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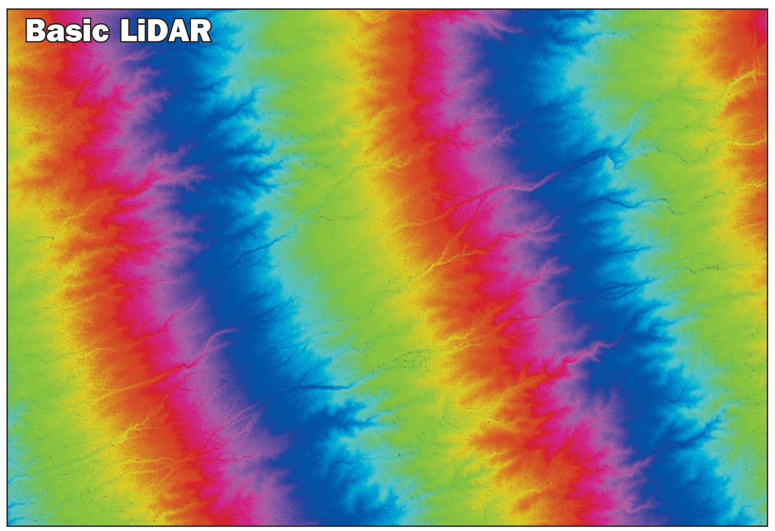
LiDAR for Mapping and GIS

Determine the Right Product for Any Project



Basic LiDAR meets most DEM needs.

Location:
Southern New Mexico, fall 2004

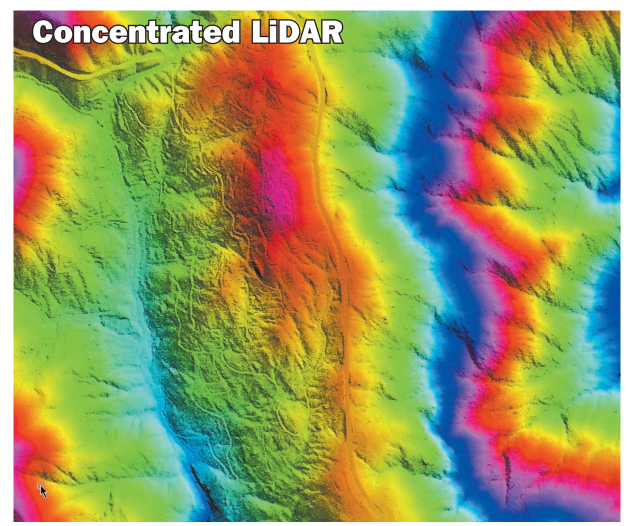
Sensor:
50khz

Elevation:
1,400 meters

Sample Density:
1.4 meters

Scan Angle:
40 degrees

Scan Frequency:
38



Concentrated LiDAR delivers a highly accurate, point-concentrated data set.

Location:
Central Arizona, summer 2005

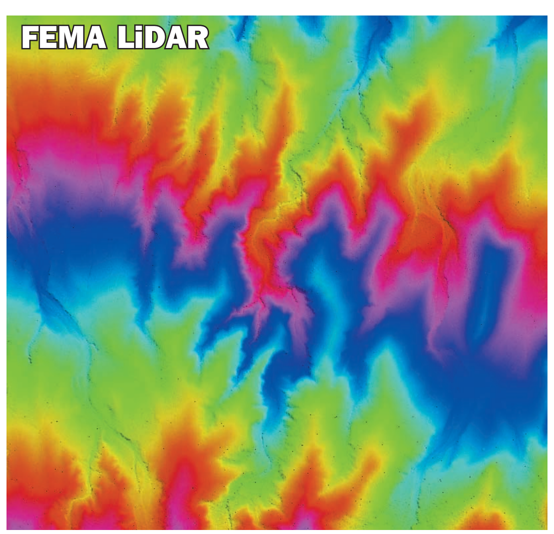
Sensor:
50khz

Elevation:
800 meters

Sample Density:
0.7 meters

Scan Angle:
30 degrees

Scan Frequency:
36



FEMA LiDAR requires much more reporting and metadata generation than a basic product.

