Introduction to Lidar, Terrestrial Laser Scanning Applications

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UNAVCO / OpenTopography, Boulder, CO
Light Detection and Ranging (lidar)

• Accurate distance measurements with a laser rangefinder
• Distance is calculated by measuring the two-way travel time of a laser pulse.
• Near IR (1550nm) or green (532nm)

Modified from Ian Madin, DOGAMI
Lidar platforms

J. Stoker, USGS
Similar technology, different platforms:

Terrestrial Laser Scanning (TLS)
- Also called ground based lidar or T-lidar.

Laser scanning moving ground based platform = Mobile Laser Scanning (MLS).

Laser scanning from airborne platform = Airborne Laser Scanning (ALS).
<table>
<thead>
<tr>
<th>System:</th>
<th>Spaceborne (e.g. GLAS)</th>
<th>High Altitude (e.g. LVIS)</th>
<th>Airborne (ALS)</th>
<th>Terrestrial (TLS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude:</td>
<td>600 km</td>
<td>10 km</td>
<td>1 km</td>
<td>1 m</td>
</tr>
<tr>
<td>Footprint:</td>
<td>60 m</td>
<td>15 m</td>
<td>25 cm</td>
<td>1-10 cm</td>
</tr>
<tr>
<td>Vertical Accuracy</td>
<td>15cm to 10m depends on slope</td>
<td>50/100 cm bare ground/vegetation</td>
<td>20 cm</td>
<td>1-10 cm Depends on range which is few meters to 2 km or more</td>
</tr>
</tbody>
</table>
Lidar & Autonomous Vehicles

Sight Lines, ScanLAB: https://vimeo.com/145248208
Light Detection and Ranging (lidar)
Lidar data collection

1. Laser scanner
2. Inertial Measurement Unit (IMU)
3. GPS

Direction of Flight

Laser

Laser Pulse

Laser Spot Size

Scan Line

15 - 20 cm
Scan line spacing, swath width, spot size and overlap can all be defined as necessary to achieve target data to specification.
Aircraft: Cessna 337 Skymaster

Personnel
- One pilot, one operator in plane
- GPS ground crew (2 to 10+ people)

Scanner: Optech near-IR

PRF: 33-900 KHz

Flying height: 600 – 1,000m AGL

Flying speed: 120 mph

Swath overlap: 50% nominal

Ground truthing: GPS (campaign & CORS)

Navigation solution: KARS

Point spacing: sub-meter

Nominal Accuracy (on open hard and flat surface)
- Vertical: 3 – 6 cm.
- Horizontal: 20 – 30 cm.
How a Lidar instrument works

- Transmits laser signals and measures the reflected light to create 3D point clouds.
- Wavelength is usually in the infrared (~1550nm) or green (532nm) spectrum.
Beam Divergence

\[ D_f = (\text{Divergence} \times d) + D_i \]

@100m, 
\[ D_f = 36\text{mm} \]

@500m, 
\[ D_f = 180\text{mm} \]

@1000m, 
\[ D_f = 360\text{mm}! \]
Angular Step

Rule of thumb: scan at least $1/10^\text{th}$ of the “wavelength” of the object you wish to image.
Riegl VZ400 Maximum measurement range as function of target material

Long Range Mode
PRR = 100 kHz

High Speed Mode
PRR = 300 kHz

- Standard clear atmosphere: visibility 23 km
- Clear atmosphere: visibility 15 km
- Light haze: visibility 8 km
- Medium haze: visibility 5 km
Discrete pulse = binary yes or no return

Full waveform = digitized backscattering waveform

Benefits of full waveform?
- More resolution between pulse width ambiguity
- Spectral property information
- Improved fitting of geometrically defined targets.
Each laser pulse can produce multiple consecutive measurements from reflections off several surfaces in its path.

