Presentation Outline

- Introduction to LiDAR
- QA/QC of LiDAR data
- Differences in LiDAR projects
- Things to know that are not often discussed
- Software applications
- Summary
- Questions
Introduction to LiDAR

• Generate an accurate 3D model of the earth’s surface
• Use a near infrared laser and scanning mirror in measurement
• Sensors have the ability to measure multiple returns from each pulse
• Also measure the intensity of each of the returns
Introduction to LiDAR

- Time of flight of the laser provides an accurate distance to the ground
- Airborne GPS provides the 3D position (XYZ)
- Inertial Navigation Systems (INS) provides the 3D rotation of the sensor (omega, phi, kappa)
- A galvanomometer provides the swing angle of the scanning mirror
- Must solve for 8 variables for each laser return
Introduction to LiDAR

• Laser rates in sensors today are generally in the 150 kHz to 200 kHz range
• Many sensors can work in the mode of discrete returns (typically $1^{st}$, $2^{nd}$, $3^{rd}$, and last) or full waveform technology
• High end systems are made by Leica, Optech, and Riegl
• Sensor costs are typically more than $1M
Introduction to LiDAR

• LiDAR is an active sensor, generating infrared light and can be flown day or night
• LiDAR is not an all weather sensor; it cannot be flown above clouds and should not be flown with standing water on the ground
• LiDAR can pass through gaps in some vegetation so generally better results will be gained during “leaf off” conditions for deciduous vegetation
Introduction to LiDAR

- Automated routines used to help classify the returns (e.g., removing artifacts, vegetation, structures, vehicles, etc.)
- These routines are typically 90 to 95% efficient
- Manual editing is necessary to produce a quality LiDAR product
Introduction to LiDAR

- Deliverables include
  - Classified data in a LAS format
  - Metadata

- Projects may include
  - Breakline collection
  - DEMs
  - Intensity images
  - Accuracy analysis
  - Hydro enforcement (flattening of water/downward flow of streams)
Some Definition of Terms

- **Nominal Post Spacing (NPS)**
  - Average distance between adjacent LiDAR points (ft or m)
- **Point Density**
  - Number of LiDAR points per unit area (points per square meter)
- **Root Mean Square Error (RMSE)**
  - Statistical value equal to the square root of the average of the squares of the differences between known points and modeled points in the LiDAR surface
- **Accuracy**
  - 95% confidence interval of the data (vertical = RMSE x 1.96)
## Introduction to Lidar

<table>
<thead>
<tr>
<th></th>
<th>Fixed Wing</th>
<th>Rotary Wing</th>
<th>Mobile Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition Heights</td>
<td>3,000-8,000’ AMT</td>
<td>300-800’ AMT</td>
<td>Ground based</td>
</tr>
<tr>
<td>Acquisition Speeds</td>
<td>90-200 knots</td>
<td>20-50 knots</td>
<td>10-60 mph</td>
</tr>
<tr>
<td>Vertical Accuracy</td>
<td>9-25 cm</td>
<td>3-15 cm</td>
<td>2-10 cm</td>
</tr>
<tr>
<td>Horizontal Accuracy</td>
<td>0.5-1.0 m</td>
<td>10-50 cm</td>
<td>3-10 cm</td>
</tr>
<tr>
<td>Point Density</td>
<td>0.5-8 ppsm</td>
<td>20-80 ppsm</td>
<td>1,000-8,000 ppsm</td>
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</tbody>
</table>

**NOTE:** All accuracies expressed as RMSE
Cincinnati Airport – Photo
Cincinnati Airport — Intensity
QA/QC of LiDAR Data

• Quantitative
  – Vertical accuracy
  – Horizontal accuracy
  – Clustering of points
  – Nominal posting

• Qualitative
  – Quality of the elevation surface (look and feel)
  – Removal of artifacts, etc.
**Vertical Accuracy**

