RIEGL
LASER MEASUREMENT SYSTEMS

Calibration of Laser Scanners and Laser Scanner Systems

EuroCOW
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RIEGL LMS GmbH

- Calibration tasks and challenges
- Discrete return versus digital signal processing
- Full waveform analysis and online waveform processing
- Extracting valuable point attributes from waveforms
- Radiometric calibration of ALS data
- Multi-target capability and resolution
- Usage of system response calibration


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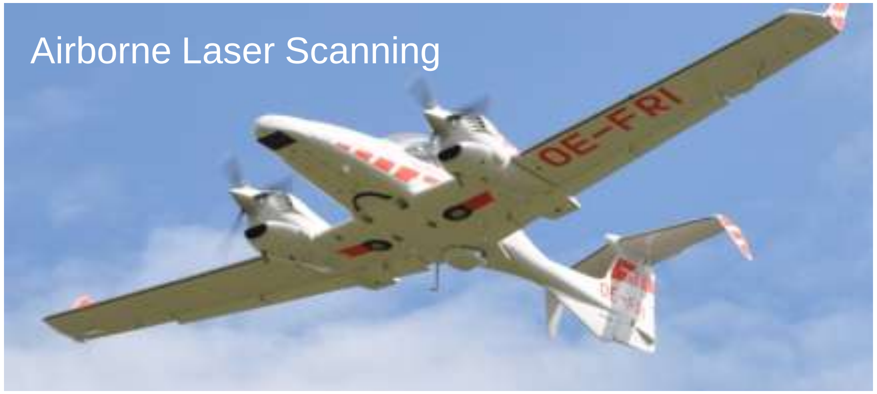
LASER MEASUREMENT SYSTEMS

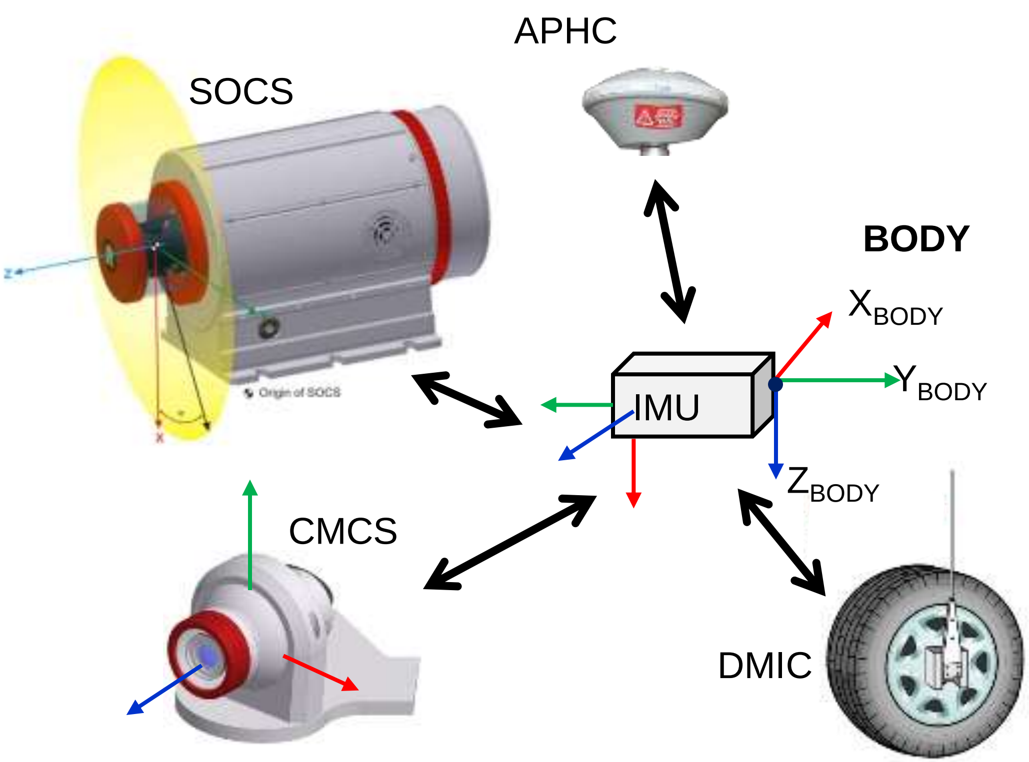

Terrestrial Laser Scanning


Airborne Laser Scanning
OE-FRI


RIEGL
VMX-250
Mobile Laser Scanning


Industrial Laser Scanning

Data acquisition with at least two "independent" subsystems:
IMU/GNSS/DMI & laser scanner(s) / cameras

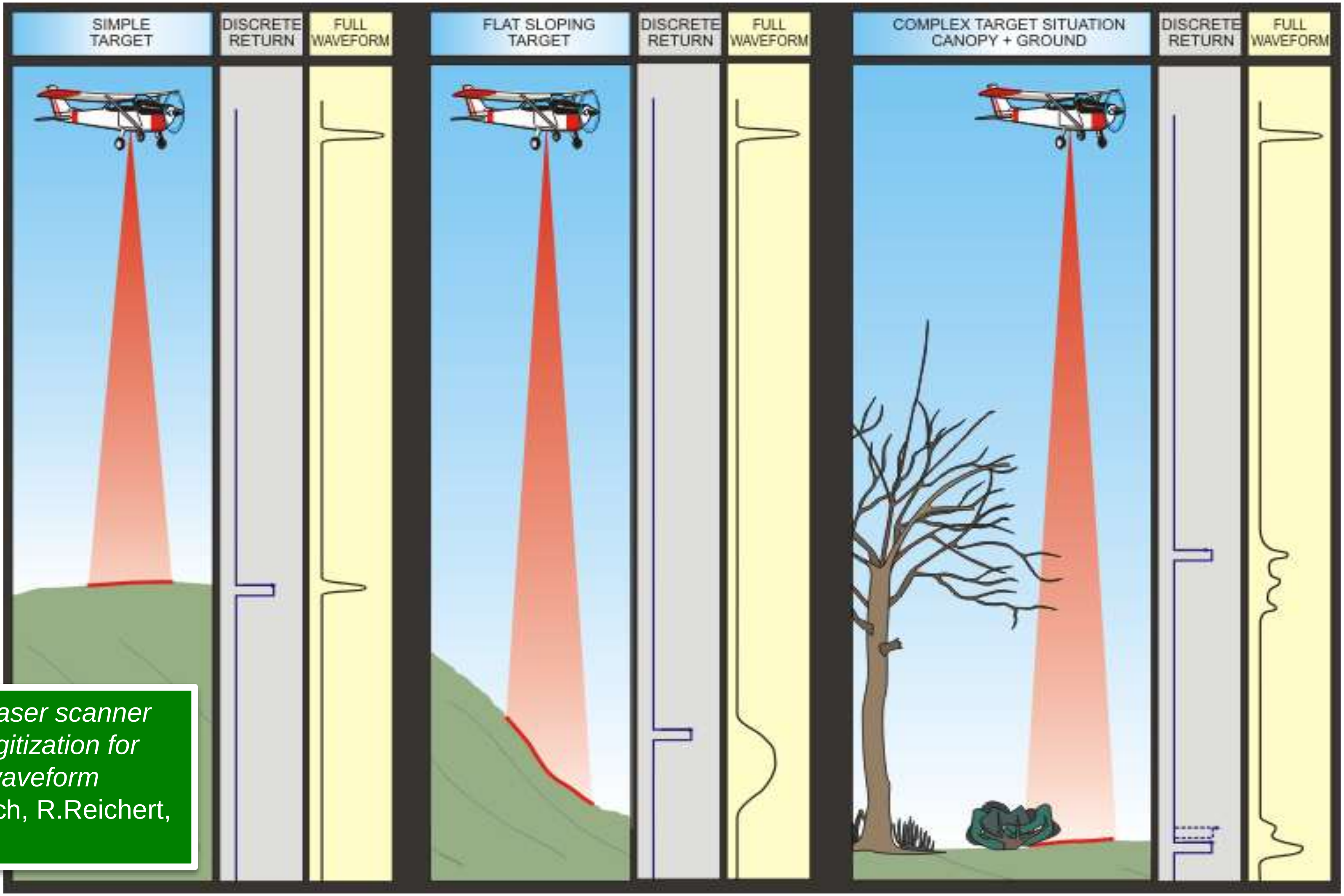


Internal orientations

- IMU axes (accelerometers and gyros)
- antenna (phase center)
- laser scanner (rangefinder, scan mechanism)
- cameras (lens distortion)

