Backscattering of individual LiDAR pulses explained by photogrammetrically derived vegetation structure

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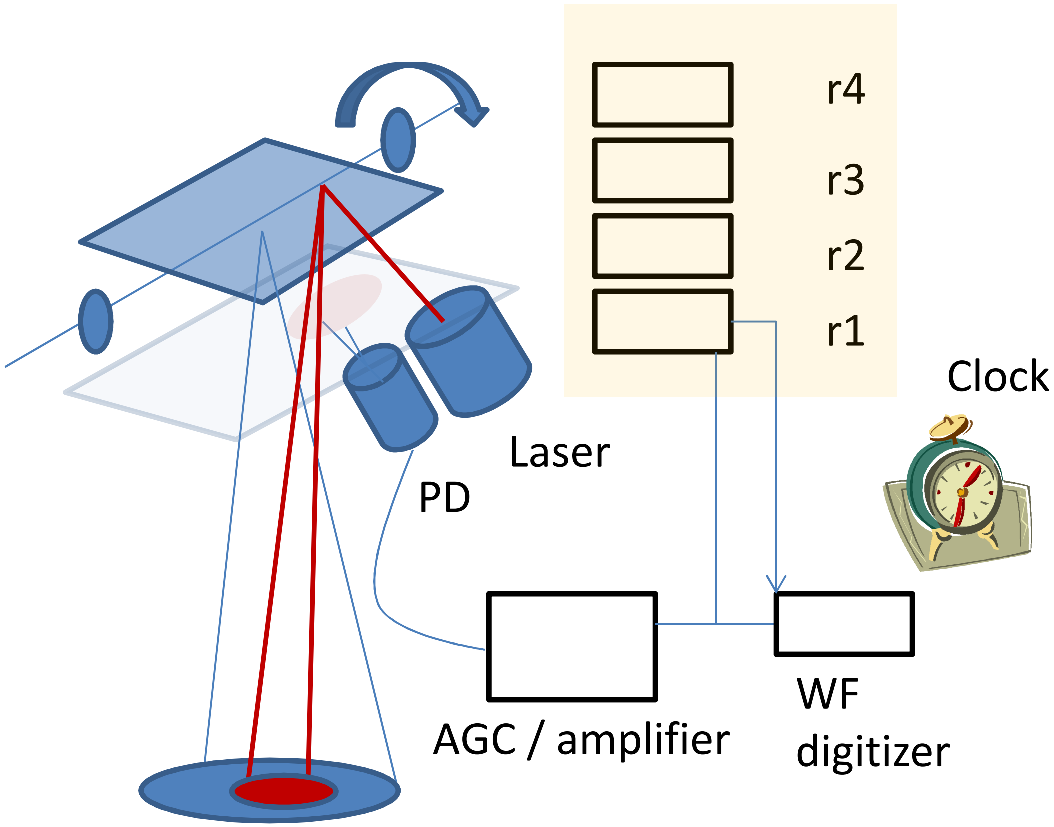
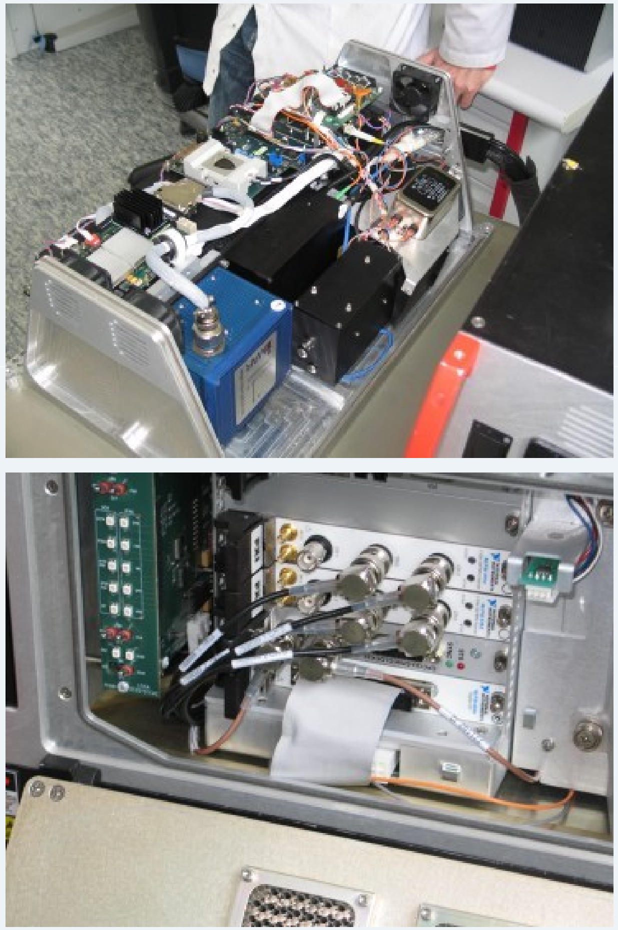
Background

Pulsed LiDAR sensors

- use time-stamped photons, short pulses
- are ranging devices
- are designed for topographic applications
- currently use a single λ and divergence

