Modern LIDAR Sensor Technologies - an Overview

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Timeline Airborne Laser Scanning


First/last Pulse  5 kHz

Airplane/Helicopter  LiDAR: Light Detection And Ranging
Light aircraft/Gyrocopter  Bathymetry/Hydrographie
UAV

Deep Bathy\textsuperscript{1)/Shallow Bathy  Topo-Bathy  UAV-Bathy

Single Wavelength LiDAR

Linear Mode LiDAR

Full waveform laser scanning

Geiger-mode LiDAR  Single Photon LiDAR

Multi-spectral LiDAR

\textsuperscript{1)}
Timeline Airborne Laser Scanning – 1997

Point density: 1-2 points/m²
ALS simulation
First/last echo

Colored by amplitude

Hessigheim, Germany
Data: BfG, Koblenz
Timeline Airborne Laser Scanning – 2015

Point density: points/m²
ALS simulation
Full waveform

Colored by reflectance
Timeline Airborne Laser Scanning – 2019

Point density: 800 points/m²
UAV LiDAR
Full waveform

Colored by reflectance

Hessigheim, Germany
Data: BfG, Koblenz
Timeline Airborne Laser Scanning – 2019

Point density: 800 points/m²
Hybrid UAV-LiDAR + camera
Full waveform

Colored by reflectance/RGB

Hessigheim, Germany
Data: BfG, Koblenz
Contents

- LiDAR basics: Geometry and radiometry
- Target detection: From discrete to returns to full waveform LiDAR
- Laser wavelengths: From single wavelength to multispectral LiDAR
- Below water: From topography to bathymetry
- Detector technology: From linear-mode to Single Photon LiDAR
- Sensor systems: From single purpose scanners to hybrid sensor systems
- Platforms: From manned platforms to UAV LiDAR (Topo+Bathy)
Comparison: single laser pulse

**Linear-mode waveform LiDAR**

- **GmLiDAR**
  - 4000-10000m

**Single Photon LiDAR**

- **2000-4000m**

**600-2500m**
Linear-mode vs Single Photon LiDAR

**Conventional LiDAR**
Linear-mode LiDAR

- Diameter of laser footprint
- Receivers's Field Of View (FOV)

**Geiger-mode LiDAR**

- Laser footprint illuminates entire receiver's FOV
- Geiger-mode Avalanche Photo Diode array (GmAPD array, 32x128)

**Single Photon LiDAR**

- 10x10 partial beams (beamlets) derived from single laser pulse via Diffractive Optical Element (DOE)
- Silicon photomultiplier (Degnan, 2019)

1 transmitter → 1 receiver (full waveform)

1 transmitter → 4096 receivers (binary detectors)

1 transmitter → 100 receivers (discrete echo detection)
**Data acquisition Single Photon LiDAR (SPL 100)**

**Flight mission parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight date</td>
<td>29.07.2018</td>
</tr>
<tr>
<td>Scan rate</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Flying altitude</td>
<td>4000m</td>
</tr>
<tr>
<td>Swath width</td>
<td>2000m</td>
</tr>
<tr>
<td>Scan pattern</td>
<td>circular (Palmer)</td>
</tr>
<tr>
<td>Field-of-View</td>
<td>30°</td>
</tr>
<tr>
<td>Overlap</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>Nom. pt. density</td>
<td>20 Pkt/m²</td>
</tr>
<tr>
<td>Nr. of strips</td>
<td>10</td>
</tr>
</tbody>
</table>

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Single Photon LiDAR (SPL): Unfiltered 3D point cloud

City of Vienna, 3rd district, Scanner: Leica SPL100
Single Photon LiDAR (SPL): Postproc. 3D point cloud

City of Vienna, 3rd district, Scanner: Leica SPL100
Full Waveform LiDAR: 3D point cloud

City of Vienna, 3rd district, Scanner: RIEGL VQ-1560i
Visual comparison of 3D point clouds

SPL

Aerial image (RGB)