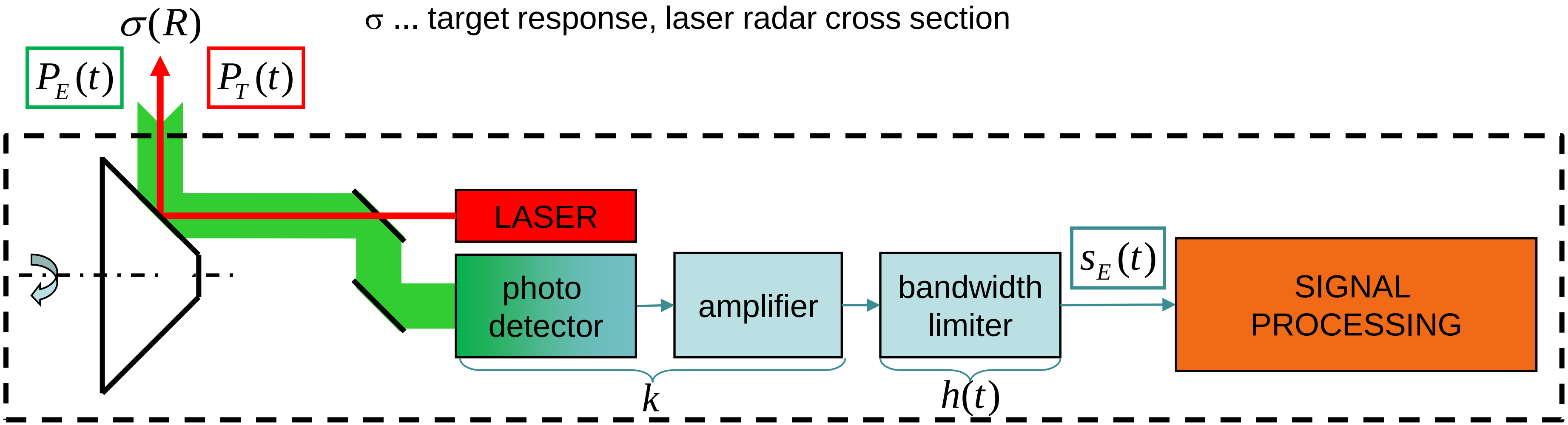
System calibration

- antenna's phase center (APHC)
- DMI's center (DMIC)
- IMU in body coordinate system (BODY)
- laser scanner's own coordinate system (SOCS) in IMU/BODY
- cameras' coordinate system (CMCS) in IMU/BODY



"*High resolution laser scanner with waveform digitization for subsequent full waveform analysis*", A. Ullrich, R.Reichert, SPIE Proc, 2005.

σ ... target response, laser radar cross section



OPTICAL

- red line: $P_T(t)$
- green: $P_E(R) = P_T(R) * \sigma(R)$

$$R = \frac{v_g}{2} t$$

ELECTRICAL

$$s_E(t) = k.P_E(t) * h(t)$$

$$s_E(t) = k.P_T(t) * \sigma(t) * h(t)$$

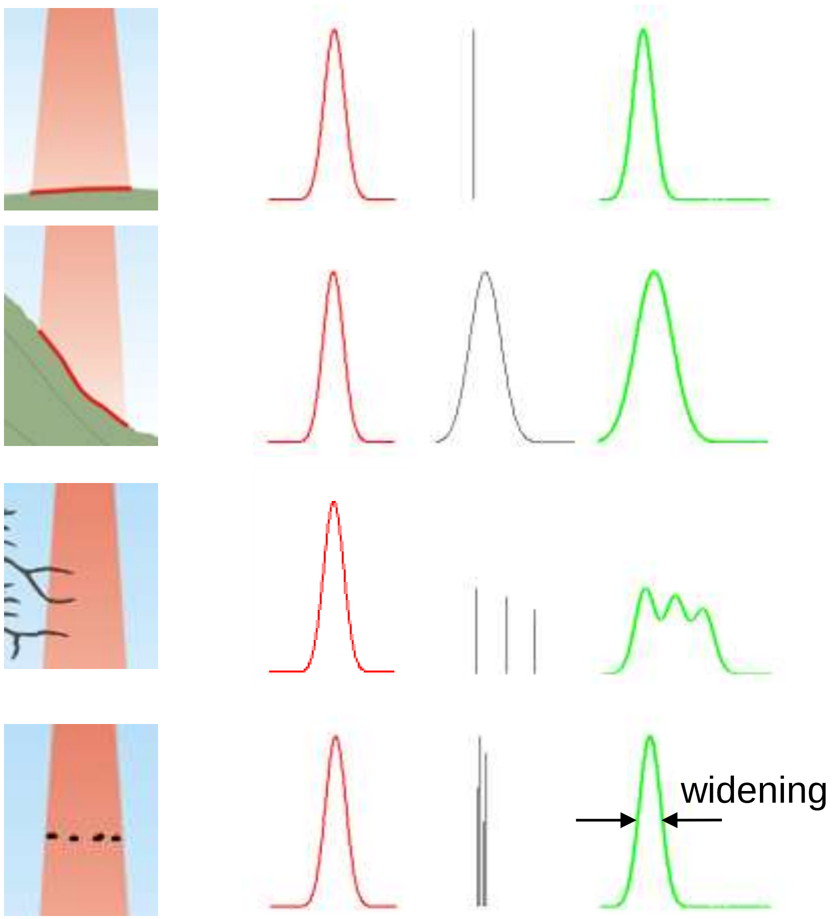
$$s_E(t) = \underbrace{k.P_T(t) * h(t)}_{\text{system response}} * \sigma(t)$$

system response

$$s_E(t) = s_R(t) * \sigma(t)$$

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

$$s_R(t) * \sigma(R) = s_E(t)$$



flat target, normal incidence
Dirac delta function (approximation)

sloping target
Gaussian response (approximation)

small targets at different ranges
sum of Dirac delta function

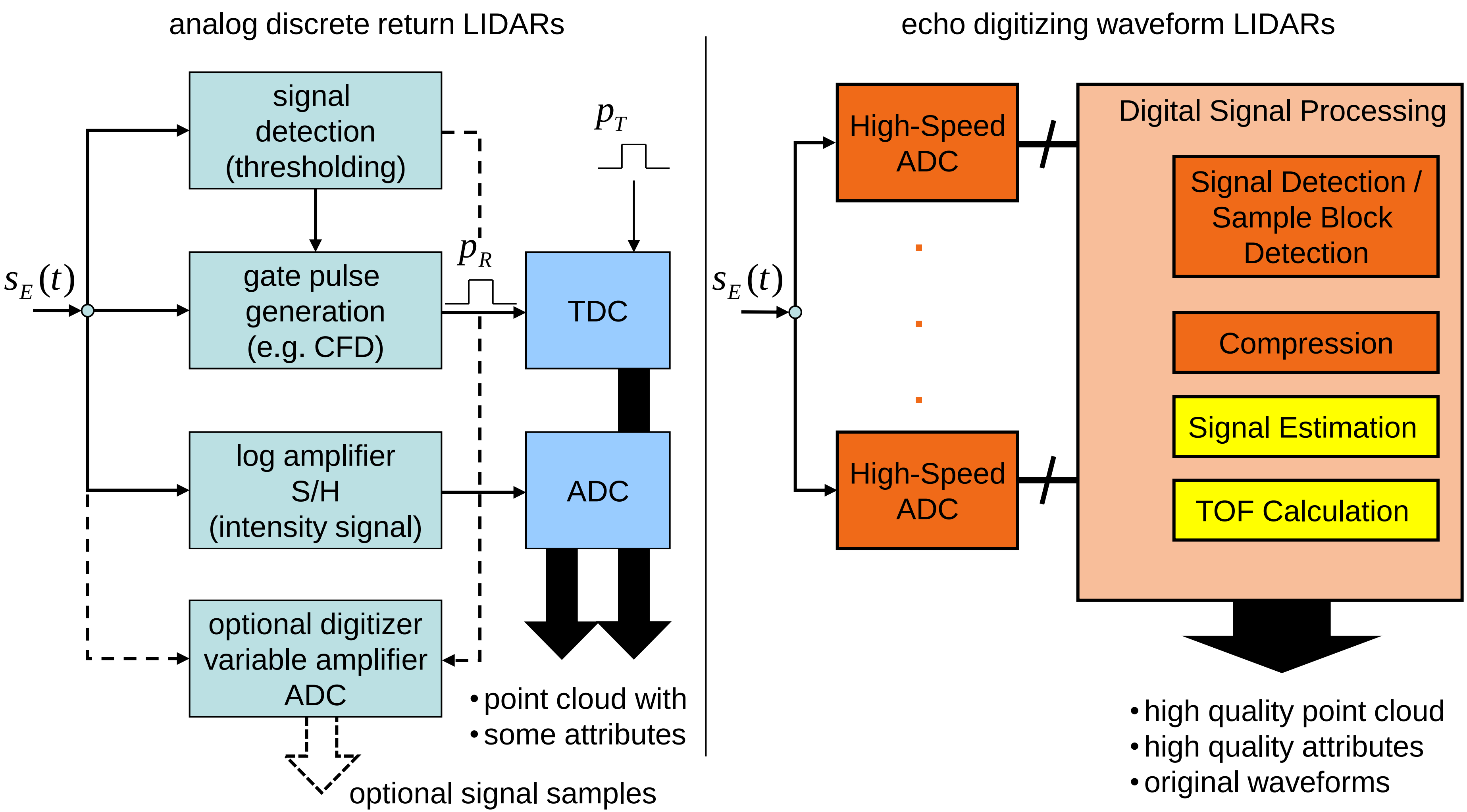
small targets at nearly the same range
sum of Dirac delta function

