„FULL-Waveform Analysis of Small Footprint Airborne Laser Scanning Data in the Bavarian Forest National Park for Tree Species Classification “

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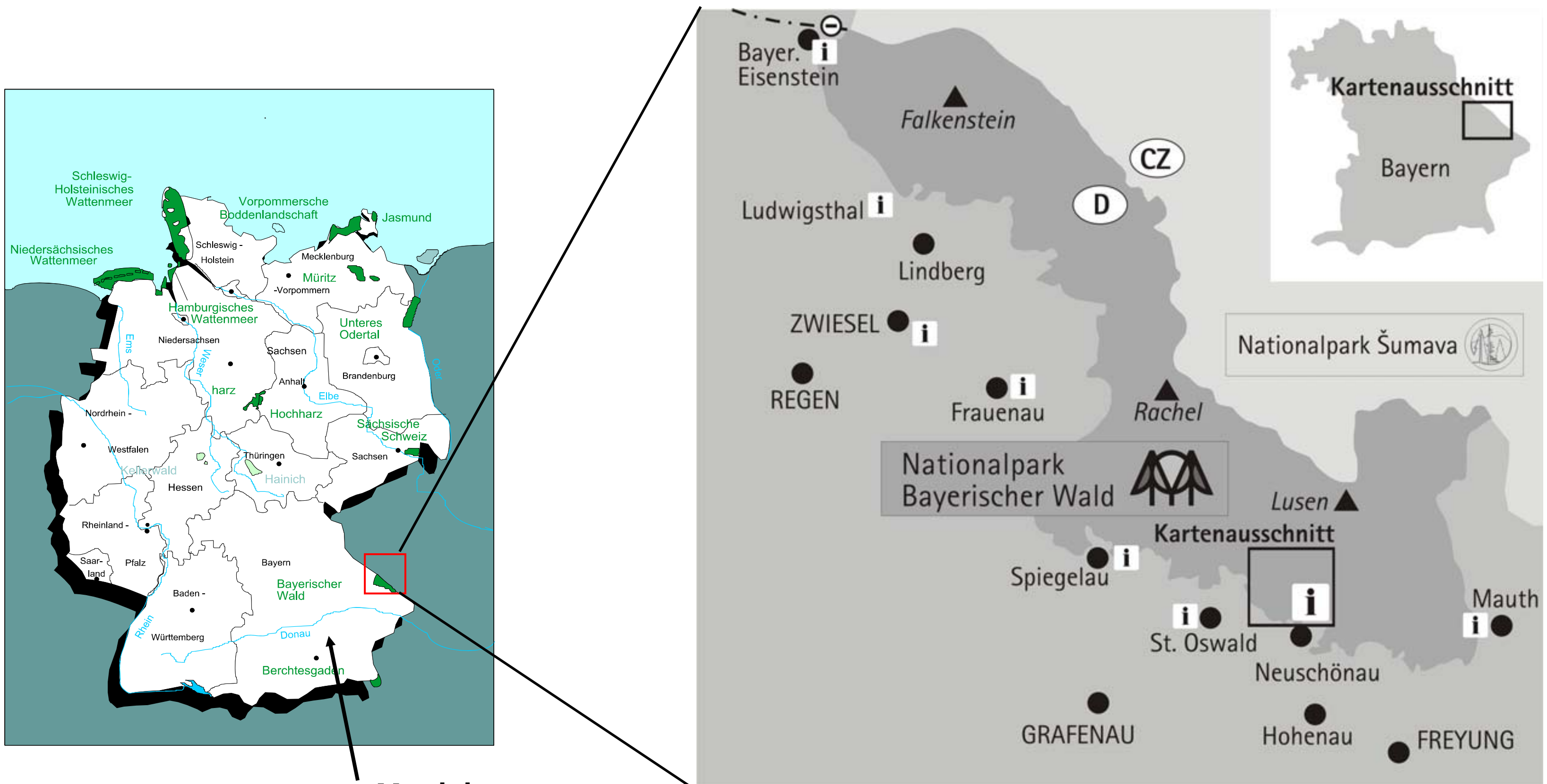
Outline

- Motivation
- Bavarian Forest National Park as study area
- Full waveform LIDAR data
- Decomposition of waveform data
  - Waveform model
  - Estimation of the model parameters
  - Extraction of 3D points
- Metrics for tree species classification
- Conclusions and outlook

Motivation

- Automatic tree species classification in forest inventory is desirable because of
  - Cost saving
  - Shorter update cycles
- Use of full-waveform data
  - More information than conventional LIDAR data
  - Data interpretation not sophisticated up to now
- First steps of processing and analyzing waveform data will be shown
  - Decomposition of waveform data
  - Distribution of derived points in trees
  - Metrics for tree species classification

