NIR spectroscopy as a tool for in-field determination of log/biomass quality index in mountain forests – SLOPE project approach

Federico Prandi

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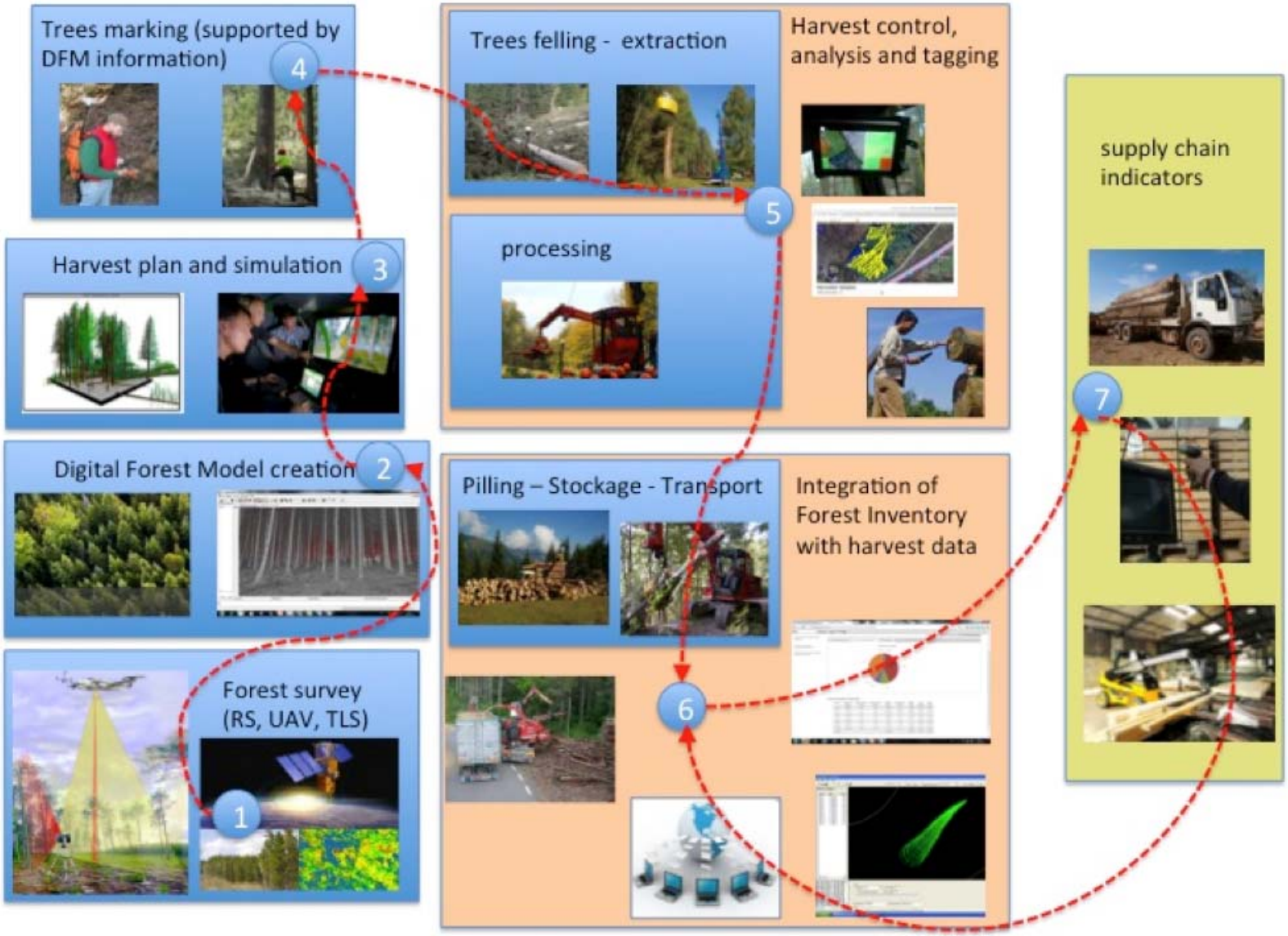
Before starting…

- The forest in mountains is peculiar, and very different than such of flat lands!!!
- Trees in mountains are (mostly) BIG…
- Big/old tree may be or superior quality, or “fuel wood”
- Trees from mountains might be of really high value
- We do support “PROPER LOG FOR PROPER USE”
- The quality of wood/log/tree is an issue!!!!!
- The quality of wood is not only external dimensions, taper and diameter…

SLOPE Project

Integrated proceSsing and controL systems fOr sustainable forest Production in mountain arEas