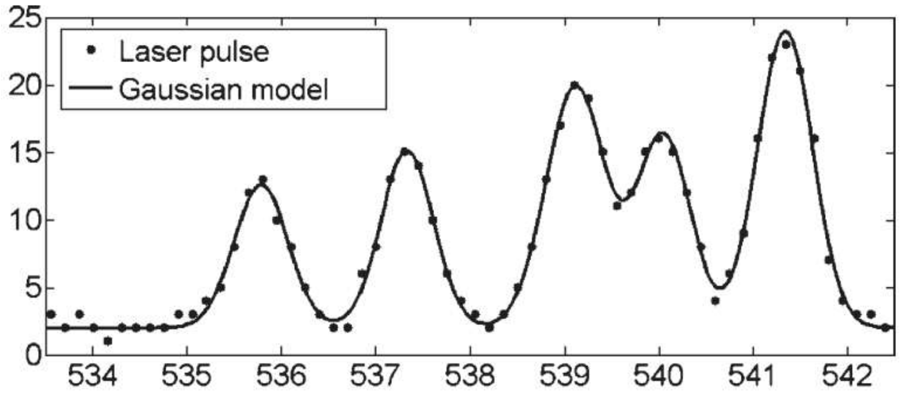
$P_E(t)$ → $s_E(t)$ → SIGNAL PROCESSING

- 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

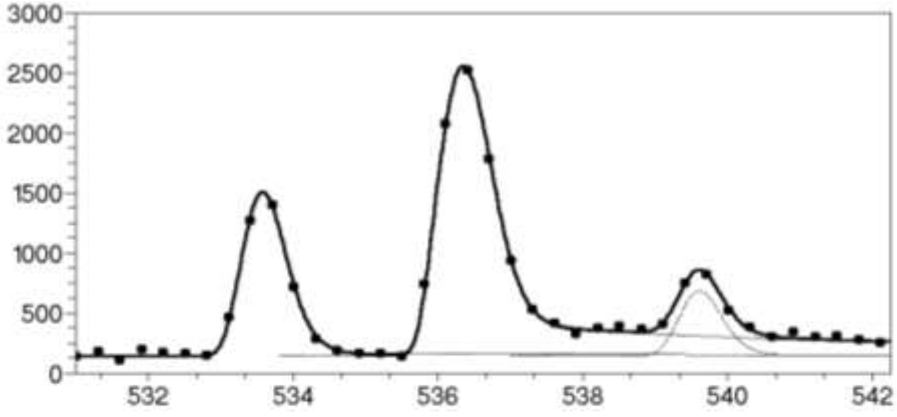
Signal Processing Tasks


analog discrete return LIDARs
echo digitizing waveform LIDARs
$s_E(t)$
signal detection (thresholding)
gate pulse generation (e.g. CFD)
log amplifier S/H (intensity signal)
optional digitizer variable amplifier ADC
p_T
p_R
TDC
ADC
• point cloud with
• some attributes
optional signal samples
$s_E(t)$
High-Speed ADC
High-Speed ADC
Digital Signal Processing
Signal Detection / Sample Block Detection
Compression
Signal Estimation
TOF Calculation
• high quality point cloud
• high quality attributes
• original waveforms



Gaussian decomposition

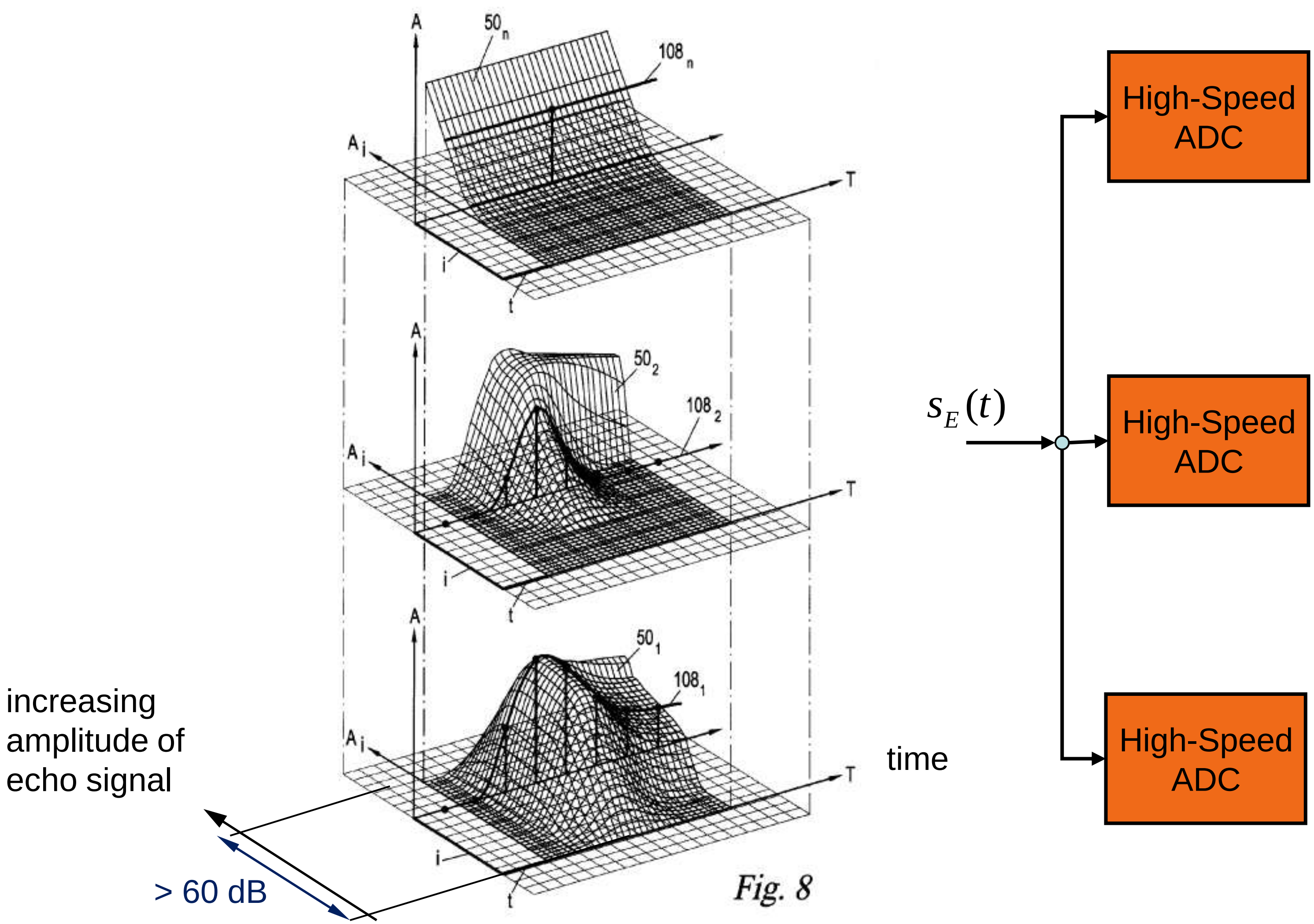
- assumes Gaussian system response
- estimates pulse width
- estimates target‘s depth (width)
- robust and fast
- *RIEGL* RiANALYZE



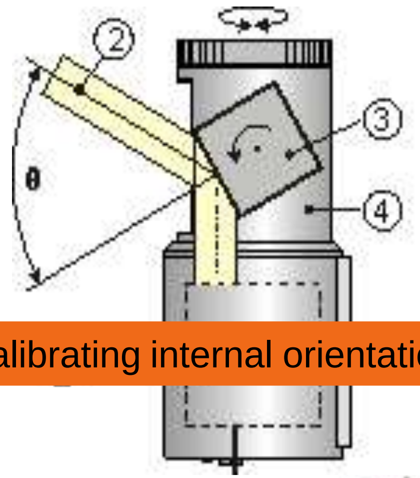
System response fitting

- 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, ...


increasing
amplitude of
echo signal
> 60 dB
time
$s_E(t)$
High-Speed
ADC
High-Speed
ADC
High-Speed
ADC
Fig. 8

DISCRETE RETURN LIDAR INSTRUMENTS



RAW MEASUREMENTS

- range *r*
- line scan angle λ
- frame scan angle ϕ
- intensity *int*
- time stamp *t*

