessing software are used worldwide by topographic survey companies, commercial enterprises, universities, and government agencies.

Optech's ALTMs are widely used for rapid, high-accuracy, topographic survey applications. Optech is the market leader in this field, selling more than two-thirds of all systems. Features of the Optech LIDAR system include:

- Solid-state laser—high energy, with a narrow beam divergence to maximize laser accuracy
- Scanner—40-degree scan range; operates at up to 90 Hz (for small-scan angles); guides both outgoing and returning laser pulses; most systems

generate sawtooth pattern, with raster and other custom patterns available

- Inertial Reference System (IRS)—OEM version specially designed for Optech; laser gyroscopes and accelerometers to measure roll, pitch, and heading

TopoSys
Obere Stegwiesen 26
D-88400 Biberach,
Germany
Phone: 49 7351 4 74 02 – 0
Fax: 49 7351 4 74 02 – 31
http://www.toposys.com

TopoSys's Falcon is an optoelectronic LIDAR system developed for 3-D data acquisition of the earth's surface. The measuring method for generating digital elevation models is based on active distance measurement by means of a laser scanner and is complemented by GPS positional determination and inertial navigation system. The Falcon design is based on many years of development and practical operation of the LIDAR TopoSys I and has been optimized for the rough service conditions in aircraft and helicopters.

To generate a geometrically stable scan pattern, TopoSys uses a fiberglass scanner in the Falcon systems. Alternative deflecting mechanisms, such as a swiveling mirror or a rotating polygon, do not guarantee the mechanical stability and constant alignment of the measuring beams. In a fiber scanner the laser light is directed to the ground by a linearly disposed fiberglass bundle and the echo is received by another fiberglass bundle of identical design.

LIDAR Software Developers

Autodesk
111 McInnis Parkway
San Rafael, CA 94903
USA
Phone: 415-507-5000
Fax: 415-507-8282
E-mail: marjie.delamontanya@autodesk.com
http://www.autodesk.com/gis

Autodesk is the leading provider of data creation, analysis, and distribution software for mapping and civil engineering professionals with more than 500,000 AM/FM/GIS users worldwide. From data creation and visualization on the desktop to large, scalable, secure online transaction processing for the enterprise, to the delivery of data to mobile devices anywhere, anytime, Autodesk brings to market the industry's only proven, end-to-end, IT-integrated solutions.

Industries served:

- Communications
- Government
- Gas utility
- Electric utility
- Oil/gas/water

ESRI
380 New York Street
Redlands, CA 92373-8100
USA
Phone: 909-793-2853
Fax: 909-793-5953
E-mail: info@esri.com
http://www.esri.com

With annual sales of more than $427 million, ESRI remains the world leader in the GIS software industry. ESRI's business involves the development and support of GIS software for all types of organizations from the one-person office to multinational corporations. ArcGIS is a scalable family of software including a complete GIS, built on industry standards, which is rich in functionality and works out of the box. Organizations deploy the software of ArcGIS™, ArcView®, ArcEditor®, ArcInfo®, ArcSDE®, and ArcIMS® in a configuration appropriate for their needs.

Intergraph Mapping & GIS Solutions
1 Madison Industrial Park
Huntsville, AL 35894-0001
USA
Phone: 800-208-8971
Fax: 888-239-6109
E-mail: gis@intergraph.com
http://www.intergraph.com/gis

Intergraph is a technical solutions and systems-integration company providing comprehensive engineering, GIS, and IT solutions for local and regional governments, as well as for the process, building, utilities, and transportation industries. From desktop to enterprise solutions, Intergraph offers software, computers, consulting, implementation, training, and technical-support services. Headquartered in Huntsville, Alabama, Intergraph is consistently ranked as a leading vendor in the markets it serves by industry analysts.

As the world's leading provider of GIS solutions for Windows NT, Intergraph understands the business challenges of integrating different types of data to work seamlessly in one environment. The GeoMedia® product suite offers solutions that enable communication geographically over internal intranet or across the Internet, allowing global decision support. The GeoMedia® product suite includes GeoMedia, GeoMedia Web Map, GeoMedia Web Enterprise, GeoMedia Professional, and GeoMedia Network.

