SEARCHING FOR THE POTENTIAL OF SINGLE PHOTON TECHNOLOGIES – TOWARDS MULTISPECTRAL SINGLE PHOTON LIDAR: FGI CASES STUDIES ON SINGLE PHOTON LIDAR

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Basic Motivation

Multispectral Laser Scanning
• output of the laser scanner: including the intensity
• several active channels at different wavelengths -> multispectral laser scanner.
• fundamental for fully using the intensity data, and their applications with ALS intensities were presented by Coren and Sterzai (2006), Ahokas et al. (2006), Wagner et al. (2006), and Höfle and Pfeifer (2007).

Single Photon
• Single photon technologies permits about 100 times higher pulse rates and data densities; limitations such as low signal to noise ratio, noisy data, and cloud cover permitting operations
• If single photon techniques can be combined with active multispectral laser scanning, then automatic 3D object recognition would be more accurate and faster, allowing completely new possibilities for various mapping and monitoring tasks

The presentation is our attempt and story towards multispectral single-photon lidar since Anttoni Jaakkola’s discovery (2016), that it is possible – with some success and with disappointments.
Single Photon/Geiger in General
Remarks (e.g. Jutzi 2017)

- **Wavelength and intensity** - visible domain (532 nm) is excellent for bathymetry, generally low reflectances from natural surfaces. Optical components are inexpensive, the detector arrays high efficiency. Near-infrared wavelength with 1064 nm (lower solar background, generally high reflectances from natural surfaces). Multi-spectral LiDAR is challenging. Surface reflectance capabilities require reasonable radiometry. The sum of photons collected by the full 10x10 array is comparable to the sum of photons collected with a conventional Multi-Photon LiDAR (MPL).

- **DTM** – SPL/SS: recovery time with 1.6 ns (respectively 24 cm in range). In GM the penetration capabilities are limited, DTM generation might be difficult. Blanking loss appears after a photon event is triggered (respectively 7.5 to 240 m in range). DSMs can be well determined, but generating DTMs might be challenging.

- **Point density** – SPL/SS: a 10x10 regular array; GM: array of APDs with 128x32 elements in total in GM. The aerial coverage with up to 2100 km²/h (@ 8 pts/m²) correspond to Maximum Flying Height of 11000 m AGL. High altitude is more sensitive to atmospheric influences and effects caused by weather conditions.

- **Scanning Geometry** - Facades of buildings.

- **Noise in data** - smoothing
Why Multispectral?

Leena Matikainen, Xioawei Yu, Kirsi Karila, Juha Hyyppä

Centre of Excellence in Laser scanning Research
FGI Multispectral LS examples


Adjustment of intensities
## Tree Species Classification

### Confusion matrix based on intensity features

<table>
<thead>
<tr>
<th></th>
<th>Pine</th>
<th>Spruce</th>
<th>Birch</th>
<th>producer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
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<tr>
<td>Pine</td>
<td>623</td>
<td>12</td>
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<tr>
<td>Birch</td>
<td>47</td>
<td>18</td>
<td>197</td>
<td>75.19</td>
</tr>
</tbody>
</table>

**user**

- Pine: 88.75
- Spruce: 85.71
- Birch: 82.08

**Overall = 86.81%**

### Confusion matrix based on point cloud and intensity features

<table>
<thead>
<tr>
<th></th>
<th>Pine</th>
<th>Spruce</th>
<th>Birch</th>
<th>producer</th>
</tr>
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<tbody>
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<td>Reference</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pine</td>
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<td>15</td>
<td>95.55</td>
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<tr>
<td>Spruce</td>
<td>18</td>
<td>201</td>
<td>20</td>
<td>84.10</td>
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<td>Birch</td>
<td>46</td>
<td>21</td>
<td>195</td>
<td>74.43</td>
</tr>
</tbody>
</table>

**user**

- Pine: 90.67
- Spruce: 85.17
- Birch: 84.78

**Overall = 88.36%**
FGI Single Photon System

Anttoni Jaakkola, Antero Kukko, Teemu Hakala, Matti Lehtomäki, Xinlian Liang, Juha Hyyppä

Centre of Excellence in Laser scanning Research
Experiment and case study

System Setup

• Range gating: 3x5 ns gate
• Size of one image is 64 pixels x 32 pixels
• Flight altitude: 100 m AGL
• 2 sequences per second:
  – 3x500 frames per seq.
  – 70m field of depth in total
• 16 cm pixel size on the ground
Experiment and case study

Point density appr. 500/m²
Tests with SPL100

Eero Ahokas, Juha Hyyppä
Centre of Excellence in Laser scanning Research
# Applied SPL and ALS Data