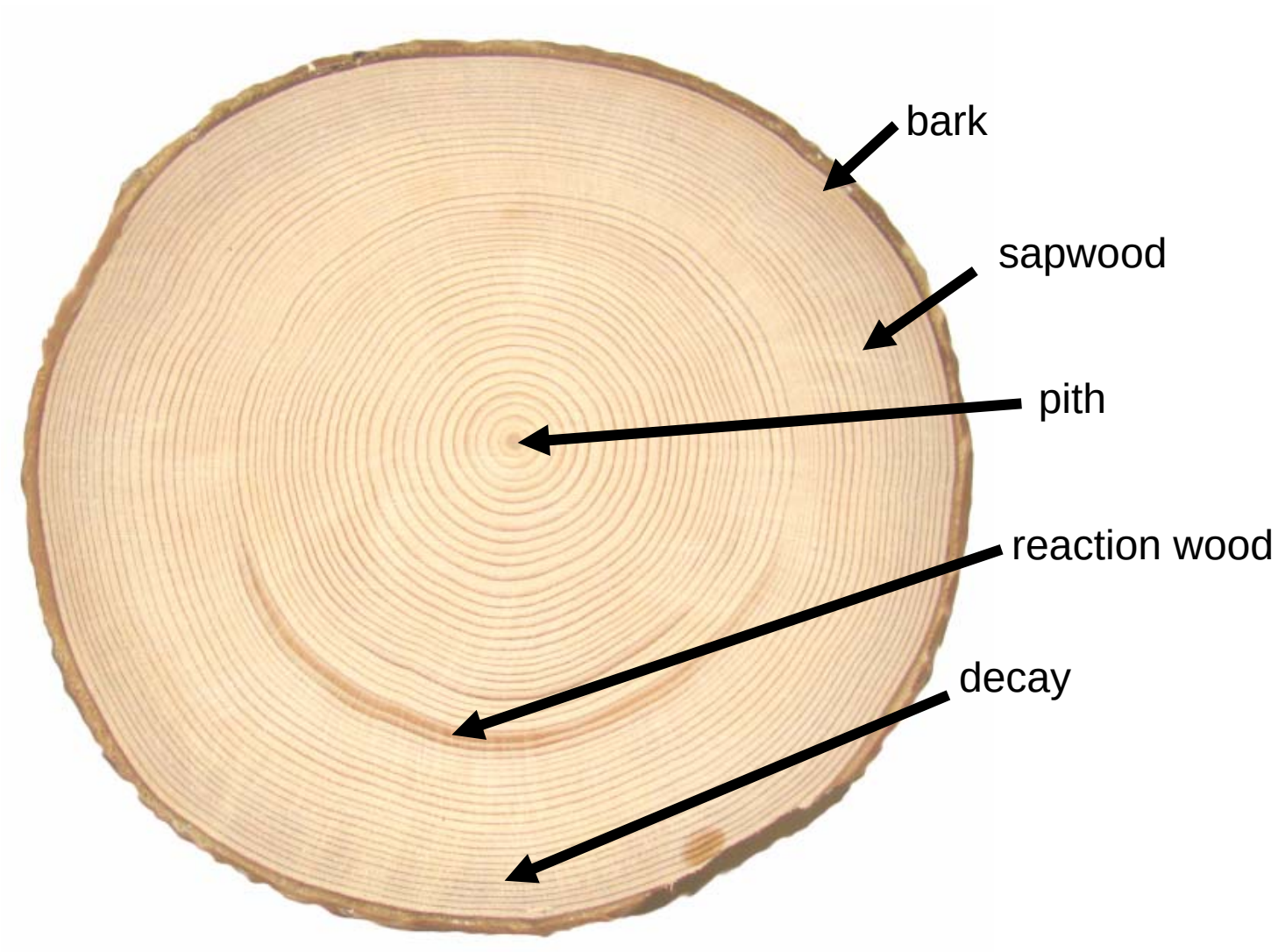
Wood might not be perfect…







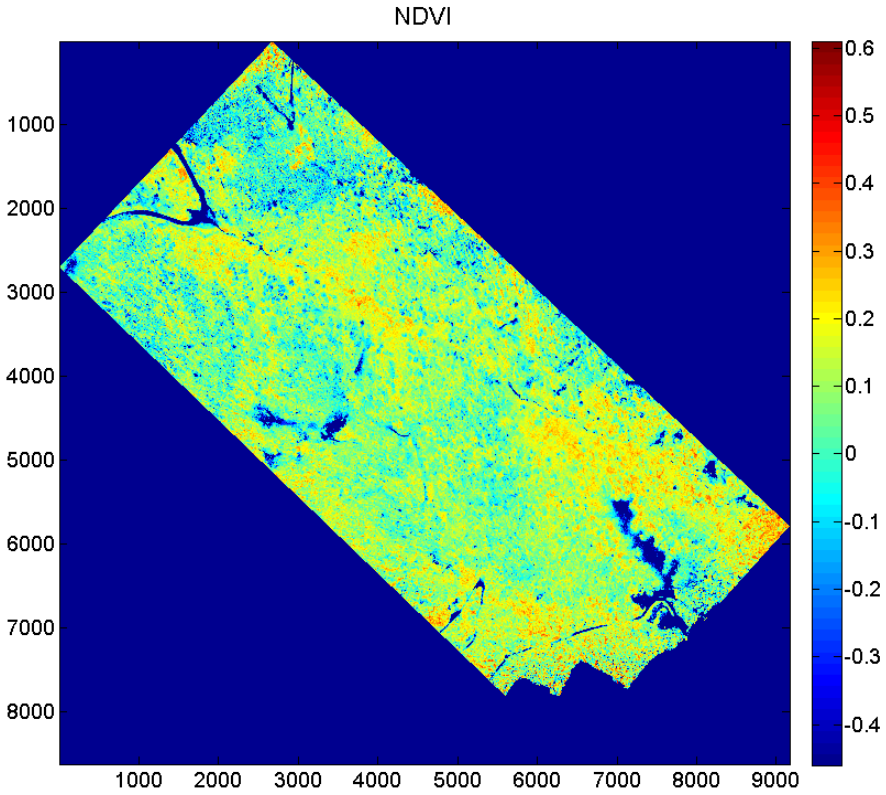
What can be detected?

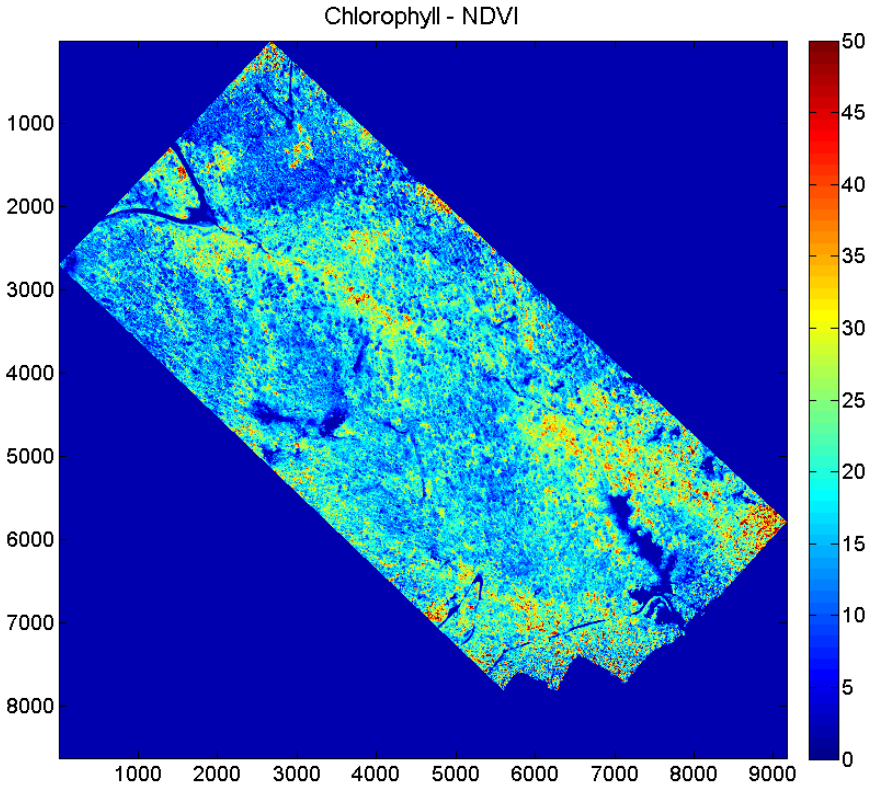


Outline

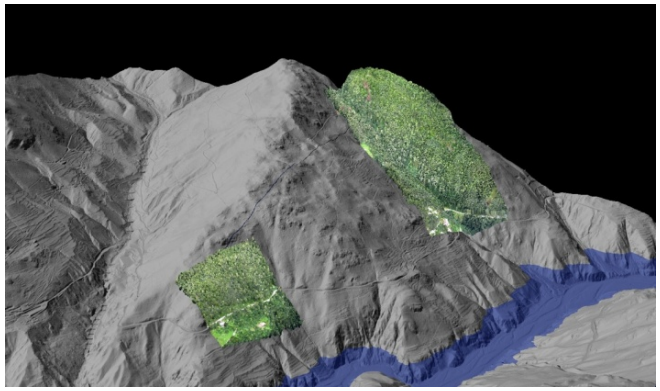
- **Current methods** for logs grading are based on **visual rating**, which is operator-dependant, time-consuming, subjective and no precise.
- The efficient grading should be conducted by means of **automatic measurement** of selected wood properties that are essential for the foreseen final product.
- The work presented here is a part of the SLOPE project, which is focused on **development of the integrated surveying system for mountainous forest**.
- The aim is to exploit the advantages of combined diagnostics techniques and multivariate data analysis for more reliable and rational assessment of the harvesting material.
- In this case usability of NIR spectroscopy for characterization of bio-resources along harvesting chain is investigated.