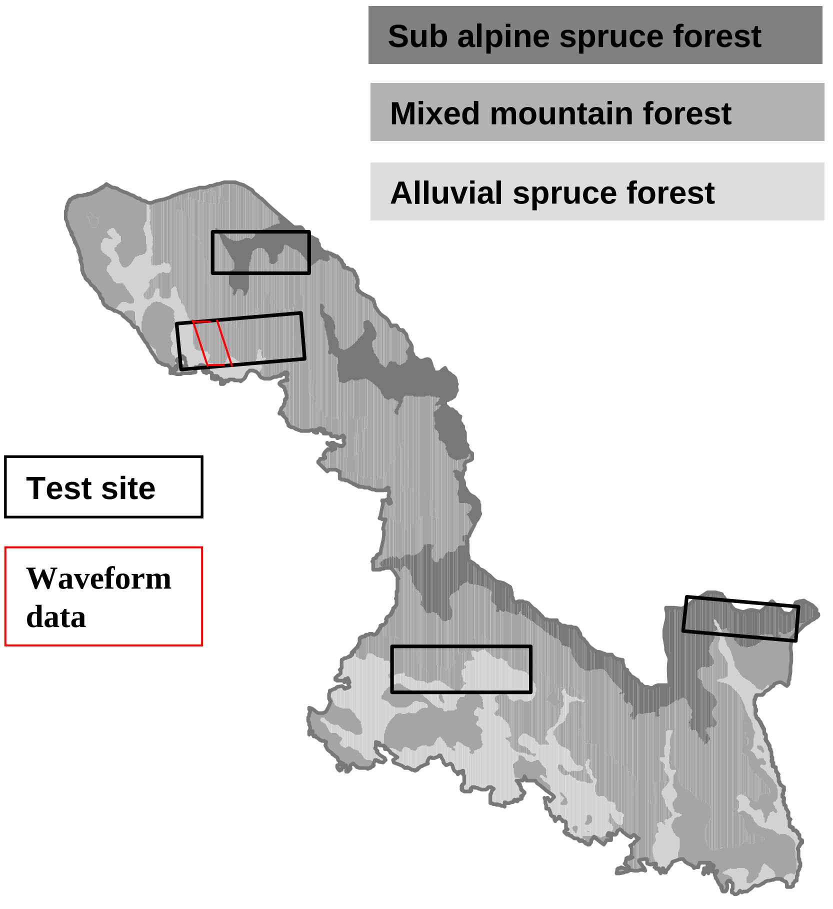
Bavarian Forest National Park



Munich

10 km

Test sites



- Test sites cover different forest structures
  - Natural forest / Managed forest
  - High elevation / Valley bottom
  - Mixed mountain forest
  - Spacious / closed

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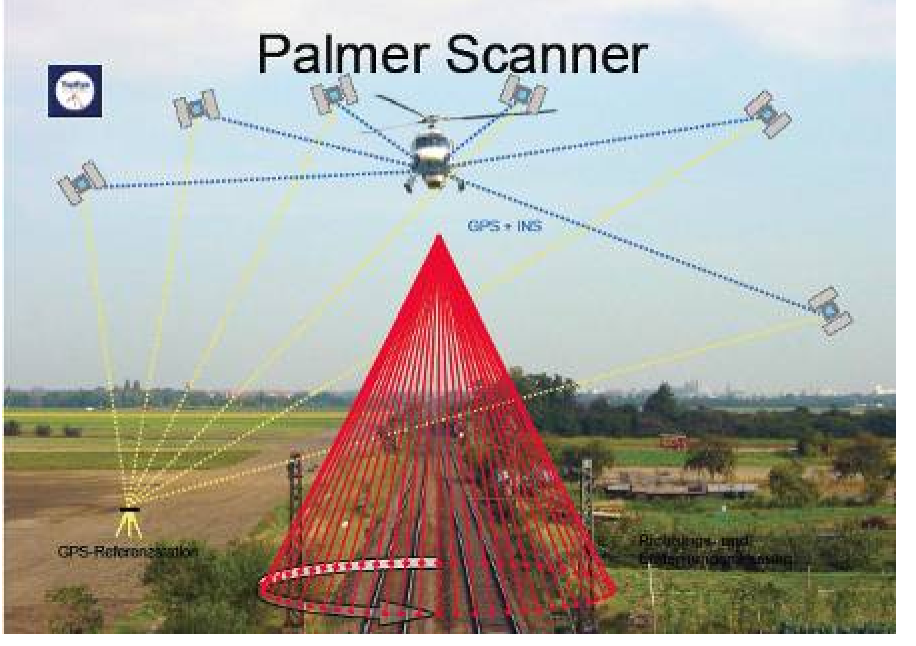
Lidar data