Merrick & Company
2450 South Peoria Street
Aurora, CO 80014-5472
USA
Phone: 800-544-1714
Fax: 303-745-0964
E-mail: gis@merrick.com
http://www.merrick.com

To complement an extensive line of services in the GIS and mapping sciences, Merrick has created the LIDAR and terrain modeling software called Merrick Advanced Remote Sensing (MARS®). This software application provides several significant advantages for managing enormous amounts of LIDAR, imagery, and other DTM information.

A summary of the MARS® functionality includes:

- Binary storage format
- Field-coverage verification
- Control network validation and reporting in Excel™ format
- Calibration validation of entire data sets
- Cross-section/profiling of the DSM
- Client shapefile tile scheme import/export
- Graphical display of data in custom tile schemes and attributes
- Ability to export selected or inclusive data segments with ease
- User-specified grid utilities
- Orthographic and 3-D perspective viewing and navigation
- Graphical point-cloud representation and navigation
- Graphical tinning and polygon representation and navigation
- Selectable gridding algorithms and output formats
- Multiple-output data formats
- Graphic color representation by elevation, flight line, multiple-feature class, return, and grayscale intensity
- Georeferenced image-background display
- Contour display, generation, and export to DGN
- Graphic data can be output in georeferenced TIF format
- 2-D and 3-D breakline compilation
- LIDAR filtering/classification/feature extraction

Opten (not a URISA member)
15, Semenovshy Perulok
Moscow 107023,
Russia
Phone/fax: 7 095 737 63 70
http://www.optensolutions.com

Specializing in overhead utilities and transportation networks, the Opten GRIDMC software operates as an Information System (IS) for storage, representation, management, and analysis of LIDAR data, with the additional possibility of data exchanging (export/import) with other GIS systems, managing of objects' certificates and equipment references, defects management, and maintenance planning.

PCI Geomatics
50 West Wilmot Street
Richmond Hill, Ontario,
Canada L4B 1M5
Phone: 905-764-0614
Fax: 905-764-9604
E-mail: info@pcigeomatics.com
http://www.pcigeomatics.com

PCI Geomatics is a leader in the development of innovative software for the remote sensing, digital photogrammetry, and data visualization markets. PCI Geomatics designs software that provides the broadest range of functionality and operates on the most extensive list of computer platforms in the industry. This software is primarily used by professionals and scientists for resource analysis and mapping applications in operations responsible for monitoring the earth and its resources. PCI Geomatics recently developed the next generation of geomatics software. Geomatica™ is a complete geomatics solution providing affordable geospatial software that is feature-rich and easy to use. Essential elements from PCI Geomatics' world-renowned products have been assembled into a highly integrated package and infused with new technologies needed to meet the growing challenges in remote sensing, spatial analysis, GIS, photogrammetry, and cartography.

Terrasolid Ltd.
Kanavaranta 7 B 28
Fin 00160 Helsinki,
Finland
Phone: 358 9 637 526
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E-mail: info@terrasolid.com
http://www.terrasolid.fi

Terrasolid Ltd. has developed user-friendly and powerful 3-D applications for surveying and infrastructural engineering. Because of the extensive development work, a wide range of applications is now available for surveying, terrain modeling, street and underground pipe network design, as well as landscaping.

LIDAR Service Providers

The following companies are known to provide LIDAR services.

Airborne 1 Corporation
300 North Sepulveda Boulevard, Suite 160
El Segundo, CA 90245
USA
Phone: 310-414-7400
Fax: 310-414-7409
http://www.airborne1.com

Airborne 1 is the offspring of a consulting engagement with the Center for Technological Innovation, a joint venture between the National Oceanographic and Atmospheric Administration (NOAA) and IC2, the business incubator and technology transfer program in the United States.

