Department of Remote Sensing and Landscape Information Systems University of Freiburg

Applications of Laserscanning in Forestry

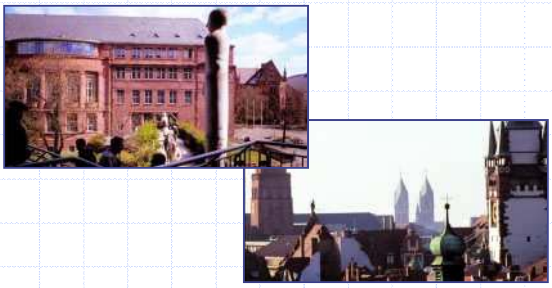
by
Christoph Straub
Dr. Holger Weinacker
Yunsheng Wang
Prof. Dr. Barbara Koch

Overview

1. Introduction to ALS in Forestry
2. Applications of Laserscanning
   2.1 Single Tree Delineation
   2.2 Forest Stand Mapping
   2.3 Estimation of Forest Characteristics
3. Software Demonstration
   TreesVis - processing, analyzing and visualisation of laserscanning data

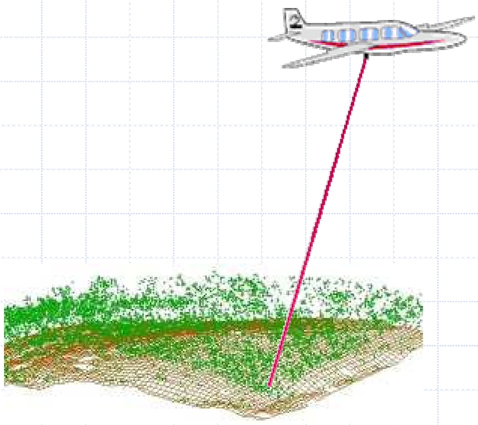
- Faculty of Forest and Environmental Sciences
- University of Freiburg i. Breisgau, Germany
- Teaching and Research:

→ Remote sensing applications in forestry and relevant neighbouring disciplines (e.g. nature conservation, landscape planning)



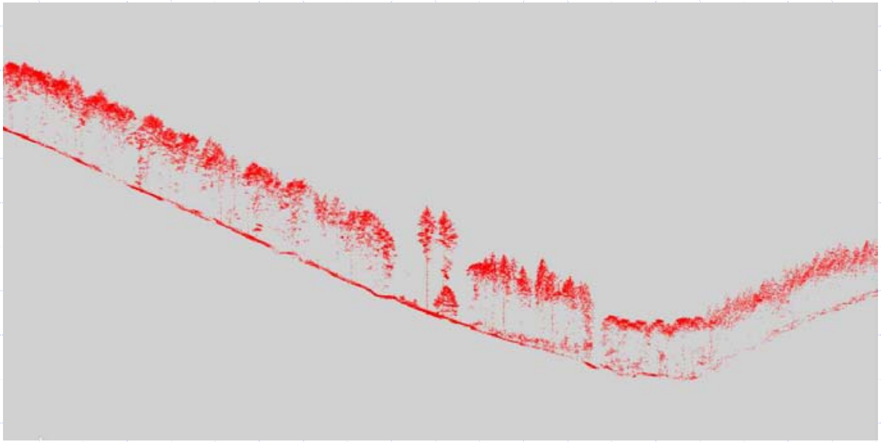
1. Introduction

Why is Airborne Laserscanning (ALS) interresting for forestry?



1. Introduction

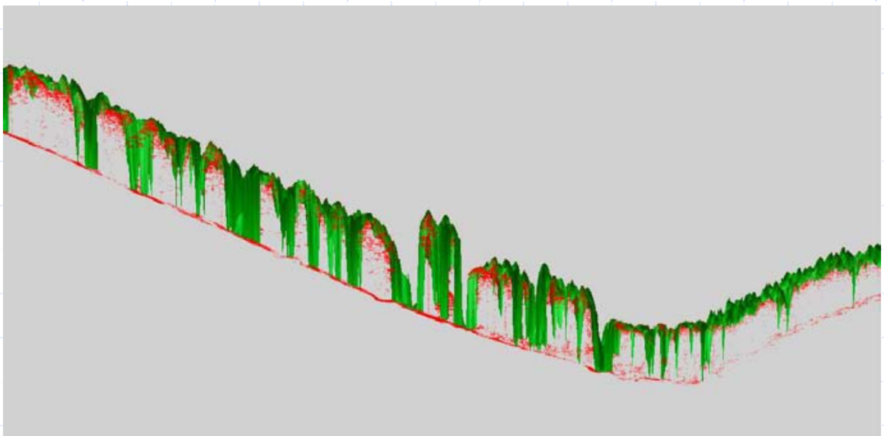
Raw Data - Profile:



Fullwave, IGI LiteMapper 5600, Summer 2005

1. Introduction

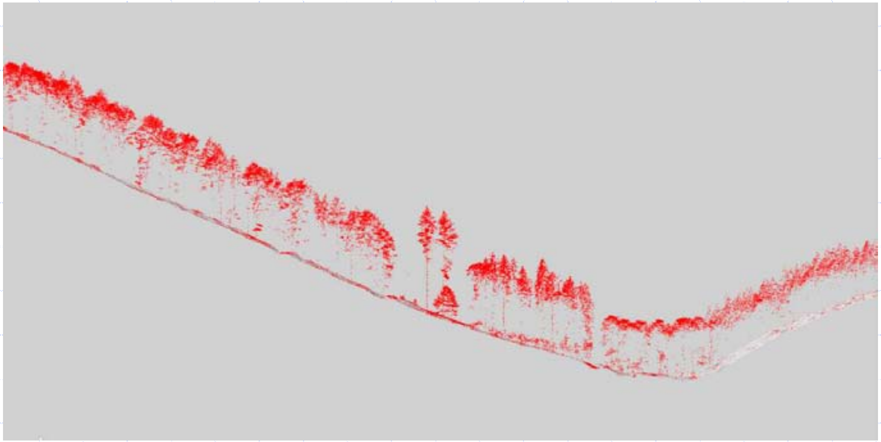
DSM:



Active Surface Algorithm (Weinacker 2004)

1. Introduction

DTM:

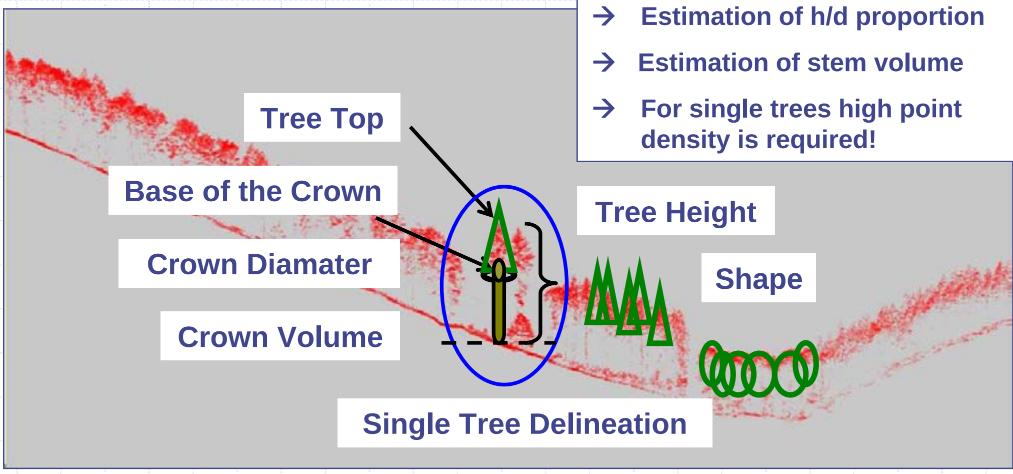


Active Surface Algorithm (Weinacker 2004)

1. Introduction

Single Trees:

- → Estimation of DBH (The stem diameter of a tree measured at breast height (1.3 meters above ground level))
- → Estimation of h/d proportion
- → Estimation of stem volume
- → For single trees high point density is required!



