What is Lidar?

- **Light Detection And Ranging**
- **Active** form of remote sensing: information is obtained from a signal which is sent from a transmitter, reflected by a target, and detected by a receiver back at the source.
- **Airborne and Space Lidar Systems.** Most are currently airborne.
- 3 types of information can be obtained:
  a) **Range to target** (Topographic Lidar, or Laser Altimetry)
  b) **Chemical properties of target** (Differential Absorption Lidar)
  c) **Velocity of target** (Doppler Lidar)
- Focus on Laser Altimetry. Most active area today.
Lidar History

- 60s and 70s - First laser remote sensing instruments (lunar laser ranging, satellite laser ranging, oceanographic and atmospheric research)
- 80s - First laser altimetry systems (NASA Atmospheric and Oceanographic Lidar (AOL) and Airborne Topographic Mapper (ATM))
- 1995 - First commercial airborne Lidar systems developed.
- Last 10 years - Significant development of commercial and non-commercial systems
  - 1994 - SHOALS (US Army Corps of Engineers)
  - 1996 - Mars Orbiter Laser Altimeter (NASA MOLA)
  - 1997 - Shuttle Laser Altimeter (NASA SLA)
  - Early 2000s - North Carolina achieves statewide Lidar coverage (used for updating FEMA flood insurance maps)

- Currently 2 predominate issues - Standardization of data formats and Standardization of processing techniques to extract useful information

Comparison of Lidar and Radar

<table>
<thead>
<tr>
<th>Lidar</th>
<th>Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uses optical signals (Near IR, visible). Wavelengths ≈ 1 µm</td>
<td>Uses microwave signals. Wavelengths ≈ 1 cm. (Approx 100,000 times longer than Near IR)</td>
</tr>
<tr>
<td>Shorter wavelengths allow detection of smaller objects (cloud particles, aerosols)</td>
<td>Target size limited by longer wavelength</td>
</tr>
<tr>
<td>Focused beam and high frequency permit high spatial resolution (&lt; 1m horizontal)</td>
<td>Beam width and antenna length limit spatial resolution (10s of meters). Synthetic aperture techniques reduce antenna length requirements.</td>
</tr>
<tr>
<td>Nadir looking sensor</td>
<td>Side looking sensor.</td>
</tr>
<tr>
<td>Limited to clear atmospheric conditions, daytime or nighttime coverage.</td>
<td>Can operate in presence of clouds. Daytime or nighttime coverage.</td>
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</table>
Topographic Lidar Operating Principles

Distinguish between **Pulsed** and **CW** Lidar systems.

- **Pulsed system**: Transmitted signal consists of a series of laser pulses, 10,000 to 150,000 pulses/second (10 - 150 kHz pulse rate).
  
  Range to target calculated from time to receive pulse:
  
  \[ \text{Range} = \frac{c \times t}{2} \]

- **CW system**: Transmits sinusoidal signal of known wavelength
  
  Range calculated from number of full waveforms and the phase difference between transmitted and received signal.
  
  Much less common technique compared to pulsed system.

Pulsed System Operation

- **Wavelengths utilized**: 1.0 - 1.5 $\mu$m (terrestrial studies)
  
  0.50 - 0.55 $\mu$m (bathymetric studies)

- **Combination of scanning mirror and moving platform produces a 2D field of range measurements.**

- **Additionally recorded information**: Angle from nadir of measurement
  
  GPS horizontal and vertical positions (1 Hz)
  
  Aircraft Inertial Measurements (pitch, roll, yaw) (50 Hz)

- **On board processing**: Slant distance calculated from range measurement + angle from nadir for each returned pulse
  
  Slant distance corrected using IMU measurements
  
  GPS data integrated to provide a georeferenced elevation value for each returned pulse.
  