Services provided include:

- Laser-generated digital terrain model. This is essentially a points file, as dense or as thin as required, adjusted to the clients data and projection needs.
- Contour mapping
- Aerial photography

- Orthophotos
- 3-D modeling
- Topo on orthophoto
- Vegetation removal through filtering LIDAR data
- Urban mapping
- Power line mapping

Dewberry[SM]
8401 Arlington Boulevard
Fairfax, VA 22031-4666
USA
Phone: 703-849-0100
http://www.dewberry.com

Dewberry's Geographic Information Services Department has a staff of more than 100 GIS professionals who partner with clients to clearly understand their needs and identify, develop, and deliver technical solutions that create exceptional value for their organizations.

GIS services provided in the following areas:
- Facilities planning and management
- Storm water management
- Hydrographic and flood modeling
- Hazardous waste management
- Water and wastewater management
- Transportation information systems
- Disaster response and preparedness/homeland security
- Environmental protection

GIS software and database platforms include:
- ESRI
- Bentley
- MapInfo
- Oracle
- Intergraph
- SQL Server
- AutoCAD

Dewberry is an ESRI authorized:
- Business partner
- Development partner
- Designated learning center

GRW Aerial Surveys, Inc.
801 Corporate Drive
Lexington, KY 40503-5401
USA
Phone: 859-223-3999
Fax: 859-219-9059
E-mail: kmeyer@grwinc.com or jpadgett@grwinc.com
http://www.grwinc.com

GRW Aerial Surveys, Inc., a wholly owned subsidiary of GRW Engineers, Inc., was formed in 1976 to provide photogrammetric mapping services to a broad range of clients. Since that time, GRW has grown to be one of the largest photogrammetric mapping and GIS firms in the United States, providing award-winning services worldwide. GRW offers a wide range of professional services, including aerial photography, GPS and conventional surveying, in-house photographic laboratory, digital mapping, digital orthophotography, GIS–AM/FM development and implementation, data conversion, and Internet-based GIS services.

Aerial photography. GRW owns and operates two airplanes with state-of-the-art aerial mapping cameras and IMU with automated triangulation processing software. GRW's precision aerial mapping cameras provide reliable and superior negatives, which are the foundation for a quality mapping project. Both planes and cameras are equipped with Trimble 4000 SSi Airborne GPS receivers, antennae, and data collectors for AGPS missions as well as the CCNS-4 Flight Management System.

Surveying. GRW's survey staff is experienced in both GPS and conventional surveying and utilizes a real-time survey system employing differential GPS, with real-time accuracy of two to three centimeters. GRW has the capacity and resources necessary to be on the job site upon notice to proceed. The GRW staff includes registered professional land surveyors in multiple states.

Photogrammetry and GIS. GRW has accomplished photogrammetric base mapping and comprehensive GIS development for federal, state, municipal, and private agencies across the United States. GRW utilizes proven, yet innovative technology to provide clients with quality controlled projects, produced on time and at substantial cost savings.

Kucera International, Inc.
38133 Western Parkway
Willoughby, OH 44094-7589
USA
Phone: 440-975-4230
Fax: 440-975-4238
http://www.kucera-gis.com

Kucera International, Inc. is a world-leading provider of imaging, mapping, and GIS services to government, industry, and the professions. Kucera's in-house specialties include aerial photography, airborne remote sensing, ground and airborne GPS, orthophotography, digital terrain modeling, digital topographic mapping, quantity surveys, data conversion, and GIS support/consulting. Kucera is widely recognized for high-quality, cost-effective performance, achieved through the use of the most advanced, proven technologies by a staff of more than 90 experienced professionals.

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E-mail: gis@merrick.com
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For 50 years, Merrick & Company has provided mapping, surveying, and engineering services to our clients. Merrick's GeoSpatial Solutions Group provides comprehensive, client-focused land information services, including:

- LIDAR acquisition
- MARS® terrain modeling software
- Ground-based LIDAR
- Image acquisition (aerial and satellite)
- Remote sensing
- GPS surveying
- Digital photogrammetry
- Asset inventory
- Aerial film scanning
- Digital ortho processing
- Cadastral mapping
- Utility network automation
- GIS database design
- GIS application programming

Merrick utilizes leading-edge processes and technologies to cost-effectively tailor data collection, editing, and translation to meet any specifications and GIS format requirement. The company's services frequently involve custom-application programming, integrating the most efficient hardware and software systems available.