Location:
Colorado, spring 2005

Sensor:
50khz

Elevation:
1,200 meters

Sample Density:
1.4 meters

Scan Angle:
40 degrees

Scan Frequency:
36

By Jamie Young, senior LiDAR engineer, Sanborn (www.sanborn.com)*, Colorado Springs, Colo.*

Light Detection and Ranging (LiDAR) technology offers an efficient way to produce digital elevation models (DEMs) for a variety of large-scale, high-accuracy mapping applications. Innovations such as multiple intensity returns and increased repetition rates have broadened the technology's usefulness. But deciding how to use LiDAR for an application can be difficult, and several requirements must be considered:

- What is the coverage area?
- How much vegetation and relief are in the coverage area?
- What are the accuracy requirements?
- What is the time frame for completion?
- Where is the project located, and how does it affect collection?
- How will the LiDAR data be used?
- How much will the project cost?

Determining such requirements during project planning, data acquisition and data processing will help ensure a project's success.

Product Selection

To simplify LiDAR selection, consider the three basic types of LiDAR products and determine which is most appropriate for a particular application: basic LiDAR, Federal Emergency Management Agency (FEMA) LiDAR and concentrated LiDAR.

Basic LiDAR

Basic LiDAR products provide low-cost, general-use, horizontal and vertically accurate elevation data sets that meet most DEM needs. Typical uses for these datasets include the following:

- Generating bare-earth elevation models in sparse to moderate vegetation terrain
- Large-area DEM applications in which vertical and horizontal accuracies are required
- Watershed and hydrological study areas
- Forestry and tree canopy analysis
- Building and man-made structure detection and 3-D modeling

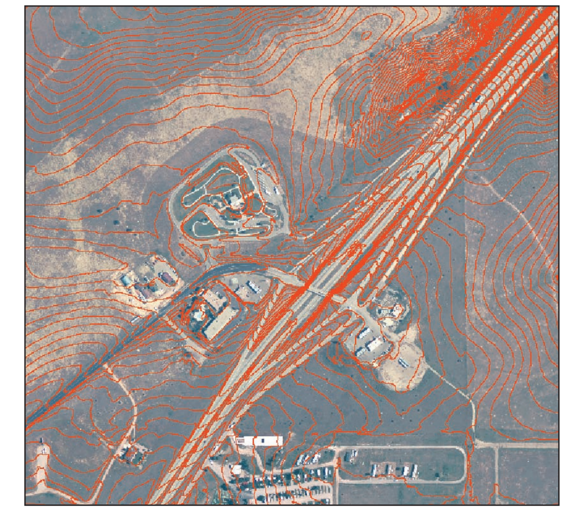
Basic LiDAR products are used as a cost-effective way to collect large-area projects in a time-constrained environment. Although collection and processing specifics vary from company to company, such products provide roughly the same results at varying costs.

The density of basic LiDAR varies, but most average 1.4-meter point spacing, and collection occurs within 45 kilometers of a ground control base station. Typically, two base stations are used, and ground control points are set up or tied to National Geodetic Survey control.

Scan frequency and scan angle values are determined by project elevation relief, along with terrain and vegetation criteria, to generate an optimal model based on the specifications of the LiDAR system used. Flight planning is done to optimally cover the project area.

It's also important to consider Positional Dilution of Precision (PDOP), the geometrical effect on GPS accuracy. The higher the PDOP value the less accurate the position solution. When collecting basic LiDAR data, the PDOP is typically at or below 3.2. Also, a KP index forecast is checked prior to collection missions to determine geomagnetic activity and its effect on Earth. No missions should be performed when the KP index is at or above 4. This activity affects GPS results, which will in turn greatly impact the accuracy of the LiDAR data. For more information on the KP index, go to *www.sec.noaa.gov/info/kindex.html.*

In addition, data voids should be considered. Typically, data voids aren't tolerated when they arise during data collection, as they usually occur between collection flight lines as a result of flying conditions and/or bad planning when relief and terrain aren't considered. Data voids also can arise from system malfunctions. All data voids can be checked during collection, and additional passes can cover these areas without affecting data accuracy or integrity. Basic LiDAR usually is delivered as a bare-earth product, so data voids resulting from vegetation and building removal in the filtering process is accepted.