- Relatively easy to assess, often required
- Normally look at various types of land cover… bare earth, urban, forest, brush, high grasses
- Typically find a location with no abrupt changes in the ground surface (within 3 to 5 meters)
- Determine precise 3D location with field techniques… then determine elevation from the LiDAR surface at that XY, subtract, and statistically summarize
- Control at least 3x better than required accuracy
Vertical Accuracy

• Fundamental, Supplemental, and Consolidated Accuracies
  – Fundamental – the accuracy in open terrain
  – Supplemental – the accuracy in other areas
  – Consolidated – the accuracy in all areas combined
Bare Earth
High Grass
## Vertical Accuracy Analysis

<table>
<thead>
<tr>
<th>Point</th>
<th>Northing</th>
<th>Easting</th>
<th>Field Elevation</th>
<th>Lidar Elevation</th>
<th>Vertical Difference</th>
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<tbody>
<tr>
<td>103</td>
<td>1,234,542.12</td>
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<tr>
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<td>106.32</td>
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<tr>
<td>117</td>
<td>1,299,493.58</td>
<td>465,820.74</td>
<td>108.44</td>
<td>108.10</td>
<td>0.34</td>
</tr>
</tbody>
</table>
Distribution of Errors

Category 1

-0.75 to -0.60
-0.60 to -0.45
-0.45 to -0.30
-0.30 to -0.15
-0.15 to 0.00
0.00 to 0.15
0.15 to 0.30
0.30 to 0.45
0.45 to 0.60
0.60 to 0.75
Normal Probability Distribution

Vertical Component

68\% 

1.96 \times \text{RMSE} \quad \text{RMSE} \quad \text{RMSE}
LiDAR Accuracy

Orange County – 204 Square Mile LiDAR Set
Ave: 0.13’  Min: -0.57’  Max: 0.90’  RMSE: 0.21’  Shots: 180

Urban Areas

Frequency

Residual Range

Less than -0.81 -0.8 to -0.61 -0.6 to -0.41 -0.4 to -0.21 -0.2 to 0 0 to 0.2 0.21 to 0.4 0.41 to 0.6 0.61 to 0.8 More than 0.81
LiDAR Accuracy

Orange County – 204 Square Mile LiDAR Set

Ave: -0.07’  Min: -0.43’  Max: 0.21’  RMSE: 0.17’  Shots: 26

High Grass, Weeds
Impact of Cover on Accuracy

Sorted Data Check Points
Meters
Open Terrain Forest Scrub/Shrub Built-Up Weeds/Crops

-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0 5 10 15 20 25 30

Sorted Data Check Points

-0.3
-0.2
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0 5 10 15 20 25 30

-0.3
-0.2
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0 5 10 15 20 25 30

Open Terrain — Forest — Scrub/Shrub — Built-Up — Weeds/Crops

PHOTO SCIENCE
Geospatial Solutions
Horizontal Accuracy

- More difficult to assess, not often required
- Possible to find identifiable objects in the intensity images... paint stripes, concrete-asphalt edges, etc.
- Building corners can be very useful; best to use multiple points on the building and intersect planes to determine the correct XY location
Building Corners

Accurate XY Location
Overlap Analysis
Qualitative Review of the Data
DIFFERENCES IN LIDAR PROJECTS
Differences & Price Variations

• Project approach and other factors can have a significant impact on project costs
• Well written, complete specifications are critically important to ensure that you get what you want
• USGS V13 specifications are a very good place to start…
Differences in Approach

- Point density, vertical accuracy, point classification, deliverables are quite often very clear in the specifications.
- **Flying height, GPS considerations (maximum PDOP), field of view, maximum baseline length, cleanliness of data, health of the LiDAR sensor, system calibration, other steps taken to ensure quality data are not always readily apparent.**
Differences in Approach

• Flying height and field of view can have significant effects on vegetation penetration and data quality