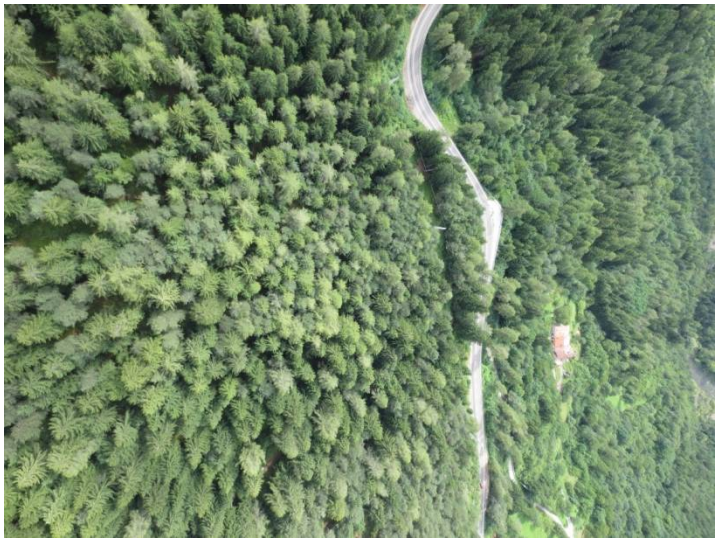
Forest survay - satalite



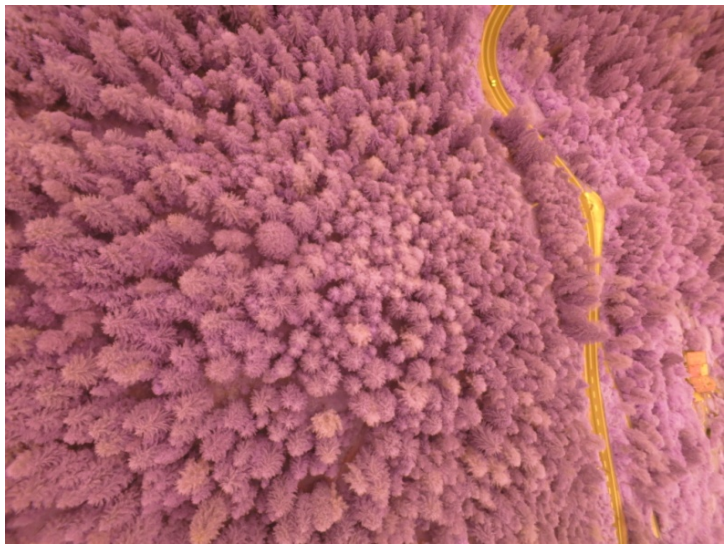


Forest survay - UAV



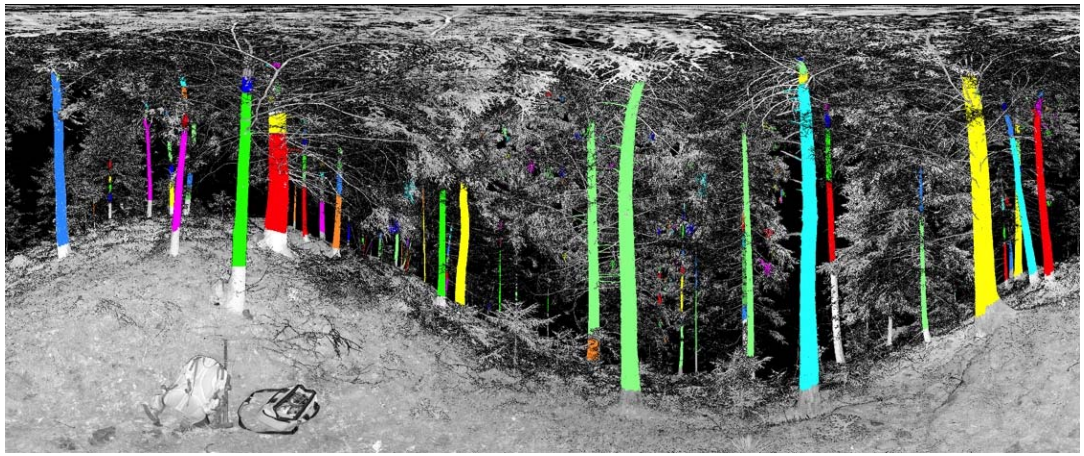


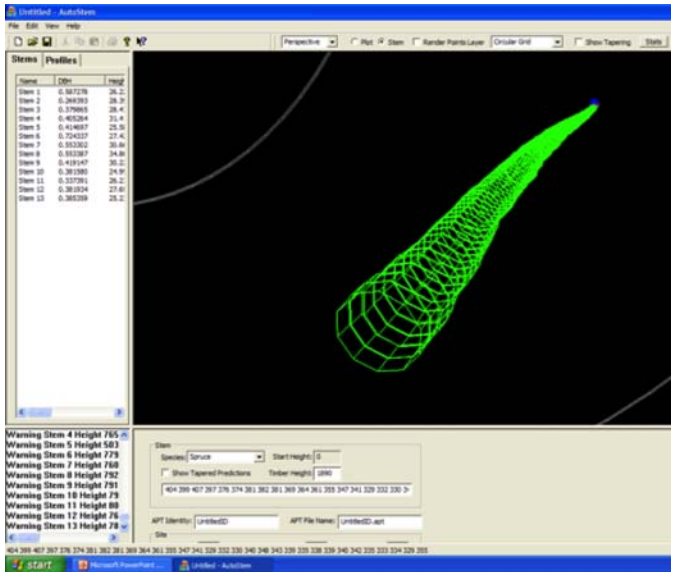
RGB UAV image



NIR UAV image

Digital Forest Models





Terrestrial Laser scanning point cloud and classification of stem

Tree marking









Selected tags

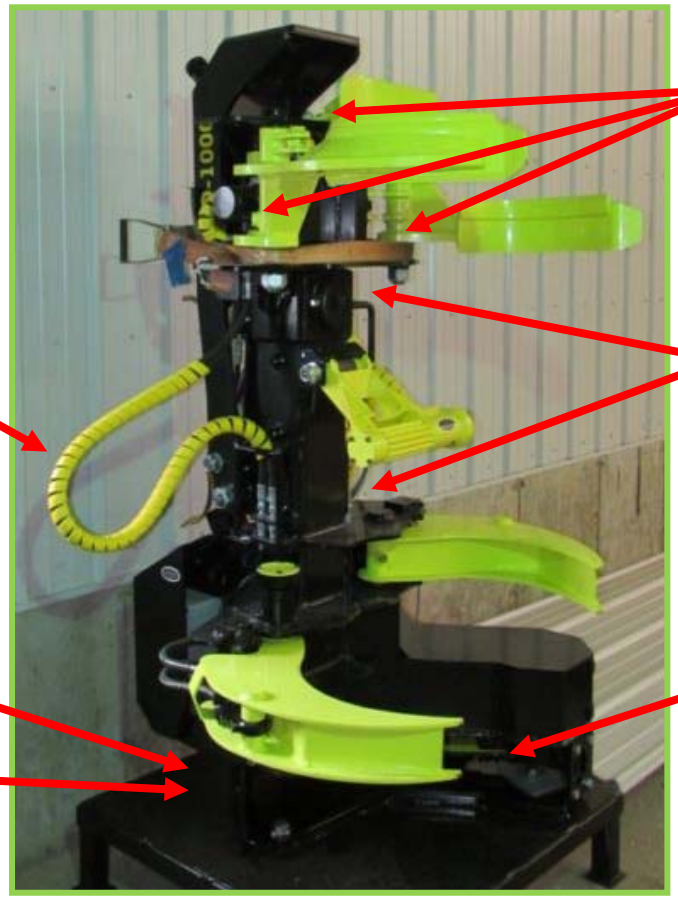
Processor head – sensors distribution

Other sensors: cameras on the stem of the head processor

Pressure sensors

RFID antenna

Pressure sensor



Load cells, microphones, pressure sensors on each knive

1 axis accelerometer + 3 axis accelerometer

Scan bar: encoder, NIR camera, camera, microphones, LEDs

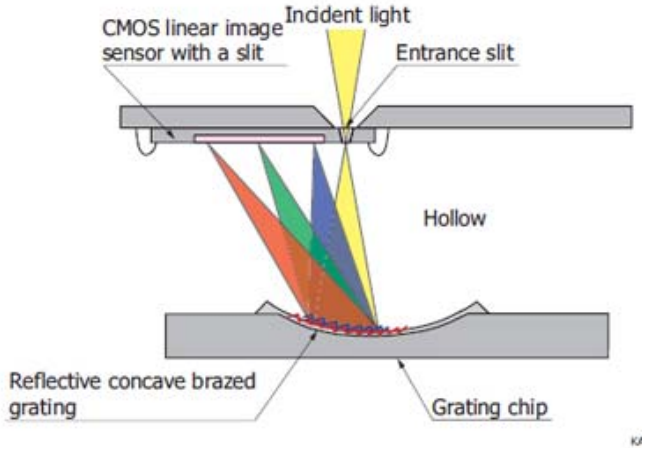
Multi-sensor model-based quality control