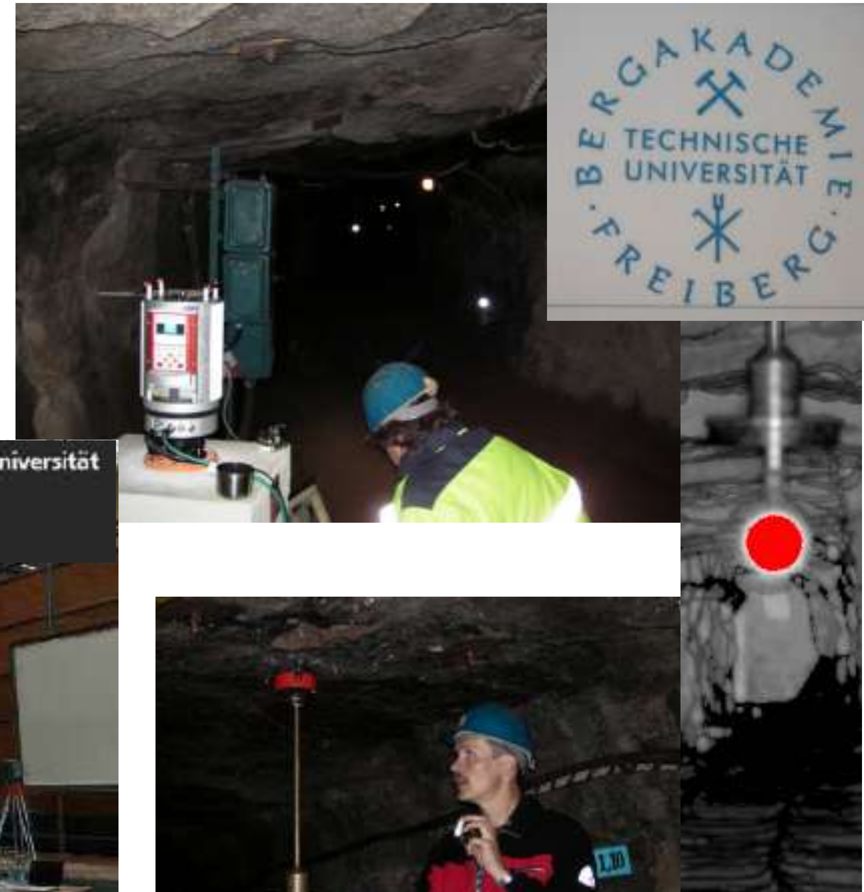
calibrating internal orientation

OUTPUT DATA

- Cartesian coordinates x,y,z
- intensity *int*
- time stamp *t*

Precisely surveyed targets in a test field

Precisely surveyed 3D test site



Precisely surveyed 320 m test range

ECHO DIGITIZING LIDAR INSTRUMENTS

RAW MEASUREMENTS

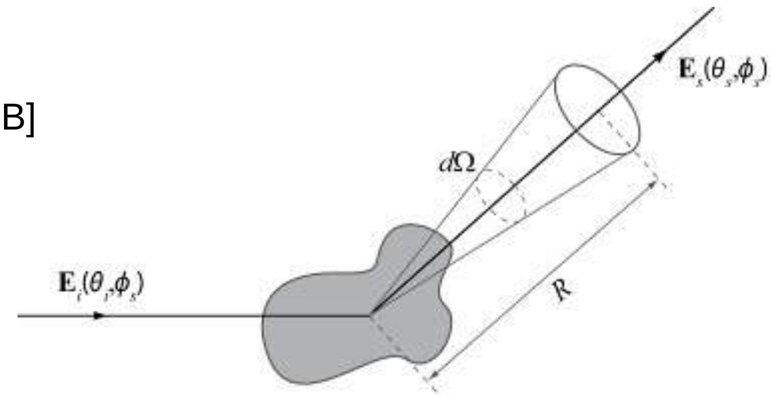
- sampled echo data *s*
- line scan angle λ
- frame scan angle ϕ
- time stamp *t*

OUTPUT DATA

- Cartesian coordinates x,y,z
- amplitude *a*
- reflectance *refl*
- echo width *w*
- pulse shape deviation *dev*
- time stamp *t*

Laser Radar Cross Section (LRCS)

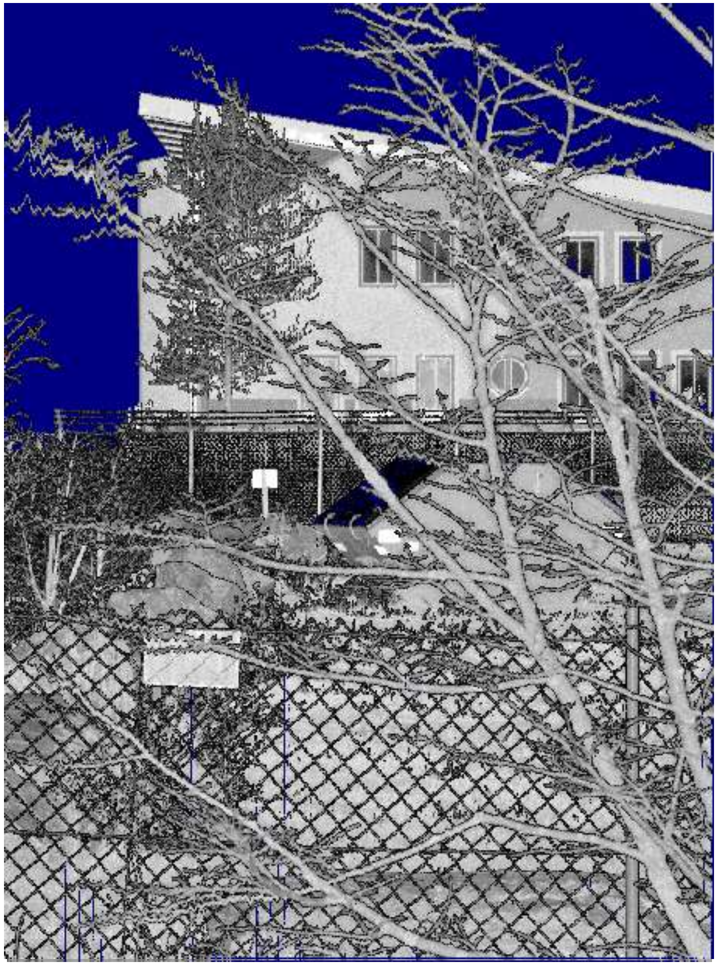
- cross section σ in [m²]
- area-normalized cross section values in [m²m⁻²] or [dB]
  - by laser footprint area: γ
  - by illuminated object area: σ^0



$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{\langle \mathbf{E}_s \cdot \mathbf{E}_s^* \rangle}{|\mathbf{E}_i|^2} = A_i \, \rho \, d$$

- A_i: actual geometric cross-section of target interacting with laser beam
- ρ: reflectance
- d: directivity of backscattered reflection

Radiometric calibration of small-footprint airborne laser scanner measurements: Basic physical concepts, Wagner, W., ISPRS Journal of Photogrammetry and Remote Sensing, **65**, 2010.



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.

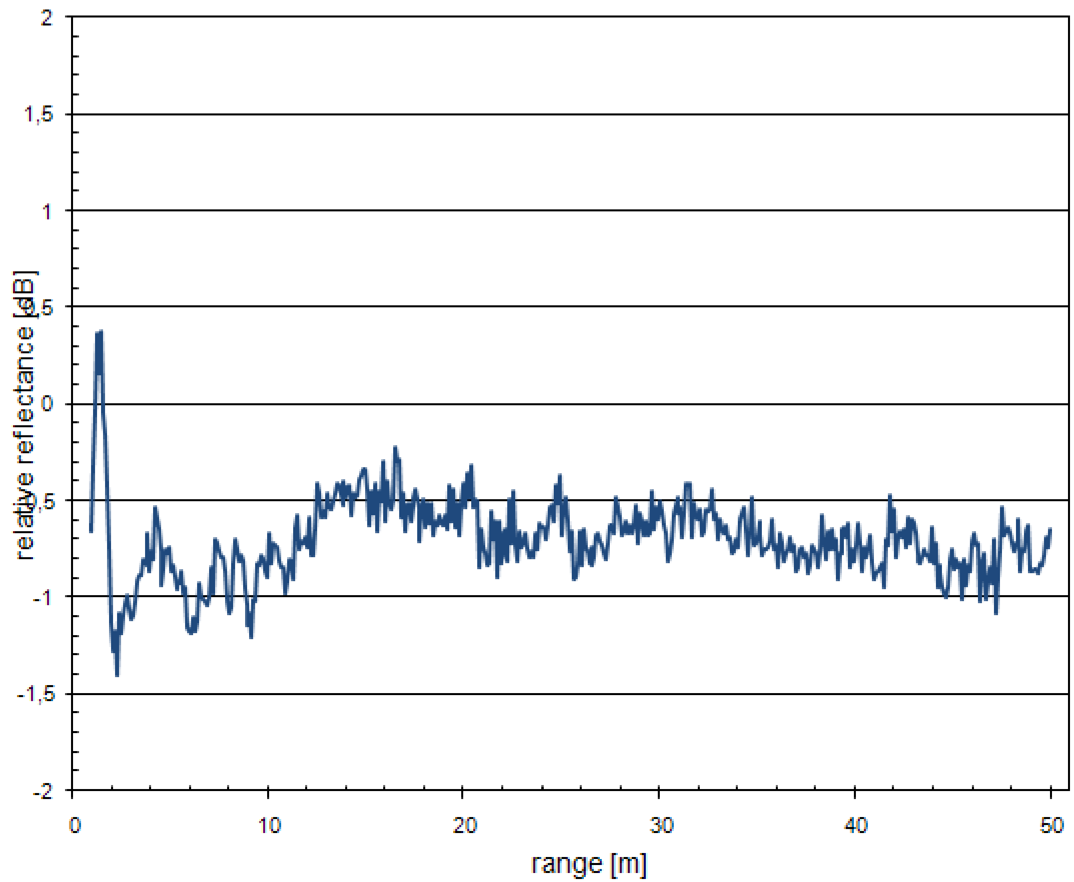
$$\rho_{rel,T} = A_{dB,T} - A_{dB,White}(R_T)$$

