Spectral-structural interactions at fine-scales

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Outline

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   - Project outline and objectives
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   - Study area
   - Airborne and field data
   - Building virtual scenes
   - DIRSIG simulation

3. Results
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   - Future work
Assessing the impact of sub-pixel vegetation structure on imaging spectroscopy
Introduction

Project outline and objectives

How large is a $60 \times 60$ m pixel?

Photograph courtesy of Howard Bruce Campbell (AirplaneHome.com)
Objective 1: Assess how leaf area index (LAI) affects the spectral response on a per-pixel basis.

- Determine a stable and valid LAI measuring protocol which could be used to collect ground truth data;
- Evaluate a range of vegetation indices (VIs), extracted from narrow-band imaging spectroscopy data, to estimate LAI; and
- Assess the scalability of selected narrow-band VIs from 20 m AVIRIS to 60 m HyspIRI data sets.
**Objective 2**: Assess how sub-pixel variations in tree canopy height, forest cover, forest clustering, and other forest inventory variables affect the spectral response on a per-pixel basis.

**Objective 3**: Evaluate how the sub-pixel structural variation interacts with the HyspIRI systems response characteristics, most notably in terms of the point spread function (PSF).
Introduction

DIRSIG simulation - overview

DIRSIG = Digital Imaging and Remote Sensing Image Generation Model
Under development for 20+ years at Rochester Institute of Technology

An overview of the general DIRSIG capabilities

http://dirsig.org

DIRSIG simulation - overview

http://dirsig.org
Methods

Study area

The National Ecological Observatory Network (NEON), Pacific Southwest Domain (D17)

1. San Joaquin Experimental Range (SJER, core site)
2. Soaproot Saddle (SOAP, relocatable site)
San Joaquin Experimental Range:
- Field data collected in 12 AOP plots during June 9 - 14, 2013

plot 36

plot 116

AOP: Airborne Observation Platform
Methods
Field collection

Soaproot Saddle:
- Field data collected in 8 AOP plots during June 16 - 20, 2013
Methods

Field collection

Measurements at each spot within 80 m × 80 m plot:

1. LAI (AccuPAR LP-80)
2. Terrestrial laser scanning (SICK LMS-151)
3. Spectra (SVC HR-1024i)
4. Hemispherical photos
5. GPS position
Methods

Airborne collection

Airborne data were collected by

1. NASA’s “classic” Airborne Visible Near-Infrared Imaging Spectrometer (AVIRIS-C),
2. NEON’s high-resolution imaging spectrometer (NIS), and
3. NEON’s small-footprint waveform-recording LiDAR

②③: http://data.neoninc.org
Methods

Building virtual scenes

Three plots were selected to build virtual scene

Plot 116
Plot 299
Plot 143
Methods
Building virtual scenes

NEON’s LiDAR products

DSM

DTM

DHM
Methods

Building virtual scenes

Leaf spectral samples
Methods

Building virtual scenes

Virtual scene layout

180 m

60 m

80 m
Methods
Building virtual scenes

The side view of plot 116 scene
Methods
Simulate AVIRIS data

Verify the plot 116 scene by simulating NEON’s high-resolution spectrometer (NIS)
Methods
Simulate AVIRIS data

Verify the model by the plot 116 scene
Methods
Simulate HyspIRI

DIRSIG key settings
- Height = 600km
- GSD = 60m
- 224 bands, 380 - 2500nm, 10nm FWHM
- Date & time: 2013-06-12T19:00:00 (UTC)
- Use MODTRAN to simulate atmospheric radiative transfer

MODTRAN key settings:
- Enable multiple scattering (IMULT = +1)
- Mid-latitude summer model (MODEL = 2)
- RURAL extinction (IHAZE = 1)
**Methods**

Simulate HyspIRI

Point spread function (PSF)
2-D Gaussian Function, FWHM = pixel size (60m GSD)

![2-D Gaussian kernel](image1.png)

![Profile of the kernel](image2.png)
Generate multiple simulated HyspIRI data sets of different:

- Leaf area index (LAI)
- Canopy cover
- Position and distribution of trees
- Tree clustering
Methods
Simulate PAR/LAI sensor

Project a hemisphere onto a plane for data collection and analysis
Methods

Simulate PAR/LAI sensor

DIRSIG key settings:
- Data-driven detector model
- Master detector array: $350 \times 350$
- Secondary detector array: $100 \times 100$
  (for sun disk)
- Use MODTRAN to simulate atmospheric radiative transfer

MODTRAN key settings:
- Enable multiple scattering ($\text{IMULT} = +1$)
- Mid-latitude summer model ($\text{MODEL} = 2$)
- Use RURAL extinction ($\text{IHAZE} = 1$)
Methods

Simulate PAR/LAI sensor

Below-canopy PAR

Real Image

DIRSIG Simulation
Methods
Simulate PAR/LAI sensor

Below-canopy PAR

Real Image

DIRSIG Simulation
Methods
Simulate PAR/LAI sensor

Below-canopy PAR

Real Image

DIRSIG Simulation
**Results**

Simulation results

Above-canopy PAR

![Graph showing above-canopy PAR](image)

Time

PAR (µmol m⁻² s⁻¹)

06/12/2013, 07:00-17:00

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**Introduction**

**Methods**

**Results**

**Conclusions/Outlook**

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2016-06-02

Jan van Aardt

2016 HyspIRI Science Symposium
Below-canopy PAR and LAI of single canopy

Simulated PAR under a canopy

LAI calculated from simulated PAR

The LAI of a single canopy can be measured along a transect.
LAI was estimated from simulated PAR measurements of a virtual PAR sensor in DIRSIG.

