Introduction to LiDAR technology

Airborne laser scanning—an introduction and overview

Nicholas Kory
Abenezer Wudenhe
LiDAR

- Lidar (Light Detection & Ranging)

Ground LiDAR

Aerial Topographic LiDAR
Airborne laser scanning—an introduction and overview

A Wehr, U Lohr - ISPRS Journal of photogrammetry and remote sensing, 1999 - Elsevier

This tutorial paper gives an introduction and overview of various topics related to airborne laser scanning (ALS) as used to measure range to and reflectance of objects on the earth surface. After a short introduction, the basic principles of laser, the two main classes, i.e., pulse and continuous-wave lasers, and relations with respect to time-of-flight, range, resolution, and precision are presented. The main laser components and the role of the laser wavelength, including eye safety considerations, are explained. Different scanning ...
Outline

- Why this problem
- Why this is important
- Why it is challenging
- What the validation method is
- What the novel contributions are
- What the limitations of the related work are
The Problem
The Problem - The Ability to “See under Trees”
The Problem - Microwave Radar Technique

Fig 2: Working principle of microwave radar techniques

Fig 3: Picture of the structure and radar image acquired through a horizontal scan
The Problem - LiDAR

Fig 4: High-density LiDAR data used to create 3D topographical maps in a variety of file formats.
The Problem - How it Works

- Measure distance based on sending & receiving light emissions
The Problem - LiDAR Systems in Airplanes

- Airborne Topographic LiDAR takes place in two phases
  - **Phase 1:** Scanning
    - Different Scan Mechanisms lead to different scan pattern on the ground
    - Patterns include (oscillating mirror, Palmer scan, fiber scanner, rotating polygon)
  - **Phase 2:** Post Scan processing
The Problem - LiDAR Systems in Airplanes

Components:
- Inertial Measurement Unit (IMU)
- Position and Orientation System (POS)
- Laser power supply
- Laser
- Scan
- Optics
- Receiver
The Problem - The Lasers Used

- Lasers
  - Pulse Laser
  - Continuous Wave Laser (CW)

Pulse:
- Range: \( R = \frac{1}{2} c \cdot t_L \)
- Range Resolution: \( \Delta R = \frac{1}{2} c \cdot \Delta t_L \)
- Max. Range: \( R_{\text{max}} = \frac{1}{2} c \cdot t_{L_{\text{max}}} \)
- Range Accuracy: \( \sigma_R = \frac{c}{2} t_{\text{rise}} \cdot \frac{1}{\sqrt{S/N}} \)

Sinusoidal CW-Modulation:
- Travelling Time by Phase Difference: \( T = \frac{2\pi}{\Phi} \) \( t_L = \frac{\Phi}{2\pi} \cdot T \)
- Range: \( R = \frac{1}{2} c \cdot \Phi \cdot \frac{T}{4\pi} \cdot \Phi \)
- Max. Unamb. Range: \( R_{\text{max}} = \frac{A_{\text{max}}}{2} \)
- Range Resolution: \( \Delta R = \frac{A_{\text{max}}}{4\pi} \cdot \Delta\Phi \)
- Range Accuracy: \( \sigma_R = \frac{A_{\text{max}}}{4\pi} \cdot \frac{1}{\sqrt{S/N}} \)
The Importance
The Importance - Flood Insurance Rate Maps

Fig 5: Lidar-derived floodplain used to delineate flood boundaries contrasted with previously mapped Federal Emergency Management Agency (FEMA) flood zone boundaries.
The Importance - Forest and Tree Studies

Fig 6: Tree canopy information

H = height
CW = crown width
S = spacing
The Importance - Coastal Change Mapping

Fig 7: Coastal studies undertaken by the U.S. Geological Survey on Dauphin Island before and following Hurricane Katrina.
The Importance - Additional

- Mapping of corridors, e.g., roads, railway tracks, pipelines, waterway landscapes
- Mapping of electrical transmission lines and towers including ground/tree clearance
- DTM and DSM generation in urban areas, automated building extraction, generation of 3-D models for city planning
- Measurement of snow- and ice-covered areas, including glacier monitoring
- Measurement of wetlands
- Derivation of vegetation parameters, e.g., tree height, crown diameter, tree density, biomass estimation, determination of forest borders
- Hydrographic surveys in depths up to 70 m.
The Challenges
The Challenges - Reflectivity