R_T … target range

- Measurement of amplitude A_{dB} vs. range from 1 m to 50 m
- Interpolation of result and extrapolation assuming $1/R^2$ law to obtain $A_{dB,Ref}(R)$
- Determine relative reflectance

$$\rho_{rel,T} = A_{dB,T} - A_{dB,Ref}(R_T)$$

for every measurement



Radiometric calibration of multi-wavelength airborne laser scanning data

Christian Briese et al.

Institut für Photogrammetrie und Fernerkundung,
Technische Universität Wien
http://www.ipf.tuwien.ac.at/

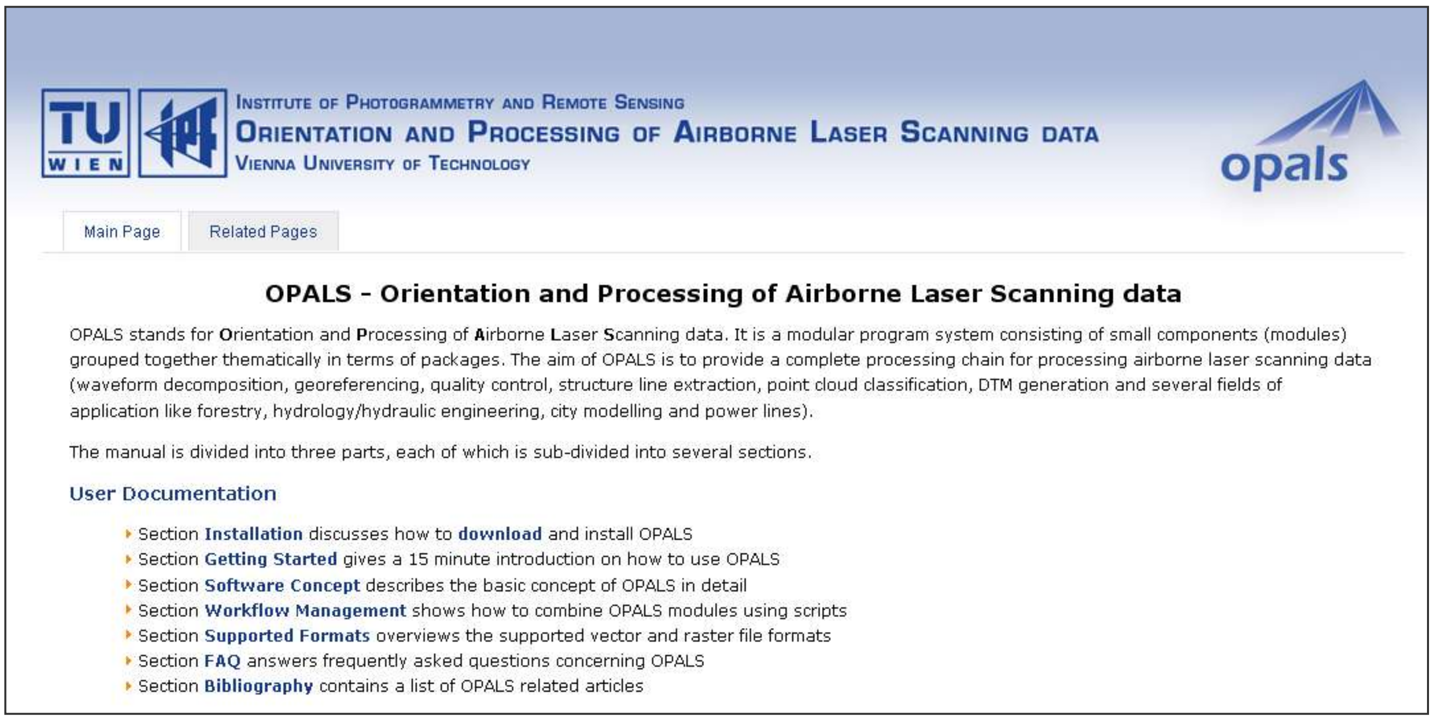
Ludwig Boltzmann Institute
Archaeological Prospection and Virtual Archaeology
Ludwig Boltzmann Institut für
Archäologische Prospektion und Virtuelle Archäologie
http://archpro.lbg.ac.at/

OPALS

OPALS - Orientation and Processing of Airborne Laser Scanning data

Modular program system consisting of small components (modules) grouped together thematically in terms of packages.

- **Software and Documentation: http://www.ipf.tuwien.ac.at/opals**



INSTITUTE OF PHOTOGRAMMETRY AND REMOTE SENSING
ORIENTATION AND PROCESSING OF AIRBORNE LASER SCANNING DATA
VIENNA UNIVERSITY OF TECHNOLOGY

Main Page | Related Pages

OPALS - Orientation and Processing of Airborne Laser Scanning data

OPALS stands for **O**rientation and **P**rocessing of **A**irborne **L**aser **S**canning data. It is a modular program system consisting of small components (modules) grouped together thematically in terms of packages. The aim of OPALS is to provide a complete processing chain for processing airborne laser scanning data (waveform decomposition, georeferencing, quality control, structure line extraction, point cloud classification, DTM generation and several fields of application like forestry, hydrology/hydraulic engineering, city modelling and power lines).

The manual is divided into three parts, each of which is sub-divided into several sections.

User Documentation

- Section **Installation** discusses how to **download** and install OPALS
- Section **Getting Started** gives a 15 minute introduction on how to use OPALS
- Section **Software Concept** describes the basic concept of OPALS in detail
- Section **Workflow Management** shows how to combine OPALS modules using scripts
- Section **Supported Formats** overviews the supported vector and raster file formats
- Section **FAQ** answers frequently asked questions concerning OPALS
- Section **Bibliography** contains a list of OPALS related articles