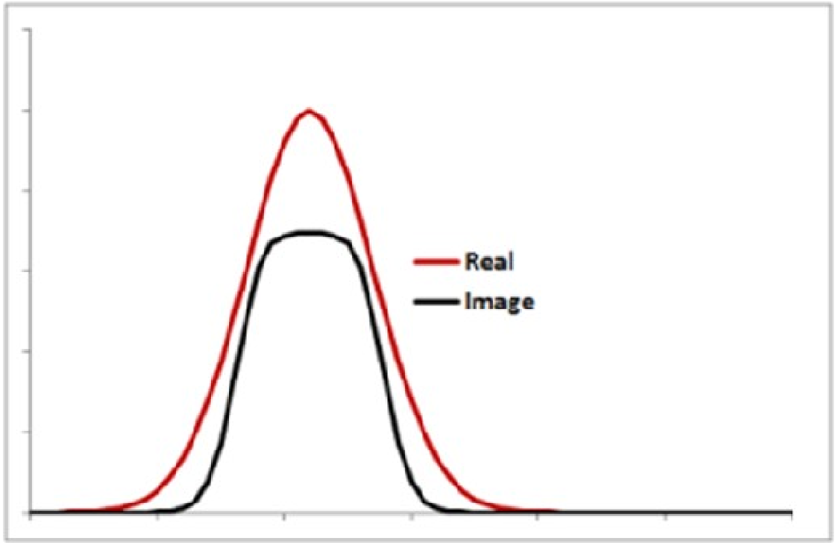




1. Leica ALS60, GPS/IMU & electronics.
2. Oscilloscopes for the AD conversion

Some basic features

- Overall HOT-SPOT view-illumination geometry, low θ.
- Transmitted pulse ~ P(t), t = 0...10 ns; stability is essential for radiometry
- iFOV ~ some mrads, (Q how is the iFOV weight function?)
- beam divergence 0.1-0.3 mrad
- Received P has P_{Sun}. Through a BPF and an aperture. (SNR)
- Receiver has a certain response; mapping input to output