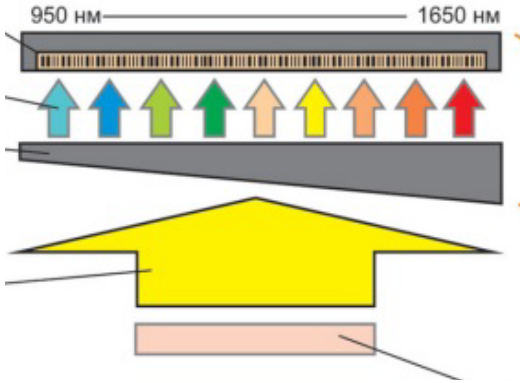
- **The goals are:**
  - to develop **an automated and real-time grading (optimization) system** for the forest production, in order to improve log/biomass segregation and to help develop a more efficient supply chain of mountain forest products
  - to design software solutions for continuous **update the pre-harvest inventory** procedures in the mountain areas
  - to provide data to **refine stand growth and yield models** for long-term silvicultural management

Selection of spectrometers

	cameras	FT-NIR	DA	LVF	DM	AOTF	MEMS
Spectral range	limited	full	limited	limited	full	limited	limited
Scanning time (s)	cont.	30	1	0.5	10	1	1
resolution	high	very high	high	limited	high	limited	limited
cost	N/A	high	middle	low	middle	middle	middle
Signal/noise	high	high	limited	limited	high	limited	limited
Calibrations transfer	limited	very good	good	good	very good	good	limited
Shock resistance	yes	no	yes	yes	no	yes	yes
Suitable for SLOPE	✓	✓	✓	✓	×	×	×

Spectrometers used (in-field)





Hamamatsu C12666MA

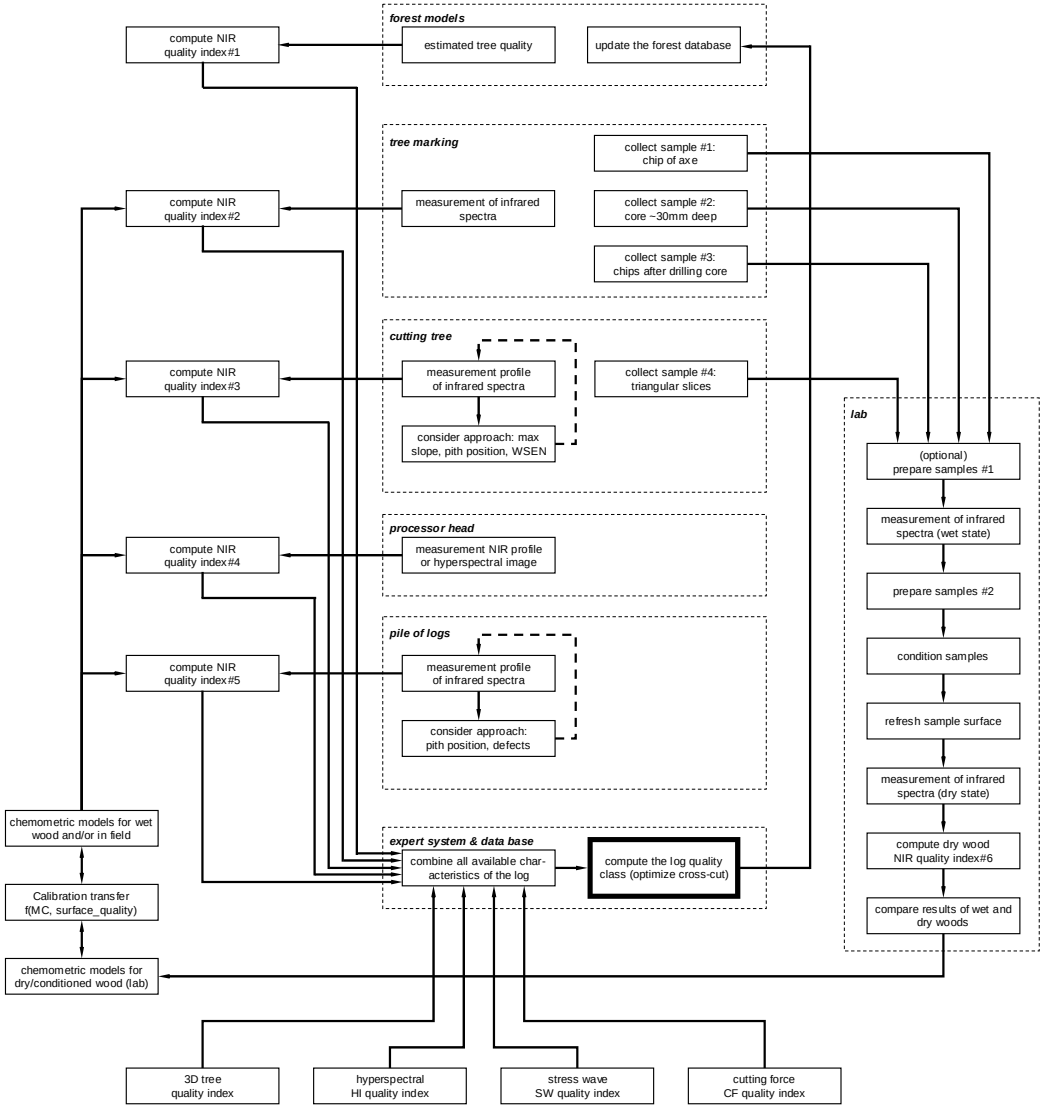
Hamamatsu C12666MA

MicroNIR

Potential for detection of defects

Instrument type		FT-NIR				dispersive				linear variable filter MicroNIR			
Moisture content of sample		wet		dry		wet		dry		wet		dry	
Surface of sample		smooth	rough	smooth	rough	smooth	rough	smooth	rough	smooth	rough	smooth	rough
Wood defects according to EN 1927-1:2008	knots	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	resin pocket	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	twist	×	×	×	×	×	×	×	×	×	×	×	×
	eccentric pith	×	×	×	×	×	×	×	×	×	×	×	×
	compression wood	✓	✓	✓	✓	✓	?	✓	✓	✓	?	✓	✓
	sweep	×	×	×	×	×	×	×	×	×	×	×	×
	taper	×	×	×	×	×	×	×	×	×	×	×	×
	shakes	×	×	×	×	×	×	×	×	×	×	×	×
	insects	?	×	✓	?	?	×	?	?	?	×	?	?
	dote	✓	?	✓	?	✓	?	✓	?	?	?	?	?
	rot	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	stain	✓	?	✓	✓	?	?	✓	?	?	?	✓	?
Other wood properties/characteristics	lignin	?	?	✓	✓	?	?	✓	✓	?	?	✓	?
	cellulose	?	?	✓	✓	?	?	✓	✓	?	?	✓	?
	hemicellulose	?	?	✓	✓	?	?	✓	✓	?	?	✓	?
	extractives	?	?	✓	✓	?	?	✓	✓	?	?	✓	?
	microfibryl angle	?	?	✓	✓	×	×	?	?	×	×	?	?
	calorific value	?	?	✓	✓	?	?	✓	?	?	?	✓	?
	heartwood/sapwood	✓	✓	✓	✓	✓	✓	?	?	✓	✓	?	?
	density	✓	✓	✓	✓	✓	?	✓	?	✓	?	✓	?
	mechanical properties	✓	✓	✓	✓	✓	?	✓	?	✓	?	✓	?
	moisture content	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	provenance	×	×	✓	?	×	×	×	×	×	×	×	×
	resonance wood	?	?	✓	?	?	?	?	?	?	?	?	?