  **GPS measurements are crucial to vertical accuracy.**
- **Pulsed systems are one of two types:**
  - **Small footprint:** Ground unit = 5 - 30 cm
    Useful for detailed local mapping, edge detection, detailed vegetation canopy studies
  - **Large footprint:** Ground unit = 10 - 25 m
    Larger swath width
    Useful for larger scale studies of canopy response

- Footprint size is a function of **IFOV**
  - Sensor altitude
  - Viewing angle from nadir
Spatial Resolution Considerations for Pulsed System

- Achievable point density is a function of:
  - IFOV of instrument
  - Altitude of platform
  - Number of points collected
    - platform speed
    - scan speed and scan angle (swath width)
    - altitude of platform
    - pulse frequency

- For a given set of operating conditions, pulse frequency becomes the primary figure of merit.

- Pulse repetition frequencies have increased from about 5 kHz in 1995 to 150 kHz presently, reducing spatial grid resolutions to < 0.5 meters.

Typical Lidar Performance Characteristics (pulsed small footprint system, 2001)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>1000-1500 nm</td>
</tr>
<tr>
<td>Pulse Rep. Rate</td>
<td>140 kHz</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>10 nsec</td>
</tr>
<tr>
<td>Scan Angle</td>
<td>40° - 75°</td>
</tr>
<tr>
<td>Scan Rate</td>
<td>25 - 40 Hz</td>
</tr>
<tr>
<td>Swath Width</td>
<td>Up to 0.7 * altitude</td>
</tr>
<tr>
<td>Z accuracy RMSE</td>
<td>Approx 15 cm</td>
</tr>
<tr>
<td>X,Y accuracy RMSE</td>
<td>10 - 100 cm</td>
</tr>
<tr>
<td>Footprint</td>
<td>0.25 - 2 m (from 1000m)</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.75 meters</td>
</tr>
<tr>
<td>GPS frequency</td>
<td>1 Hz</td>
</tr>
<tr>
<td>IMS Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Operating Altitude</td>
<td>500 - 2000 m</td>
</tr>
</tbody>
</table>
Post-Processing of Topographic Lidar Data

- Near IR pulses capable of reflection off of multiple surfaces
- Profile of received signal depends on nature of target surface:
  - **Vegetation** - first return (crown)  
    intermediate returns (underlying branches/leaves)  
    last/ground return (earth surface)
  - **Buildings** - single return (first = last)
  - **Bare Earth** - single return (first = last)
- **Older Systems** - Detected single (first) return from each pulse.  
  Elevation profile is a Digital Surface Model (DSM).
- **Newer Systems** - Capable of detecting multiple returns from each pulse (Waveform Capture).
  Dataset is unfiltered point cloud.
  Post Processing needed to distinguish between first, intermediate, and last returns.

From Flood, 2001
Post Processing Techniques

- Filtering Last Returns from point cloud to generate Bare Earth DEM. Capable of producing bare earth DEMs in areas with moderately dense vegetation cover.
- First Return - Last Return to determine Canopy Height
- Filtering First and Intermediate returns to estimate vegetation biomass, tree densities, individual tree structure information
- Separate First Return signals at abrupt edges to delineate Building Features (small footprint systems)
- Several Filtering Methods are currently being developed. Most combine automated algorithms with manual correction.

Lidar Applications

- Update digital elevation models (NED)
- Glacial Monitoring
- Detecting Faults and measuring uplift
- Forest Inventory
- Shoreline and Beach Volume Changes
- Bathymetric Surveying (SHOALS)
- Landslide Risk Analysis
- Habitat Mapping
- Subsidence Issues
- Telecom Planning
- Urban Development
Free Lidar Sources

- Puget Sound LIDAR Consortium
- OR Dept. of Geology and Mineral Industries (DOGAMI). Portland DEMs.
- Louisiana State University
- Red River Basin Decision Information Network
- NOAA Coastal Services Center
- USGS Center For Lidar Information Coordination and Knowledge (CLICK)
- USACE Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX)
- North Carolina Floodplain Mapping Program

Comparison of Lidar versus standard USGS 10m DEM

Bainbridge Island, WA. From Puget Sound Lidar Consortium
San Andreas Fault Detection Using Lidar

http://quake.usgs.gov/research/geology/lidar/example1.html

Dome Formation, Mt. St. Helens

from USGS Cascades Volcano Observatory
References


NOAA Coastal Services Center: http://www.csc.noaa.gov/crs/rs_apps/sensors/lidar.htm