<table>
<thead>
<tr>
<th>Material</th>
<th>Reflectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension lumber (pine, clean, dry)</td>
<td>94</td>
</tr>
<tr>
<td>Snow</td>
<td>80–90</td>
</tr>
<tr>
<td>White masonry</td>
<td>85</td>
</tr>
<tr>
<td>Limestone, clay</td>
<td>Up to 75</td>
</tr>
<tr>
<td>Deciduous trees</td>
<td>Typ. 60</td>
</tr>
<tr>
<td>Coniferous trees</td>
<td>Typ. 30</td>
</tr>
<tr>
<td>Carbonate sand (dry)</td>
<td>57</td>
</tr>
<tr>
<td>Carbonate sand (wet)</td>
<td>41</td>
</tr>
<tr>
<td>Beach sands, bare areas in desert</td>
<td>Typ. 50</td>
</tr>
<tr>
<td>Rough wood pallet (clean)</td>
<td>25</td>
</tr>
<tr>
<td>Concrete, smooth</td>
<td>24</td>
</tr>
<tr>
<td>Asphalt with pebbles</td>
<td>17</td>
</tr>
<tr>
<td>Lava</td>
<td>8</td>
</tr>
<tr>
<td>Black neoprene (synthetic rubber)</td>
<td>5</td>
</tr>
</tbody>
</table>

Tbl 1: Typical reflectivity of various diffuse reflecting materials for 900 nm wavelength

Fig 8: Correction factor for maximum laser range, depending on target reflectivity
The Challenges - Spot Size
The Challenges - Frequency

Fig 10: LiDAR used to image a room
The validation method
What is the validation method?

- Calibration
  - At the time of the paper, multiple ways to calibrate and not officially standardized
  - Recorded along with POS Data & Ranges for post scan processing
  - Includes mounting parameters of the laser
  - 2 types of calibration
    - System calibration
      - Factory Calibration (Manufacturer provides some calibration method)
      - In-Situ calibration (Performed by flying over calibration site that has been accurately surveyed using GPS)
    - Data Calibration (Rigorous data adjustment)
What is the validation method?

- **Processing Chain**
  - Adjustment to ranges made during multiple stages after scanning
  - Includes both mathematical model adjustment and human quality check
  - Can still result in holes in data

Fig. 12. Typical processing steps for laser scanner data.
What is the validation method?

- Accuracy
  - Now multiple industry and government host LIDAR data
  - Example:
    - National Standard for Spatial Data Accuracy (NSSDA) w/ American Society for Photogrammetry and Remote Sensing (ASPRS)
      - Require vertical accuracy with confidence of 95% or higher
      - Require a minimum of 20 checkpoints (30 preferred) for each type of land mass

\[
Lidar\ Horizontal\ Error (RMSE_r) = \sqrt{(GNSS\ positional\ error)^2 + \left(\frac{\tan(IMU\ error)}{0.55894170} \times flying\ altitude\right)^2}
\]

ASPRS Lidar Horizontal Error Formula
The novel contributions
What are the novel contributions?

- The paper gave a proper introduction and overview of lidar for topology and geographical use
- Seminal paper with >1500 citations
- Define the pipeline structure to create lidar systems
The limitations of the related work
What are the limitations of the related work?

- Currently have to do all processing post scanning
- Post processing is slow compared to scanning at the time of the paper
- Some software for processing is proprietary leading to irregular processing among different people
- Improve filter/removal and classification/separation of object methods
Sources

- Christopher Parrish. Lidar and Height Mod Workshop
  link: https://www.ngs.noaa.gov/corbin/class_description/Parrish_Lidar_and_Height_Mod_Presentatio
  n.pdf
  introduction to LiDAR technology, data, and applications. NOAA Coastal Services Center, 2.
  link: https://ibis.geog.ubc.ca/courses/geog373/lectures/Handouts/LiDARforDummies.pdf
- Lidar Wikipedia. link: https://en.wikipedia.org/wiki/Lidar