- Signal has noise (speckle, photodiode, circuts, AD-conversion)



Aperture of an ALS50-ii sensor. Oscillating mirror in resting position, collimating lens on the right.

Time-stamped photons on a deflected, yet known path

- scan zenith angles 0-20 °
- mirror angle; GNSS / imu
- Pulse path < 0.2-0.4 m in XY, < 0.1 m in Z
- Gaussian PSF
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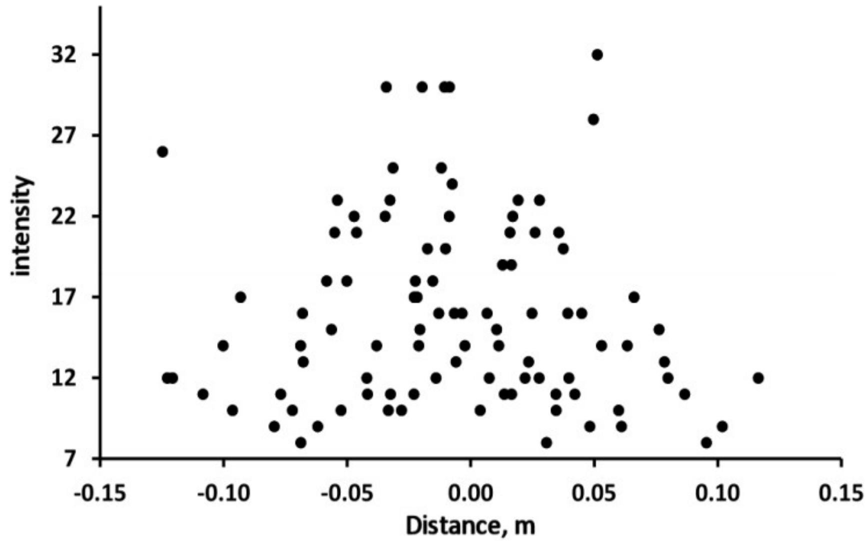
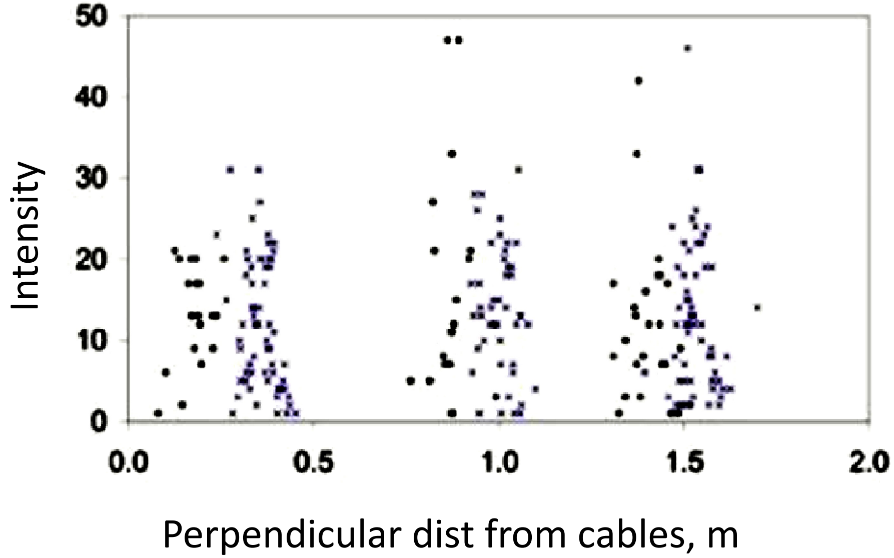
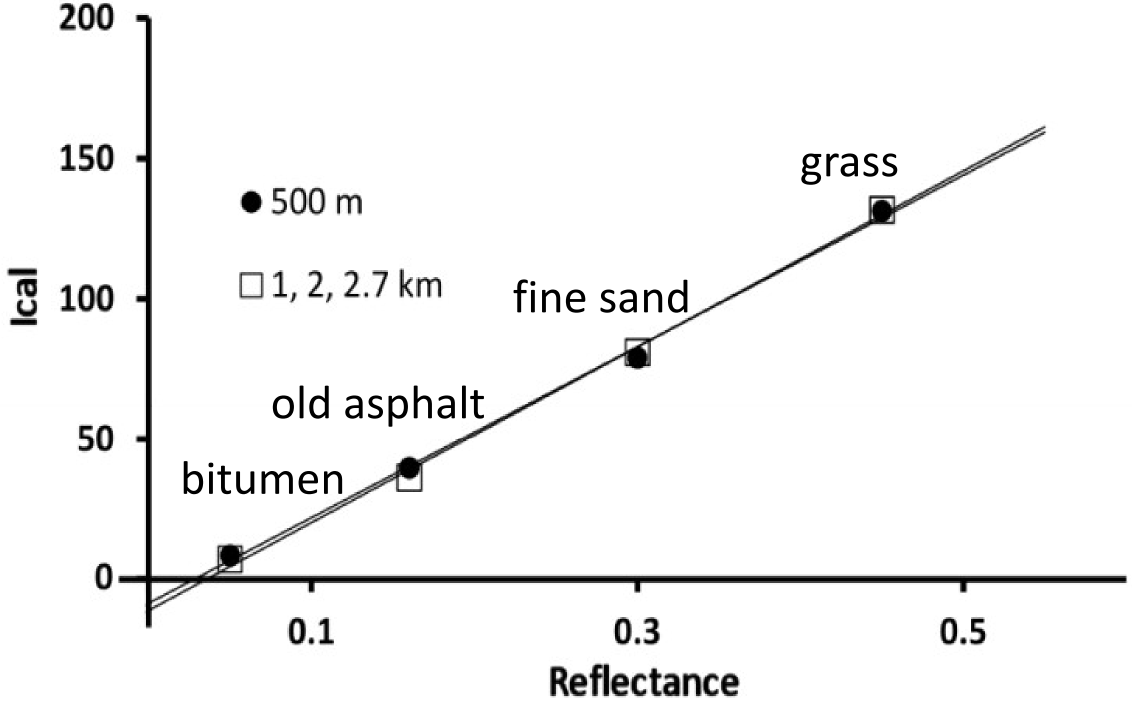