Normalized Difference Vegetation Index (NDVI) was extracted from simulated imaging spectroscopy data.

$\text{LAI} = 8.826 \cdot \text{NDVI} - 1.506$

$R^2 = 0.92$

The LAI of forest can be measured along multiple transects.
Simulation results

sparse forest LAI: other vegetation indices

\[ LAI = 1.612 \times SR - 2.007 \]
\[ R^2 = 0.929 \]

\[ LAI = 116.435 \times MCARI - 0.468 \]
\[ R^2 = 0.891 \]

\[ LAI = 13.795 \times MCARI1 - 0.292 \]
\[ R^2 = 0.890 \]

\[ LAI = 14.003 \times MCARI2 - 0.187 \]
\[ R^2 = 0.911 \]

\[ LAI = 0.384 \times TVI - 0.323 \]
\[ R^2 = 0.889 \]

Sparse forest LAI: other vegetation indices

- **SAVI**
  \[ \text{LAI} = 15.221 \times \text{SAVI} - 1.718 \]
  \[ R^2 = 0.895 \]

- **NLI**
  \[ \text{LAI} = 7.139 \times \text{NLI} + 3.829 \]
  \[ R^2 = 0.879 \]

- **MSR**
  \[ \text{LAI} = 4.982 \times \text{MSR} - 0.772 \]
  \[ R^2 = 0.936 \]

- **MNLI**
  \[ \text{LAI} = 15.767 \times \text{MNLI} + 3.627 \]
  \[ R^2 = 0.914 \]

- **RDVI**
  \[ \text{LAI} = 15.767 \times \text{RDVI} - 1.693 \]
  \[ R^2 = 0.902 \]

Canopy cover (CC)

CC = 0.20

Spectrum of the center pixel
Canopy cover (CC)

CC = 0.22

Spectrum of the center pixel
Results

Simulation results

Canopy cover (CC)

**CC = 0.24**

Spectrum of the center pixel
Canopy cover (CC)

CC = 0.25

Spectrum of the center pixel

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Results

Simulation results

Canopy cover (CC)

CC = 0.30

Spectrum of the center pixel
Results

Canopy cover (CC)

CC = 0.36

Spectrum of the center pixel
Canopy cover (CC)

CC = 0.40

Spectrum of the center pixel
Canopy cover (CC)

CC = 0.43

Spectrum of the center pixel
Results

Simulation results

Canopy cover (CC)

CC = 0.50

Spectrum of the center pixel
Canopy cover (CC)

CC = 0.61

Spectrum of the center pixel
Tree canopy cover refers to the proportion of land area covered by tree crowns ($m^2/m^2$).
Canopy cover (CC)

\[ CC = 1.163 \cdot \text{NDVI} - 0.184 \]

\[ R^2 = 0.97 \]
Narrow band vegetation indices (VIs) to characterize the canopy cover

\[ VI = \frac{Band1 - Band2}{Band1 + Band2} \]

**Simulation results**

**Results**

Reflectance VI

Radiance VI
Tree position

Tree at (0, 0)

Spectrum of the center pixel
Results

Simulation results

Tree position

Tree at (10, 0)

Spectrum of the center pixel

Wavelength (nm)

Reflectance
Results

Simulation results

Tree position

Tree at (20, 0)

Spectrum of the center pixel
Results

Simulation results

Tree position

Tree at (30, 0)

Spectrum of the center pixel
Results

Simulation results

Tree position

Tree at (40, 0)

Spectrum of the center pixel

R.I.T

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Results
Simulation results

Tree position

Tree at (50, 0)

Spectrum of the center pixel
Results

Simulation results

Tree position

Tree at (60, 0)

Spectrum of the center pixel
Results

Simulation results

Tree position

<table>
<thead>
<tr>
<th>Reflectance</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2000</td>
</tr>
<tr>
<td>0.4</td>
<td>1500</td>
</tr>
<tr>
<td>0.3</td>
<td>1000</td>
</tr>
<tr>
<td>0.2</td>
<td>500</td>
</tr>
</tbody>
</table>

Legend:
- (0, 0)
- (10, 0)
- (20, 0)
- (30, 0)
- (40, 0)
- (50, 0)
- (60, 0)
Results

Simulation results

Tree position

![Graph showing reflectance vs. wavelength for different tree positions](image-url)
Results

Simulation results

Tree position

![Graph showing tree position results over wavelength range from 500 to 2000 nm. Reflectance values range from 0 to 0.5.](graph.png)
Tree position: spectral angle

\[ \theta(x, y) = \cos^{-1} \left[ \frac{x(x, y) \cdot x_0}{\|x(x, y)\| \cdot \|x_0\|} \right] \]
Results indicate:

1. HyspIRI is sensitive to forest density in the blue and red spectral regions due to pigment concentration changes, as well as the SWIR region due to water content variation.

2. The effect of tree position is determined by the system’s PSF.

3. The system’s suitability for consistent global vegetation structural assessments could be improved by adapting calibration strategies to account for this variation in sub-pixel structure.
Conclusions/Outlook

Future work

1. Increase the number of simulations to assess other sub-pixel vegetation structural variables:
   - tree clustering
   - crown size

2. Quantify the simulation results:
   - employ statistical methods (wavelength pair-wise comparison, derivative analyses) to analyze simulation results

3. Investigate LiDAR-based approaches for calibration of HyspIRI structural estimates
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