<table>
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<th>SPL120</th>
<th>Titan</th>
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<tr>
<td><strong>flight lines</strong></td>
<td>7</td>
<td>5</td>
<td>37</td>
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<tr>
<td><strong>flight altitude AGL (m)</strong></td>
<td></td>
<td></td>
<td>1644-1736 ft</td>
</tr>
<tr>
<td><strong>wavelength (nm)</strong></td>
<td>532</td>
<td>532</td>
<td>532/1064/1550</td>
</tr>
<tr>
<td><strong>FOV</strong></td>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td><strong>laser pulse rate (kHz)</strong></td>
<td>60</td>
<td></td>
<td>250</td>
</tr>
<tr>
<td><strong>scan frequency (Hz)</strong></td>
<td>up to 25</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td><strong>point density (pts/m2)</strong></td>
<td>67.4</td>
<td>22.4</td>
<td>41.7</td>
</tr>
<tr>
<td><strong>stripe wide (m)</strong></td>
<td>1030</td>
<td>2060</td>
<td>214</td>
</tr>
<tr>
<td><strong>divergence (mrad)</strong></td>
<td>0.08 (1/e2)</td>
<td>0.08 (1/e2)</td>
<td>Channel 1,2: 0.35 (1/e), Channel 3: 0.7 (1/e)</td>
</tr>
</tbody>
</table>
Data from walls/balconies
Data from walls/balconies
Data from walls/balconies

Point count (pixel size 20 cm)  Standard deviation of height
Use of pulse information, blue =1. pulse, red=only pulse
Car and deciduous tree – penetration in deciduous canopies
Sometimes good penetration with deciduous trees
Penetration into water, large number of underground points
Dirty Water, Espoo, max penetration 1.24 m
Asphalt road – elevation std 4 cm
Details and different pulses in built environment
Shadows in the data using pulse information
Ground points even 2m below ground level – filtering problem
Tram – electric wires are visible
Shadows in building area
Pulse mode sometimes gives the storey numbering
Tests with SPL100 for forests and DTM

Xiaowei Yu, Juha Hyyppä
Centre of Excellence in Laser scanning Research
**Study area and reference data**

**Reference data**
- 91 sample plots of 32 m x 32 m
- Dominant species:
  - Scots pine, Norway spruce, birch
- Measurements:
  - tree height, DBH, tree species.

**EVO test site and sample plots**
Features of ground points

Titan data

SPL data
Tests with SPL100 for building mapping

Arttu Järvinen, Antero Kukko, Harri Kaartinen, Juha Hyyppä

Centre of Excellence in Laser scanning Research
Testsie: Espoonlahti

~ 265 ha
Surface area differences (m²)

<table>
<thead>
<tr>
<th>Block of flats 1</th>
<th>Warehouse</th>
<th>VUX</th>
<th>VUX</th>
<th>Trash shelter</th>
<th>Block of flats 2</th>
<th>VUX</th>
<th>VUX</th>
<th>Car shelter</th>
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<td>33.69</td>
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<tr>
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<td>Titan</td>
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<td>+4.05</td>
<td>Titan Ch3</td>
</tr>
</tbody>
</table>

| Trash shelter          |           |          |          |          |          |          |          |          |          |
| miniVUX                |           | SPL-100_1 | +10.59 | SPL-100_1 | +107.30 | SPL-100_1 | +107.30 | SPL-100_1 | +107.30 |
| SPL-100_2              | +32.54    | SPL-100_2 | +31.98 | SPL-100_2 | +31.98 | SPL-100_2 | +31.98 | SPL-100_2 | +31.98 |
| Titan                  | +44.15    | Titan | +33.18 | Titan |       | Titan | +33.18 | Titan |       |
| Titan Ch1              | +5.59     | Titan Ch1 | -4.61 | Titan Ch1 |       | Titan Ch1 | -4.61 | Titan Ch1 |       |
| Titan Ch2              | +14.92    | Titan Ch2 | +0.16 | Titan Ch2 |       | Titan Ch2 | +0.16 | Titan Ch2 |       |
| Titan Ch3              | +59.27    | Titan Ch3 | +52.71 | Titan Ch3 |       | Titan Ch3 | +52.71 | Titan Ch3 |       |
Simulation of multispectral single photon data for mapping/land cover classification

Leena Matikainen, Paula Litkey, Kirsi Karila, Eero Ahokas
Juha Hyyppä

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Some DSM experiments

SPL, Min height, 100 cm
SPL, Max height, 100 cm

Another laser dataset, Min height, 100 cm
Another laser dataset, Max height, 100 cm

SPL, Min height, 100 cm / 20 cm

- Processing methods used for other laser scanner datasets are not necessarily directly applicable to SPL data
- More experiments are needed
Intensity has some block structure
Automatic classification of SPL data into 6 land cover classes

- Results are acceptable on a coarse level
- Details such as narrow roads are not accurately detected
Towards Autonomous Single Photon System

Anttoni Jaakkola, Tero Heinonen, Antero Kukko, Juha Hyyppä
Centre of Excellence in Laser scanning Research
FGI Autonomous Driving Research Team
Longest range flash LiDAR

Developed in 6 months in 2018

Created in collaboration between FGI and industry

Inventors and creators FGI researchers Dr. Anttoni Jaakkola and Tero Heinonen