Contact: opals@ipf.tuwien.ac.at

Radiometric calibration: practical workflow

Selection of reference target

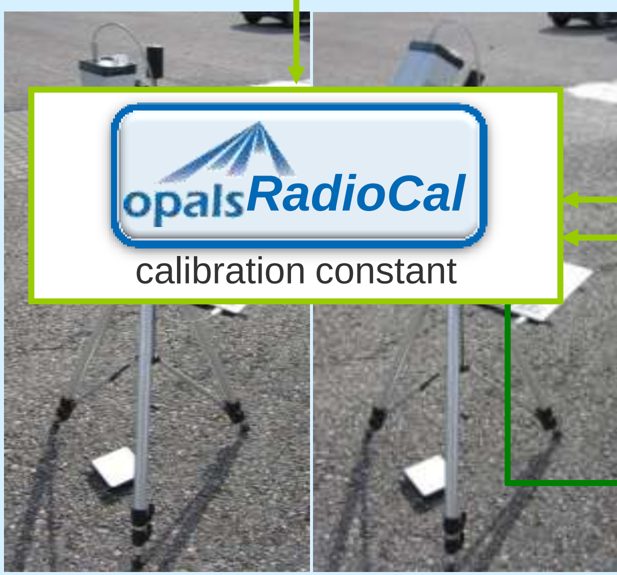
Meteorological data

Full-waveform ALS data

Calibration with Reflectometer
reflectance and polygon of reference target

Modelling of atmosphere
atmospheric attenuation coefficient

opals**Fullwave**
opals**DirectGeoref**
opals**Georef**
opals**Normals**



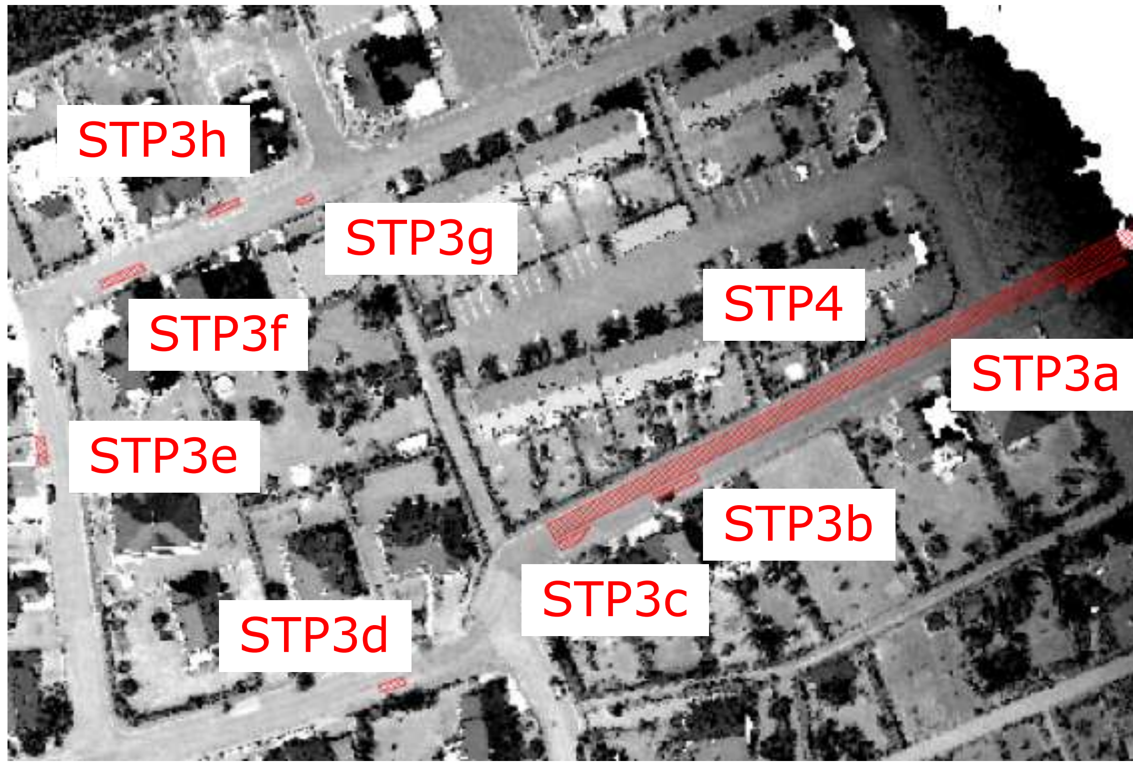
opals**RadioCal**
calibration constant

ALS point cloud with range, amplitude, echo width and local surface normal

opals**RadioCal**
Calibrated radiometric values for all echoes

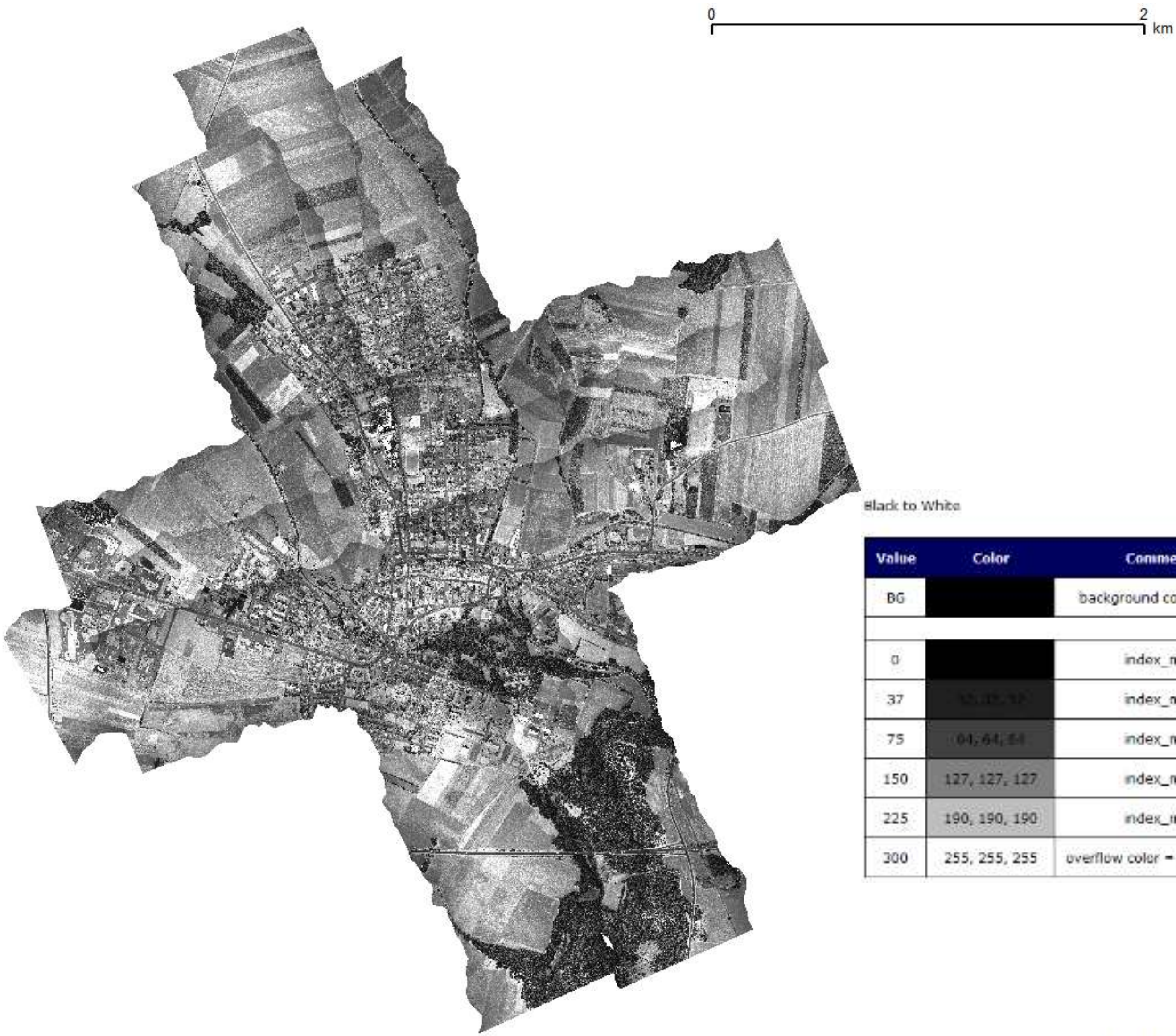
Radiometric in-situ measurements II

- Localisation of the radiometric measurements via differential GNSS



ALS – Flight Horn 2011 09 22: *RIEGL* LMS-Q680i

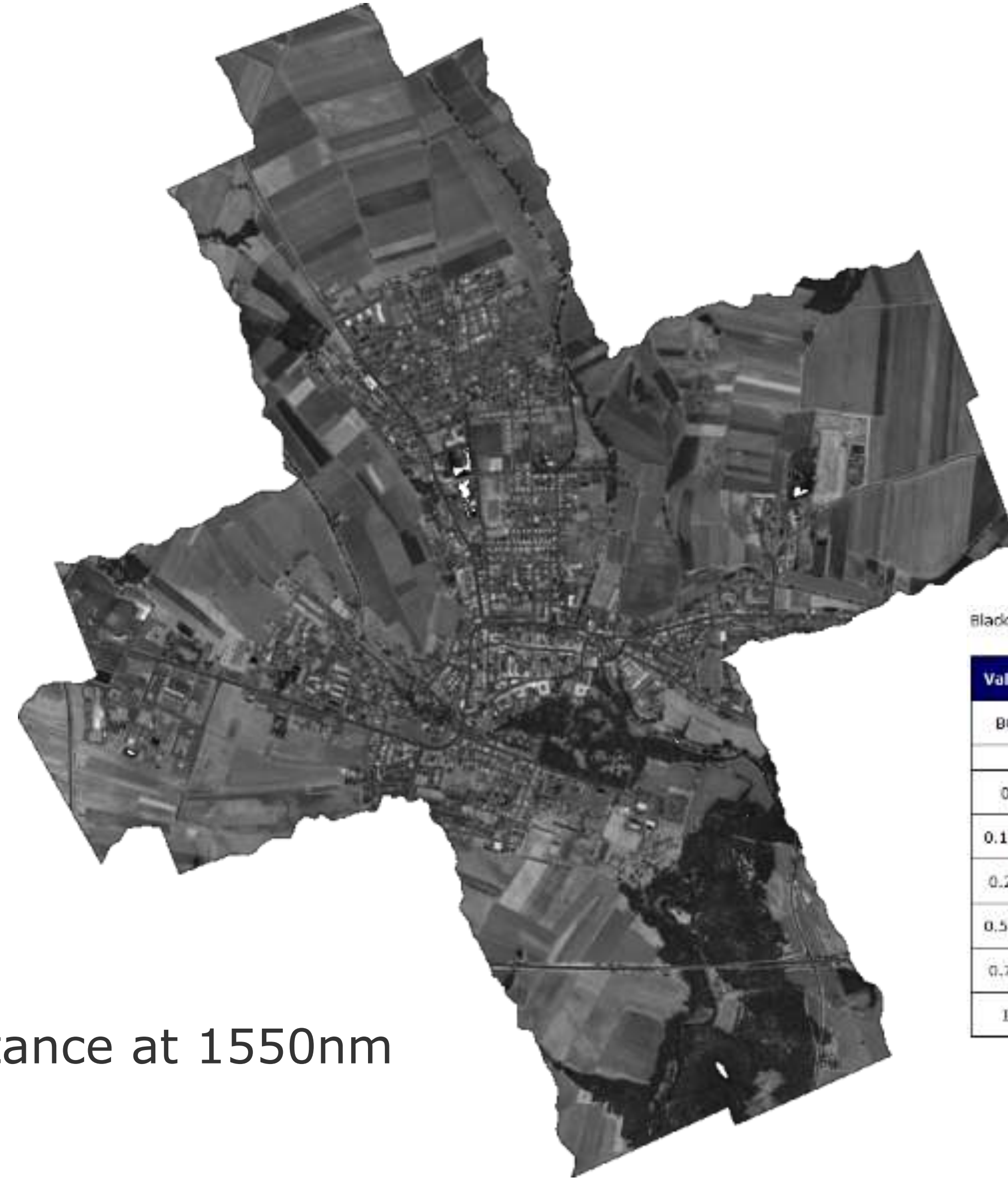
Amplitude



Black to White

Value	Color	Comment
BG		background color white
0		index_min
37	[illegible]	index_min