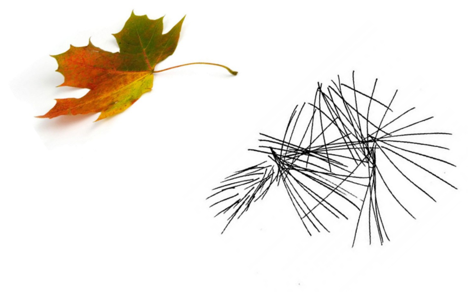
Vicarious refl. calibration for well-defined surfaces

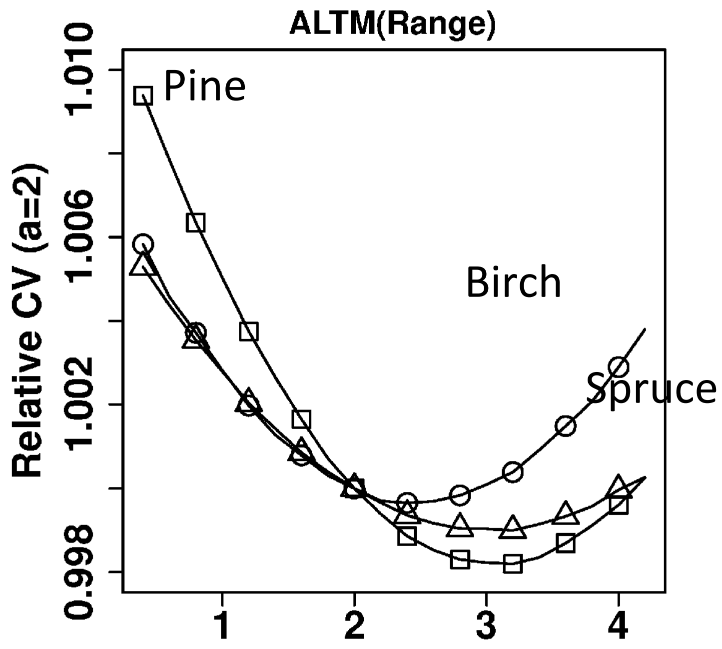


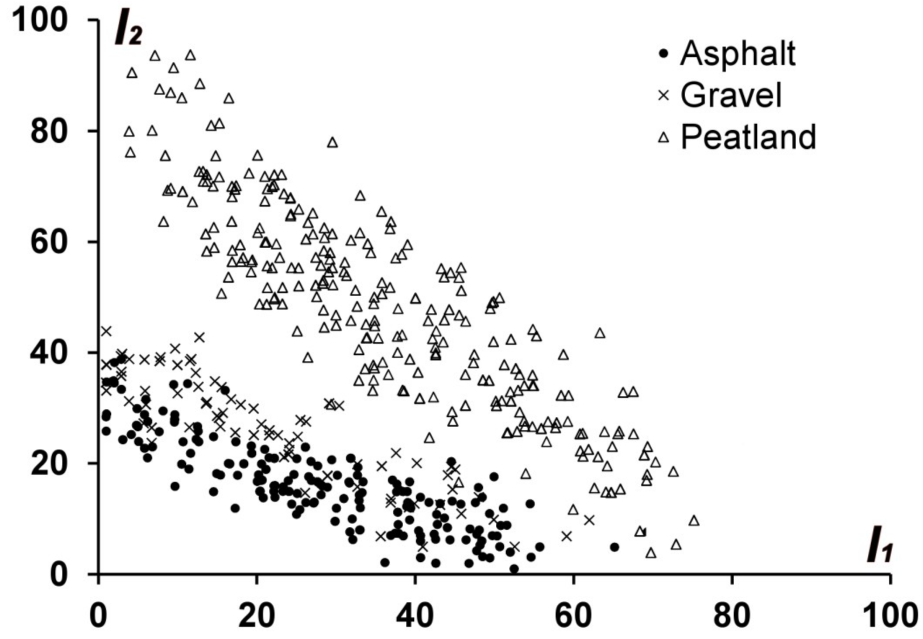
Hemispherical – conical reflectance factors @ 900 nm vs.
1064 nm backscattering (intensity)

’Flat’; ∠ 90 °; larger than footprint -surfaces

LiDAR – challenging radiometry in vegetation



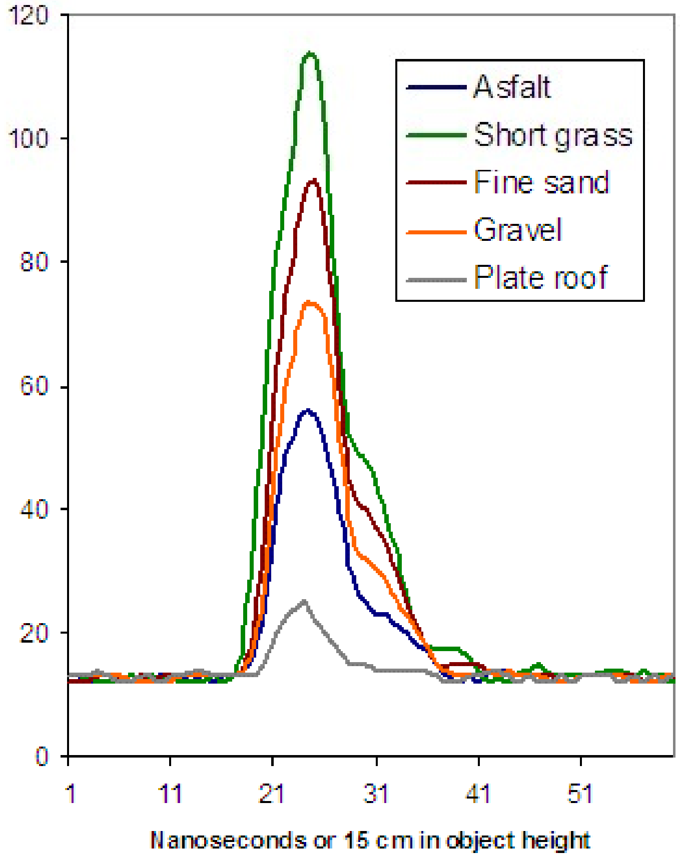




Single pulse ~ stochastic

Multiple pulses ~ structure, gaps, joint distributions , spatial dependencies, ...
=> constrain ill-posed nature

Wafeform sampling – amplitude sequences



Waveform, WF(t) is the output, affected by the system response, mm.

Reflectance properties and orientation of the surface(s); their density and spatial configuration in the iFOV of P(t) + ’noise’ => contributions to WF(t)

