Assessing sub-pixel vegetation structure from imaging spectroscopy data via simulation

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Outline

1. Introduction
   - Project outline and objectives
   - DIRSIG

2. Methods
   - Study area
   - Airborne and field data
   - Building virtual scenes
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   - Simulating AVIRIS & HyspIRI data
   - Assessing sub-pixel vegetation structure

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Introduction

Project outline and objectives

- Estimating LAI from VIs
- Sub-pixel structural variation
- DIRSIG simulation
- System study
- HyspIRI PSF
Stage 1: Estimating LAI from VIs

**AVIRIS Data** → **Extracting VIs** → **Down sampling VIs** → **VIs**

**Field LAI** → **Down sampling LAI** → **Estimating LAI from VIs**
Stage 2: Sub-pixel structural variation

- Estimating LAI from VIs
- HyspIRI PSF
- Airborne data
- Field data
- DIRSIG simulation
- System study
- HypIRI PSF

- Canopy structure
- DBH
- Stem position
- Volume
- Biomass
- Structural variation
- Grass biomass
- NEON’s high res data
- Assess the impact on spectra
- AVIRIS data
- Volume
- Biomass
- Structural variation
- Grass biomass
- NEON’s high res data
- Assess the impact on spectra
- AVIRIS data
Stage 3: DIRSIG simulation

DIRSIG: The Digital Imaging and Remote Sensing Image Generation
Stage 4: System study

- Simulated HyspIRI pixel
- Virtual scenes
- Simulated AVIRIS pixel
- HyspIRI PSF
- AVIRIS PSF

**Project outline and objectives**

- DIRSIG
- Estimating LAI from VIS
- Sub-pixel structural variation
- DIRSIG simulation
- System study
- HyspIRI PSF
Introduction

DIRSIG simulation - overview

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

- Image Modalities
  Visible through thermal infrared
  (0.4 - 20.0 μm)
  Passive sensing
  Active Laser sensing
  Active RF sensing

- Instruments
  Single pixel, 1D arrays and 2D arrays.
  Filter, diffraction/refraction, or interferogram-based photon collection

- Platforms
  Ground, air or space on static or moving platforms

http://dirsig.org
Methods

Study area

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

1. San Joaquin Experiment Range (Core site)
2. Soaproot Saddle (Relocatable site)

Figure from Google Earth
Methods

Field collection

1. San Joaquin Experiment Range:
   - June 9 - 14, 2013: 12 AOP sites (4, 8, 36, 112, 116, 361, 824, 952)
   - Oct 5 - 7, 2014: 3 AOP sites (36, 116, 824)
Methods
Field collection

Soaproot Saddle:
- June 16 - 20, 2013: 8 AOP sites (43, 63, 95, 143, 299, 331, 555, 1611)
- Oct 8 - 10, 2014: 3 AOP sites (43, 143, 299)
Methods

Field collection

Measurements at each spot within $80 \times 80m$ site:

1. LAI (AccuPAR LP-80)
2. Ground-based lidar (SICK LMS-151, RITTL)
3. Spectra (SVC HR-1024i)
4. Hemispherical photos
5. GPS position
Methods

Airborne collection

- AVIRIS data collected during HyspIRI preparatory airborne campaign, summer 2013 & fall 2014.
- NEON imaging spectrometer (NIS) & LiDAR data collected in summer 2013.
Methods

Register multiple Terrestrial Laser Scanner (TLS) scans and extract stem map from TLS data

- **Algorithm:**
  Extract coordinates of trunk-ground intersection as tie-points for registration
  Rank potential correspondence sets using geometric constraints
  Use RANSAC to query candidate point set matches

- **Features:**
  No markers are placed in the scene
  No initial pose estimation is required

By Dave Kelbe, PhD student
Methods
Simulate NEON’s high-resolution spectrometer data

NIS data

DIRSIG data

Site 116  Site 299  Site 143
Methods

Simulate HyspIRI

DIRSIG key settings

- Height = 600km
- GSD = 60m
- 224 bands, 380 - 2500nm, 10nm FWHM
- 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

Profile of the kernel
Simulated forest LAI vs NDVI

5 m transect spacing

\[
\text{LAI} = 8.826 \cdot \text{NDVI} - 1.506 \\
R^2 = 0.92
\]

10 m transect spacing

\[
\text{LAI} = 8.928 \cdot \text{NDVI} - 1.566 \\
R^2 = 0.77
\]

