HYPERFOREST
Combining LiDAR and hyperspectral data to support forest management

Pieter Kempeneers (VITO)
Frieke Van Coillie (UG)
Kris Vandekerckhove (INBO)

F. Morsdorf (RSL)
Renato Cifuentes (KUL)
Franz Kai Ronellenfitsch (GLI)
Remote sensing in support of forest management

Hyperspectral

+ Tree species mapping, biophysical and chemical properties
- Poor tree delineation, forest structure

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Objectives

Hyperspectral and Lidar data fusion

- Improved hyperspectral pre-processing
- Improved forest parameter retrieval
- Improved tree species mapping
Study area

Wijnendale forest

Kersselaerspleyn

Aelmoeseneie forest
Study area

Kersselaerspleyn

- Low structural complexity
- Homogeneous old beech stands
- Limited admixture of oak
Study area

Wijnendale forest
- **Medium structural complexity**
- Mixed oak forest with maple, beech, larch, hazel, …
Study area

Aelmoeseneie forest

- **High structural complexity**
- Mixed oak, beech, ash and larch stands
- Rich understorey
Data

Field measurements (FieldMap technology)

Full dendrometric inventories
- Tree position
- Species
- DBH all trees > 5 cm diameter
- Tree heights all trees upper canopy

Canopy gaps
- Hemispheric photos

Tree vitality
- On a selection of trees: evaluation of discoloration and leaf loss (international methodology for vitality evaluation).
Data

» Field measurements (FieldMap technology)

Full dendrometric inventories
- Tree position
- Species
- DBH all trees > 5 cm diameter
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Tree vitality
- On a selection of trees: evaluation of discoloration and leaf loss (international methodology for vitality evaluation).
Data

» Field measurements (FieldMap technology)

» LiDAR

» Terrestrial TLS (FARO LS 880HE; range: 70 m; wavelength: 785 nm)
Data

- Field measurements (FieldMap technology)
- LiDAR
  - Terrestrial TLS (FARO LS 880HE; range: 70 m; wavelength: 785 nm)
  - Airborne ALS (Riegl LMS Q560 full waveform; wavelength: 1560 nm; point density > 10 points/m²)
Data

» Field measurements (FieldMap technology)

» LiDAR

  » Terrestrial TLS (FARO LS 880HE; range: 70 m; wavelength: 785 nm)
  » Airborne ALS (Riegl LMS Q560 full waveform; wavelength: 1560 nm; point density > 10 points/m²)

» Hyperspectral data

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spectral resolution</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASI</td>
<td>96 bands (368-1052 nm)</td>
<td>1 m</td>
</tr>
<tr>
<td>AHS</td>
<td>63 bands (452-2552 nm)</td>
<td>5 m</td>
</tr>
<tr>
<td>APEX</td>
<td>301 bands (375-2500 nm)</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>

Apex - Kersselaerspleyn
Work packages

- **Data acquisition**
  - WP2: LiDAR
  - WP1.2: Hyperspectral imagery
  - WP1.1: Field data collection

- **Preprocessing**
  - WP2: DSM
  - WP3.1: Canopy structure
  - WP3.2: Atm. cor BRDF cor.

- **Value added product generation**
  - WP4: Level 1
    - Radiometric cal. geom. cor.
  - WP5: Classification Quantitative RS
    - Species structure vitality
  - WP6: Level 3

- **Output**
  - WP7: Reports
  - WP5: Maps

Forest products: species maps, vitality reports,...
Contribution of vegetation structure on spectral signature

- Full scene
- 50% leaves thinned
- Lower canopy only
- Upper canopy only

Graph showing reflectance vs. wavelength (nm) for different conditions.
Advanced HS image pre-processing

- Improving Dense Dark Vegetation mask for visibility estimation
- Additionally, shadow detection algorithm
Advanced HS image pre-processing