• USGS V13: 34° preferred, 40° maximum

• 5,000’ AMT & 34° Swath of 3,057 feet
• 5,500’ AMT & 40° Swath of 4,005 feet
• Increase of 31%
THINGS TO KNOW

And That aren’t always disclosed
Things to Know

• Horizontal accuracy of the surface is important
• Vertical accuracy is more difficult in sloping terrain
Things to Know

• Vertical accuracy of LiDAR is commonly specified as the Root Mean Square Error (RMSE$_z$), not an “absolute” accuracy

• RMSE$_z$ is the 68% confidence interval
• RMSE$_z$ x 1.96 is the 95% confidence interval
• RMSE$_z$ x 3.0 is the 99.7% confidence interval
Things to Know

• All sensors have a vertical discrimination ranging from about 1 to 3 meters
• This is the minimum distance between successive returns…
• May lose ground
**Things to Know**

- Proper calibration of both the sensor and LiDAR surface are critical to quality
Things to Know

• There is significant value in manual cleanup (after automatic filtering)… this also is a significant cost factor
• Up to 90% of the post-processing costs can be associated with manual edits
• Ensure clear communication with LiDAR provider regarding expectations
Things to Know

- For cost efficiency, projects should be designed for compatibility in accuracy and posting.

- Compatible pairs would include:
  - 9.25 cm RMSE<sub>z</sub> & 0.5 m point spacing
  - 15 cm RMSE<sub>z</sub> & 1 m point spacing
  - 25 cm RMSE<sub>z</sub> & 2 m point spacing

- Not a major issue, but openly discuss options with your LiDAR provider.
Things to Know

• Achieving ultra high densities can result in
  – Significant costs
  – Increased data storage
  – Data manipulation issues
• Acquisition costs can increase to 2x or 4x
• Data requirements:
  – 1 ppsm point density would equate to 200 Megabytes per square mile
  – 4 ppsm would be 4X, or 800 Megabytes per mi²
  – 8 ppsm would be 8X, or 1.6 Gigabytes per mi²
SOFTWARE APPLICATIONS
Software Applications

• COTS software has made significant gains recently and overall is very good

• Very important as a LiDAR provider to have programming staff to automate and assist in LiDAR processing
  – intersecting building corners
  – flagging and removing anomalies
  – assessing completeness
Software Applications

• Software to ingest the LAS format for classified LiDAR data
  – ESRI
  – MicroStation
  – AutoCAD

• QT Modeler, LP 360

• Freeware for viewing, manipulating, rendering, etc.
  – US Forest Service LDV (LiDAR Data Viewer)
Questions

mark.meade@photoscience.com
• Laser Pulse Rate or Repetition Rate – The speed at which the laser is pulsed during LiDAR collection. Maximum laser pulse rates on new sensors today generally range from between 150 kHz to 200 kHz (150,000 to 200,000 outgoing laser pulses per second).

• Scan Rate – The speed at which the scanning mirror (that directs the laser pulses back and forth over the ground) is moved during LiDAR acquisition. Maximum scan rates on new sensors are generally around 100 Hz (100 times per second).
• Nadir – The direction pointing straight down from the aircraft.

• Field of View – The angular swing of the mirror during acquisition. Typically the mirror moves in a perpendicular direction to the line of flight. The USGS V13 specifications call for a maximum FOV of 40 degrees (20 degrees each side of nadir), with a preferred maximum of 34 degrees.
- Illuminated Footprint – The diameter of the laser beam as it reaches the earth. The laser beam exits the sensor as a very narrow, highly focused beam but diverges slightly on its path from the sensor to the ground. The illuminated footprint increases with increased flying height, but is generally around 1 to 3 feet when using a fixed wing aircraft.
• **Swath Width** – The linear width of the laser coverage during acquisition, which varies with the flying height and FOV. Increased swath widths result in increased productivity and lower acquisition costs.

• **Along Track** – The direction in the line of the flight of the aircraft during acquisition.

• **Cross Track** – The direction perpendicular to the flight of the aircraft during