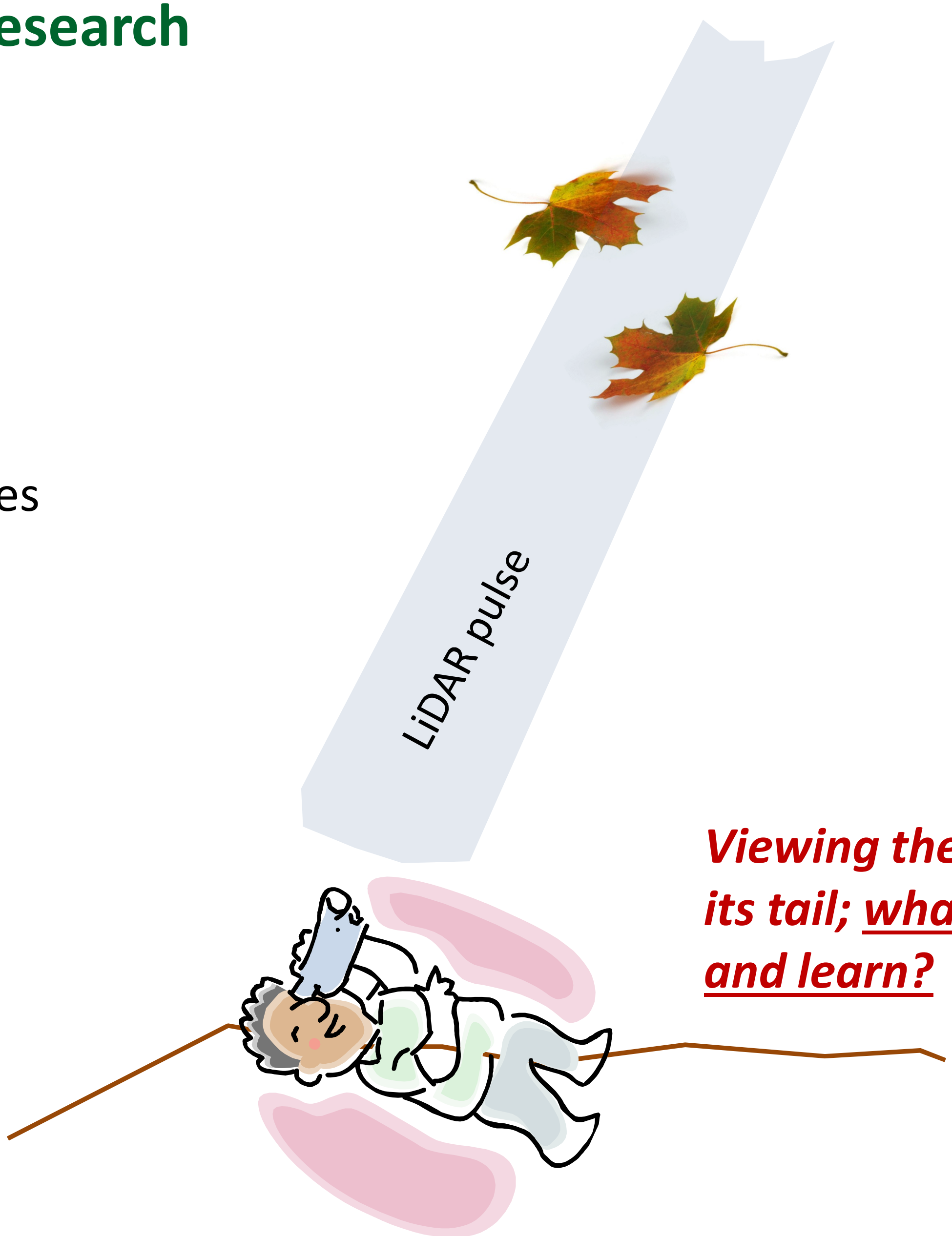
WFs ’tell more’ about the volumetric scattering than discrete peak amplitude data.

Experimental research

Nominal scale

* mature trees
* understory trees
* forest floor flora
* mire flora samples

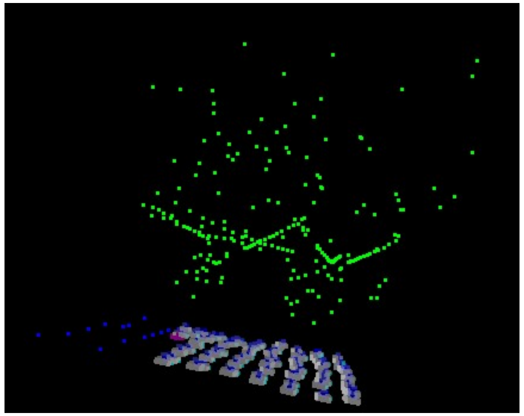
Ratio scale?