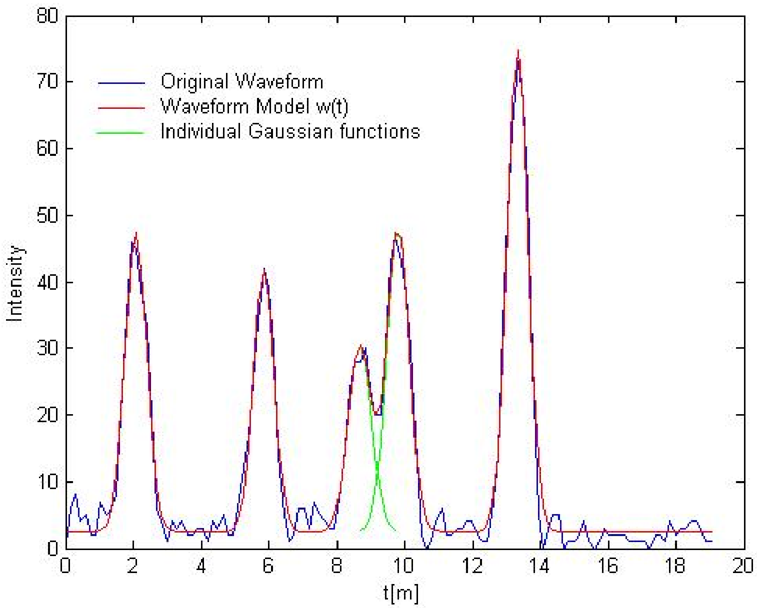
- Flight in September 2004
- TopEye MK II system
- Palmer scanner => scan angle between 14 and 20 degrees
- Wavelength 1550 nm
- Pulse rate 50 kHz
- Pulse length 5 ns
- Flying height 200 m
- 25 points/m^2
- Full waveform data
  - 128 samples (fixed length)
  - Sample rate: 15 cm
  - Waveform limited to 19 m



Waveform model

- Waveform as a sum of Gaussian functions plus a bias:

$$w(t) = \varepsilon + \sum_{m=1}^{N_p} A_m \exp\left[-\frac{(t - t_m)^2}{2\sigma_m^2} \right]$$



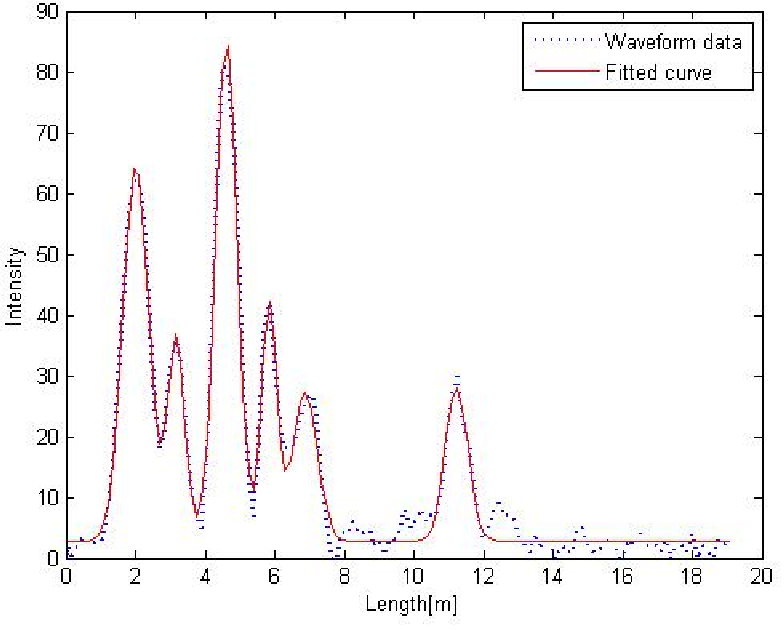
  - ε : Bias (noise level) of the waveform
  - N_p: Number of peaks in the waveform
  - A_m: Amplitude of the m[th] peak
  - t_m : Time position of the m[th] peak
  - σ_m: half-width of the m[th] peak at a height of $\frac{A_m}{\sqrt{e}}$ (standard deviation).