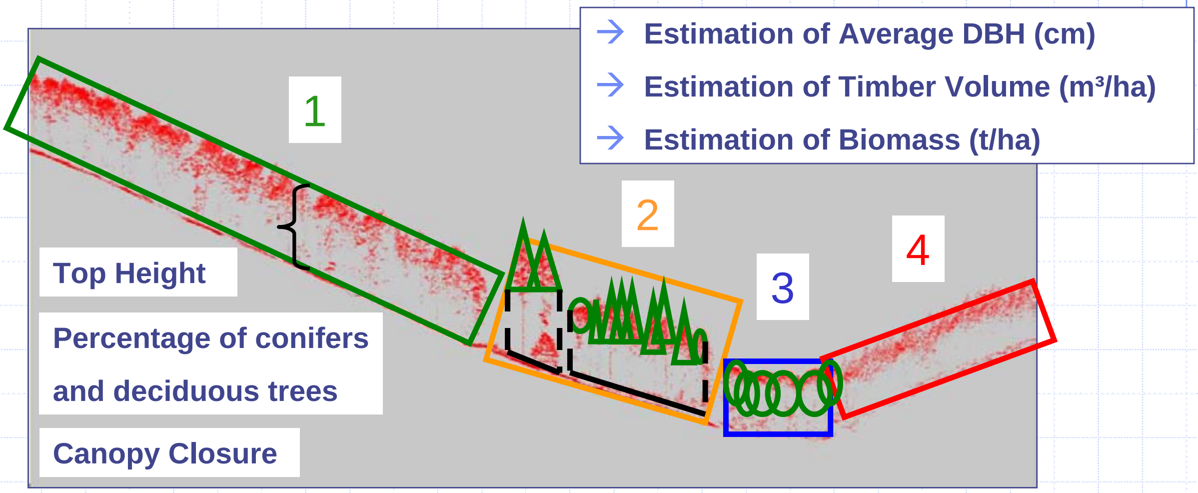
→ Classification into conifers and deciduous trees; (during winter: penetration rate);

In boreal forest: differentiation of birch, spruce, pine

→ Species with spectral image data (RGB and <u>CIR</u>)

1. Introduction

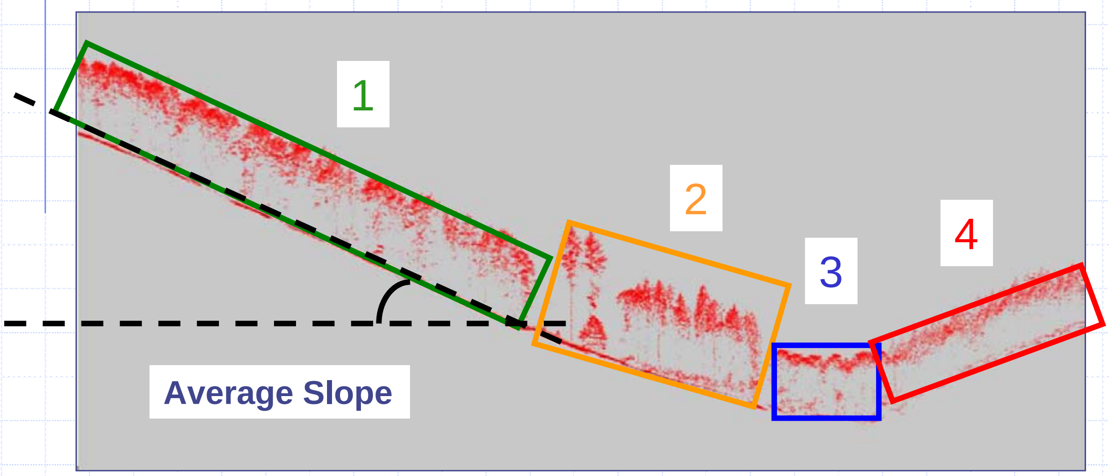
Forest Stands (management units):



Tree Number and Stand Density

1. Introduction

Forest Stands (management units):



1. Introduction

→ Applicability of automated harvesting methods

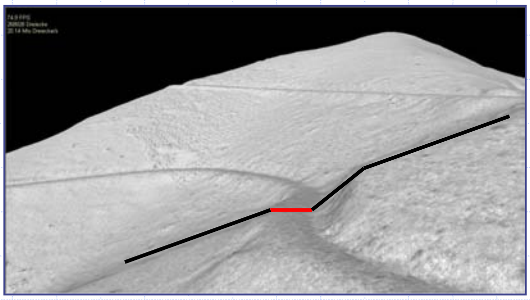
→ Harvester (machine that fells trees, delimbs them and crosscuts them into logs):

→ Steepness of terrain and DBH are limiting factors for highly automated harvesters (Heisig et al. 2005)

1470D Rad Harvester
Forsttechnik GmbH (John Deere)
http://www.forstgmbh.at

1. Introduction

Forest Roads:



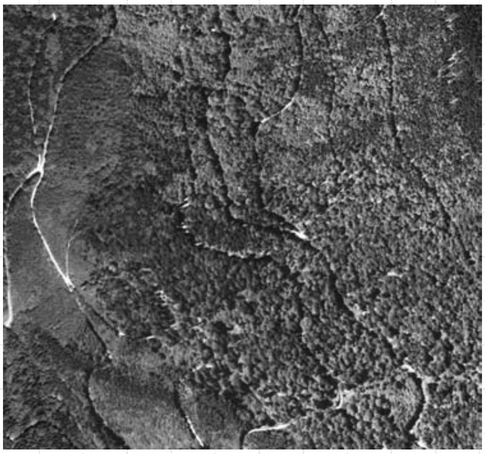
Local Slope in %:
low high

The documentation of the road and path network in the forest:

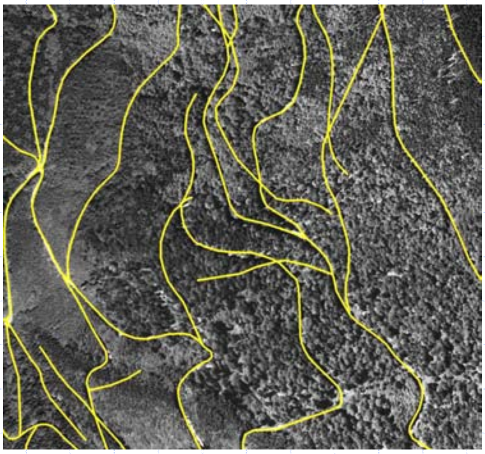
→ precondition for an optimization of timber transport

→ high importance for soil conservation

1. Introduction



Orthoimage

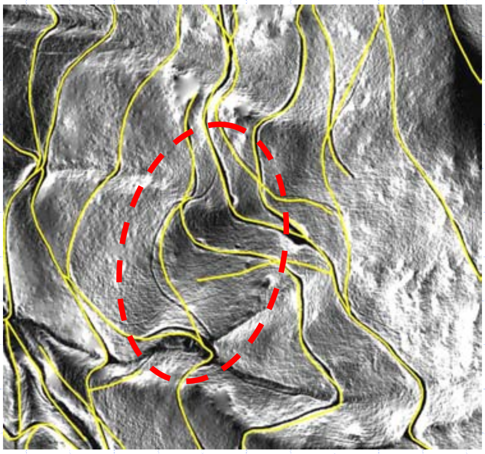


Orthoimage with roads

as digitized line features

1. Introduction

Slope image from LIDAR

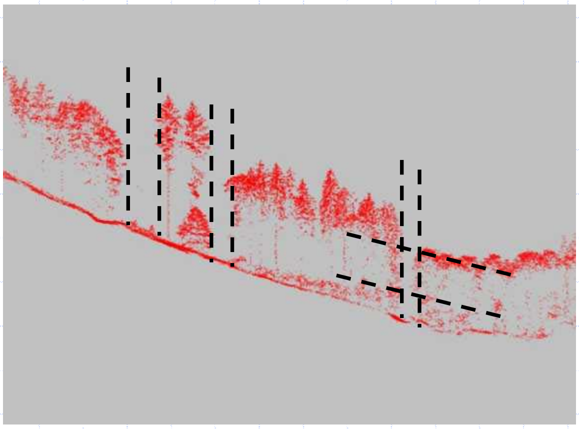


→ Accuracy can be improved

→ With LIDAR additional attributes can be collected e.g. slope per road segment, road width ...