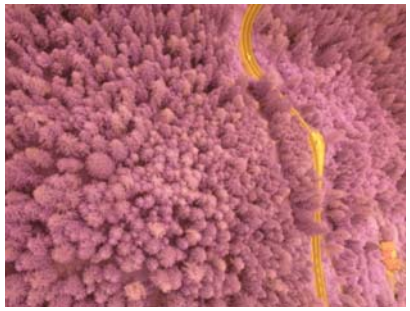
Protocol of NIR measurement sceanrio



Quality indexes

Forest modeling

NIR quality index #1 will be related directly to the health status, stress status and to the productivity capabilities of the tree(s) foreseen for harvest



Tree marking

Direct measurement of the NIR spectra by means of portable instruments (DA and LVF) will be performed in parallel to the tree marking operation. The spectra will be collected and stored for further analysis (NIR quality index #2)

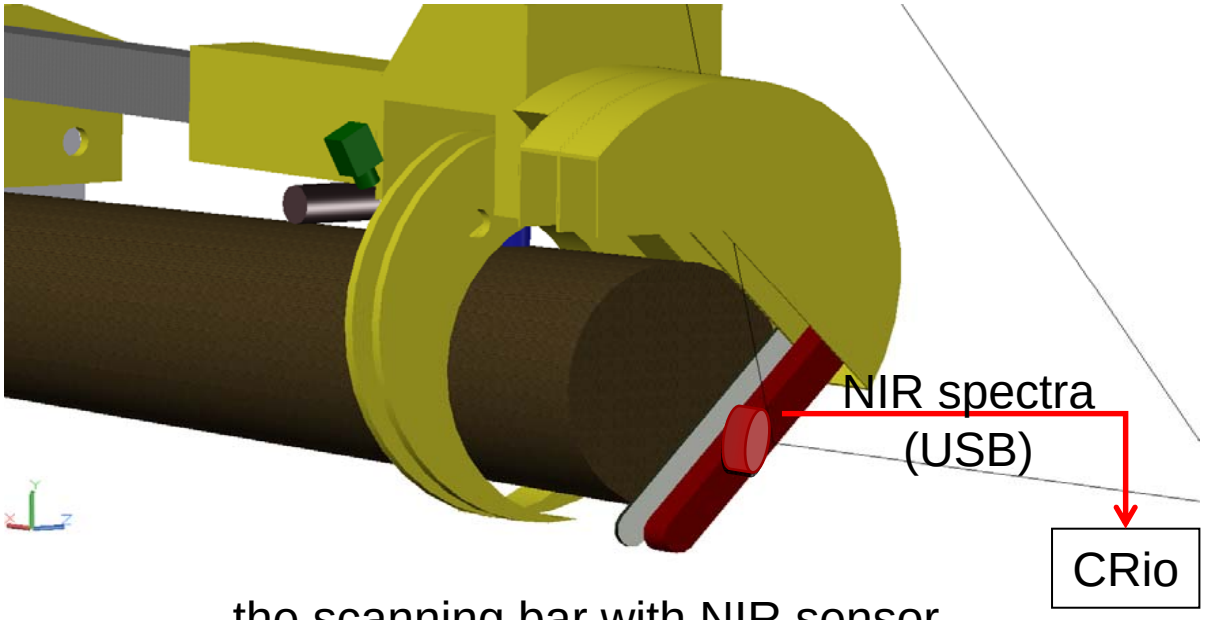
Cutting of tree

testing the possibility of collecting sample of wood in a form of the triangular slice being a part of the chock cut-out from the bottom of the log (NIR quality index #3)

Quality indexes

Processor head

NIR sensors will be integrated with the processor head (NIR quality index #4). All the sensors will be positioned on a lifting/lowering bar on the head processor near the cutting bar. The cutting bar will be activated in two modes: automatic and manual



the scanning bar with NIR sensor

Quality indexes

Pile of logs

The cross section of logs stored in piles is easily accessible for direct measurement. Such measurements will be repeated periodically in order to monitor the quality depreciation and to determine the most optimal scanning frequency. The result of measuring NIR spectra of logs stored in piles will be NIR quality index #5

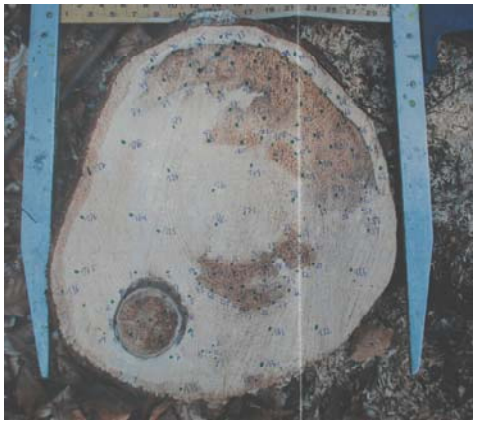
Laboratory

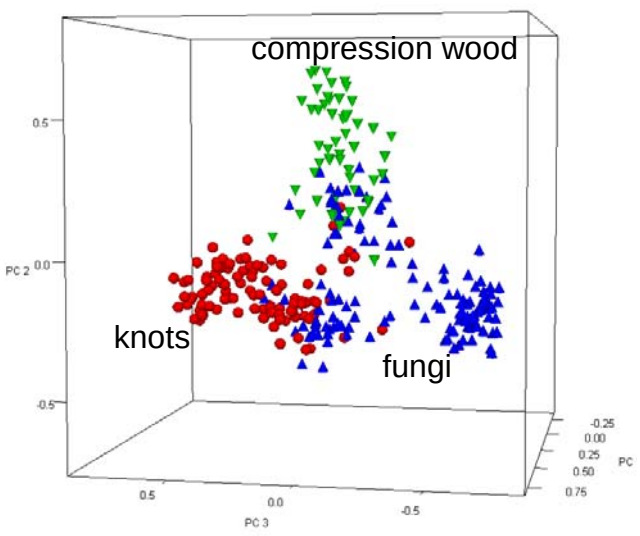
Samples collected in the forest will be measured instantaneously after arrival in the laboratory (at the wet state and with rough surface) by using the bench equipment (NIR quality index #6). However, samples will be conditioned afterward and their surfaces prepared (smoothed) in order to eliminate/minimize effects of the moisture variations and light scatter due to excessive roughness on the evaluation results of fresh samples.