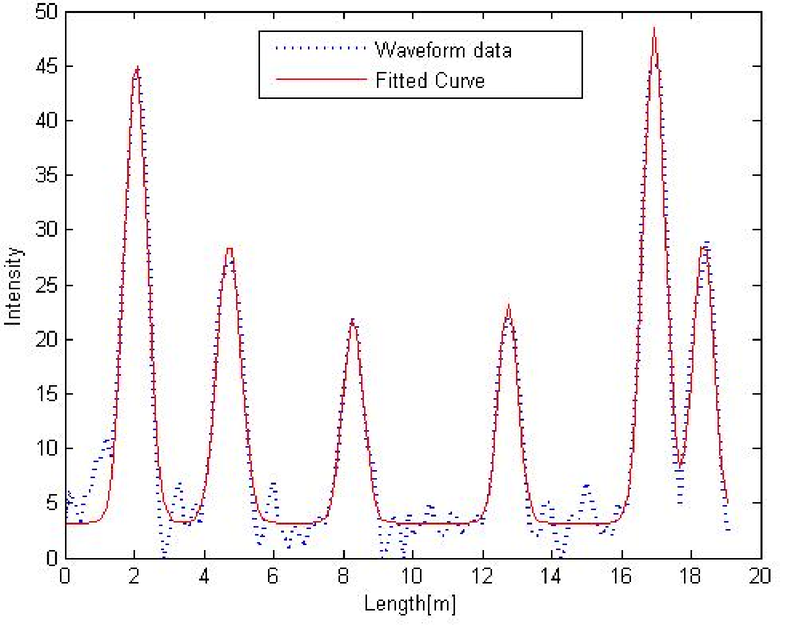
Estimation of the model parameters

- Least squares adjustment to estimate the model parameters (ε, A_m, t_m, σ_m)
- Initial values necessary because of nonlinear adjustment:
  - Median of the waveform => ε
  - Smoothing => local maxima => threshold based on the mean absolut deviation of the waveform (MAD) => A_m, t_m
  - Standard deviation of the transmitting pulse => σ_m
- Levenberg-Marquardt iteration scheme to avoid divergence
  - In cases of inexact initial values
  - In cases of strong overlaying returns
- Estimation of quality measures of the model parameters by error propagation
  - Standard deviation of t_m ~ 2 cm (< 1/7 sample rate)

Examples

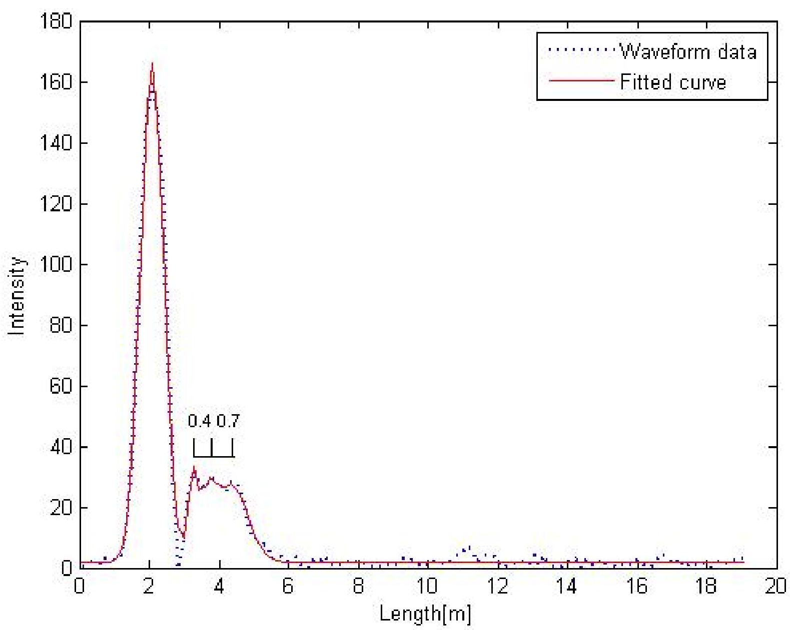
- Up to 4 or 5 additional peaks between first and last reflection

