Processing full-waveform lidar data: Modelling raw signals

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Outline

1. Introduction
   - Background on FW lidar data
   - Context

2. Methodology
   - FW processing: approach
   - Modelling functions
   - Point extraction algorithm

3. Results
   - Point extraction
   - Modelling functions

4. Conclusion and future work
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Background on full-waveform lidar data

- Entire backscattered signal recorded,
- Acquisition of a continuous altimetric section (∼ 30 m profiles).
  (1 ns → 30 cm).

**Advantages:**

- Waveform post-processing,
- Additional information on the illuminated surface structure,
- Physical properties can be found.

▷ More control in the interpretation process.
Full-waveform lidar data to study forested areas

- Full-waveform lidar data
- Gaussian mixture decomposition
- 3D point cloud with attributes
- Classification
  - DTM
  - Tree species classification
  - Forest parameters (tree height, LAI, ...)

[Wagner IJPRS06]

[Reitberger PCV06]
Context

- Full-waveform lidar data to study forested areas

In the context of processing full-waveform lidar data, the following steps are involved:

1. Full-waveform lidar data
2. Gaussian mixture decomposition
3. 3D point cloud with attributes
4. Classification
   - DTM
   - Tree species classification
   - Forest parameters (tree height, LAI, ...)
5. Advanced modelling

[Wagner IJPRS06]

[Reitberger PCV06]
Full-waveform lidar data to study forested areas

- Full-waveform lidar data
  - Gaussian mixture decomposition
  - Advanced modelling
- 3D point cloud with attributes
- Classification
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  - Forest parameters (tree height, LAI, ...)
- Morphological interpretation

References:
- Wagner IJPRS06
- Reitberger PCV06
Full-waveform lidar data to study forested areas

- Full-waveform lidar data
- Gaussian mixture decomposition
- 3D point cloud with attributes
- Classification
- DTM
  - Tree species classification
- Forest parameters (tree height, LAI, ...)
- Advanced modelling
  - Improves
  - Morphological interpretation
  - Improves

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Waveform processing: approach

Decomposing waveforms into a sum of components (echoes):

\[ y = f(x) = \sum_{j=1}^{n} f_j(x) \]

- parametric approach
- targets characterized by model functions \( f_j \)
Waveform processing: approach

**Gaussian**

\[ a_j \exp \left( -\frac{(x-\mu_j)^2}{2\sigma_j^2} \right) \]

3 parameters

symmetric
Waveform processing: approach

Waveform $\rightarrow$ Modelling functions $\rightarrow$ Point extraction algorithm

**Gaussian**

$$a_j \exp \left( - \frac{(x - \mu_j)^2}{2\sigma_j^2} \right)$$

- 3 parameters
- Symmetric

**Lognormal**

$$a_j \exp \left( - \frac{(\ln(x - s_j) - \mu_j)^2}{2\sigma_j^2} \right)$$

- 4 parameters
- Asymmetric
Waveform processing: approach

**Gaussian**

\[ a_j \exp \left( -\frac{(x-\mu_j)^2}{2\sigma_j^2} \right) \]

3 parameters, symmetric

**Lognormal**

\[ a_j \exp \left( -\frac{\left( \ln(x-s_j)-\mu_j \right)^2}{2\sigma_j^2} \right) \]

4 parameters, asymmetric

**Generalized Gaussian**

\[ a_j \exp \left( -\frac{|x-\mu_j|^{\alpha_j^2}}{2\sigma_j^2} \right) \]

4 parameters, flattened or peaked
Point extraction algorithm

Waveform → Modelling functions → Point extraction algorithm

Example of full-waveform raw data

Amplitude

Time (bins)
Point extraction algorithm

1. Estimate number of components

```
| Waveform | Modelling functions | Point extraction algorithm |
```

Estimate number of components

```
Amplitude
0 10 20 30 40 50 60
Time (bins)
0
10
20
30
```

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Point extraction algorithm

1. Estimate number of components
2. Parameter optimization

Non-linear least-squares fitting
Point extraction algorithm

1. Estimate number of components
2. Parameter optimization
3. Detect missing peaks

Enhanced peak detection

- Waveform
- Modelling functions
- Point extraction algorithm
Point extraction algorithm

1. Estimate number of components
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3. Detect missing peaks
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Available full-waveform data

- **RIEGL LMS-Q560** device,
- Acquisition over Biberach City (Germany),
- Footprint size: 0.25 m,
- Pulse density: 2.5/m²

Data provided:
- **Waveform**: 1 or 2 sequence(s) of 60 samples
- **3D point cloud**: echoes found by embedded system.
Point cloud densification

- up to +50% points in 3D point cloud over vegetated areas
- up to +5% in urban areas (building edges)

Weak First/last echoes detection improvement

Amplitude image of the first echoes displayed in the sensor geometry.
Point extraction

Point cloud densification

- +50% points in 3D point cloud over vegetated areas
- +5% in urban areas (building edges)

Weak First/last echoes detection improvement

Image of altimetric differences between our first/last echoes and first/last echoes found by the embedded system.
Lognormal and generalized Gaussian models

- Lognormal: only improvement in isolated peaks inside a waveform
- Generalized Gaussian model globally improves the quality of fit

Histogram of residuals on the whole survey for Gaussian and generalized Gaussian models.
Modelling functions

$\alpha$ values histogram

- Building roofs
- Asphalt streets
- Dense vegetation

<table>
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<th>Mean</th>
<th>Std deviation</th>
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<td>1.57</td>
<td>0.09</td>
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<tr>
<td>1.56</td>
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</table>
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Conclusion and future work

Conclusion

- Raw waveform analysis leads to:
  - 3D point cloud densification
  - better modelling of the raw signal with generalized Gaussian

Future work

- Mixture of functions using RJMCMC algorithm
- Validation of DTM with field measurements
- Use morphological interpretation for species classification.
Conclusion and future work

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Thank you!