Echo Digitization and Waveform Analysis in Airborne and Terrestrial Laser Scanning

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σ ... target response, laser radar cross section

\[ P_E(t) \quad P_T(t) \]

\[ \sigma(R) \]

\[ R = \frac{v_g t}{2} \]

- analog (discrete return)
- digitization and offline analysis
- digitization and online processing
- digitization, online processing and offline analysis
Examples of Convolution

\[ s_R(t) \ast \sigma(R) = s_E(t) \]

- Flat target, normal incidence
  - Dirac delta function (approximation)
- Sloping target
  - Gaussian response (approximation)
- Small targets at different ranges
  - Sum of Dirac delta function
- Small targets at nearly the same range
  - Sum of Dirac delta function

**Signal Processing Tasks**

- Signal detection
  - Discrimination against noise
  - Threshold detection (fixed, range dependent, dynamic threshold)
- Signal estimation
  - Temporal position → time of flight → range to target
  - Signal strength → amplitude → laser radar cross-section / reflectance
  - Signal-to-noise ratio → range noise
  - Signal shape →
    - Pulse width (Gaussian decomposition)
    - Pulse shape deviation (V-Line)
- Point in 3D
- Point attributes (radiometric)
- Point precision
- Additional information for filtering / classification
**Signal Processing Electronics**

**Categories of Waveform Data**

- **Full waveform data**
- **Echo waveform data**
- **Echo signal samples**
- **Loosely-coupled samples**

**no precise ranging**
Full Waveform Analysis Methods

Gaussian decomposition
• assumes Gaussian system response
• estimates pulse width
• estimates target’s depth (width)
• robust and fast
• RIEGL RiANALYZE

System response fitting
• relies on knowledge of system response
• copes with non-linear distortion of receiver
• estimates pulse shape deviation
• real-time computation (3 MTargets/sec)
• RIEGL V-Line Online Waveform Processing

- Deconvolution
- B-Spline Deconvolution
- CFD, zero crossing, 2nd derivate detection, ...

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Laser Radar Cross Section (LRCS)
- cross section $\sigma$ in [m²]
- area-normalized cross section values in [m²m⁻²] or [dB]
  - by laser footprint area: $\gamma$
  - by illuminated object area: $\sigma^0$

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \frac{\langle E_s \cdot E_s^* \rangle}{|E_i|^2} = A_i \rho d$$

actual geometric cross-section of target interacting with laser beam
reflectance
directivity of backscattered reflection

Radiometric Calibration

Encoding by **calibrated amplitude**
(0 dB to 50 dB above detection threshold)
Brightness decreases from near objects to far objects.

\[ A_{dB} = 10 \cdot \log \left( \frac{P_{echo}}{P_{DL}} \right) \]

- \( A_{dB} \) ... calibrated amplitude [dB]
- \( P_{echo} \) ... echo signal power [W]
- \( P_{DL} \) ... detection limit [W]

Encoding by **reflectance** (-20 dB to 3 dB, with respect to diffuse white target)
Brightness independent of object distance.

\[ \rho_{rel,T} = A_{dB,T} - A_{dB,White}(R_T) \]

- \( \rho_{rel,T} \) ... target range
- \( R_T \) ... target range

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Close-up on Merging Targets

- **Clear separation of target returns**
  - FWA → perfect result
  - OWP → perfect result
  - DRS → accurate results

- **Merging of target returns**
  - FWA → perfect result
  - OWP → satisfying result
  - DRS → range error on second target

- **Severe merging of target returns**
  - FWA → nearly perfect result
  - OWP → just one target, but detection of pulse shape deviation
  - DRS → just one target, no hint to second target

**FWA** .. Full Waveform Analysis  **OWP** .. Online Waveform Processing  **DRS** .. Discrete Return System

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- Deviation $\delta$ of echo pulse shape from emitted pulse shape
- Similarity of echo pulse to instrument-specific system response
- Measure for “reliability of range result”

<table>
<thead>
<tr>
<th>$\delta$ unlimited</th>
<th>$\delta_{\text{max}} = 50$</th>
<th>$\delta_{\text{max}} = 25$</th>
<th>$\delta_{\text{max}} = 6$</th>
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Deviation of Echo Pulse Shape

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LIDAR with full waveform analysis is a research topic, but not practical for real surveying in everyday use at numerous service providers, mass data production, high-rel applications, but also the basis for numerous scientific papers.

Discrete return delivers same multi-pulse resolution (it's all about resolution).

Echo digitization delivers best resolution, AND a lot of additional valuable attributes.

You can generate / synthesize waveform data from discrete return signals.

No, you can't recover information that has been lost in the detection process.

If you really have to have FW data, make use of the optional digitizer.

The optional digitizer is loosely coupled and provides just some data with questionable usability.
RIEGL echo digitizing LIDAR systems are widely used in surveying (TLS, MLS, ALS, ILS)

- Full waveform analysis, online waveform processing, or combination of both
- Echo digitizing LIDAR systems provide data with:
  - high accuracy and high precision
  - multi-target capability
  - calibrated amplitude data
  - calibrated reflectance data
  - data to „clean-up“ point clouds
  - data to improve classification