» Spectral smoothing
Advanced HS image pre-processing

- Improving geometric correction with LiDAR-based DSM

Geometric correction using LiDAR-based DSM

Geometric correction using traditional DTM
Advanced HS image pre-processing

» Improving BRDF correction
Advanced HS image pre-processing

» Improving BRDF correction
Advanced HS image pre-processing

» HS image denoising
Advanced HS image pre-processing

» HS image denoising
Advanced HS image pre-processing

» HS image denoising

Band 100 original

Band 100 denoised
Advanced HS image pre-processing

» HS image denoising
Advanced HS image pre-processing

» HS image denoising
Advanced HS image pre-processing

» HS image denoising
Improved forest canopy parameter retrieval

Canopy height model

Height profiles

[Image of canopy height model and height profiles]
Improved forest canopy parameter retrieval

Fractional vegetation cover

Height profiles
Improved forest canopy parameter retrieval

DART – Radiative transfer model

Spectral Profile

Reflectance

Wavelength

VITO

vision on technology
Improved forest canopy parameter retrieval

LAI proxy

Leaf chlorophyll content

LAI Proxy - Aelmoseneiebos

Leaf Chlorophyll content (μg/cm²)
Improved tree species mapping

Tree height distribution

Hyperspectral data (quicklook)

Insufficient information for accurate tree species classification
### Improved tree species mapping

#### Accuracy assessment: no data fusion

<table>
<thead>
<tr>
<th>Species</th>
<th>Tree heights</th>
<th>Tree structure</th>
<th>Hyperspectral</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VHM</td>
<td>PHV</td>
<td>APEX</td>
</tr>
<tr>
<td>PA</td>
<td>PA</td>
<td>UA</td>
<td>PA</td>
</tr>
<tr>
<td>Beech</td>
<td>55</td>
<td>35</td>
<td>83</td>
</tr>
<tr>
<td>Ash</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Larch</td>
<td>13</td>
<td>43</td>
<td>23</td>
</tr>
<tr>
<td>Poplar</td>
<td>68</td>
<td>61</td>
<td>81</td>
</tr>
<tr>
<td>Copper beech</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Chestnut</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oak</td>
<td>37</td>
<td>34</td>
<td>64</td>
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<tr>
<td>Overall acc.</td>
<td>43</td>
<td>63</td>
<td>82</td>
</tr>
<tr>
<td>Kappa</td>
<td>0.24</td>
<td>0.50</td>
<td>0.76</td>
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</table>
Improved tree species mapping

Accuracy assessment: data fusion

<table>
<thead>
<tr>
<th>Species</th>
<th>Decision fusion</th>
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<tbody>
<tr>
<td>PA</td>
<td>UA</td>
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<tr>
<td>Beech</td>
<td>96</td>
</tr>
<tr>
<td>Ash</td>
<td>91</td>
</tr>
<tr>
<td>Larch</td>
<td>99</td>
</tr>
<tr>
<td>Poplar</td>
<td>97</td>
</tr>
<tr>
<td>Copper beech</td>
<td>99</td>
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<tr>
<td>Chestnut</td>
<td>97</td>
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<td>Oak</td>
<td>95</td>
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<tr>
<td>Overall acc.</td>
<td></td>
</tr>
<tr>
<td>Kappa</td>
<td></td>
</tr>
</tbody>
</table>
# Forest vitality assessment with HS data

