Investigating the impact of spatially-explicit sub-pixel structural variation on the assessment of vegetation structure from imaging spectroscopy data: II Simulation approach

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Consider HyspIRI is a system $H\{\}$. The inputs related to sub-pixel vegetation structural variation include:

- species of trees: $t(x, y)$
- density of the forest: $d(x, y)$
- position and distribution of trees: $p(x, y)$
- height of trees: $h(x, y)$
- crown size: $c(x, y)$
- ... 

and the output is the spectrum:

$s(x, y) = H\{t(x, y), d(x, y), p(x, y), h(x, y), c(x, y), \cdots \}$
Outline

1 Introduction
   • Project outline and objectives
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2 Methods
   • Study area
   • Airborne and field data
   • Building virtual scenes
   • DIRSIG simulation

3 Results
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Introduction

Project outline and objectives

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

Airborne data

Field data
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

- Stem position
- DBH
- Canopy structure
- Volume
- Biomass
- Structural variation
- LAI(VIs)
- Grass biomass
- Assess the impact on spectra
- AVIRIS data
- Ground spectra
- NEON’s high res data
- Spatially explicit
- Ground based LiDAR

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

Introduction
Project outline and objectives

Methods

Results

Conclusions/Outlook

DIRSIG

Project outline and objectives

2014-10-16 Wei Yao
2014 HyspIRI Science and Application Workshop
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
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
Introduction

DIRSIG simulation - overview

Example scene:
• > 5,000 objects
• > 500+ million facets
• 1.6 km² (0.6 mi²)
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)

Site 36

AOP: Airborne Observation Platform

Site 116
Methods
Field collection

2 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 $80 \times 80 m$ 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
AVIRIS data collected during HyspIRI preparatory airborne campaign, summer 2013:

- June 12, 2013: f130612t01r09 (San Joaquin)
- June 12, 2013: f130612t01r07 (Soaproot)

NEON’s spectrometer data collected in the same time:

- June 13, 2013: NIS1_20130613_xxxxxx_atmcor.h5 (San Joaquin)
- June 12, 2013: NIS1_20130612_xxxxxx_atmcor.h5 (Soaproot)
Methods

Extract stem map from Terrestrial Laser Scanner (TLS) data

- **Method:**
  Model tree stems using iterative cylinder-following approach

- **Results:**
  Detailed structural modeling
  Tree Location $R^2 = 0.99$
  Stem Density $R^2 = 0.86$ for visible stems
  Tree Diameter $R^2 = 0.80$

By Dave Kelbe, PhD student
Methods

Register multiple TLS scans

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

Building virtual scenes

Virtual scene layout

- Terrain size: 180 × 180 meters, which corresponds to 3 × 3 HyspIRI pixels (60m GSD, red grid), or 12 × 12 AVIRIS pixels (15m GSD, cyan grid)
- Elevation is derived from the airborne lidar data
- The center 80 × 80 meters area corresponds to the actual vegetation structure of our study area
- 3D tree models are generated by OnyxTREE
- The reflectance spectra of leaf, bark, grass, soil, rock are measured by RIT field team and NEON AOP team
- Two black panels and two white panels are placed at the corners and used as reference objects for empirical line method (ELM) atmospheric compensation
Methods

Building virtual scenes

The side view of site 116 scene
Methods
Simulate NEON’s high-resolution spectrometer data

NEON’s spectrometer data

Simulated data

Site 116
Site 299
Methods
Simulate AVIRIS data

Verify the model by the Site 116 scene

AVIRIS data

Simulated data
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
Methods

Simulate HyspIRI

Generate multiple simulated HyspIRI data sets of different:

- density of the “forest”
- position and distribution of trees
- height of trees
- crown size
- species of trees.
Density of the “forest”

Density = 0.1

Spectrum of the center pixel
Density of the “forest”

Density = 0.2

Spectrum of the center pixel
Density of the “forest”

Density = 0.3

Spectrum of the center pixel
Results

Density of the “forest”

Density = 0.4

Spectrum of the center pixel
Density of the “forest”

Density = 0.5

Spectrum of the center pixel
Density of the “forest”

Density = 0.6

Spectrum of the center pixel
Density of the “forest”

Density = 0.7

Spectrum of the center pixel
Results

Simulation results

Density of the “forest”

Density = 0.8

Spectrum of the center pixel
Density of the “forest”

Density = 0.9

Spectrum of the center pixel
Results

Simulation results

Density of the “forest”

Density = 1

Spectrum of the center pixel
Density of the "forest"
Results
Update of field work

Site 43 (Jun 17, 2013)

Site 43 (Oct 9, 2014)
Results

Simulation results

Position of tree

Tree at (0, 0)

Spectrum of the center pixel
Results

Simulation results

Position of tree

Tree at (10, 0)

Spectrum of the center pixel
Results

Position of tree

Tree at (20, 0)

Spectrum of the center pixel
Results

Simulation results

Position of tree

Tree at (30, 0)

Spectrum of the center pixel
Position of tree

Tree at (40, 0)

Spectrum of the center pixel
Results

Simulation results

Position of tree

Tree at (50, 0)

Spectrum of the center pixel
Position of tree

Tree at (60, 0)

Spectrum of the center pixel
Position of tree
Results
Simulation results

Position of tree

![Graph showing reflectance vs. wavelength with different tree positions indicated.](image-url)
Results
Simulation results

Position of tree

[Graph showing reflectance vs. wavelength with annotations for Tree @ (60, 0), Tree @ (50, 0), Tree @ (40, 0), Tree @ (30, 0), Tree @ (20, 0), Tree @ (10, 0), Tree @ (0, 0)].
Position of tree
Conclusions/Outlook

Conclusions

Early 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 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.

3. HyspIRI is stable on the sub-pixel position of tree.
Stage 4: System Study

Simulated HyspIRI pixel

Virtual scenes

Simulated AVIRIS pixel

HyspIRI PSF

AVIRIS PSF
Conclusions/Outlook

Future work

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

2. Quantify the simulation results:
   - Define narrow band vegetation indices (VIs) to characterize the sub-pixel vegetation structure
   - Employ statistical methods (wavelength pair-wise comparison, derivative analyses) to analyze simulation results

3. Investigate Lidar-based approaches for calibration of HyspIRI structural estimates
Conclusions/Outlook

Future work

Review our hypotheses:

1. Fine-scale, within-pixel structural assessments can be used to improve our understanding of HyspIRI-based estimates of leaf area, leaf area index (LAI), and vegetation biomass;

2. From a systems perspective, the spatially explicit within-pixel structural variations are quantifiable when it comes to their impact on the HyspIRI systems response (point spread function);

3. An improved understanding of (1) and (2) will lead to proper calibration of HyspIRI based vegetation structure estimates.
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