Sanborn
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Fax: 719-528-5093
E-mail: information@sanborn.com
http://www.sanborn.com

With technology centers across the United States and abroad, Sanborn offers a full suite of photogrammetric mapping and GIS services to federal, state, and local government agencies, as well as the private sector. Sanborn is uniquely positioned to offer local presence, extensive resources, quick responses, and exceptional value, backed by superior customer support. Sanborn's services include:

- Data acquisition
- Digital mapping

- Data conversion
- GIS services

For more than a century, Sanborn has experienced, and been part of, the rapid growth of the mapping industry. Sanborn has the resources to develop and implement the best solutions to meet specific needs. Whether the need is to build, enhance, or maintain a GIS, clients can count on Sanborn. Sanborn offers total geographic information.

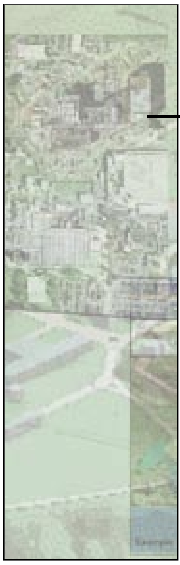
Surdex Corporation
520 Spirit of St. Louis Boulevard
St. Louis, MO 63005
USA
Phone: 636-532-3427
Fax: 636-537-9638
E-mail: info@surdex.com
http://www.surdex.com

Surdex has been recognized as a premier geospatial data provider since 1954, supplying accurate and precise information to federal, state, county, municipal, and private agencies—on time and within budget. Surdex's success is attributed to an unwavering commitment to quality products, exceptional staff and equipment resources, and to the satisfaction of clients.

One key factor distinguishing Surdex from other photogrammetric firms is a commitment to helping clients realize and achieve their organizations' goals and objectives. With a highly trained and experienced staff, Surdex can provide a complete customized geographic solution. Surdex will discuss short-term and long-term needs, offer options, and make specific recommendations to meet project needs. Surdex works with clients to develop a database design, customize GIS applications, and develop an implementation plan for achieving the goals in a timely and cost-effective manner.

In addition to Surdex's comprehensive GIS services, Surdex provides the following services:

- Aerial photography acquisition
- Ground and AGPS control surveys
- Fully analytical aerotriangulation
- Photogrammetric data compilation
- Digital orthophotography generation
- Applications development and programming services



AUTHORS

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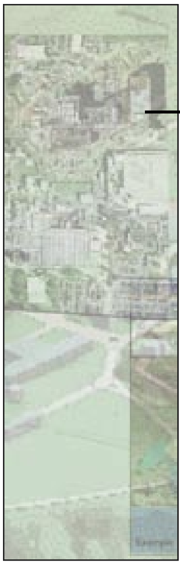
Jim is an ASPRS Certified Photogrammetrist and Vice President of Strategic Accounts for the Sanborn Map Company. He has over 18 years of experience in the GIS and remote sensing industry. Prior to joining Sanborn, Jim was the Manager of PlanGraphics Eastern regional office where he worked with numerous cities, counties, and utilities on a wide range of GIS implementation projects. Jim has an M.S. degree from the University of Tennessee in Geography and Computer Cartography. Jim has been a member of URISA since 1990.

Brian Raber

Brian is a Certified Mapping Scientist with ASPRS and the Vice President of the GeoSpatial Solutions Group for Merrick & Company. He has been with Merrick for the past 14 years and has over 24 years of experience in the GIS and mapping sciences. Brian has an M.S. degree in Geography from the University of Idaho (1984), and a B.A. degree with a Geography and Cartography emphasis from West Virginia University (1980). Brian has been a member of URISA since 1987.



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