High Spectral And Spatial Resolution Sensor Images for Mapping Urban Areas

- **Dar A. Roberts:** UCSB Geography
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Outline

• Introduction
  – Why urban, why imaging spectrometry?

• Urban spectroscopy

• Example Analysis
  – Classification
    • Spectral separability
    • Spectral and spatial tradeoffs
  – Matched filters
  – Pavement Quality
  – Multiple Endmember Spectral Mixture Analysis

• Summary
Why is Urban remote sensing important?

• Urban areas are where a majority of humans live
  – > 50% urban population and rising

• Urban areas are centers of human activity
  – Major sinks for raw and fabricated materials
  – Major consumers of energy, sources of airborne and waterborne pollutants

• Urban areas are vulnerable to disaster, require planning
  – Flood management/water quality
  – Fire danger
  – Urban infrastructure, transportation
    • Reduced energy consumption, reduced emissions
Remote Sensing of Urban Environments

• Remote Sensing is a Crucial Technology
  – Urban areas are growing rapidly
  – Many urban areas are poorly mapped globally
  – Rapid response and planning require current maps

• Urban Environments are Challenging
  – The diversity of materials is high
  – The scale at which surfaces are homogeneous is typically below the spatial resolution of spaceborne and airborne sensors

• New Remote Sensing Technologies have considerable promise
  – Hyperspectral: AVIRIS, Hyperion, HYMAP
  – Hyperspatial: IKONOS Panchromatic
  – LIDAR: Fine vertical resolution
  – SAR: Interferometry
Considerable data
   Image sources
   Field spectra
Complex urban environment
Urban Spectroscopy

• What are the spectral properties of typical urban materials?
• How many unique spectra are present?
• Which spectra are likely to be confused?
• Which wavelengths are important for distinguishing materials?
• How can spectral and spatial information be used to map roads and roof types and road quality?
Image Sources
Each pixel is a spectrum
Potential for library development is large

AVIRIS 991011

Red = 1684 nm
Green = 1106 nm
Blue = 675 nm
Field Spectra Collection
ASD Full-Range Spectrometer

Sample Concrete Spectra

Roberts and Herold, 2004
Field photos were taken & metadata recorded at each field site...

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Ready
Field Spectra Summary

- Over 6,500 urban field spectra were collected throughout Santa Barbara in May & June 2001
- Field spectra were averaged in sets of 5 and labeled appropriately in building the urban spectral library
- The resulting urban spectral library includes:
  - 499 roof spectra
  - 179 road spectra
  - 66 sidewalk spectra
  - 56 parking lot spectra
  - 40 road paint spectra
  - 37 vegetation spectra
  - 47 non-photosynthetic vegetation spectra (ie. Landscaping bark, dead wood)
  - 27 tennis court spectra
  - 88 bare soil and beach spectra
  - 50 miscellaneous other urban spectra
Transportation Surfaces

Asphalt Roads

Material composition and age are critical

Hydrocarbon absorption

Parking Lots

Concrete

Material composition and age are critical
Transportation surfaces change
Asphalt roads generally become lighter as they age
Cracking, patching and oil generally darken road surfaces
Street Paints

Reflectance vs. Wavelength (um)

- Old White
- Fresh White
- Blue
- Fresh Red
- Yellow
- Fresh Yellow

Age:
- Hydrocarbon Vibrational bands
- Pigments
Composite Shingles

Generally comprised of asphalt with minerals imbedded in the surface for color.
Vary depending upon age, mix of materials that provide color.
Highly variable – these show only a selection of those present in the region.
Other Roof Materials

Dark Roofs

Bright Roofs

Iron oxide

Ligno-cellulose
The Challenge of Roads and Roofs

Some roads and roofs are quite distinct (Red tile)
Composite shingle and asphalt roofs can be spectrally similar
Aging, illumination and condition complicate analysis
Classifying Urban Landscapes

Key Questions
1) Which classes are spectrally distinct?
2) What is the optimal spatial resolution?
3) How do hyperspectral and broad band sensors compare?
4) How might LIDAR improve analysis?

From Herold and Roberts, 2006
*Int. J. Geoinformatics* 2(1) 1-14
## Urban Classification Schemes

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### Anderson Classification:
Hierarchical classification scheme

### VIS model: Vegetation-Impervious-Soil (Ridd, 1995)

**Herold et al., 2003**
Spectral Separability Measures:
Bhattacharyya Distance

• Screening of spectral characteristics of urban targets
• Separability measures – Bhattacharyya distance:

\[ B = \frac{1}{8} [\mu_1 - \mu_2]^T \left[ \frac{\Sigma_1 + \Sigma_2}{2} \right]^{-1} [\mu_1 - \mu_2] + \frac{1}{2} \ln \frac{1}{2 \left[ \frac{\Sigma_1 + \Sigma_2}{2} \right]} \sqrt{\Sigma_1 \Sigma_2} \]

\[(\mu - \text{mean value} \mid \Sigma - \text{Covariance)}\]

• Maximum Likelihood based image classification
Most suitable spectral bands
Top 14 selected based on Bhattacharyya distance

# Spectral Separability Matrix

Table 2

Average and minimum spectral separability (B-distance) for different land cover types

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<td>366</td>
<td>511</td>
<td>156</td>
<td>880</td>
<td>887</td>
<td>2288</td>
<td>953</td>
<td>1266</td>
<td>72</td>
<td>84</td>
<td></td>
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<tr>
<td>13:</td>
<td>438</td>
<td>627</td>
<td>330</td>
<td>230</td>
<td>652</td>
<td>542</td>
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<td>840</td>
<td>2196</td>
<td>801</td>
<td>638</td>
<td>731</td>
<td>218</td>
<td></td>
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<tr>
<td>14:</td>
<td>1152</td>
<td>780</td>
<td>1145</td>
<td>477</td>
<td>1568</td>
<td>1073</td>
<td>1413</td>
<td>1035</td>
<td>1249</td>
<td>1614</td>
<td>889</td>
<td>881</td>
<td>354</td>
<td></td>
</tr>
</tbody>
</table>