Viewing the pulse from its tail; <u>what can we see and learn?</u>

Photogrammetry in the forest

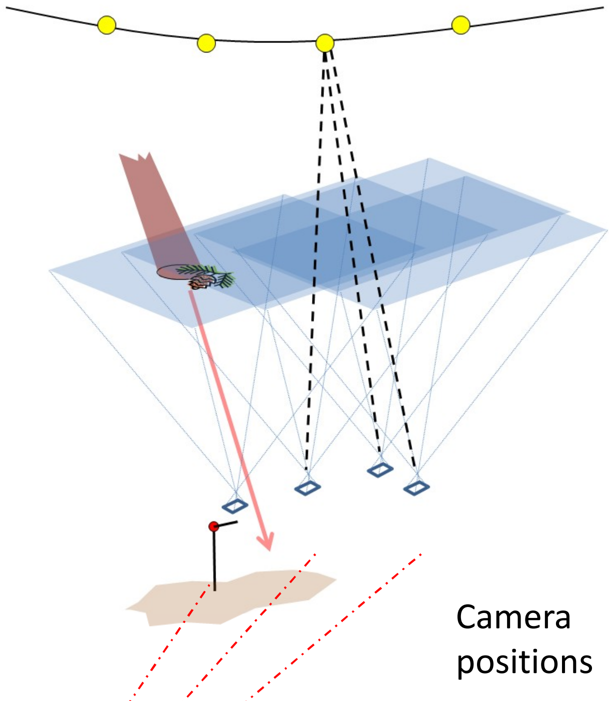
Geometry was essential

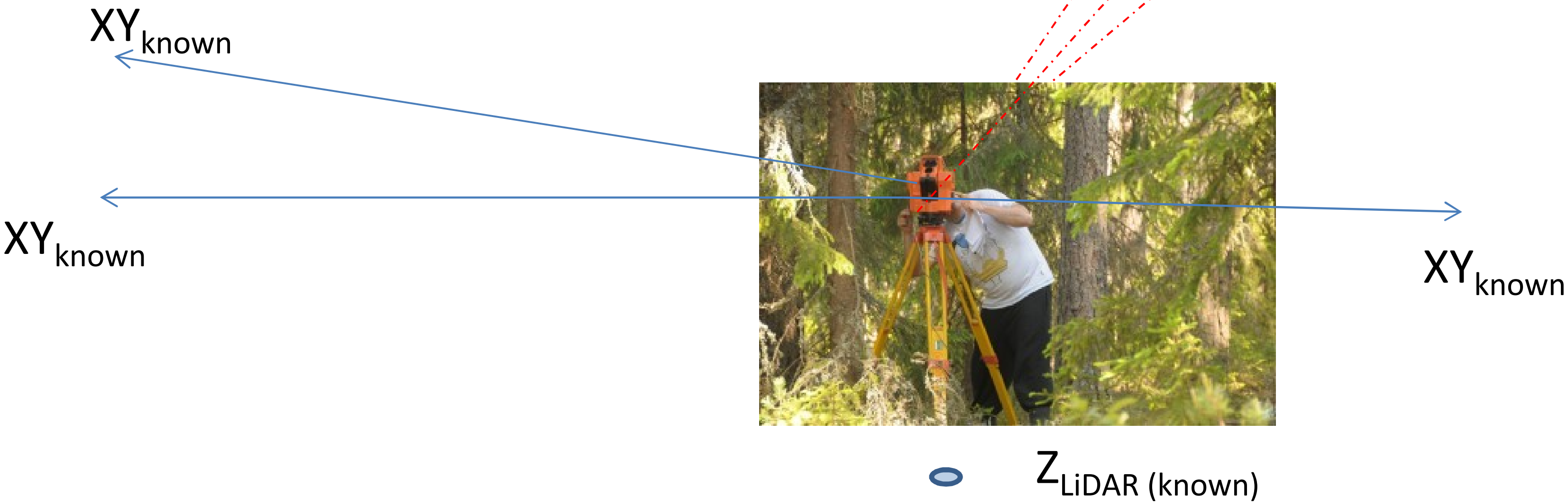


Geometry: 3D system of the images ⇒ transformation to the 3D system of the LIDAR data

Photogrammetric XYZ +
(ΔX, ΔY, ΔZ, rotation about Z) ⇒
XYZ of LiDAR data

Remnant offsets < 5–10 cm





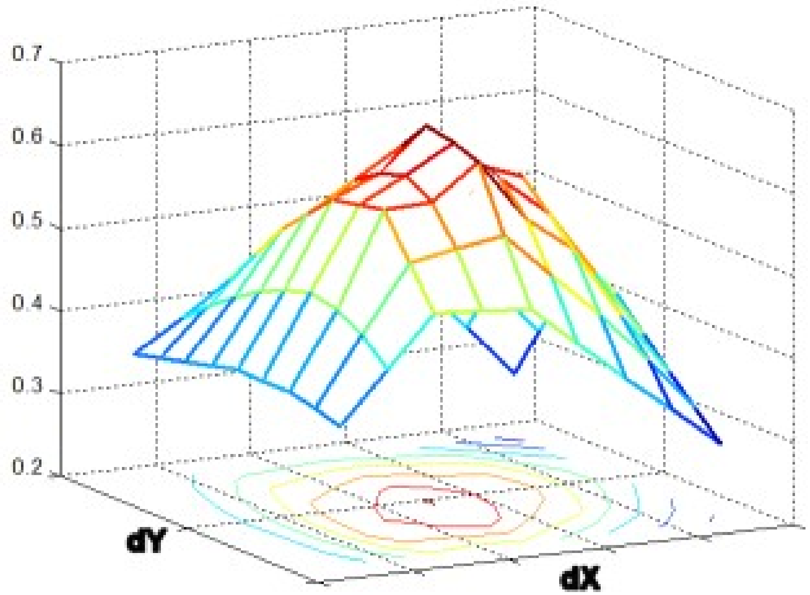
Remaining geometric LiDAR inaccuracy

* Between-strip offsets and drifts
* Short-term ’noise’

⇒ XY strip adjustment (local offset removal) using footprint silhouettes measured from the pulse tail -images, shifted ones.

Correction for a site and LiDAR Strip.