Waveform LiDAR

Signal intensity [DN]
Comparison: longitudinal section

Legend:
- SPL unfiltered
- SPL postprocessed
- Waveform LiDAR
Sensor systems

From range finders to integrated multi-purpose sensors
## Hybrid Aerial Sensors

<table>
<thead>
<tr>
<th>Produkt</th>
<th>Laser channels [nm]</th>
<th>Scan rate [kHz]</th>
<th>Camera</th>
<th>Type</th>
<th>Pixel size [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optech Titan</td>
<td>532/1064/1550</td>
<td>3 x 300</td>
<td>CM-10000</td>
<td>80 MP, RGB</td>
<td>5.2</td>
</tr>
<tr>
<td>Optech Galaxy</td>
<td>1064</td>
<td>1000</td>
<td>CM-10000</td>
<td>80 MP, RGB</td>
<td>5.2</td>
</tr>
<tr>
<td>Riegl VQ-1560-DW</td>
<td>532/1064</td>
<td>2 x 666</td>
<td>PhaseOne</td>
<td>100 MP, RGB</td>
<td>4.6</td>
</tr>
<tr>
<td>Leica TerrainMapper</td>
<td>1064</td>
<td>2000</td>
<td>RCD30</td>
<td>80 MP, RGBI</td>
<td>5.2</td>
</tr>
<tr>
<td>Leica CityMapper</td>
<td>1064</td>
<td>700</td>
<td>5 x RCD30</td>
<td>80 MP, RGB(I)</td>
<td>5.2</td>
</tr>
</tbody>
</table>

*Titan* | *Galaxy* | *VQ-1560i-DW* | *TerrainMapper* | *CityMapper-2*
Hybrid sensor systems, Leica CityMapper-2

- **Laser scanner**: 1064 nm
- **Pulse repetition rate**: 2000 kHz
- **Beam divergence ($1/e^2$)**: 0.25 mrad
- **Flying altitude**: 300 – 2500 m
- **Scan mechanism**: Risley Prisma
- **4 x oblique cameras**: RCD30, RGBI, 150 Mpix
- **1 x nadir camera**: RCD30, RGBI, 150 Mpix


*Arbitrary scan patterns by coupling of two rotating prisms (Risley prism)*
Fusion of LiDAR and Images

Data: Riegl VQ-1560i, PhaseOne iXU-RS1000, Vienna
Colored by signal intensity
Fusion of LiDAR and Images

Data: Riegl VQ-1560i, PhaseOne iXU-RS1000, Vienna
Hybrid sensor orientation (Glira, 2019)

Schematic representation of laser/camera sensors on an airborne platform

Glira et al., 2019, Hybrid Orientation of Aerial Lidar Point Clouds and Aerial Images. ISPRS Annals, Geospatial Week, Enschede, The Netherlands
Hybrid sensor orientation (Glira, 2019)

- Correspondence between two lidar strips (STR-to-STR)
- Correspondence between CPC and lidar strip (CPC-to-STR)
- Correspondence between images (tie point) (IMG-to-IMG)
- Correspondence between tie point and GCP (IMG-to-GCP)

Minimization of point-to-plane distance in object space
Minimization of point-to-plane distance in object space
Minimization of image residuals in image space
Minimization of image residuals in image space

strip adjustment of lidar point clouds
aerial triangulation

hybrid adjustment: lidar strip adjustment + aerial triangulation
Height differences LiDAR – Dense Image Matching

Laser only orientation

Hybrid sensor orientation

Relative Orientation: strips-to-strips
Relative Orientation: strips-to-images
Deviation: laser block vs. optimum orientation

Data: Hessigheim, BfG, Koblenz

Deviation: laser block vs. optimum orientation

median = 0.000
$\text{sig}_{\text{mad}} = 0.004$

median = 0.000
$\text{sig}_{\text{mad}} = 0.004$

median = 0.000
$\text{sig}_{\text{mad}} = 0.006$

median = 0.000
$\text{sig}_{\text{mad}} = 0.000$
Platforms

From manned aircrafts to Unmanned Aerial Vehicles
Manned and unmanned platforms

Transport aircraft (Source: Wiki)

Light aircraft (Source: Diamond aircraft)

Helicopter (Source: SPAR3D)

UAV (Source: Wallace et al. Forests)

Gyrocopter (Source: IGI systems)
Unmanned platforms

(a) Octocopter UAV (MTOM: 25 kg)
- rotors
- GNSS+ radio data link antennas
- batteries
- laser scanner (1) + IMU
- cameras

(b) Octocopter UAV (MTOM: 35 kg)
- rotors
- GNSS+ radio data link antennas
- batteries
- laser scanner (4)
- camera or IR laser