Basic LiDAR products are appropriate for large-area DEM applications in which vertical and horizontal accuracies are required. Here LiDAR-generated contours are draped over digital orthophotography in Pueblo County, Colo.

There are many different filtering processes from which to choose, depending on point density, relief, terrain and vegetation. When filtering basic LiDAR, a minimum of 89 percent of all artifacts are removed automatically. A minimum 90 percent of all outliers will be removed without any manual editing. Processes may vary within the project to account for variances in vegetation, features and terrain.

A basic LiDAR product's quality and accuracy are relatively consistent for most systems. To ensure quality data, most providers routinely calibrate their systems every project or even every mission. Manufacturer specifications, collection parameters and industrial standards determine accuracy requirements. Vertical accuracies are 18.5-centimeter RMSE or better in flat terrain and meet 2-foot contour requirements; for rolling and hilly areas expect 37-centimeter RMSE or better and 4-foot contour requirements. Horizontal accuracy—usually at or less than 1-meter RMSE—is a function of flight altitude and beam divergence.

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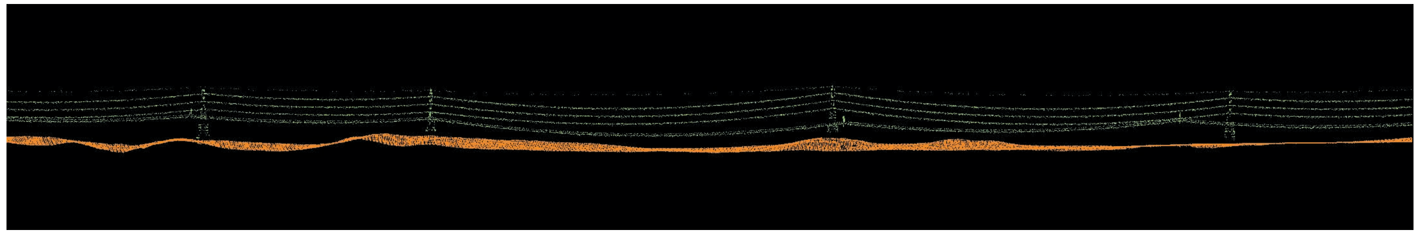


Concentrated LiDAR frequently is used for utility and pipeline mapping projects. Here a powerline was flown in two passes using a Leica ALS-50 LiDAR system.

Basic Components of Laser Mapping

A LiDAR collection system uses a powerful laser sensor comprising a transceiver and receiver, a geodetic-quality Global Positioning System (GPS) receiver, an Inertial Measurement Unit (IMU) and a scanner. Mounted in an aircraft, the laser sensor measures terrain by a light pulse return—the time it takes for light to travel from the surface to the sensor and back.

LiDAR systems use a scanning mirror to generate a swath of light pulses. Swath width depends on the mirror's angle of oscillation, and ground-point density depends on factors such as aircraft speed and mirror oscillation rate. An IMU inside a LiDAR unit collects and calculates the aircraft's orientation 200 times a second, and the GPS collects the aircraft's position every second. Thus, combining GPS, IMU and scanner information allows a LiDAR unit to calculate a precise position and orientation for the source of each laser range.

The parameters of flying height, swath angle, scanner rate and aircraft velocity determine the point density as a system moves through the air, and these parameters are tailored to accommodate project requirements. First-generation commercial LiDAR systems operated between 5 to 10khz, meaning the systems provided first and last return data from 5,000 to 10,000 pulses per second. Advances in electronics and laser systems increased the repetition rates to 25 to 50khz, providing multiple intensity return systems. Currently, the 50khz systems are widely accepted for most applications.

In recent years, LiDAR pulse return rates have doubled, operating up to 100khz. Now LiDAR systems can collect elevations every meter on the ground at a rate up to 100,000 times per second, creating mass quantities of instantaneously available data never imagined until recently. Although repetition rate is a function of altitude, the increased rates are effective for corridor applications such as power line planning, re-rating and maintenance, and pipeline and transportation infrastructure mapping.