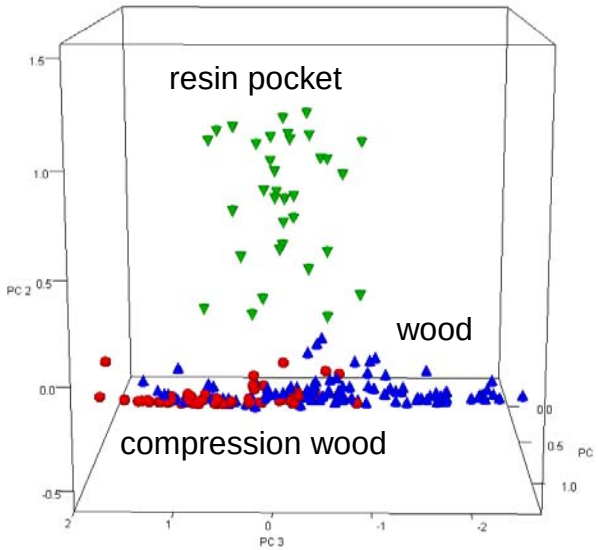
Quality indexes - calculations

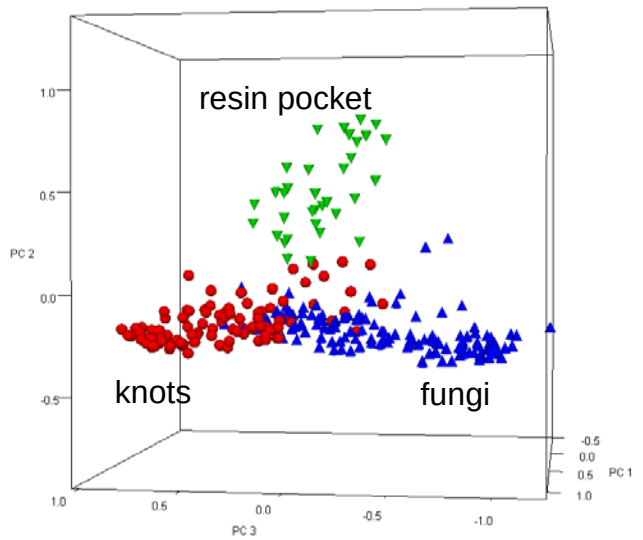
- PLS models for suitability indexes (0= no suitable, 1 – perfectly suitable) for different uses (structural, pulp, resonance etc.)
- PLS models for prediction of logs moisture, density, calorific value etc.
- Clasifications models for defects detection
- Classification models for quality class assignment (A,B,C,D)

First results – defects detection

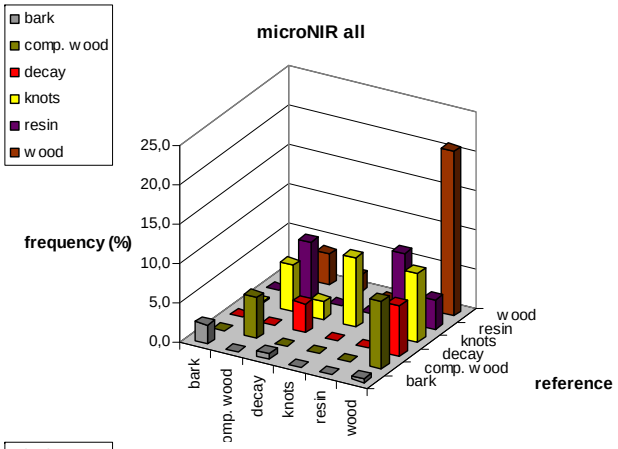


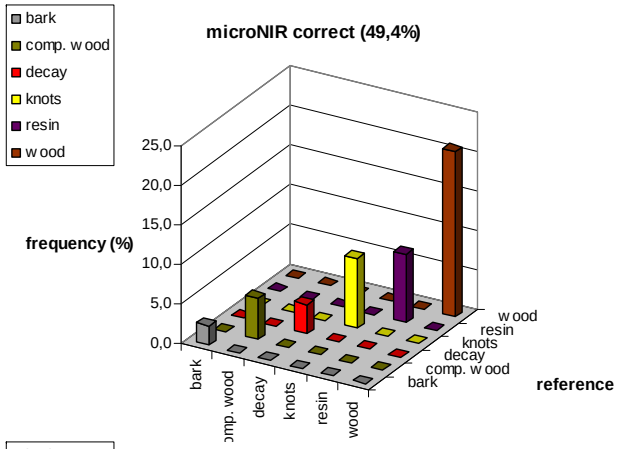


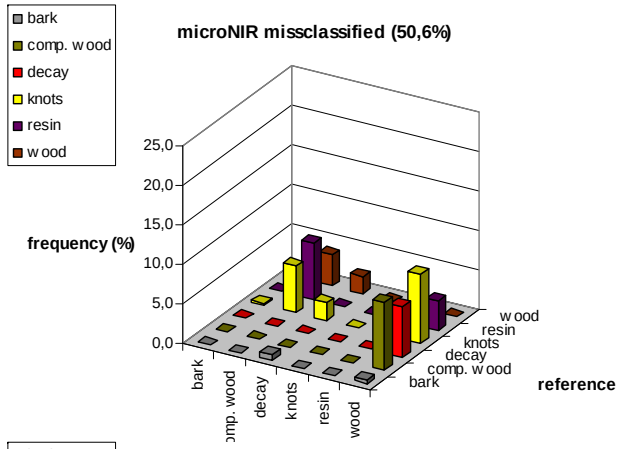


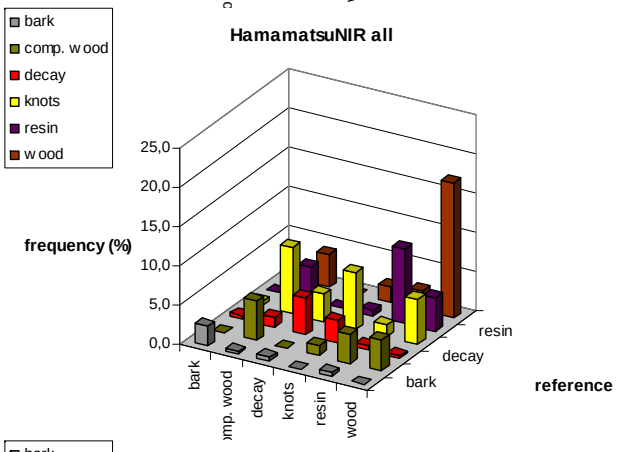


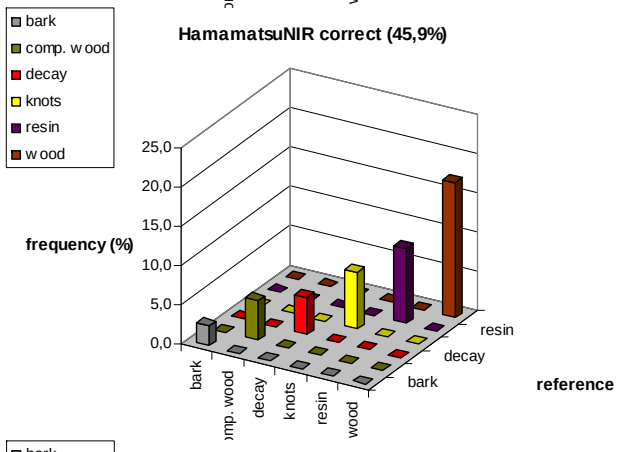
Lab measurement on wet rough samples, range of portable device 12500-5900cm^{-1}, 2nd derivative + VN