75	64, 64, 64	index_min
150	127, 127, 127	index_min
225	190, 190, 190	index_min
300	255, 255, 255	overflow color = index_max

ALS – Flight Horn 2011 09 22: RIEGL Q680i



Black to White

Value	Color	Comment
BG		background color white
0		index_min
0.125	32, 32, 32	index_min
0.25	64, 64, 64	index_min
0.500	127, 127, 127	index_min
0.75	190, 190, 190	index_min
1	255, 255, 255	overflow color = index_max

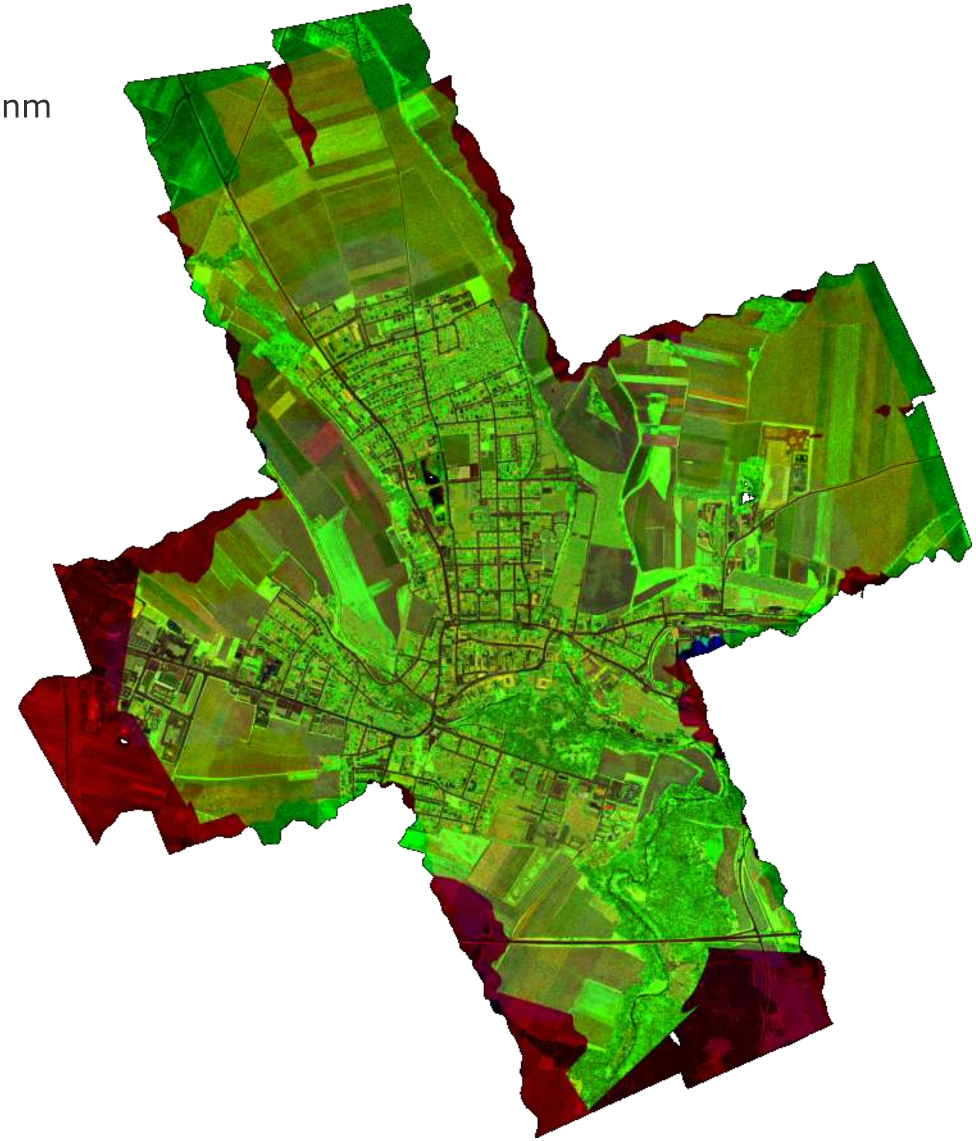
Calibrated reflectance at 1550nm

Calibrated multi-wavelength reflectance I

RIEGL LMS-Q680i 1550nm

Black to Red

Value	Color
BG	
0	
0.25	64, 0, 0
0.5	128, 0, 0
0.75	191, 0, 0
1.0	255, 0, 0



RIEGL VQ-580 1064nm

Black to Green

Value	Color
BG	
0	
0.25	0, 64, 0
0.5	0, 128, 0
0.75	0, 191, 0
1.0	0, 255, 0

RIEGL VQ-820-G 532nm

Black to Blue

Value	Color
BG	
0	
0.25	0, 0, 64
0.5	0, 0, 128
0.75	0, 0, 191
1	0, 0, 255

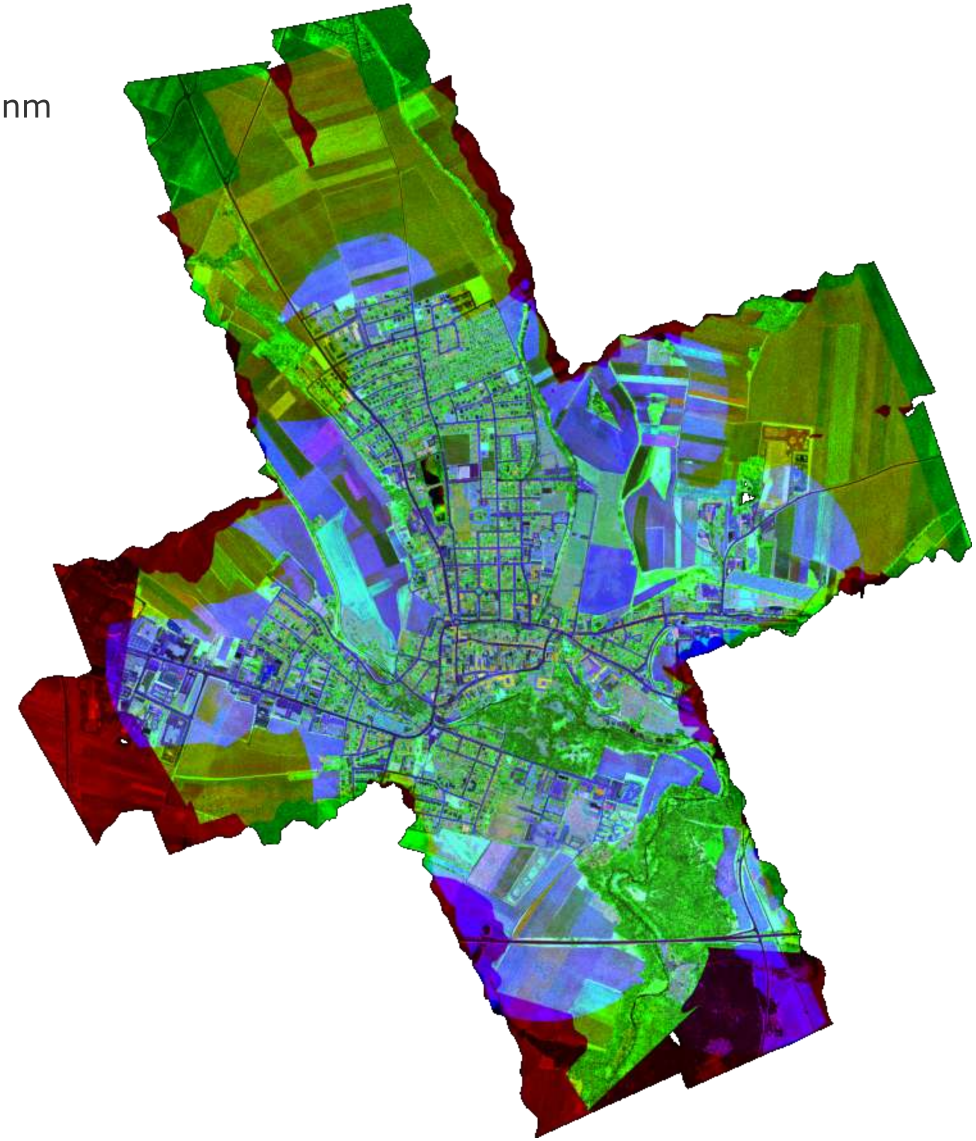
Calibrated reflectance at 532nm (blue), 1064nm (green) and 1550nm (red)