- Left = point cloud view of the tree in the photo on the right. Each point is colored by which return it was from a particular pulse:
  - Red = 1st
  - Yellow = 2nd
  - Green = 3rd

Ian Madin, DOGAMI
Multiple Return lidar systems

- All returns (16,664 pulses)
- 1\textsuperscript{st} returns
- 2\textsuperscript{nd} returns (4,385 pulses, 26%)
- 3\textsuperscript{rd} returns (736 pulses, 4%)
- 4\textsuperscript{th} returns (83 pulses, <1%)

Image courtesy Hans-Erik Anderson

J. Stoker
Comparison: ALS vs TLS

J. Oldow, UTD

Study Area

Los Angeles County

San Gabriel Mountains
Comparison: ALS vs TLS

San Gabriel Mountain 1-m DEM from airborne LiDAR

J. Oldow, UTD
Comparison: ALS vs TLS
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J. Oldow, UTD
Comparison: ALS vs TLS
Showcase Tool #1: TLS Terrestrial Laser Scanner
TLS Research Applications

- Project: 2011 Japan Tsunami measurements
- PI: Hermann Fritz (Georgia Tech)
- NSF RAPID project
April 4, 2010
Mw 7.2
~100km rupture
CA-Mexico border to the gulf

> 3m right-normal slip north of epicenter
< 1m right-normal blind faulting south of epicenter
Motivations: Data Collection

- Preserve primary rupture features for:
  - Remote measurement/analysis
  - Comparison to future scans

- Scan ruptures in a variety of geologic and geomorphic settings

Site 4
Site 2
Site 1
Site 3

Paso Superior Fault
Borrego Fault

Sierra Cucapah

P. Gold, UCD
Scale of TLS coverage

- Shaded T-lidar point cloud
- Photo from helicopter
- Scarp Height = 1.6m
- Borrego Fault
- No data
- View to SW

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El Mayor-Cucapah Earthquake, 2010

~200m along-strike distances

P. Gold, UCD
Data Collection

El Mayor-Cucapah Earthquake, 2010

Vegetation schematic x-sxn

TLS boundary

2010 rupture

Reg. target

Scan position

P. Gold, UCD

Site 3 (Riegl scanner)

3 days

~100 million pts

0.15 km², 500 pts/m²
Change Detection – Scarp Erosion

Austin Elliott (UC Davis Ph.D. student)
SoCal Paleoseismology

T. Rockwell, SDSU
Precariously Balanced Rocks, PBRs

- Project Highlight: Precariously balanced rock (PBR) near Echo Cliffs, southern California.
- PI: Ken Hudnut, USGS.
- Goal: generate precise 3D image of PBR in order to calculate PBR’s center of gravity for ground motion models useful for paleoseismology, urban planning, etc. (Hudnut et al., 2009)
Precariously Balanced Rocks, PBRs

3D surface model and simulated 1994 Northridge waveforms

Northridge 1994 simulation by Rob Graves

3D model by Gerald Bawden and Sandra Bond
Four Mile Fire, CO, Erosion (PIs: Moody, Tucker)
Repeat surveys give ability to quantify temporal change.

Integration of TLS and ALS data

Steve DeLong, USGS
• 10-15 Antarctic and Arctic Projects per yr
• Remote locations, challenging logistics (helicopter, icebreaker, backpack)
• Extreme environmental conditions:
  ➢ -35C to +15C, 20-65 knot winds

Science:
• Geomorphology: Frost polygons and ancient lake beds
• Glaciology: Glacier melt and ablation
• Biology/Ecology: Weddell Seal volume; Microtopology of tundra in Alaska
• Archaeology: Human impact of climate change
Mount Erebus, Antarctica

- Lava lake scanned 2008 - 2013, revealing behaviors invisible to naked eye
- Inner crater scan used to augment and truth 2003 aerial scans
- Scans of ice caves and ice towers help determine thermal / energy budget of volcano

Scans of ice caves and ice towers help determine thermal / energy budget of volcano
Using TLS to Obtain Volumetric Measurements of Weddell Seals in the McMurdo Sound

Seal body mass = proxy for availability of marine food resources
Hadrosaur Trackways on Denali

Fiorillo, et al., 2014, Geology, DOI: 10.1130/G35740.1
• Scanning to measure biomass in Everglades National Park (PI: Wdowinski).
Everglades Biomass, Wdowinski
Thanks!
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