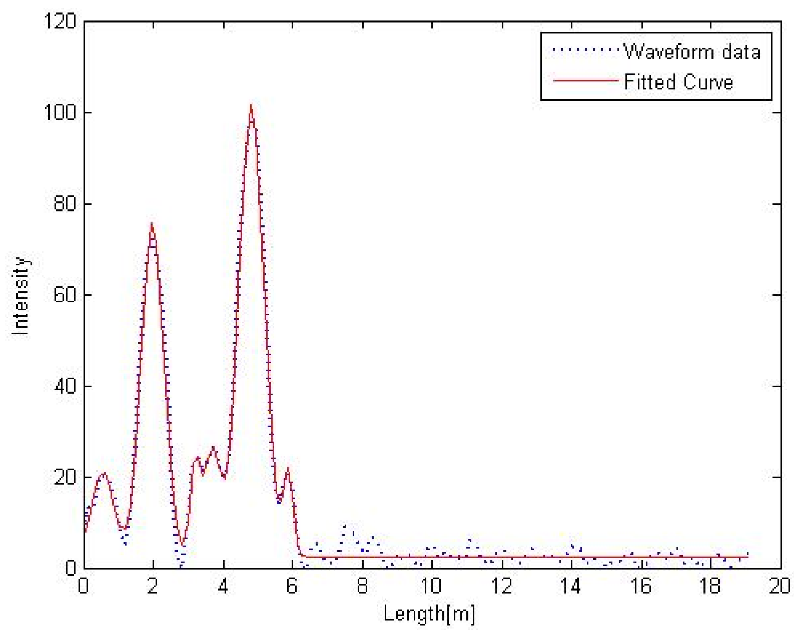




Overlaying return pulses

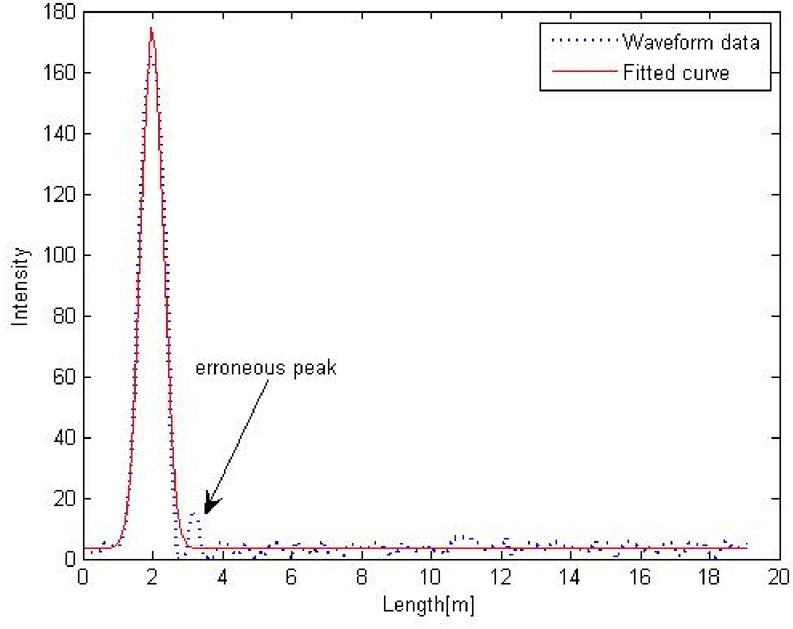
- Adjustment approach separates overlaying return pulses clearly
- Height discernability superior to conventional lidar systems





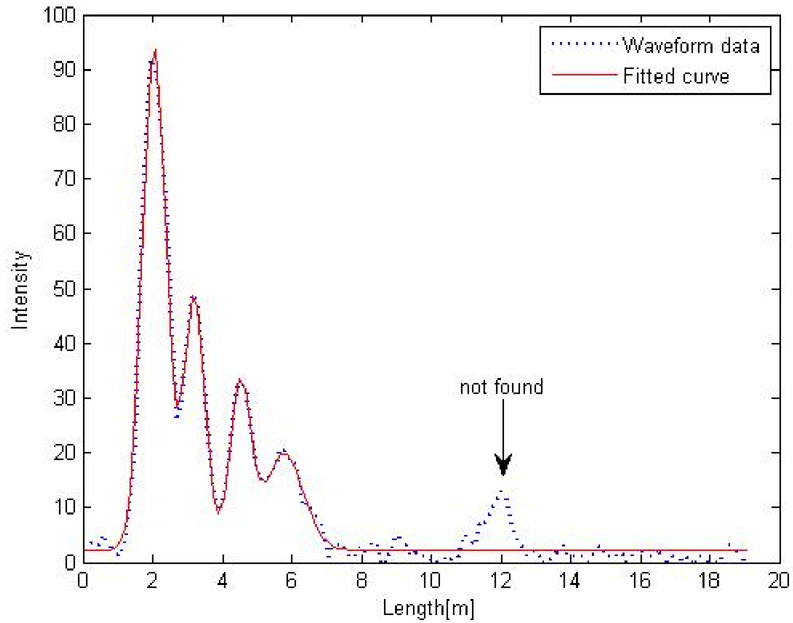
Avoidance of pseudo peak detection

- Erroneous peaks right after big ones because of „ringing“
- => rules are established to overcome these errors
- Exclusion of peak if
  - Second peak is closer than 1.5 m to the first peak
  - Amplitude is smaller than 1/5 of the amplitude of the first peak



Distinction between real peaks and noise

- Thresholding of the initial values works well in most cases
- In few cases smaller peaks are not found
- Possible improvement:
    - Stepwise reducing the threshold by considering sigma0 of adjustment