1. Introduction

Nature Conservation – Biodiversity / Stand Structure:



→ Gaps in forest stands are important ecological elements and can support the biodiversity of forest ecosystems

→ Multi-storied forest stands support high diversity and thus biodiversity

→ Modelling of habitat quality

1. Introduction

→ In Scandinavia (Norway): LIDAR is already used for forest inventories (Næsset 2002)

→ In Germany: LIDAR for forest inventories is still a research topic; in the moment: terrestrial surveys → expensive

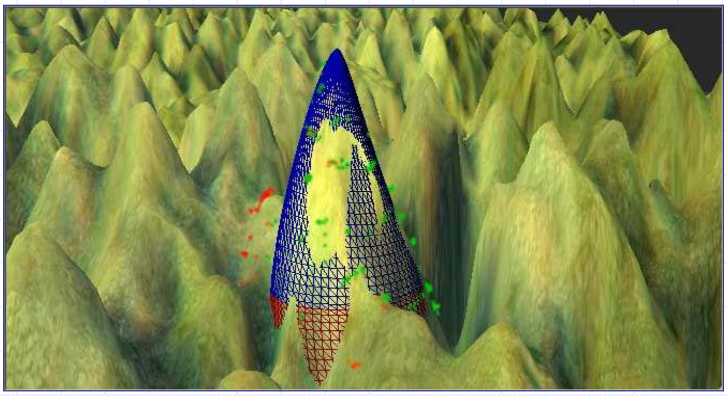
→ LIDAR as an alternative to support or even replace field measurements (?)

→ Orthoimages are used for forest stand mapping (costs are reduced 30-40%)

→ Monitoring of forest damages e.g. bavarian national park (insects, fire, windstorm…)

2. Applications of Laserscanning

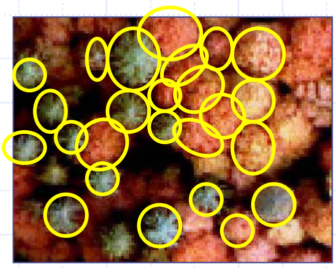
2.1 Automatic Single Tree Delineation



2.1 Automatic Single Tree Delineation

→ A difficult task.

→ No straight lines, no right angles, no planes, overlapping crowns, many different crown shapes and sizes:



2.1 Automatic Single Tree Delineation

Different approaches for automatic single tree delineation – some examples:

- **HIGH-SCAN Project: First European wide attempt to derive single tree information from laserscanner data (Hyyppä 2001)**
- **Swedish Defence Research Agency: Algorithm for boreal trees (Persson 2001, Persson et al. 2002)**
- **FeLIS: Algorithm developed under German conditions (Koch et al. 2006)**

→ **“Watershed Segmentation”: Segmentation of an image by means of a flooding simulation (Soille 1999)**

2.1 Automatic Single Tree Delineation

FeLIS - Single Tree Delineation (main processing steps):

1. **INPUT: Rasterized laser data (DSM/DTM)**
2. **DSM is smoothed (Gaussian Smoothing)**
3. **Tree tops are extracted (Local Maxima)**
4. **„Pouring Algorithm“ (raindrop model)**
5. **Final detection of crown edges by searching vectors from the tree tops → „Ray Algorithm“**
6. **Knowledge-based assumptions on the shape of trees**

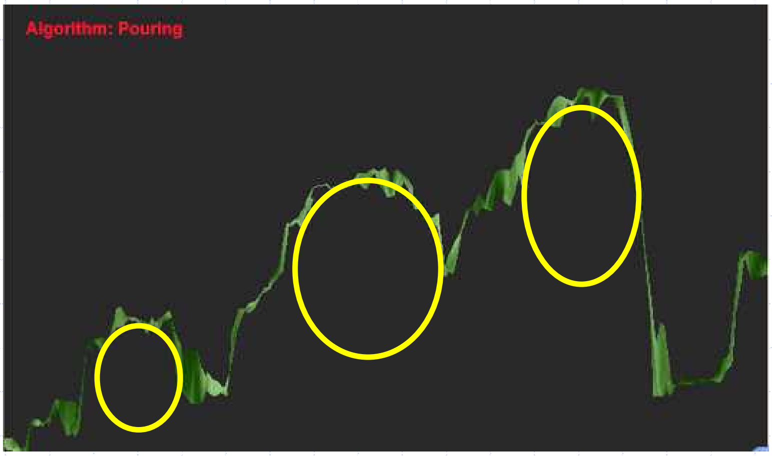
→ **Minimum size**

→ **Minimum distance between tree tops**

→ **Crown shape (compactness, circularity)**

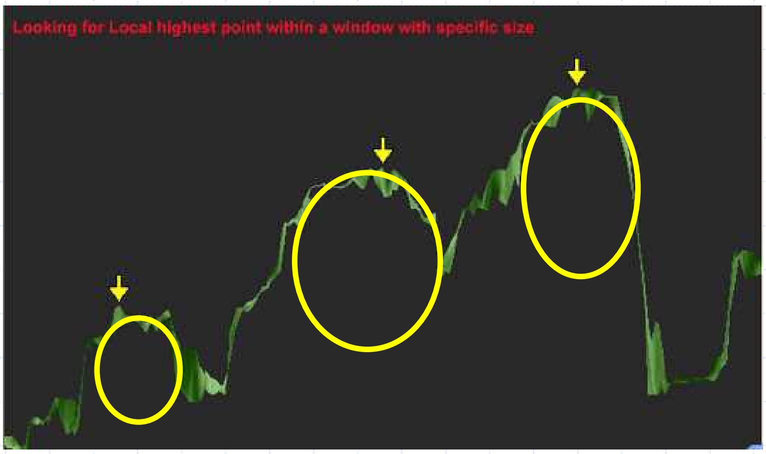
2.1 Automatic Single Tree Delineation

Profile of DSM
(individual trees are expected within each salient curve)



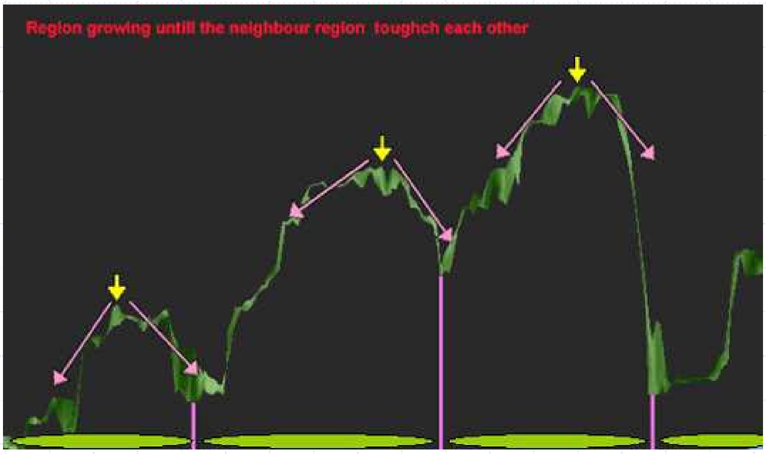
2.1 Automatic Single Tree Delineation

Pouring (first step) - Local Maxima detection:



2.1 Automatic Single Tree Delineation

Pouring (second step) – expansion:

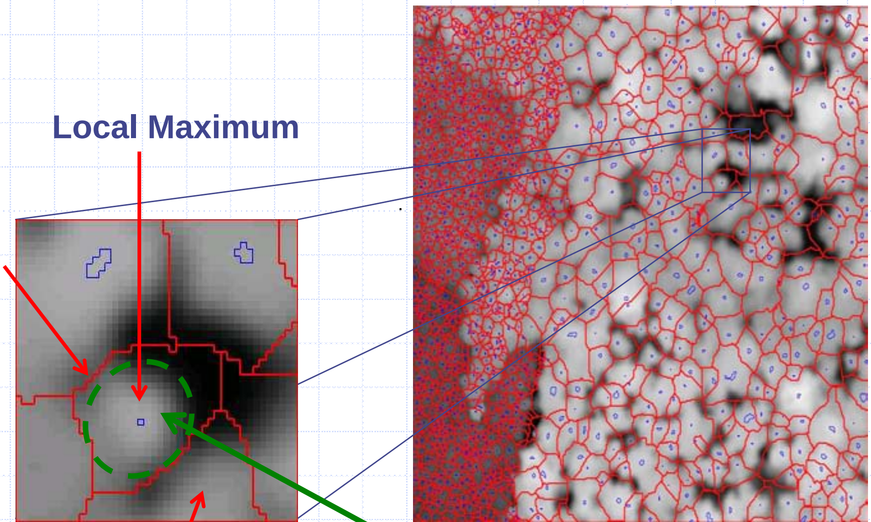


1. Maxima are the starting points for an expansion until „valley bottoms“ are reached.
2. The expansion is done as long as there are chains of pixels in which the gray value gets smaller (like raindrops running downhill from the maxima in all directions)