**Coding of values:**

- **Bold:** Average separability (lower left part of matrix)
- **Italic:** Minimum separability (upper right part of matrix)

**Coding of background:**

- Average value ≤150 / Minimum value ≤20
- 151 ≤ Average value ≤ 300 / 21 ≤ Minimum value ≤ 40

- All values are B-distance scores: Larger values = more separable
- Lower left part of matrix: average separability
- Upper right part of matrix: minimum separability
- Light grey are moderately separable, dark grey are problems

Land Cover Mapping

- 14 most suitable bands
- 26 land cover classes
- 22 built up classes
- Inter-class confusion confirms sep. analysis
- Spectral limitations:
  - # and location of bands
  - Narrow vs. broadband

Small-footprint LIDAR

LIDAR first return elevation

LIDAR last return elevation

IKONOS 4/2/1

Elevation difference first/last (m)
Spatial-spectral tradeoffs

**Producer’s accuracy**
Correct/Reference

- Class buildings/roofs
- Class green vegetation

**User’s accuracy**
Correct/Mapped

- Class buildings/roofs
- Class green vegetation

Spatial resolution

Herold et al., 2006
Matched Filter Analysis

Confusion is minimal between wood shingle and other materials
Considerable error occurs between Roads and composite shingle roofs

Roberts and Herold, 2004
Pavement Quality

• Two aspects are of interest
  – How old is a road?
  – What is its condition?
    • Cracks, patches

• Data Sources
  – Field spectra
  – High spatial resolution imagery
Asphalt Aging

Herold and Roberts, 2005

<table>
<thead>
<tr>
<th>Age</th>
<th>PCI (Roadware)</th>
<th>Structure (Roadware)</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 1 year</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>3 years</td>
<td>86</td>
<td>100</td>
</tr>
<tr>
<td>more than 10 years</td>
<td>32</td>
<td>63</td>
</tr>
</tbody>
</table>

Surface spectra 1

Surface spectra 2

Surface spectra 3

Minerals

Iron oxide

Hydrocarbon
Asphalt Condition

Asphalt ASD ground spectra - cracking

Herold and Roberts, 2005
Band Differences for RS data analysis

**VIS2 Difference** = (830nm-490nm)

**SWIR Difference** = (2120nm-2340nm)

Herold and Roberts, 2005
HyperSpectir (HSI) data
Ultra-fine spatial resolution is needed for mapping road quality

- Goleta, CA
- www.spectir.com
- HSI-1 data
- spatial res. ++
- 0.5 m / 40 m swath
- spectral cal. --
- Only VIS/VNIR use
- Improv. sensor now

Herold and Roberts, 2005
Spatial distribution of VIS2-Difference

Herold and Roberts, 2005
HSI signal versus Roadware data

Herold and Roberts, 2005

Graph 1: Pavement condition index vs. Hyperspectir VIS2 ratio [reflectance]

Graph 2: Structure index vs. Hyperspectir VIS2 ratio variance

Equation 1:
y = -15.331x + 140.79
R² = 0.63

Equation 2:
y = -91.735x + 115.53
R² = 0.55
Pavement condition index derived from VIS2 Difference

Herold and Roberts, 2005
Mapping Impervious Surfaces and Vegetation Cover in an Urban area using MESMA

• **Objective**
  – Identify optimal spectra for discriminating impervious and pervious surfaces
  – Accurately estimate subpixel vegetation cover with variable backgrounds

• **Approach**
  – Multiple Endmember Spectral Mixture Analysis
    • Allows number and types of endmembers to vary per pixel
    • Addresses challenges of spectral diversity in urban areas

• **Data**
  – Field spectral library of over 900 materials
  – AVIRIS high resolution image
  – 2000+ spectra for accuracy assessment
Building a Spectral Library

000606, 1650, 830, 645 nm RGB

Wood Shingle Roof
Selecting Impervious and Pervious Spectra

Count Based Endmember Selection

- **Objective**
  - Identify spectra that best discriminate pervious and impervious surfaces

- **Spectra sorted by two categories**
- **Optimum spectra selected from each category using CoB**
- **51 spectra selected**
  - 20 pervious
    - 4 GV
    - 4 NPV
    - 5 soils
    - 7 water
  - 31 impervious
    - 21 roofs
    - 10 roads
Model Selection: Two Endmembers

- **Legend**
  - Vegetation: Dark purple
  - Senesced Grass: light purple
  - Woodshingle roofs: Aquamarine
  - Parking lots: Dark blue
  - Roads and Streets; Green

**Accuracy Assessment:**
Unclassified: 156 (100 of water)
Overall: 86.3%
Pervious: 327/400 (81.8%)
  - 72% Soil, 77% GV, 92% NPV
Impervious: 1720/1973 (87.2%)
MESMA Fraction Images

- 4 Endmember Model
- NPV, GV, Soil/Impervious (RGB)
- Fractions highly accurate
  - Readily accounts for spectral variability in backgrounds
Summary

• Urban environments are challenging due to fine spatial requirements and large spectral heterogeneity
• Imaging spectrometry is critical for improving our understanding of urban spectroscopy
• Imaging spectrometry provides improved spectral discrimination
  – Roofs and roads remain difficult to separate
  – Wood shingle is particularly easy to map
• Adding a vertical dimension vastly improves accuracy
• New tools, such as MESMA have considerable promise
Questions?