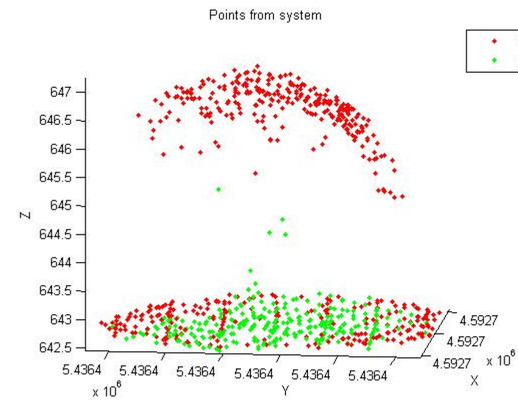


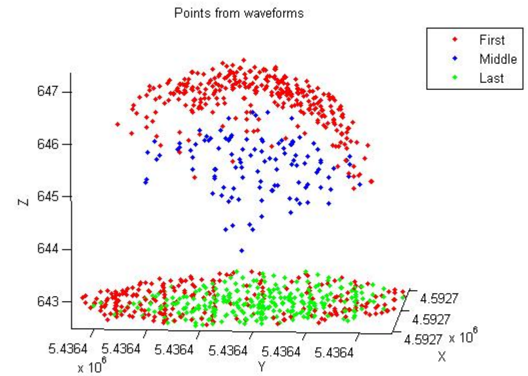
Point distribution

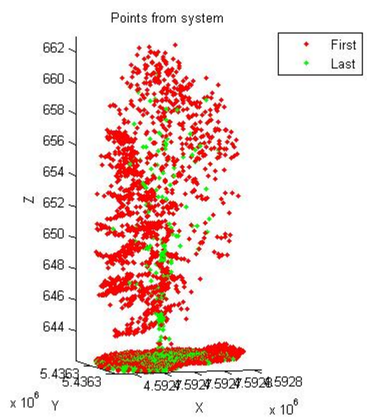
- Up to 100% more points from the waveforms than from the standard first- and last pulse mode of the TopEye system, because
  - Points between first and last echo are ignored by the conventional method
  - Lower sensitivity of the conventional method

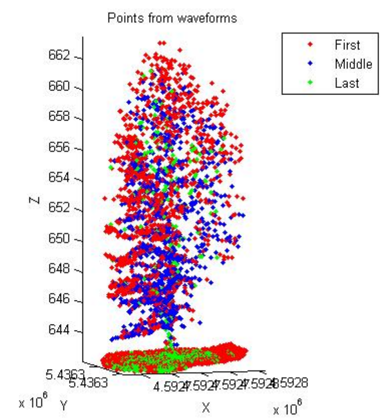
Area	Tree specie	Size [m^2]	Points from TopEye			Points derived from waveforms			
			Total	First	Last	Total	First	Last	Middle
1	deciduous (leaf-on)	21,9	768	503	265	943	553	280	110
2	deciduous (leaf-off)	72,2	5594	4168	1426	7436	4648	1548	1240
3	coniferous	22,2	1109	882	227	2555	1483	727	345
4	deciduous (leaf-on) and coniferous	86,7	1602	1191	411	3261	1678	969	614
5	meadow	28,3	362	362	0	456	456	0	0