2.1 Automatic Single Tree Delineation

Local Maximum

Result after
„Pouring Operator“
(Individual crowns can be expected within each segment. Further analysis are needed to extract the exact shape of crowns)

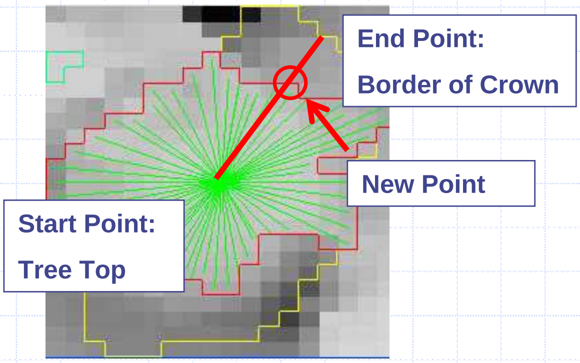


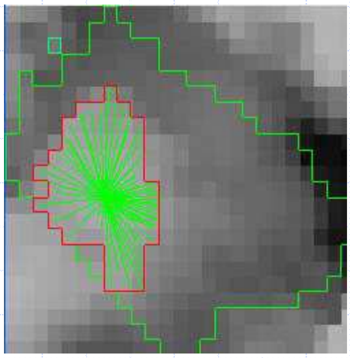
Smoothed DSM

„exact shape“

2.1 Automatic Single Tree Delineation

Extraction of individual crowns (ray algorithm)

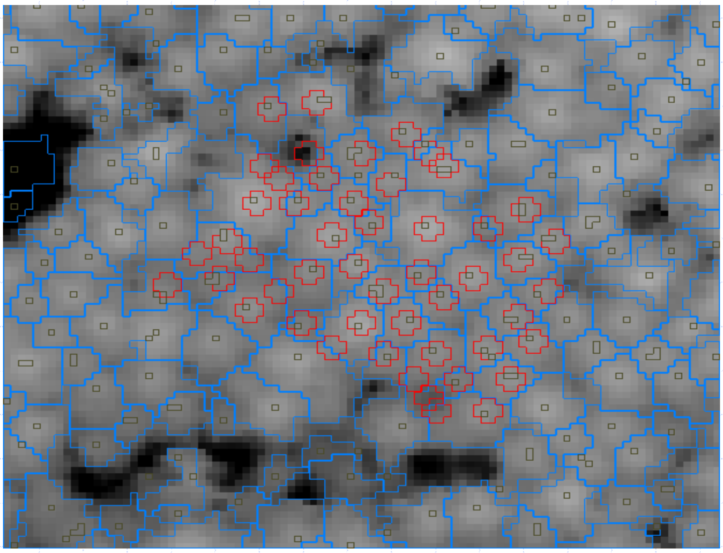




1. Assumption: The height change within an individual crown must be continuous
2. Virtual rays between the tree tops and border points are generated
3. New border points of the tree crown are created if there is an interruption of the continuous height changes by pixels with high difference in elevation

2.1 Automatic Single Tree Delineation

Verification of the algorithm (field measurements):



Red: Positions of trees measured with GPS during field work

Blue: Segmentation result

2.1 Automatic Single Tree Delineation

Verification with field measurements:

Coniferous trees (Pseudotsuga menziesii):

No of trees:	Identified correctly:
49	87%

Deciduous trees (Carpinus betulus, Acer pseudoplatanus, Fraxinus excelsior):

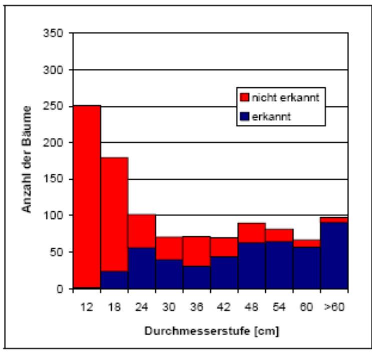
No of trees:	Identified correctly:
49	50%

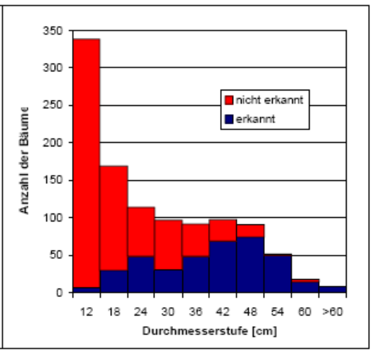
(Koch et. al 2006)

2.1 Automatic Single Tree Delineation

- → Verification with 2575 trees
- → 998 trees were indentified (~39%)
- → 74.7 % of timber volume

Coniferous trees: Deciduous trees:





(from Heurich 2006)

2.1 Automatic Single Tree Delineation

Summary of the verification:

- Good results for conifers
- Problems with small and suppressed trees
- Stem numbers are underestimated
- Most dominant trees are found (→ trees with high timber volume)
- Crown areas are overestimated

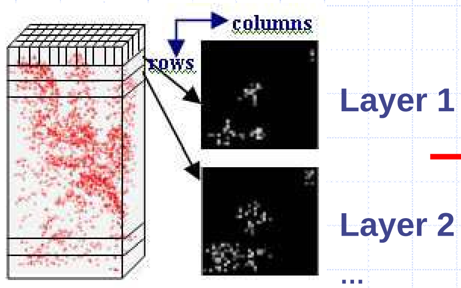
Mean crown area for segmented trees:	Mean crown area for reference trees:
11m²	8.2m²

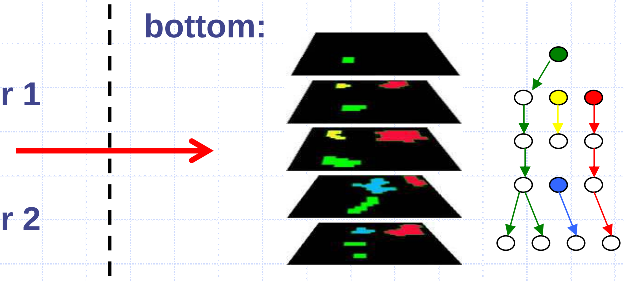
(Koch et. al 2006)

2.1 Automatic single tree delineation

"New Ideas" (Wang 2007) :

Tree structure is traced from top to bottom:





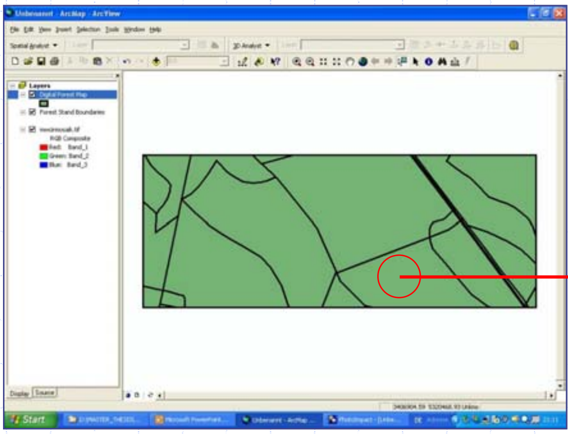
„Voxel-Model" of point cloud

(dividing the area into small three-dimensional cells).

Layers are created and number of lasercanner points is calculated in each voxel and stored into 2d image.