FEMA LiDAR

FEMA LiDAR is a U.S. government map-modernization product that meets the agency's guidelines for LiDAR-based elevation models. Typical uses for these datasets include the following:

- FEMA flood plain map-modernization programs
- Digital Flood Insurance Rate Map updates
- Watersheds and other hydro studies per FEMA specifications
- County and state mapping programs
- Mapping programs that include accuracy verification, reporting and metadata
- Projects that require the creation of 2-foot contours

FEMA LiDAR products have gained broad acceptance for flood plain mapping. Now many LiDAR users have adopted FEMA LiDAR products as their standard. Specifications and guidelines for the product are detailed in "Appendix A: Guidance for Aerial Mapping and Surveying," provided by FEMA at *www.fema.gov*.

In general, this product is much like a basic LiDAR product, but with some variations in specifications and collection parameters. FEMA LiDAR requires much more reporting and metadata generation than a basic product. Collection occurs within 20 kilometers of the ground base stations. In addition, ground survey points are collected in different vegetation classifications for accuracy verification. Flight planning parameters and requirements for the two products are the same, as are requirements for data voids with one exception: FEMA LiDAR requires additional ground data in areas of dense vegetation.

Filtering processes for FEMA LiDAR vary from basic LiDAR. When filtering FEMA LiDAR, users can expect artifacts removal at 90 percent or better. About 95 percent of LiDAR collection outliers will be removed. The resulting bare earth model yields 95 percent of all vegetation removed and 98 percent of all buildings removed. Data quality requires the use of cross-flight verification and a single mission calibration as outlined in FEMA's guidelines and specifications section A.8.6.5.

Concentrated LiDAR

Concentrated LiDAR is a project-specific, high-accuracy and point-concentrated data set. Concentrated LiDAR products meet most needs for LiDAR-based elevation models in dense vegetation and terrain-constrained areas.

Typical uses for these datasets include the following:

- Heavily vegetated project areas
- Remote and limited-access project areas
- Land development, transportation and other corridor projects
- County mapping projects requiring sub-meter point postings
- Terrain, forestry and volumetric analysis
- Utility and pipeline mapping projects
- Change detection and 3-D modeling in dense urban areas

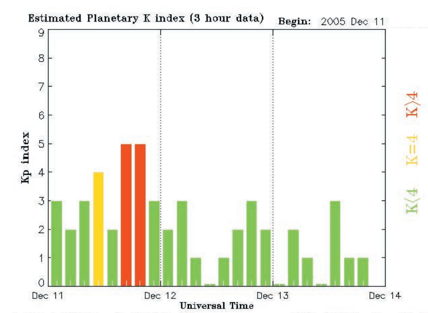
Concentrated LiDAR has been used in a variety of mapping applications and has grown dramatically as a result of advancing technology. The increased sample density has improved the statistical probability for more accurately defining the surface model and structures mapped while systematically improving anomaly budgets.

Concentrated LiDAR specifications and accuracies vary depending on the project, but overall the requirements for this product are more stringent than basic and FEMA products. On average, the point density is 0.7 meters and higher for corridor mapping. Baselines for collection vary between 8 kilometers and 40 kilometers, depending on project requirements. Ground control requirements for point accuracies are consistent with other products, as well as fight planning parameters, including PDOP and KP index. Flight line spacing and number of passes are determined based on the LiDAR system used for the project to achieve the desired point density, which in some cases can be eight points per square meter. Data void consideration and system calibration should follow the same constraints as any other LiDAR product.