XY LiDAR strip adjustment with detached branches



Silhouette – backscatter strength correlation peaked at some xy offset

Silhouette area vs. Backscattering

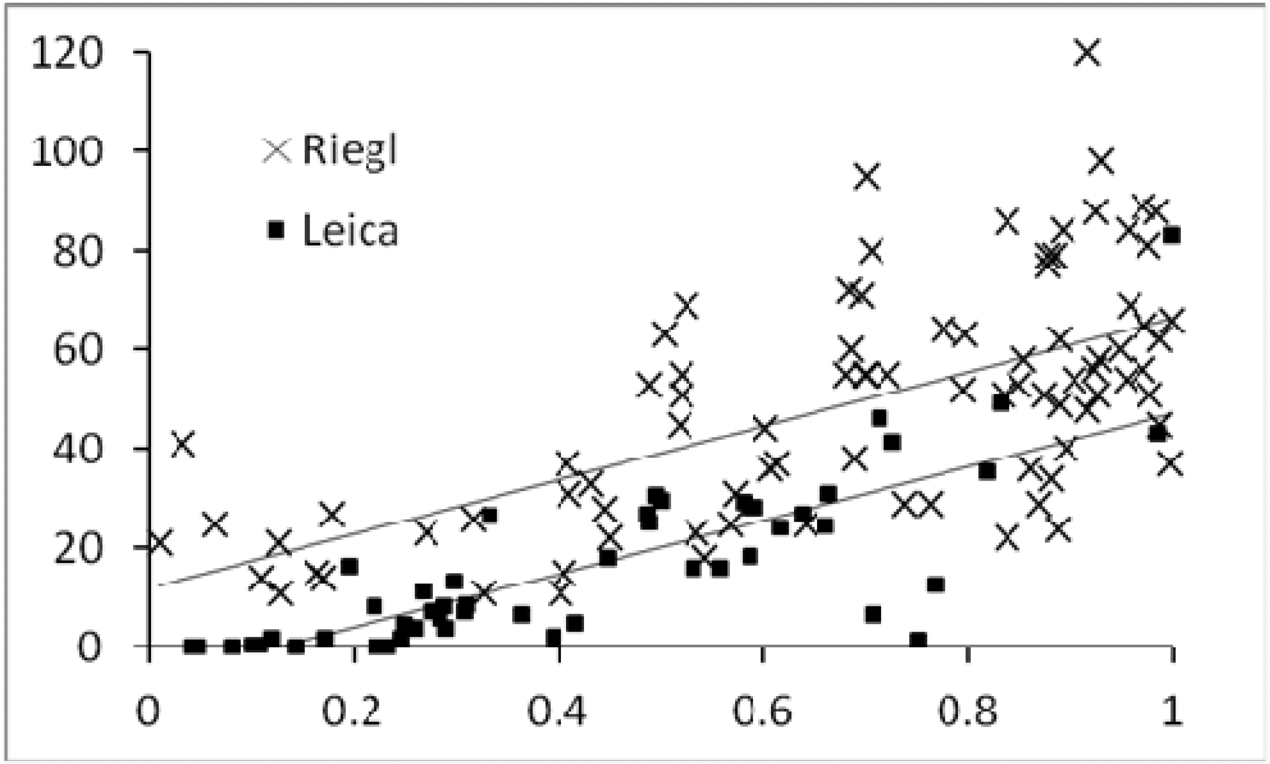
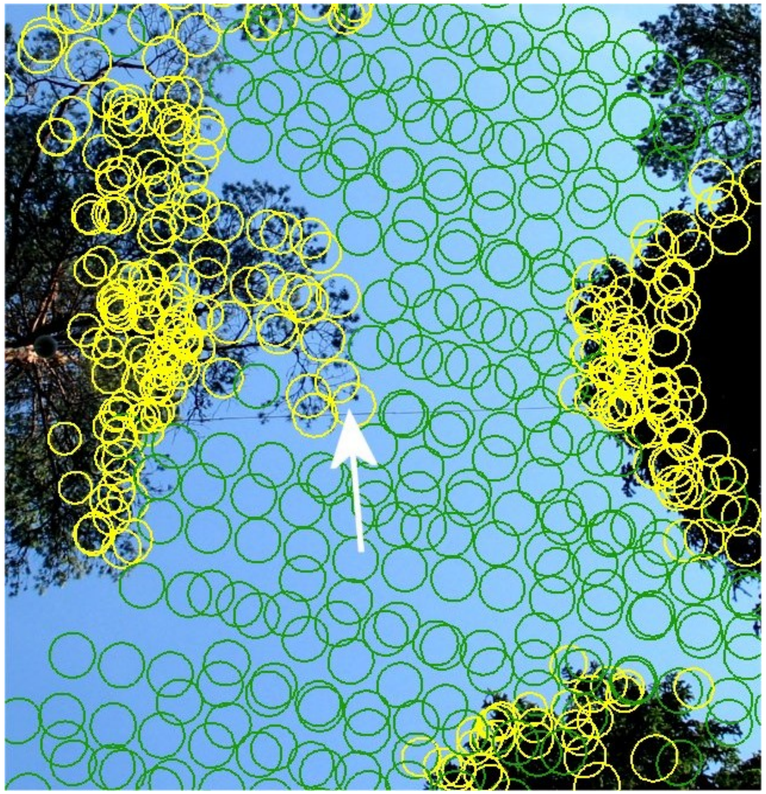