Point distribution

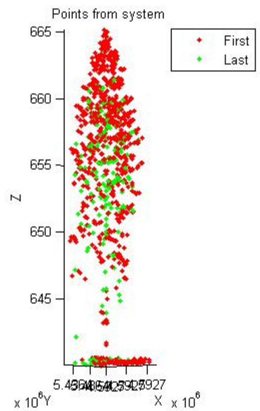


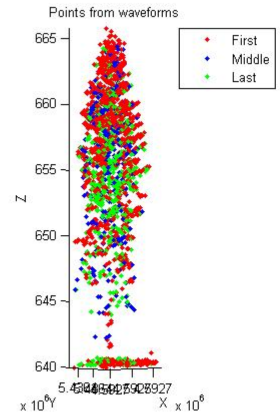


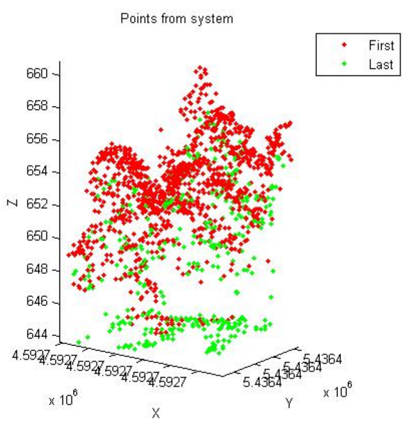


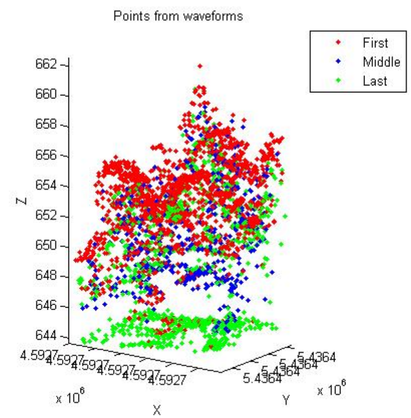


Point distribution



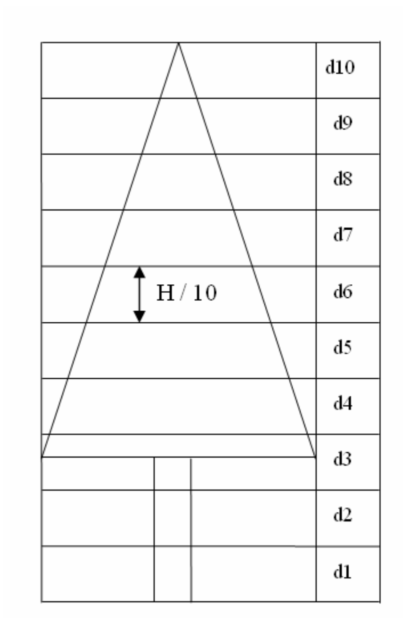




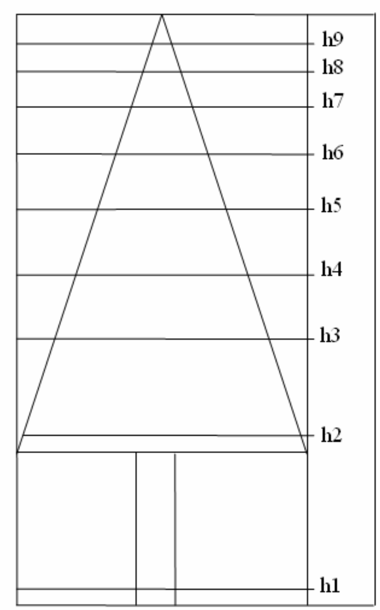


Tree species classification

- Metrics from 3D points as features
  - Density dependent variables: Proportion of the number of points in a given tree height segment to the total number of points
  - Height dependent variables: Percentiles of the point height distribution