2.2 Forest Stand Mapping

Digital Forest Stand Maps:



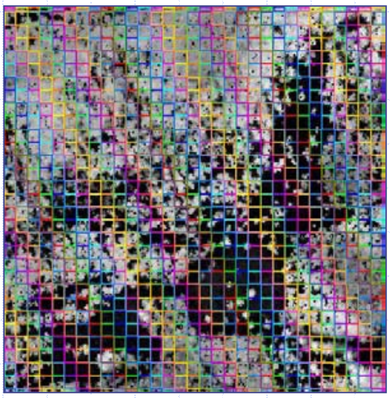
Forest Area is classified into „management units“ based on:

- species
- age
- structure
- composition

Size
Age
Main Tree Species
…

2.2 Forest Stand Mapping

Subdivision of study area into cells (20x20m, nDSM in the background):



Classification of the cells based on:

1. Percentage of conifers, deciduous trees and forest floor

→ Classes: Conifers-, Deciduous-, Mixed, Forest Floor

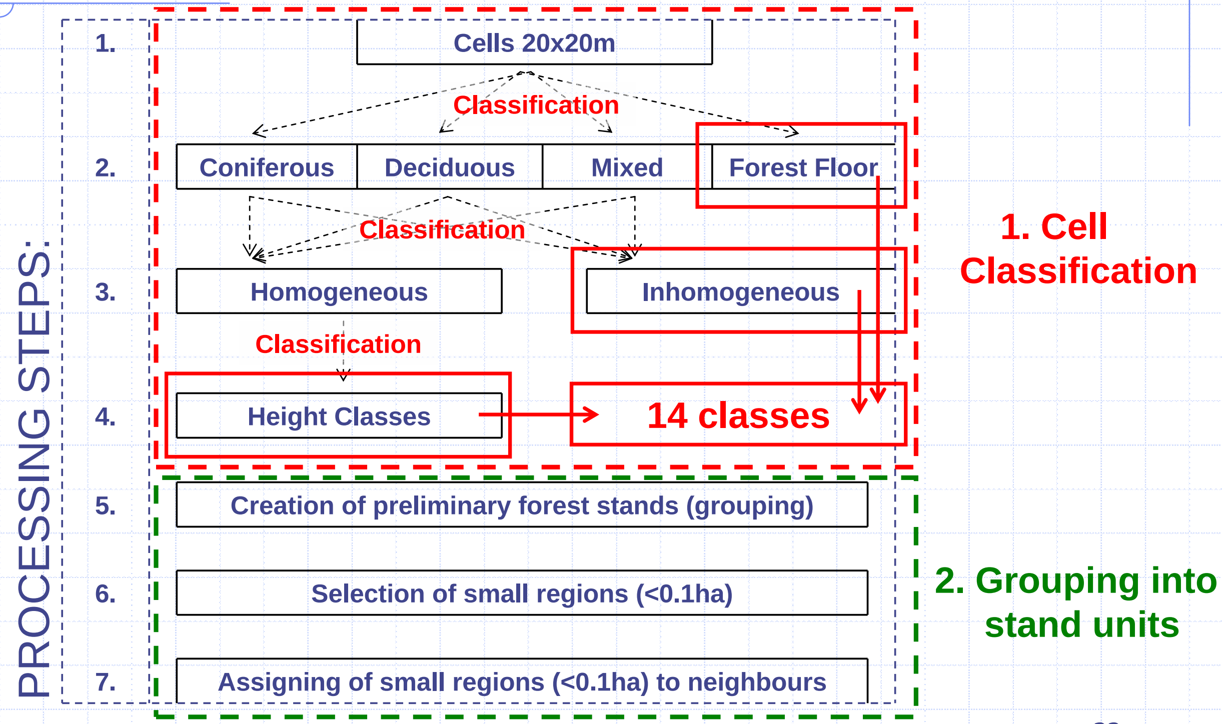
2. Surface Roughness (variation of height values):

→ Classes: homogeneous, inhomogeneous

3. Height Classes:

Dev. Stage	Height
Sapling	3-10 m
Pole	10-15 m
Mature Trees	15-25 m
Old Trees	> 25 m

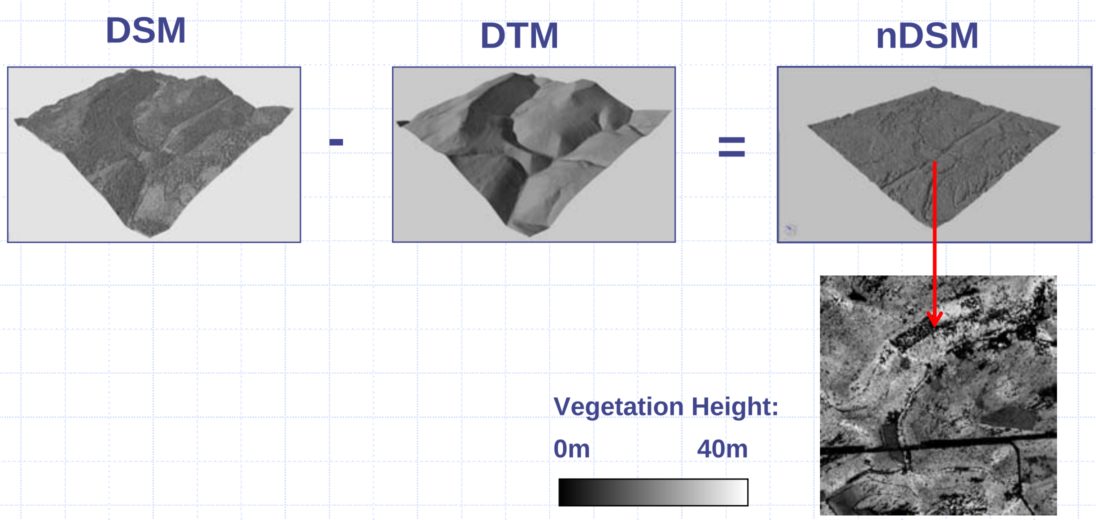
2.2 Forest Stand Mapping



2.2 Forest Stand Mapping

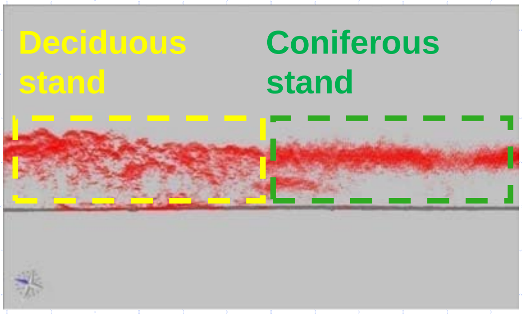
Example for stand mapping (during winter (leaf-off) conditions):

„Quellgebiet Wieslauter" in the biosphere reserve „Pfälzerwald"

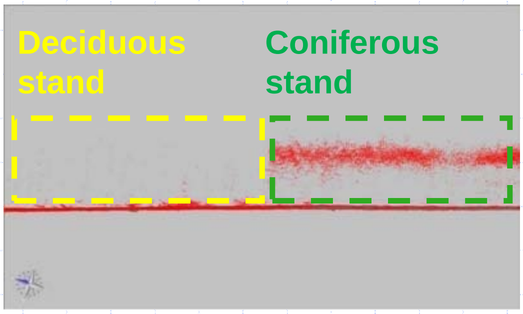


2.2 Forest Stand Mapping

STEP 1: Modelling of deciduous and coniferous stands during winter (leaf-off) conditions:



Winter: First Echo

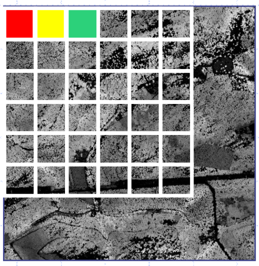


Winter: Last Echo

2.2 Forest Stand Mapping

STEP 1: Modelling of deciduous and coniferous stands during winter (leaf-off) conditions:

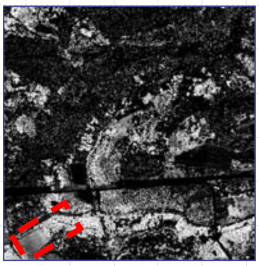
First Echo (nDSM):



All trees

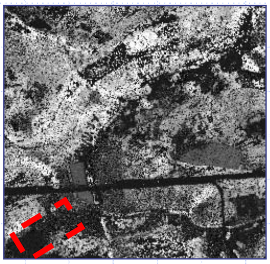
-

Last Echo (nDSM):



Coniferous trees

=



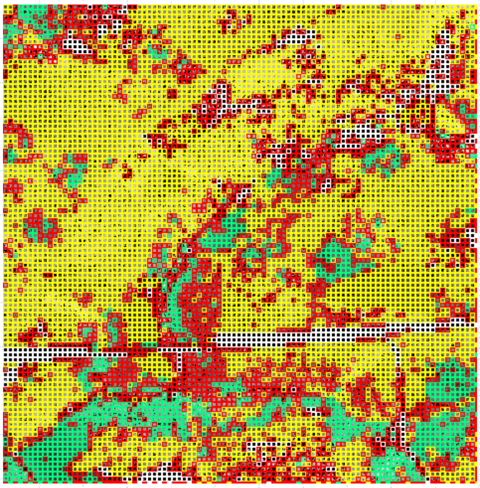
Deciduous trees

→ Regions with forest floor
→ Regions with coniferous trees
→ Regions with deciduous trees