(c) Hexacopter UAV (MTOM: 15.5 kg)
- rotors
- GNSS antennas
- batteries
- laser scanner (1) + IMU
- cameras
- profile array laser scanner (5)

(d) Fixed wing UAV (MTOM: 15.5 kg)
- rotors
- GNSS+ radio data link antennas
- batteries
- profile array laser scanner (5)

Source: 4D-IT, www.4d-it.com
Source: Quantum systems, https://www.quantum-systems.com
Source: YellowScan, https://www.yellowscan-lidar.com/
### UAV LiDAR – Sensor overview

<table>
<thead>
<tr>
<th>ID</th>
<th>sensor</th>
<th>mass [kg]</th>
<th>wavelength [nm]</th>
<th>max range [m]</th>
<th>prec/acc</th>
<th>meas. rate [kHz]</th>
<th>meam div. [mrad]</th>
<th>footprint @50m agl</th>
<th>FOV</th>
<th>channels</th>
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<tbody>
<tr>
<td>1</td>
<td>VUX1-UAV</td>
<td>3.75</td>
<td>1550</td>
<td>300</td>
<td>5/10</td>
<td>500</td>
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<td>25</td>
<td>330</td>
<td>1</td>
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<tr>
<td>2</td>
<td>miniVUX-2UAV</td>
<td>1.60</td>
<td>905</td>
<td>250</td>
<td>10/15</td>
<td>200</td>
<td>1.6 x 0.5</td>
<td>80 x 25</td>
<td>360</td>
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<tr>
<td>3</td>
<td>VUX-240</td>
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<td>1064</td>
<td>650</td>
<td>15/20</td>
<td>1500</td>
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<td>18</td>
<td>75</td>
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<tr>
<td>4</td>
<td>VQ-840-G</td>
<td>12.00</td>
<td>532</td>
<td>---</td>
<td>15/20</td>
<td>200</td>
<td>1.0 - 6.0</td>
<td>50 - 300</td>
<td>40</td>
<td>1</td>
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<tr>
<td>5</td>
<td>Puck LITE-G</td>
<td>0.59</td>
<td>903</td>
<td>100</td>
<td>--/30</td>
<td>300</td>
<td>3.0 x 1.2</td>
<td>150 x 60</td>
<td>360</td>
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<td>6</td>
<td>Alpha Puck</td>
<td>3.50</td>
<td>903</td>
<td>300</td>
<td>--/30</td>
<td>2400</td>
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<td>150 x 75</td>
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<td>128</td>
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<td>7</td>
<td>CL-90</td>
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<td>175</td>
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<td>500</td>
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<td>15</td>
<td>90</td>
<td>1</td>
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<tr>
<td>8</td>
<td>CL-360</td>
<td>3.50</td>
<td>1550</td>
<td>300</td>
<td>5/10</td>
<td>500</td>
<td>0.3</td>
<td>15</td>
<td>360</td>
<td>1</td>
</tr>
</tbody>
</table>

![Images of sensors](1-8)

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Mandlburger: Modern LIDAR technologies
UAV-LiDAR Hessigheim

LiDAR point cloud colorised with oblique imagery

Data: Hessigheim, BfG, Koblenz
Sensor: Riegl VUX1-UAV+2xSony A6000
Bathymetric UAV Laser Scanning: Riegl VQ-840-G
Data capturing, Neubacher Au, Pielach, Aug 27th 2019

Landing of RiCopter-M carrying VQ-840-G bathymetric laser scanner after surveying a 500m section of Pielach River
Summary

• Constant progress in lidar technology
  - Echo detection:
    • Discrete echo $\rightarrow$ full waveform capture $\rightarrow$ online waveform processing
  - Measurement rate:
    • Increased measurement range and scan rate $\rightarrow$ multiple pulses in the air
  - Multiple wavelengths:
    • Single wavelength $\rightarrow$ multispectral laser scanning
  - Receiver sensitivity:
    • Linear-mode LiDAR $\rightarrow$ Single Photon LiDAR
  - Comprehensive systems:
    • Scanner only $\rightarrow$ Hybride sensor system (scanner + cameras)
  - Miniaturization:
    • Manned platforms $\rightarrow$ UAV LiDAR $\rightarrow$ small footprint $\rightarrow$ high spatial resolution