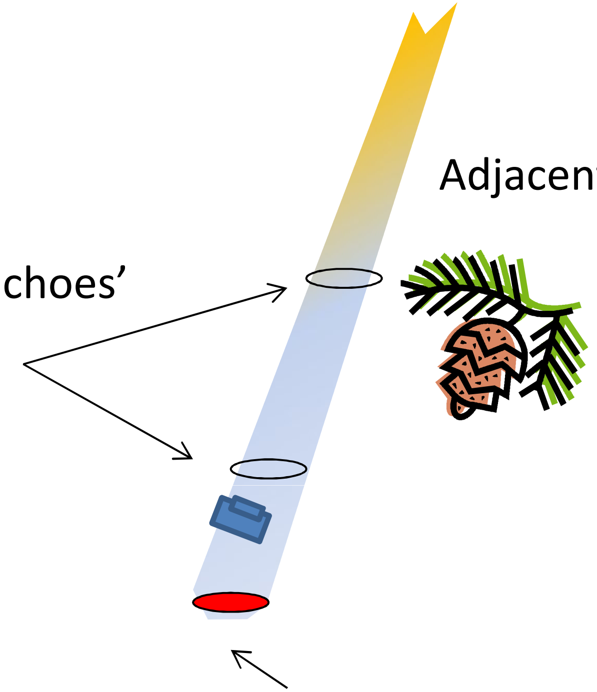
Fig. 8b. Dependence between non-weighted relative silhouette area (0-1) and the intensity of the first return in the 60-yr-old pine stand. The figure shows data from a 1-km ALS60 strip (2012) and a 750-m Riegl LMS-Q680i strip that had been found the best xy-match.

Silhouette area vs. Backscattering

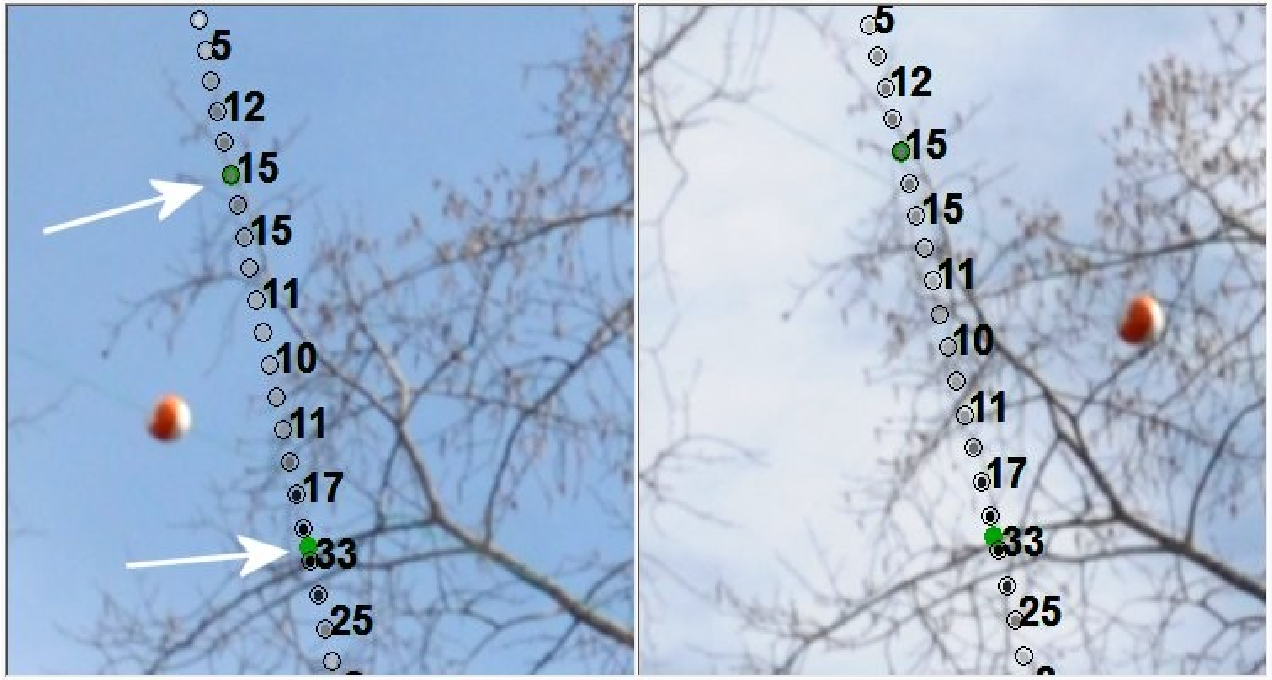
In LMS (first strip, 9 degrees off nadir) some 40% of the amplitude variation was explained by the silhouette (here corrected for dX = -0.5 m , dY = 0.10 m)

Smallest echo/WF triggering targets?





Some notes on results



- Close-range photogrammetry is feasible, an alternative to TLS (direct spherical).
- in-situ strip adjustment with branches,yes, but don’t recommend
- Silhouette explains 50–90% of signal level (shallow targets, single species)
- Smallest objects in the upper canopy triggering an observation can be quite small
- Could not verify that E (W/m2) has a Gaussian spread across the footprint.
- Calibration for ’real silhouette’ –> CC/LAI modeling
- What scatterers contributed to the WF, observable, to some degree

What next?

- Experimenting is tedious, slow and expensive, yet needed
- A good simulator would provide guidance (Aarne's talk), but that is tedious too (basic data on scattering, morphology)

Interesting topics to look at (airborne LiDAR)

- Is the (long-term goal) idea of synthetic training data (imputation of LiDAR features) feasible with simulators?
- Multidivergent LiDAR data; better probing of canopy structure?
- WF analysis in tree species recognition, species is bottleneck
- How far from optimal are the current sensors?
- Role of passive multispectral data to be combined?


Thanks!