NIR spectroscopy for
the rapid measurement
of wood properties

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Overview

- Description of NIR spectroscopy
- Application of NIR to whole-trees
- Application of NIR to lumber
- Application of NIR to short clears
- Application of NIR to cores
NIR spectrum of a typical wood sample

Log (1/Reflectance)

Wavelength (nm)

Bands arise from rotations, vibrations of bonds in molecules

C-H vibration throughout spectrum
Methodology

- Estimation of a parameter involves the following steps:
  - Collect spectra of calibration samples
  - Develop a calibration (regression)
    \( y = B_0 + X_1 B_1 + X_2 B_2 + \ldots + X_N B_N \)
  - Collect NIR spectra of test (or unknown) samples
  - Estimate parameter of interest for test set samples using the calibration
Partial least squares regression

**CALIBRATION SET**

- $n$ samples
- Absorbance
- Wavelength (nm)

- $p$ variables
- $n \times p$ matrix

**MEASURED PROPERTIES**

- $q$ variables
- $n \times q$ matrix

**TEST SET**

- Absorbance
- Wavelength (nm)

**REGRESSION COEFF.**

- Predicted MOE, MOR, MFASG, MC

**PREDICTED PROPERTIES**

- Measured MOE, MOR, MFASG, MC

**DECOMPOSE MATRICES**

**CALIBRATION MODEL**
Pulp yield calibration for Tasmania

Laboratory determined pulp yield (%) vs. NIR fitted pulp yield (%)

- n = 133
- 4 factors
- $R^2 = 0.88$
- SEC = 0.84

Pulp yield range = 45.6 to 57.1 %
Within-tree property variation

Microfibril Angle
Within-tree property variation

Extractives

Lignin

Hemicellulose

Cellulose
Application of NIR to whole-trees

- Many studies, since late 1980’s
- Pulp yield, cellulose, lignin, extractives
- Based on whole-tree composite chips
- Examination of within-tree variation of PY
- Studies have shown that breast height cores provide similar calibration statistics to composite chips for whole-tree properties
- = nondestructive estimation of whole-tree properties
Within-tree variation of pulp yield

- Little is known about the within-tree variation of pulp yield. NIR predictions of pulp yield can be used to obtain maps that show the variation.
Whole-tree chip versus core calibrations

• Core and whole-tree calibrations were similar for basic density, pentosans, specific cons and total lignin

• Core calibrations could be used to rank trees

• 1.30 m identified as the most suitable sampling height

Application of NIR to lumber

- Meder et al. (2003)
- 185 *P. radiata* cant centers scanned by NIR in mill scale trial
- Aim to ID corewood stiff enough to be graded as MGP 8 (lowest structural grade)
- MGP 8 worth $80/m³ more than non-structural
- Data from 409 boards available for regression
- Calibration $R^2 = 0.54$ (big logs)
- Calibration $R^2 = 0.57$ (small logs)
- Sufficient for economic segregation of cants
Bruker Matrix-F scanning a cant

Scanning speed approx. 2 m/s

Picture courtesy A. Thumm and R. Meder, Forest Research, New Zealand
Application of NIR to lumber

- Meder et al. (2003) cont.
- Based on stiffness, 50% of central boards could be upgraded to MGP 8
- Further calibration expected to increase percentage of upgraded boards
- Many upgraded boards were unstable
- Both stiffness and stability (twist) must be predicted for NIR to be useful for segregating radiata pine structural timber
- Calibration for twist investigated ($R^2 = 0.26$)
Application of NIR to short-clears

- Several studies reported, different species and approaches
  - Hoffmeyer and Pedersen (1995) *P. abies*
  - Gindl et al. (2001) *L. decidua*
  - Thumm and Meder (2001) *P. radiata*
  - Schimleck et al. (2001) *E. delegatensis*
    - Schimleck et al. (2001) *P. radiata*
  - Via et al. (2003) *P. palustris*
  - Kelley et al. (2004) 6 softwood species
  - Density, MOE and MOR examined
Measuring Mechanical Properties

Increment Core (SilviScan)

Bending Specimen (Instron)

NIR
Stiffness (Bending Specimens)

Calibration (313 spectra)

Prediction (156 spectra)

NIR-MOENIR-MOE

Instron-MOE

8 factors

$R^2=0.82$

SEC=0.4 Mpsi

R²=0.79

SEP=0.4 Mpsi
Strength (Bending Specimens)

Calibration (313 spectra)

- 8 factors
- $R^2=0.80$
- SEC=4 Kpsi

Prediction (156 spectra)

- $R^2=0.75$
- SEP=4 Kpsi
Application of NIR to cores

Properties examined:

- Tracheid length (FQA)
- Cellulose, sugars, lignin (wet chemistry)
- Air-dry density, MFA, stiffness, tracheid properties (SilviScan)

Radial strips cut from cores used but core surface OK for NIR spectroscopy
Georgia-wide calibrations

- *P. taeda* grown in 3 regions in Georgia
- Three sites selected as being representative of each region
- Selection based on site index
- Ten trees selected per site representing a range of breast height diameters
- Pith-bark breast height samples obtained
Georgia-wide calibrations

- Strong calibrations for density, MFA, stiffness and tracheid coarseness, length and wall thickness
- These calibrations performed well on the separate test set
- Strong calibrations for cellulose, lignin, glucan, arabinan, mannan and xylan
- Moderate prediction accuracy - possibly due to the small number of samples
MFA – 729 MSC treated spectra

Factors = 8
R² = 0.90
SEC = 2.33
SECV = 2.38
RPD = 3.11
Predicted MFA (225 spectra)

Measured MFA (degrees) vs. Predicted MFA (degrees)

Factors = 8

- $R^2 = 0.84$
- $SEP = 3.12$
- $RPD = 2.34$
What resolution??

- Increasing resolution = decrease in calibration accuracy
- Management of spectra becomes difficult owing to large number of spectra
- Fiber optic probes with a small spot size provides options
2 mm MFA calibration (4156 spectra)

8 Factors

$R^2 = 0.75$

SEC = 4.05

SECV = 4.10

RPD = 1.48
2 mm MFA prediction
2 mm MFA prediction

Distance from pith (mm)

MFA (deg)
Wood property calibrations – green versus dry wood

[Graph showing the relationship between wavelength (nm) and Log (1/R) for different wood properties: T - green, RL - green, T - dry, RL - dry.]
Stiffness (green wood spectra)

Calibration

SS2-stiffness vs. NIR-stiffness

5 factors
$R^2=0.88$
SEC=1.8 GPa

Prediction

$R^2=0.81$
SEP=3.0 GPa
Stiffness (dry wood spectra)

Calibration

NIR-stiffness vs. SS2-stiffness

- 6 factors
- $R^2 = 0.95$
- SEC = 1.1 GPa

Prediction

NIR-stiffness vs. SS2-stiffness

- $R^2 = 0.92$
- SEP = 1.9 GPa
NIRVANA – Near Infrared Visual & Automated Numerical Analysis

- Automated spectra collection
- High resolution video camera
- Real time property predictions
- Ideal for process monitoring & QC applications
MOE Variation

MOE (GPa) vs. Core Length (mm)
Conclusions – NIR spectroscopy

- Determination of within-tree variation
- Estimation of whole-tree properties
- Applicable to milled wood, short-clears, increment cores
- Automatic scanning of cores possible
- Important to improve resolution
- Green wood can be examined