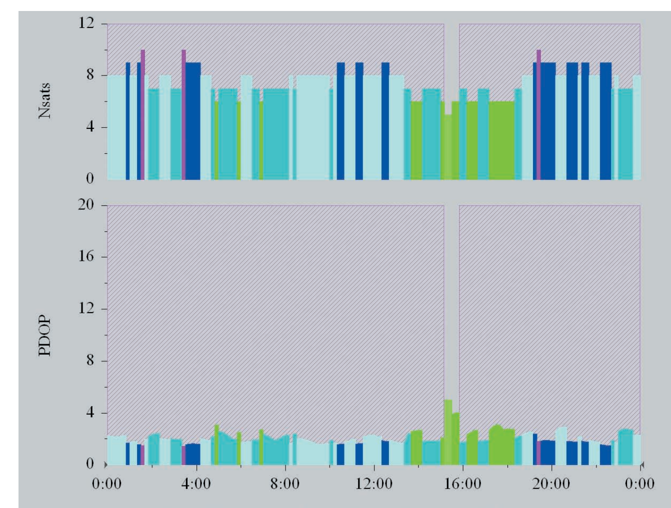
Filtering process and sample density for concentrated LiDAR will consistently yield a significantly more detailed model than other products. Artifact removal for this product is about 95 percent, depending on terrain and vegetation. Outlier point removal is at 98 percent. The filtered resulting bare earth model yields 97 percent of all vegetation and 98 percent of all buildings removed.

Data quality and accuracy for this product is more refined than other products, but varies depending on project application. Most often collection of static and kinematic ground control is required. System calibration will be performed for every mission using a post-processing differential kinematic survey in addition to a basic calibration process. Vertical accuracies are 15 cm RMSE or better, while horizontal accuracies are usually at or under .5 meter RMSE. However, higher accuracies have been achieved. Many LiDAR providers base accuracy analysis on several different collection and manufacturer specifications.

Although the products mentioned here meet most project requirements, LiDAR can provide additional tools using intensity returns generated from the LiDAR pulses. LiDAR systems collect 12-bit intensity information for several pulses depending on the system. This information is usually best represented in an 8-bit georeferenced gray shade image representing the intensity values transformed between 0 and 256. The accuracy of such an image is a function of the beam foot-print, point density, scanner encoder and reflective nature of the surface, and it varies depending on the system. Applications for the technology are still growing, but recent uses include 2-D and 3-D break line generation, location and risk studies, and rough image interpretation. For more information on LiDAR's diverse uses, see "Limitless LiDAR Applications" at right.



A typical planetary KP index is shown for a three-day period using magnetometers in several locations (left). No missions should be performed when the KP index is at or above 4. Flight planners also need to consider PDOP to determine the geometrical effect on GPS accuracy (below). A planned flight would be based on PDOP values less than 3.2 and satellite availability greater than six satellites.



Limitless LiDAR Applications

LiDAR advances and a better understanding of the technology have greatly improved the usefulness of LiDAR as a valuable mapping tool. Potential applications include, but are not limited to, the following:

Flood Mapping and Planning: The high-resolution elevation data provided by LiDAR technology provides valuable insight into flood-prone areas and how to mitigate flood damage. The Federal Emergency Management Agency (FEMA) has initiated a modernization of floodplain maps throughout the United States using LiDAR data in its Map Modernization initiative.

Disaster Management: LiDAR is used to assess damage and support infrastructure rebuilding after a disaster.

Coastal Erosion: LiDAR data help detect coastal changes to study and remediate coastal erosion.

Aviation Safety: LiDAR is used to identify vertical airfield obstructions to aviation.

Forestry: LiDAR can detect forest canopy change to support forest management.

Nautical Charting: LiDAR is used to measure seabed depths and topographic elevations for navigation, nautical chartering, rapid environmental assessment and regional costal zone mapping.

Corridor, Network and Land Use Mapping and Planning: LiDAR is used for pipeline right-of-way analysis for oil and gas companies as well as transmission line right-of-way analysis for power companies. Also, network planning can be accomplished for telecom propagation modeling for wireless and mobile network planning. LiDAR data also are used to determine optimal location sites for commercial facilities planning.

Geological: LiDAR detects geological features in heavy vegetated areas such as old-growth forests. Recently, LiDAR has detected faults and karst formations in the Pacific Northwest and Alaska.

Reclamation: LiDAR is a valuable tool in quarry projects.

Volumetric Studies: LiDAR data are used to determine accurate volumetric calculations for earth work and quarry stock pile inventories.

Transmission: LiDAR is a valuable tool for re-rating and inventory studies for power line resources.

3-D Modeling: LiDAR applications have been developed to model structures in urban areas.

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