Calibrated multi-wavelength reflectance II

RIEGL LMS-Q680i 1550nm

Black to Red

Value	Color
BG	
0	
0.25	64, 0, 0
0.5	128, 0, 0
0.75	191, 0, 0
1.0	255, 0, 0



RIEGL VQ-580 1064nm

Black to Green

Value	Color
BG	
0	
0.25	0, 64, 0
0.5	0, 128, 0
0.75	0, 191, 0
1.0	0, 255, 0

RIEGL VQ-820-G 532nm

Black to Blue

Value	Color
BG	
0	
0.038	0, 0, 64
0.075	0, 0, 128
0.113	0, 0, 191
0.15	0, 0, 255

Calibrated reflectance at 532nm (blue), 1064nm (green) and 1550nm (red)

Calibrated multi-wavelength reflectance III

RIEGL LMS-Q680i
1550nm

Black to Red

Value	Color
BG	
0	
0.25	64, 0, 0
0.5	128, 0, 0
0.75	191, 0, 0
1.0	255, 0, 0

RIEGL VQ-580
1064nm

Black to Green

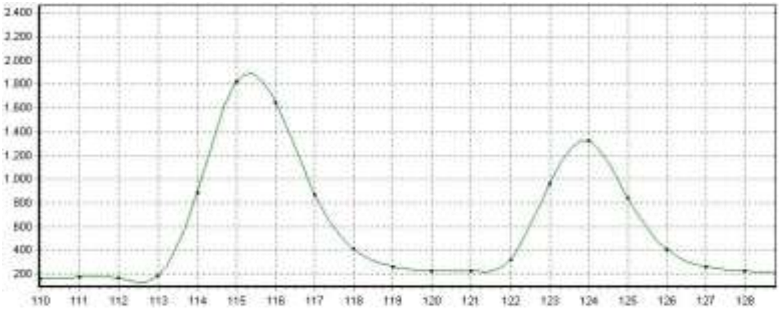
Value	Color
BG	
0	
0.25	0, 64, 0
0.5	0, 128, 0
0.75	0, 191, 0
1.0	0, 255, 0

RIEGL VQ-820-G
532nm

Black to Blue

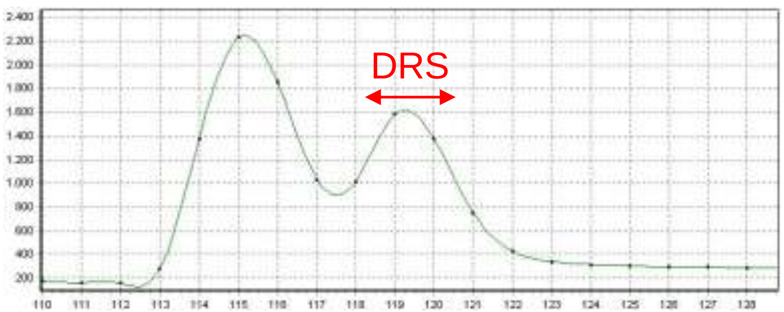
Value	Color
BG	
0	
0.038	0, 0, 64
0.075	0, 0, 128
0.113	0, 0, 191
0.15	0, 0, 255

Detail: Rotated to the left



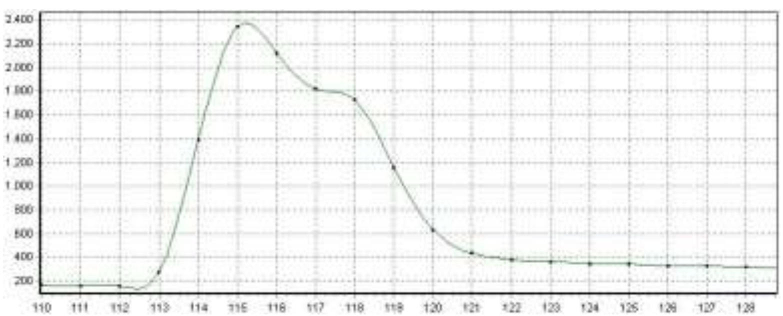
clear separation of target returns

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



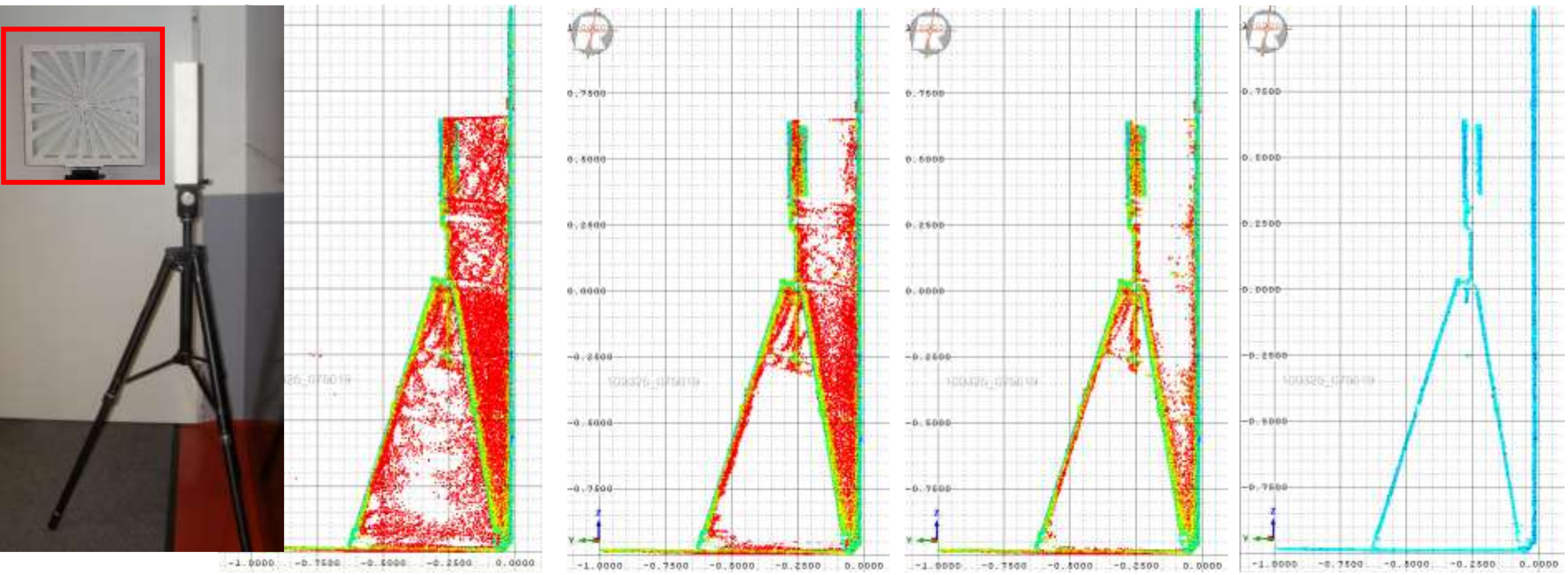
severe merging of target returns

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

- Deviation *dev* of echo pulse shape from expected system response
- Measure for “reliability of range result”
- Used to “clean-up” point cloud or assist classification

dev unlimited | $dev_{max} = 50$ | $dev_{max} = 25$ | $dev_{max} = 6$



LMS-Q680i

***RIEGL* VZ-1000**

sdf

sdf

wfm

RiWaveLIB

DIY
Full Waveform Analysis

PulseWaves
Vendor Independent Waveform Format
http://groups.google.com/group/pulsewaves

- Echo digitizing LIDAR systems with
- Full waveform analysis, online waveform processing, or combination of both
- provide data with
  - high accuracy
  - high precision
  - best multi-target capability

  - calibrated amplitude data
  - calibrated reflectance data
  - data to „clean-up“ point clouds
  - data to improve classification

Thank you!

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