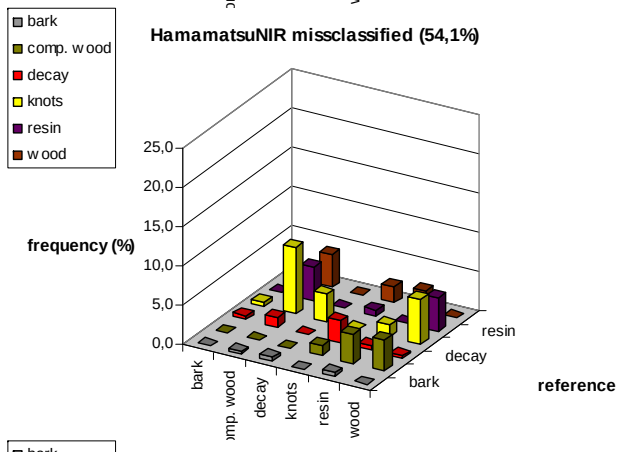

microNIR all
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted

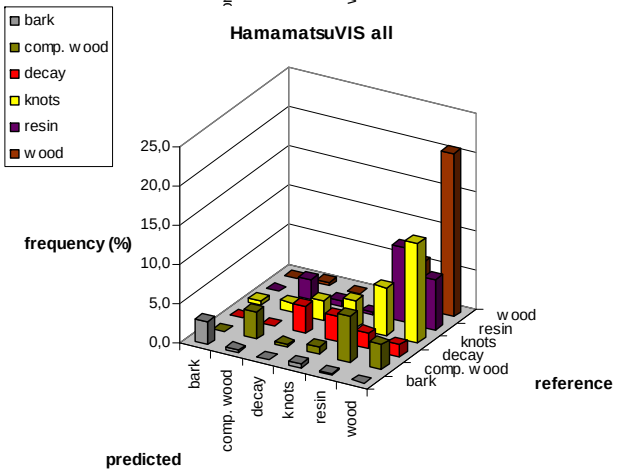

microNIR correct (49,4%)
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted

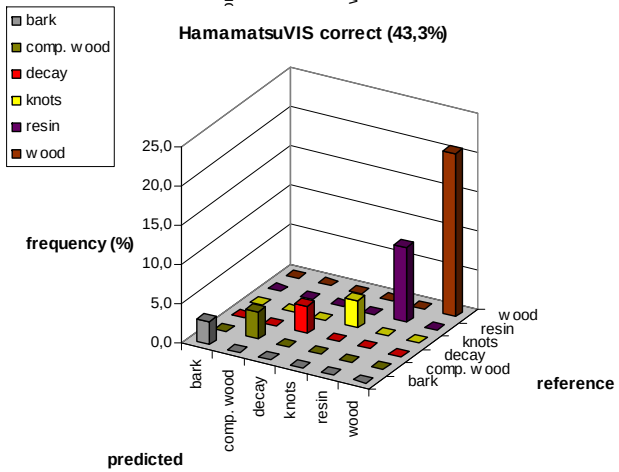

microNIR missclassified (50,6%)
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted

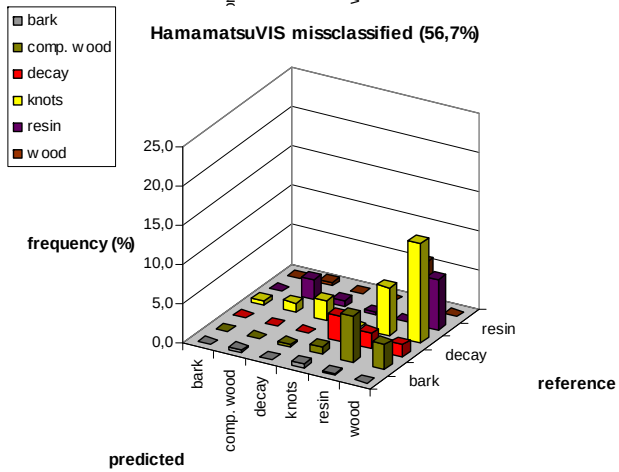

HamamatsuNIR all
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted


HamamatsuNIR correct (45,9%)
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted


HamamatsuNIR missclassified (54,1%)
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted


HamamatsuVIS all
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted


HamamatsuVIS correct (43,3%)
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted

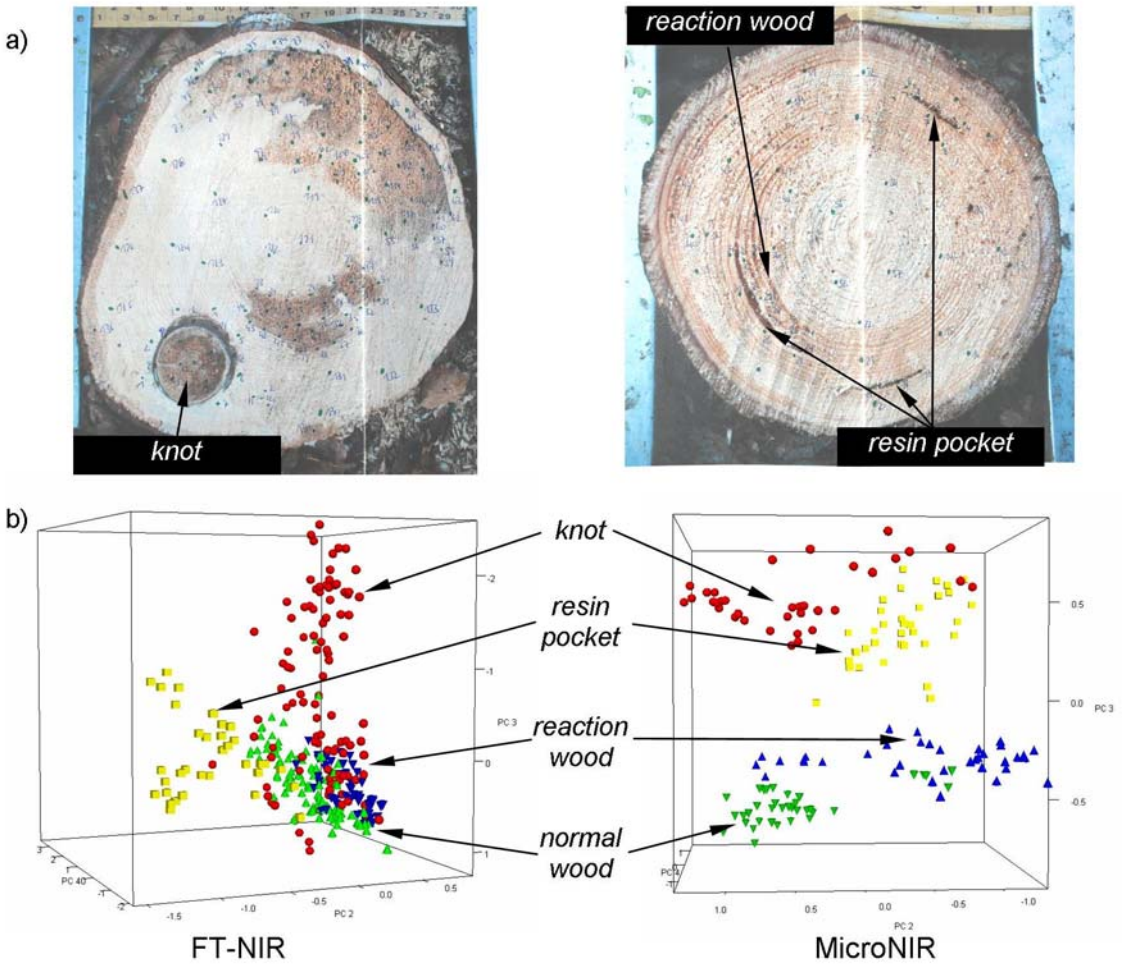

HamamatsuVIS missclassified (56,7%)
bark
comp. wood
decay
knots
resin
wood
frequency (%)
25,0
20,0
15,0
10,0
5,0
0,0
reference
predicted

a)

b)