…used for classification of cells

2.2 Forest Stand Mapping

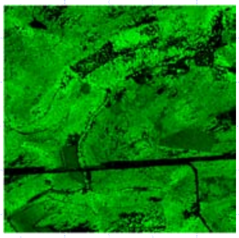
Classification Result:



- Coniferous forest
- Deciduous forest
- Mixed forest
- Forest floor and small vegetation

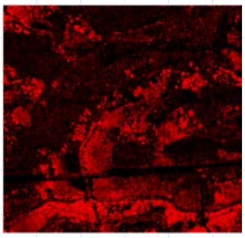
2.2 Forest Stand Mapping

nDSM FirstPulse



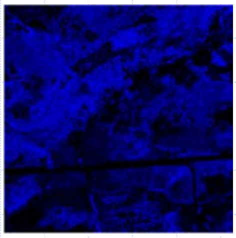
Green

nDSM LastPulse

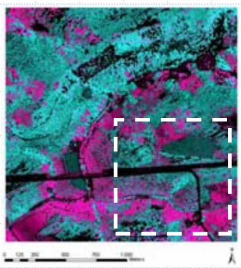


Red

[nDSM FirstPulse - nDSM LastPulse]



Blue



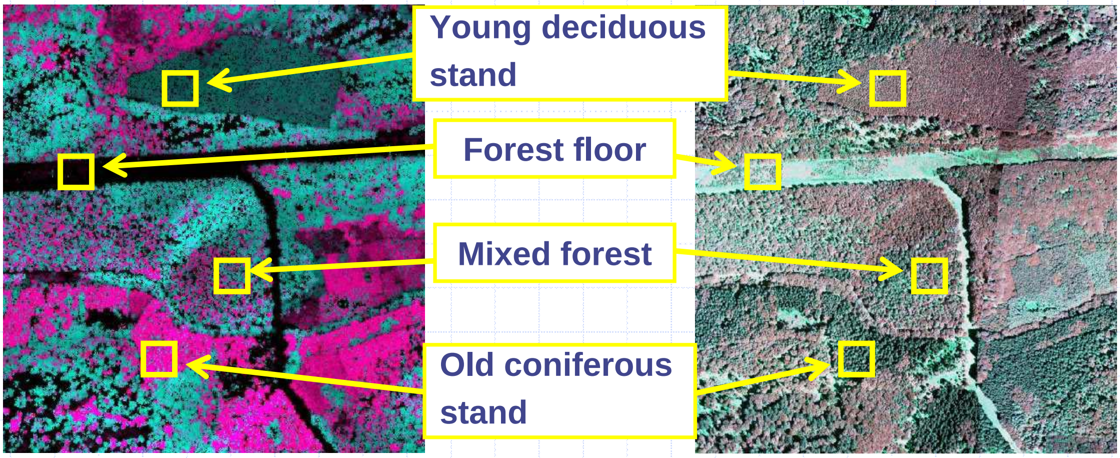
„Laserscan-RGB“

→ for visual interpretation

→ combination of height and differentiation into con. and dec. trees

2.2 Forest Stand Mapping

„Laserscan-RGB“ „CIR-Orthophoto“

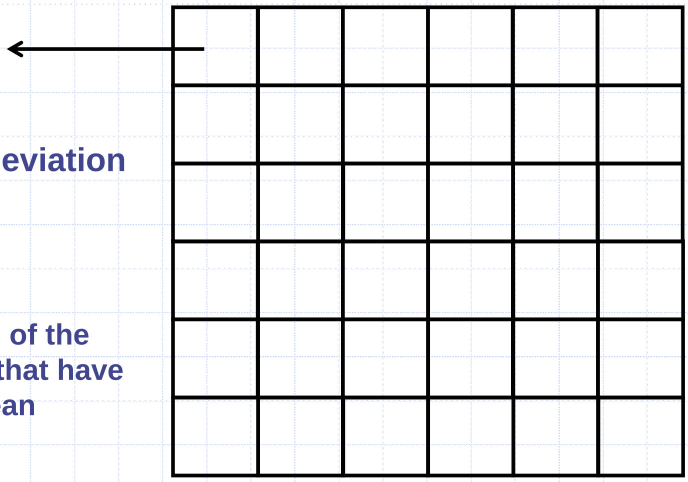


2.2 Forest Stand Mapping

STEP 2: Classification based on variation of height values:

→ coefficient of variation (Cv) of height values in each cell as a measure for the surface roughness

$$C_v = \frac{\sigma}{\mu}$$



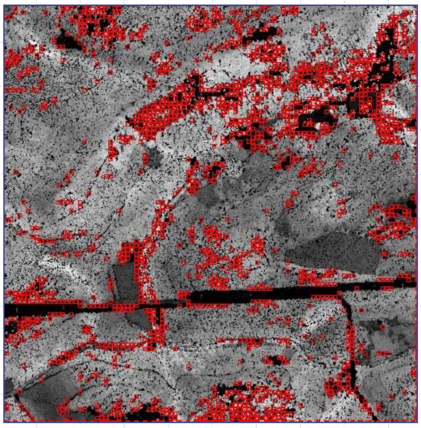
σ standard deviation

μ mean

… Cv allows comparison of the variation of populations that have significantly different mean values.

2.2 Forest Stand Mapping

Homogeneous and inhomogeneous canopy structure:

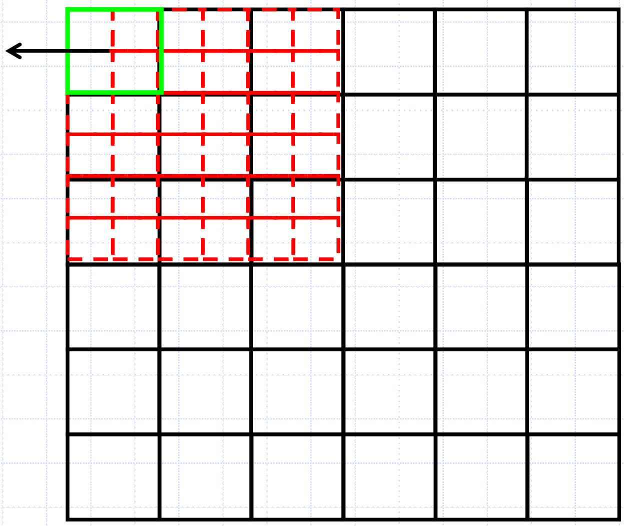


■ = Regions with „high vertical structure“

2.2 Forest Stand Mapping

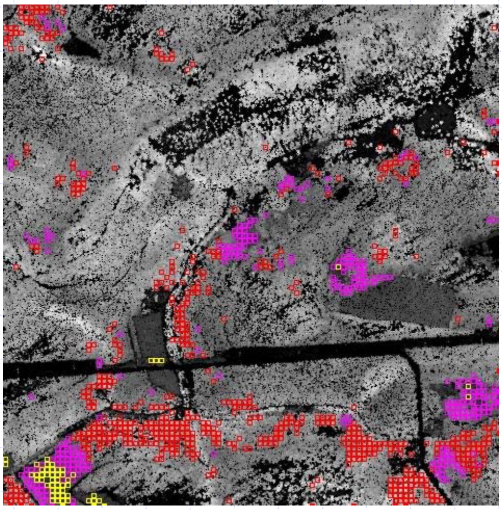
STEP 3: Height classes based on Top Height:

$$Top\_Height = \frac{Max(1) + Max(2) + ... + Max(n)}{n}$$



2.2 Forest Stand Mapping

„Coniferous Forest Cells“ classified with height classes:

