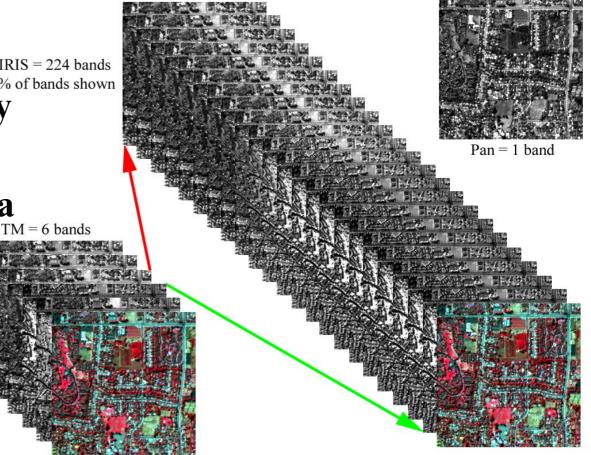
High Spectral And Spatial Resolution Sensor Images for Mapping Urban Areas

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- Martin Herold: University of Jena



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

Study Site: Santa Barbara, California Oct 11, 1999 low-altitude data - 4 meter pixels



Red 1684 nm Green 1106 nm Blue 675 nm

Considerable data

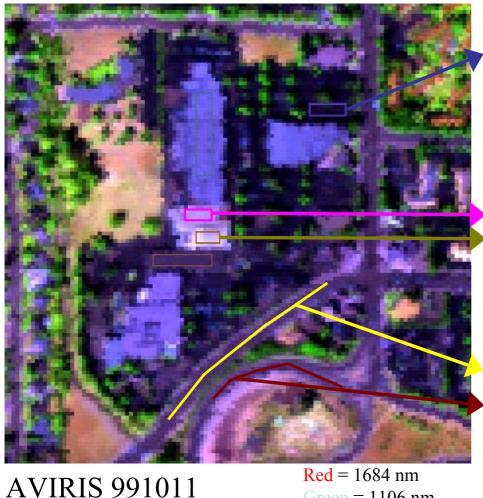
Image sources Field spectra Complex urban environment



Urban Spectroscopy

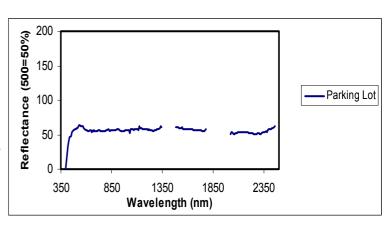
- What are the spectral properties of typical urban materials?
- How many unique spectra are present?
- Which spectra are likely to be confused?
- Which wavelengths are important for distinguishing materials?
- How can spectral and spatial information be used to map roads and roof types and road quality?

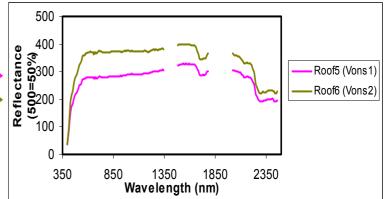
Image Sources Each pixel is a spectrum Potential for library development is large