## Chlorophyll indices

<table>
<thead>
<tr>
<th>Index no.</th>
<th>Formula</th>
<th>Alias</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$R_{710}/R_{760}$</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>2</td>
<td>$(R_{710}+R_{730})/(R_{710}+R_{705})$</td>
<td>NDI</td>
<td>Gitelson &amp; Merzlyak 1994</td>
</tr>
<tr>
<td>3</td>
<td>$R_{500}/R_{580}$</td>
<td>DVI</td>
<td>Jordan 1969</td>
</tr>
<tr>
<td>4</td>
<td>$(R_{780}+R_{710})/(R_{780}+R_{680})$</td>
<td>/</td>
<td>Maccioni et al. 2001</td>
</tr>
<tr>
<td>5</td>
<td>$(R_{750}+R_{705})/(R_{750}+R_{705}+2*R_{445})$</td>
<td>mND705</td>
<td>Sims &amp; Gamon 2002</td>
</tr>
<tr>
<td>6</td>
<td>$(R_{720}+R_{445})/(R_{705}+R_{445})$</td>
<td>mSR705</td>
<td>Vogelman et al. 1993</td>
</tr>
<tr>
<td>7</td>
<td>$R_{540}/R_{750}$</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>8</td>
<td>$(R_{734}+R_{741})/(R_{715}+R_{720})$</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>9</td>
<td>$(R_{734}+R_{741})/(R_{715}+R_{720})$</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>10</td>
<td>$R_{665}/R_{820}$</td>
<td>CRT1</td>
<td>Carter et al. 1996</td>
</tr>
<tr>
<td>11</td>
<td>$R_{680}/R_{660}$</td>
<td>CRT2</td>
<td>/</td>
</tr>
<tr>
<td>12</td>
<td>$(R_{500}+R_{680})/(R_{500}+R_{680})$</td>
<td>RVI</td>
<td>Hilker et al. 2009</td>
</tr>
<tr>
<td>13</td>
<td>$[(1/R_2)-(1/R_0)]/[(1/R_2)+(1/R_0)]$</td>
<td>CHL1</td>
<td>/</td>
</tr>
<tr>
<td>14</td>
<td>$[(R_{700}+R_{660})-0.2*(R_{700}-R_{550})]*R_{700}/R_{700}$</td>
<td>Meari</td>
<td>Haboudane et al. 2002</td>
</tr>
<tr>
<td>15</td>
<td>$3*[(R_{700}-R_{445})-0.2*(R_{700}-R_{550})]*R_{700}/R_{700}$</td>
<td>Tcari</td>
<td>/</td>
</tr>
<tr>
<td>16</td>
<td>$(R_{700}+R_{550})/(R_{550}+R_{510})$</td>
<td>NDVI</td>
<td>Gamon et al. 1992</td>
</tr>
</tbody>
</table>

## Water indices

<table>
<thead>
<tr>
<th>Index no.</th>
<th>Formula</th>
<th>Alias</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>$(R_{610}+R_{645})/(R_{610}+R_{645})$</td>
<td>NDII</td>
<td>White et al. 2007</td>
</tr>
<tr>
<td>18</td>
<td>$(R_{660}+R_{1241})/(R_{660}+R_{1241})$</td>
<td>NDWI</td>
<td>Eitel et al. 2006</td>
</tr>
<tr>
<td>19</td>
<td>$R_{1500}/R_{381}$</td>
<td>MSI</td>
<td>Merton 1998</td>
</tr>
</tbody>
</table>

## Legend

- **Buiten drempelwaarden**
- **Licht tot sterk beschadigde bomen**
- **Onbeslist**
- **Gezonde bomen**
Project output


- P. Kempeneers, F. Devriendt, F. Van Coillie, K. Vandekerkhove, F. Morsdorf, Combining LiDAR and hyperspectral remote sensing data to improve information extraction for forestry, Silvilaser September 16-19, 2012, Vancouver, Canada
- Somers B., Pieter Kempeneers, Flore Devriendt, Friekje Vancoillie and Kris Vandekerkhove, APEX and LiDAR remote sensing supporting fine-scale forest management, BruHyp Airborne Imaging Spectroscopy Workshop 2012 – Bruges, Belgium, 4 september 2012
- P. Kempeneers, K. Vandekerkhove, F. Devriendt, F. Van Coillie, Propagation of shadow effects on typical remote sensing applications in forestry, proceedings Whispers 2013, June 2013, Gainsville USA.
- P. Kempeneers, F. Van Coillie, F. Devriendt, W. Liao, K. Vandekerkhove, Tree species mapping by combining hyperspectral with LiDAR data, conference proceedings IGARSS 2014, July 2014, Quebec, Canada
- P. Kempeneers, F. Van Coillie, W. Liao, K. Vandekerkhove, Data fusion of airborne LiDAR and hyperspectral data for tree species mapping, conference proceedings Forestsat 2014, November 2014, Riva del Garda, Italy
Project output

In conclusion

HYPERFOREST project showed potential of LiDAR and HS data for forestry applications

» HS image pre-processing
» Forest parameter retrieval
» Species mapping and forest health assessment