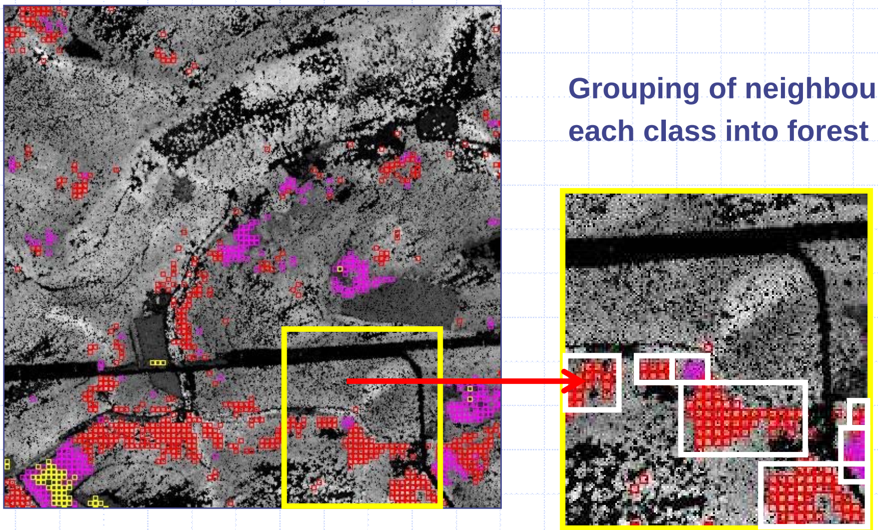


“juvenile”:	h < 3m	
“sapling”:	3 =< h <10m	
“pole”:	10 =< h <15m	yellow
“mature trees”:	15 =< h <25m	magenta
“old trees”	25m =< h	red

2.2 Forest Stand Mapping

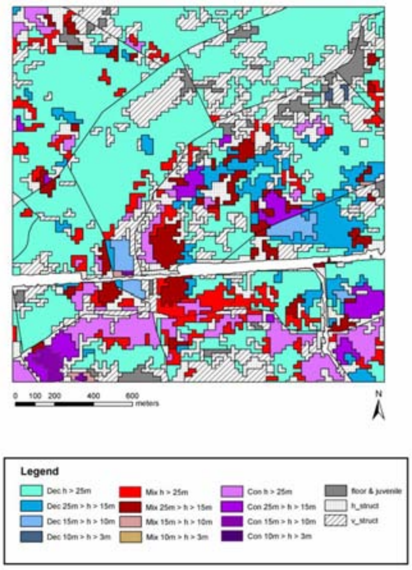
Grouping of cells :

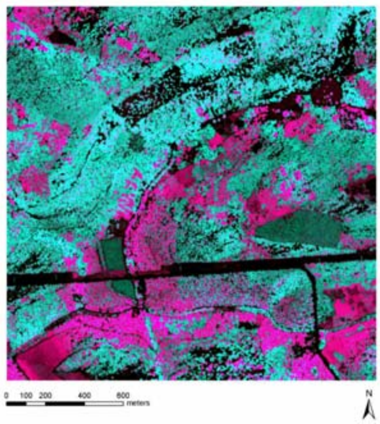
Grouping of neighbouring cells within each class into forest stands:



2.2 Forest Stand Mapping

Result of the automatic delineation into stand units:

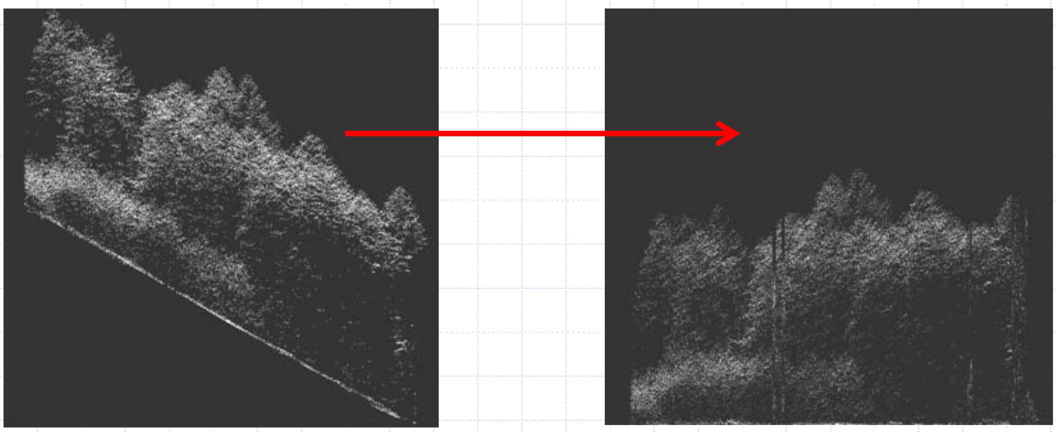




2.2 Forest Stand Mapping – vertical structure analysis

“Normalization” of Raw Data Points:

RawPoint(x,y).Height – DTM(x,y).Height = RawPoint(x,y).Normalized_Height

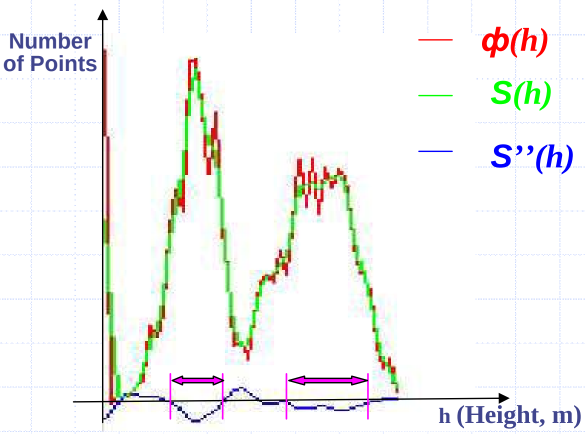


„Original“ point cloud

„Normalized“ point cloud

2.2 Forest Stand Mapping – vertical structure analysis

Height Distribution Function:

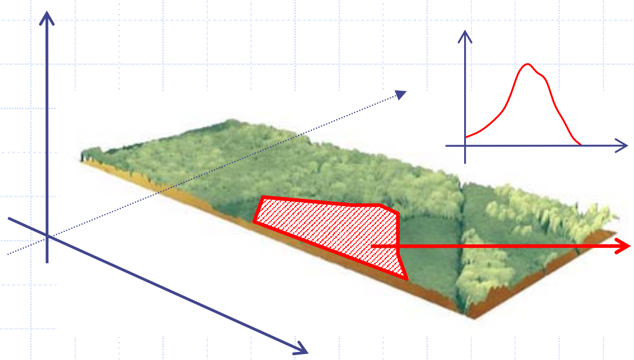


ϕ(h): Height distribution function
S(h): Smoothed height distribution function
S''(h): Second derivative of *S(h)*

At the intervals of h where S''(h)<0, there must be salient curves of function S(h);

→ The intervals of h are considered as height ranges of tree canopy layers.

2.3 Estimation of Forest Characteristics



Size:	1.84ha
Top Height:	23.4m
Developmental Stage:	Mature
Canopy Closure:	99%
Volume:	440m³
Slope:	3 %

Field Measurements vs. LIDAR

2.3 Estimation of Forest Characteristics

Two possibilities to analyze the data:

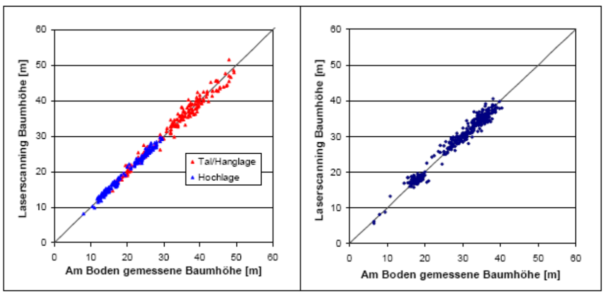
1. High resolution data → single tree variables can be estimated

2. Low resolution data → plot or forest stand characteristics can be estimated

2.3 Estimation of Forest Characteristics

Tree Height (single trees):

Coniferous trees: **Deciduous trees:**



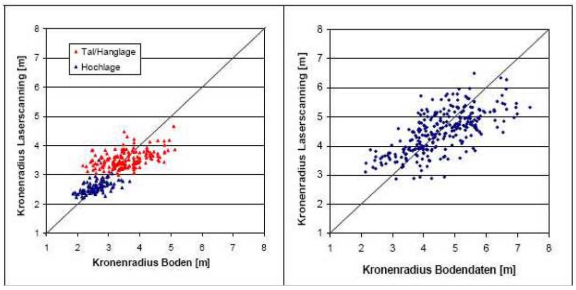
	n	ln	b_0	b_1	b_2	b_3	b_4	R^2	RMSE [m]	VK_{RMS} [%]
Laubbäume	371	nein	-1.673	1.125	0.009	0.017	-0.001	0.97	1.25	4.36
Nadelbäume (Hochlage)	169	nein	-1.439	1.268	-0.461	-0.007	0.086	0.99	0.59	2.95
Nadelbäume (Tal- und Hanglage)	281	nein	-0.687	1.081	-0.304	0.000	0.012	0.98	1.19	3.37