15 m transect spacing

\[
\text{LAI} = 12.61 \cdot \text{NDVI} - 2.457 \\
R^2 = 0.66
\]

Forest LAI can be measured along multiple transects.
Results
Estimating LAI from VIs

Measured forest LAI vs NDVI

Regression model from simulated data:

\[
\text{LAI} = 8.928 \cdot \text{NDVI} - 1.566 \\
R^2 = 0.77
\]

\[
\text{LAI} = 8.858 \cdot \text{NDVI} - 1.725 \\
R^2 = 0.61
\]

Forest LAI can be measured along multiple transects.
Methods
Simulating AVIRIS data

Verify the model using site 116 scene

AVIRIS data

Simulated data

![Graphs showing AVIRIS and simulated data for different wavelengths and radiances]
Density of the “forest” is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.

\[ d = 0.20 \]

Spectrum of the center pixel
Density of the “forest” is quantified by tree canopy cover ($d$), the proportion of land area covered by tree crowns.

$d = 0.22$
Density of the “forest”

Density of the “forest” is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.

\[ d = 0.24 \]

Spectrum of the center pixel

2015-10-14 Wei Yao

2015 HyspIRI Science and Application Workshop
Results
Assessing sub-pixel vegetation structure

Density of the “forest”

Density of the “forest” is quantified by tree canopy cover ($d$), the proportion of land area covered by tree crowns.

$d = 0.25$

Spectrum of the center pixel
Density of the “forest”

$d = 0.30$

Density of the “forest” is quantified by tree canopy cover ($d$), the proportion of land area covered by tree crowns.
Results
Assessing sub-pixel vegetation structure

Density of the “forest”

\[ d = 0.36 \]

Spectrum of the center pixel

Density of the “forest” is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.
Density of the “forest” is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.

d = 0.40
Density of the “forest”

\[ d = 0.43 \]

Density of the “forest” is quantified by tree canopy cover \( (d) \), the proportion of land area covered by tree crowns.
Results
Assessing sub-pixel vegetation structure

Density of the “forest”

\[ d = 0.50 \]

Spectrum of the center pixel

Density of the “forest” is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.
Density of the “forest”

\[ d = 0.61 \]

Density of the “forest” is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Density of the “forest”

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**Reflectance**

<table>
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**Wavelength (nm)**

500 1000 1500 2000
Results

**NDVI vs density**

- **Normalized Difference Vegetation Index (NDVI)**
  \[
  NDVI = \frac{NIR - Red}{NIR + Red}
  \]

- **“Forest” density**
  Tree canopy cover refers to the proportion of land area covered by tree crowns ($m^2/m^2$).

![Graph showing the relationship between NDVI and canopy cover. The R^2 value is 0.9735.](image)
Results

Narrow band vegetation indices (VIs) to characterize the forest density

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

\[ R^2 \] value of regression models

Reflectance VI

Radiance VI
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (0, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (10, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (20, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (30, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (40, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (50, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

Tree at (60, 0)

Spectrum of the center pixel
Results
Assessing sub-pixel vegetation structure

Tree position

![Graph showing reflectance vs wavelength for different tree positions at various wavelengths. The graph includes data points at (0, 0), (10, 0), (20, 0), (30, 0), (40, 0), (50, 0), and (60, 0).]
Results
Assessing sub-pixel vegetation structure

Tree position

![Graph showing reflectance vs. wavelength for different tree positions.](image)
Results
Assessing sub-pixel vegetation structure

Tree position
Results
Assessing sub-pixel vegetation structure

Tree position

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

The spectral angle distribution

\[ \theta = \cos^{-1} \left( \frac{x_1 \cdot x_2}{\|x_1\| \|x_2\|} \right) \]
Results indicate:

1. VIs could be used to estimate forest density from HyspIRI data.
2. The effect of vegetation’s position is mainly determined by the PSF of spectrometer.
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.
Re-run current simulations according to updated VSWIR specification:
- 30 m GSD
- new PSF

Increase the number of simulations to assess other sub-pixel vegetation structural variables:
- height of trees
- crown size
- forest species

Quantify the simulation results.

Investigate Lidar-based approaches for calibration of HyspIRI structural estimates.
Refereed journal articles


Conclusions/Outlook

Associated Publications

Conference Proceedings & Posters


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