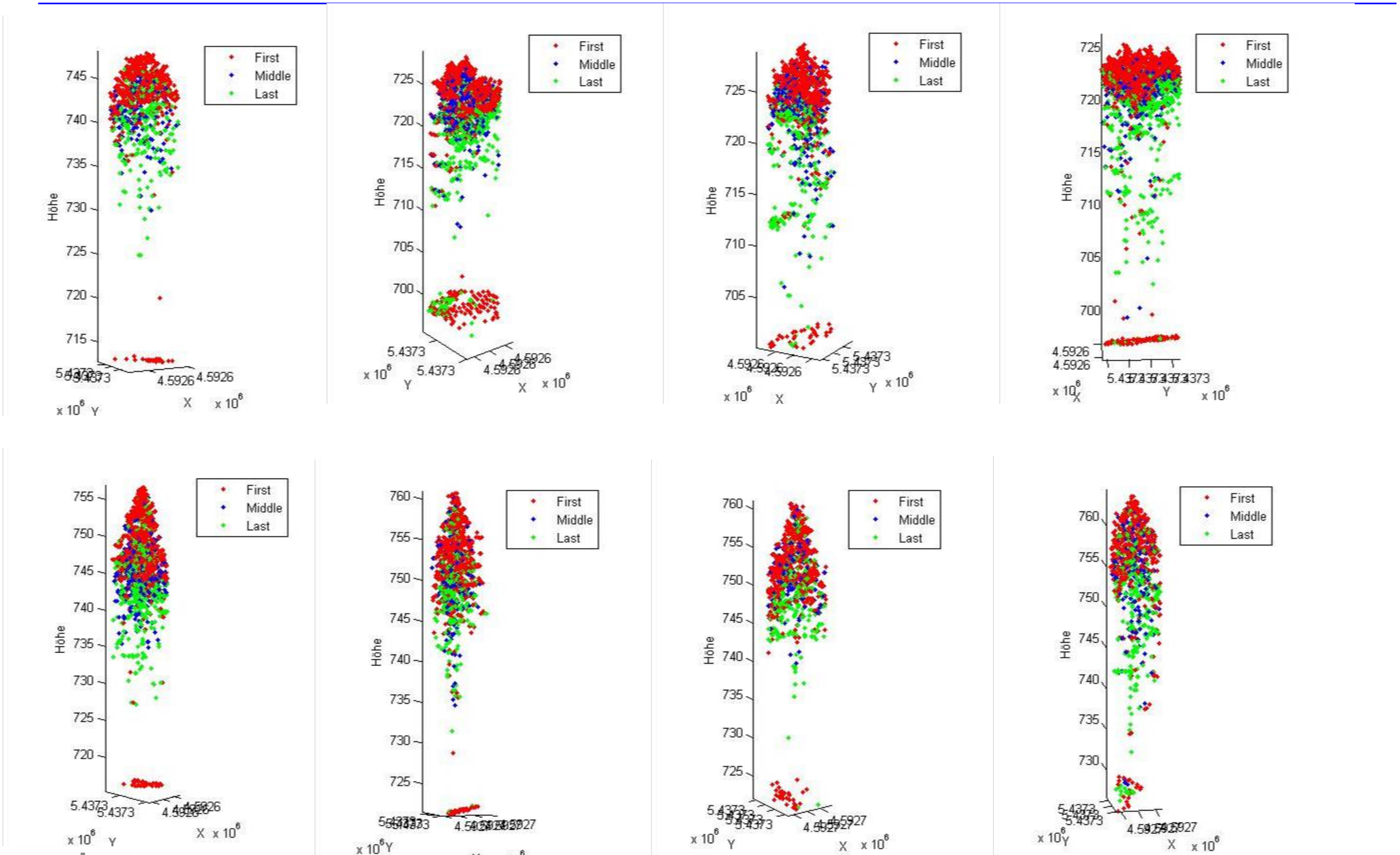


Naesset, 2003



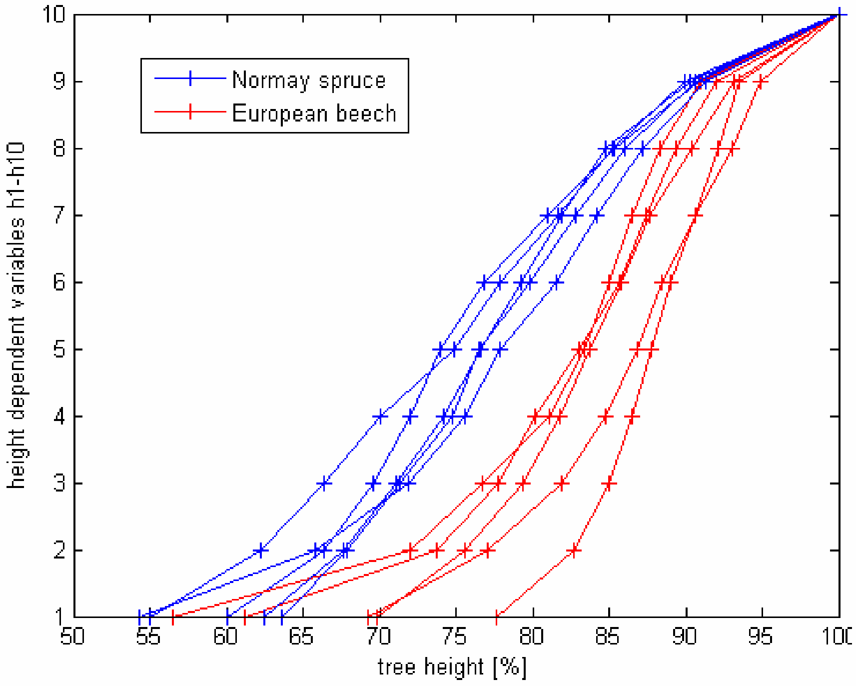
Naesset, 2003

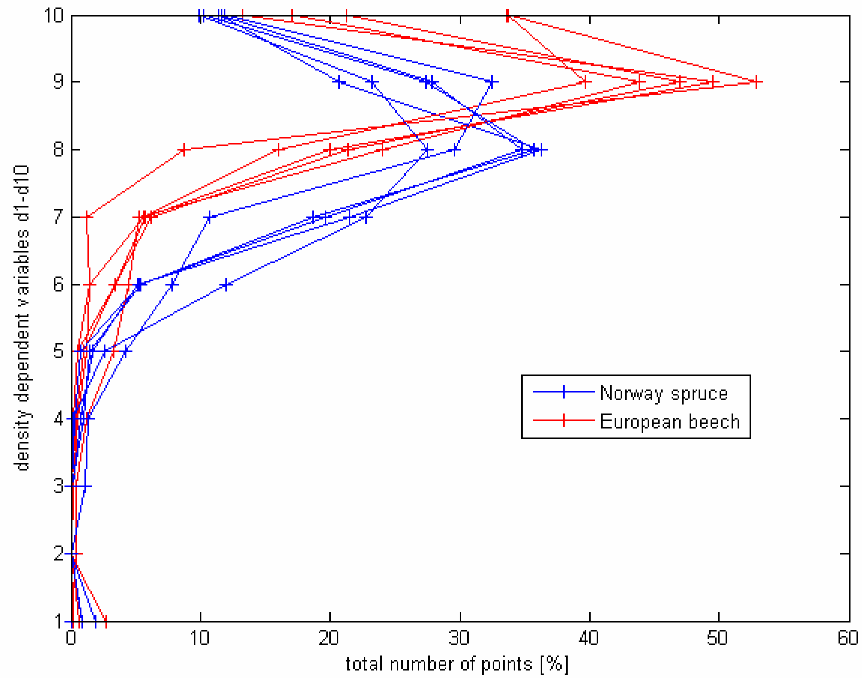
European beech and Norway spruce



Examples

- Metrics are clearly different for the two tree species in the upper parts of the trees
- Classification appears highly promising





Conclusions and outlook

- The potential of full waveform data for the analysis of tree structures is shown
- Significantly more points from the waveforms than from the system

  => More detailed tree structures
- Internal quality measures are provided by the adjustment

  => Quality control
- Relieable metrics can be provided by just using the geometry of the derived points

  => Tree species classification appears highly promising
- Further steps are the use of the point attributes (Intensity, Width) and the directly use of the signal information of the waveform

Thank you