(From Heurich 2006)

2.3 Estimation of Forest Characteristics

Crown Radius (single trees):

Coniferous trees: **Deciduous trees:**



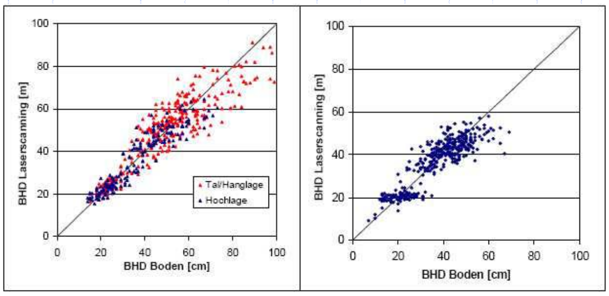
	n	ln	b_0	b_1	b_2	b_3	b_4	R^2	RMSE [m]	VK_{RMS} [%]
Laubbäume	278	ja	1.368	-0.043	0.000	0.005	0.001	0.46	0.79	17.3
Nadelbäume (Hochlage)	160	ja	1.124	-0.073	0.246	0.002	-0.027	0.31	0.32	12.5
Nadelbäume (Tal- und Hanglage)	93	nein	8.223	-0.375	0.183	0.006	-0.018	0.19	0.57	16.1

(From Heurich 2006)

2.3 Estimation of Forest Characteristics

DBH (single trees):

Coniferous trees: **Deciduous trees:**



	n	ln	b_0	b_1	b_2	b_3	b_4	R^2	RMSE [cm]	VK_{RMS} [%]
Laubbäume	368	ja	1.592	0.089	0.081	-0.003	-0.001	0.82	5.84	15.7
Nadelbäume (Hochlage)	171	ja	1.682	0.087	0.211	-0.001	-0.029	0.90	5.10	14.1
Nadelbäume (Tal- und Hanglage)	287	ja	1.684	0.074	0.075	0.000	-0.004	0.86	7.90	15.3

(From Heurich 2006)

2.3 Estimation of Forest Characteristics

Standard volume function for single trees:

$$V = \frac{\pi}{4} \cdot (DBHp)^2 \cdot Hp \cdot f$$

V = volume

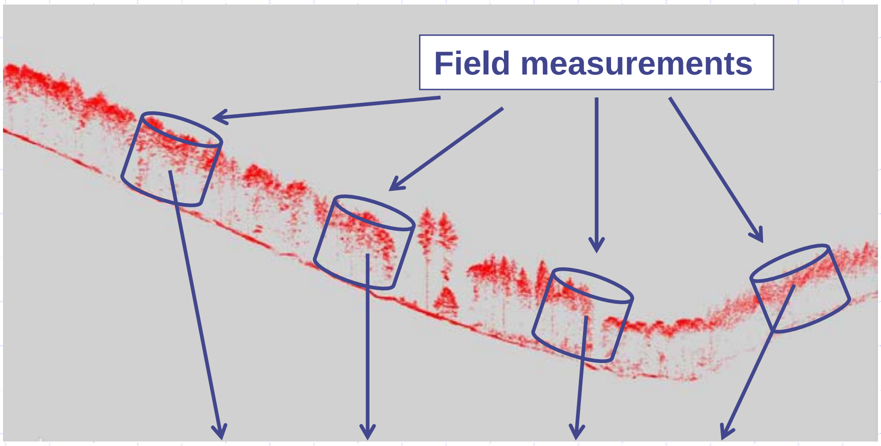
$DBHp$ = diameter of tree (predicted)

Hp = height of tree (predicted)

f = form factor

2.3 Estimation of Forest Characteristics

Plotwise approach:

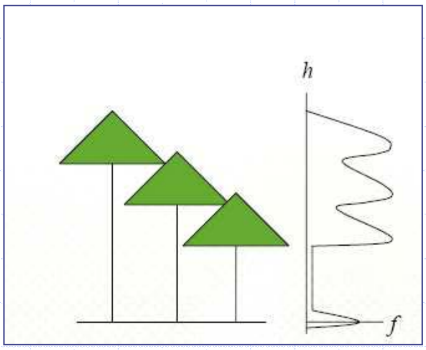


For each georeferenced plot properties from raw data points are extracted and are related to field plot data by regression analysis (→ calibration of regression models)

2.3 Estimation of Forest Characteristics

Properties which may be extracted from ALS data (Næsset 2003):

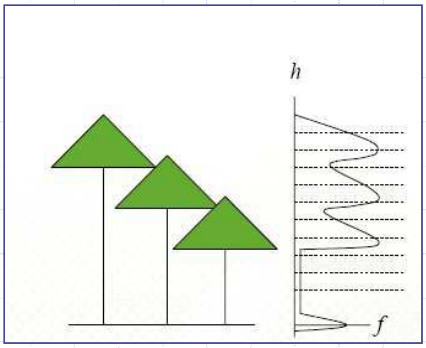
Height related variables:



Height-related variables:

Percentiles of the heights: hp0, hp10, …., hp90 , hcv, hmean …

Density related variables:



Densities of 10 vertical layers: d0, d1, …., d9
Proportions of points above percentiles of the heights for 0%, 10%, …90% to total number of points

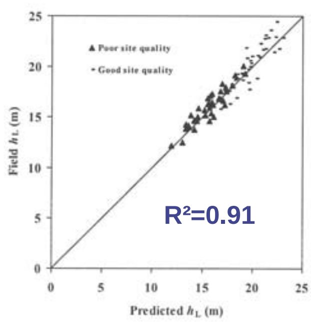
2.3 Estimation of Forest Characteristics

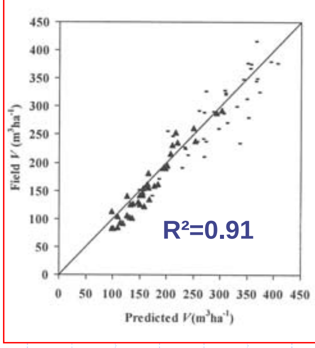
Results of study in Norway (Næsset 2002):

Stand Height:

Timber Volume:

Figure 1: Scatterplots of observed stand attributes as a function of attributes predicted using regression models estimated from the sample plot inventory





2.3 Estimation of Forest Characteristics

Forest Inventories (plotwise) proposed by (Næsset 2003), modified:

Stand boundaries

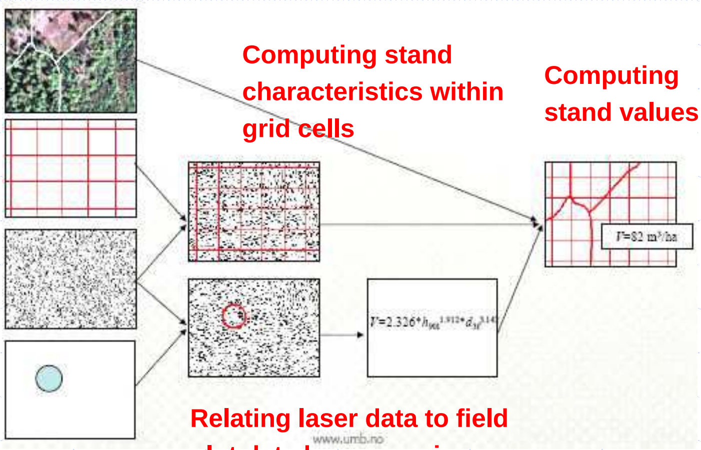
Study area subdivided into cells

Laserscanning data

Field measurements

Computing stand characteristics within grid cells

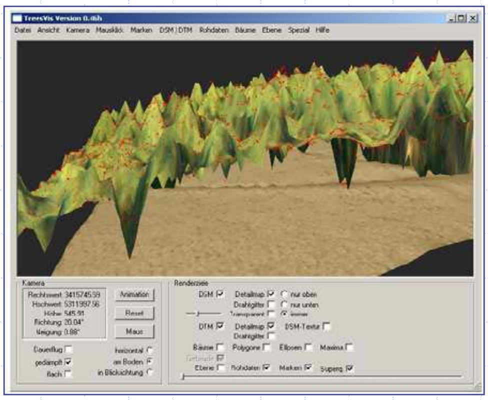
Computing stand values



Relating laser data to field plot data by regression analysis

3.0 Software Demonstration

TreesVis - processing, analyzing and visualisation of laserscanning data



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