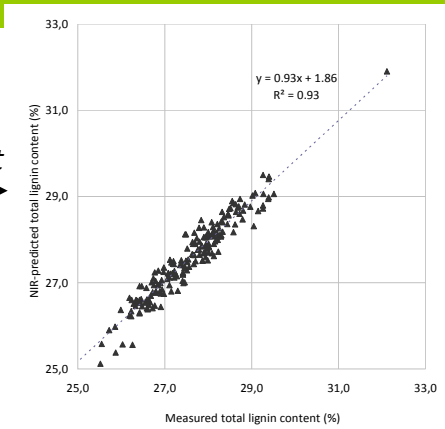
c)

d)


a)
knot
reaction wood
resin pocket
b)
knot
resin pocket
reaction wood
normal wood
FT-NIR
MicroNIR

measurement of samples with equipment #1

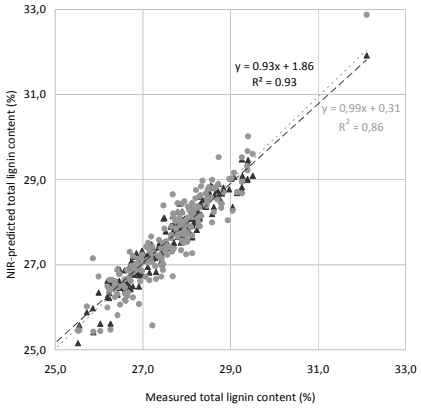
model #1 development



selection of calibration samples by Kennard Stone algorithm

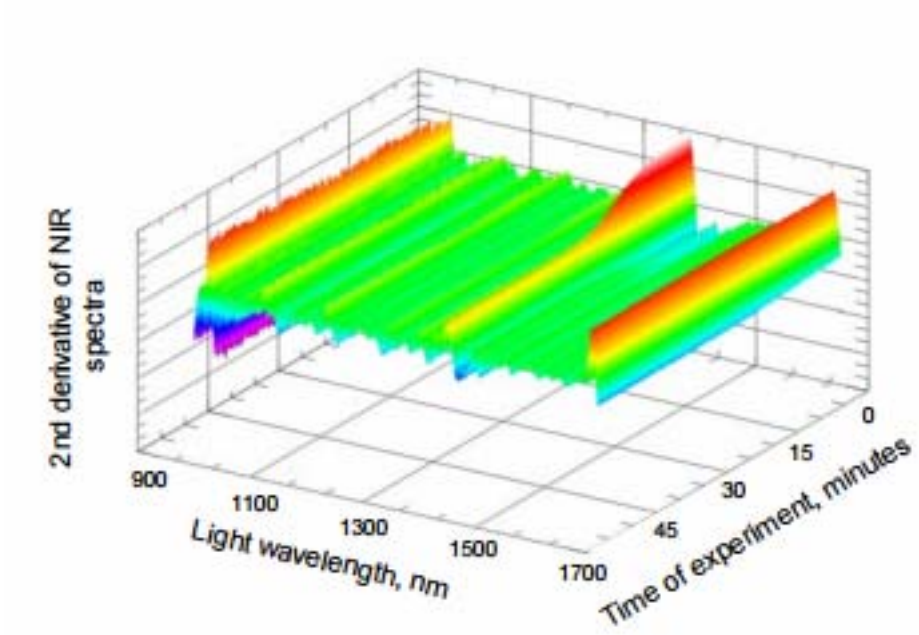
measurement of selected samples with equipment #2

calculation of transfer matrix

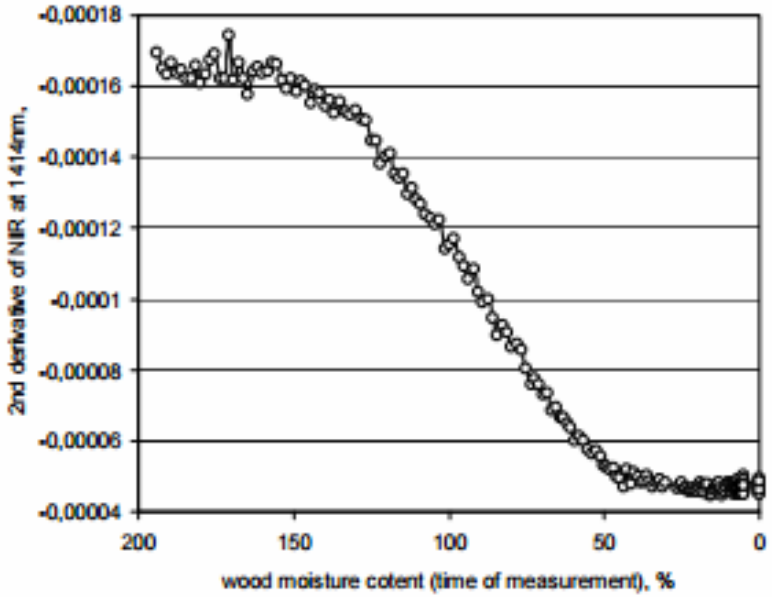


equipment #2 model development based on samples measured with instrument #1

Moisture estimation – portable NIR



Pattern of changes of the NIR spectra (2nd derivative) during natural drying test as measured with MicroNIR sensor

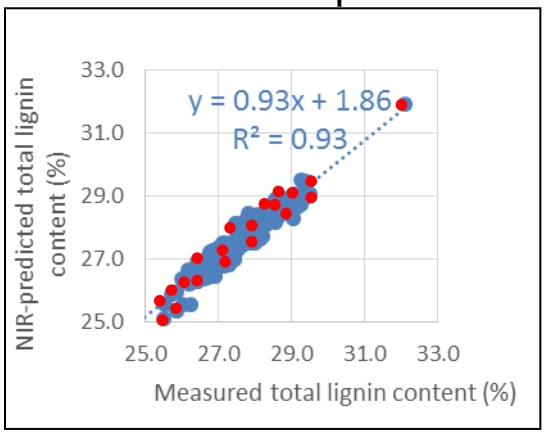


Relation between 2nd derivative of NIR spectra at 1414nm (7073cm^{-1}) and wood moisture content as measured during natural drying test

Calibration transfer

Measurements eg. 200 samples with laboratory equipment

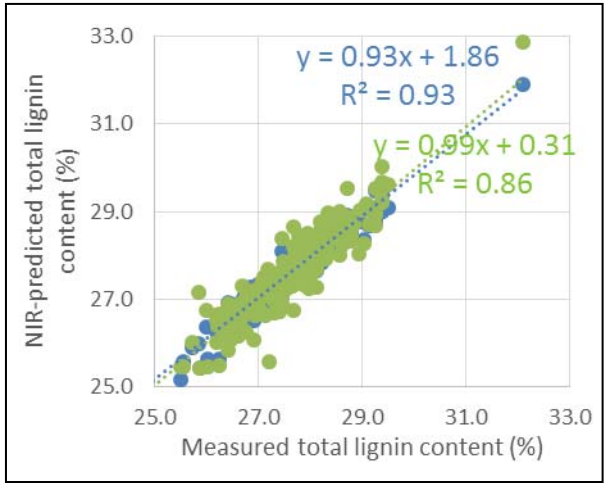
Model development



Measurements eg. 20 out of the 200 samples with field equipment

Calibration sample (20) selection using the Kennard Stone algorithm

Calibration transfer algorithm:
- Bias/slope correction
- Picewise direct standardization
- Wavelets
- …..



Field model development based on the 200 transfered samples of the laboratory equipment

Slide 27

miboe1 Please use here a picture of the micronir sensor!
Michael Böhm, 10/13/2015

Acknowledgment

This work has been conducted within the framework of the project SLOPE receiving funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under the NMP.2013.3.0-2 (Grant number 604129).

Thank you