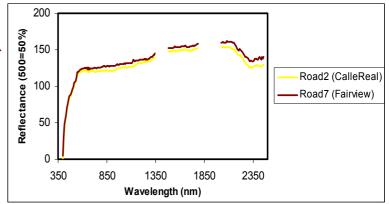


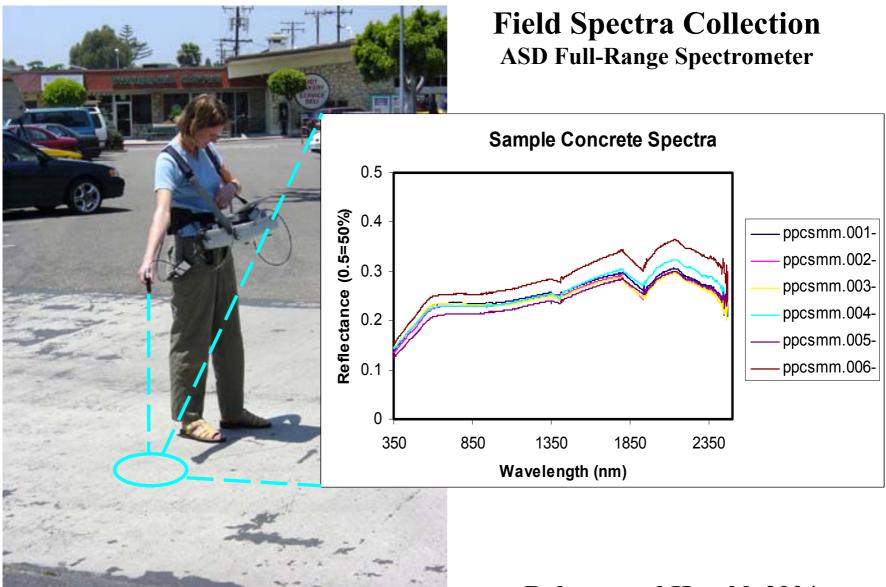
Green = 1106 nm

Blue = 675 nm









Roberts and Herold, 2004

Field photos were taken & metadata recorded at each field site...

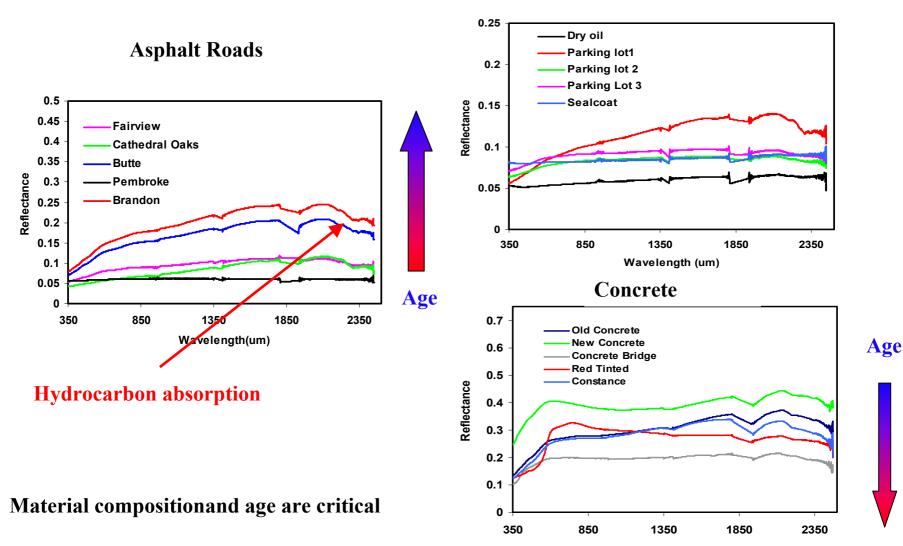
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Field Spectra Summary

- 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

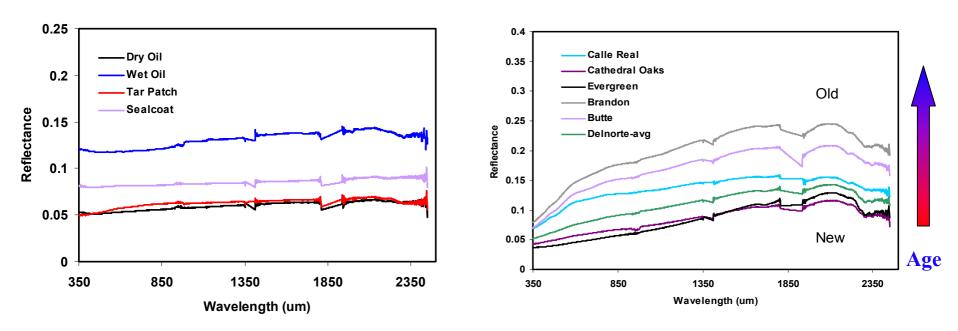
Transportation Surfaces

Parking Lots



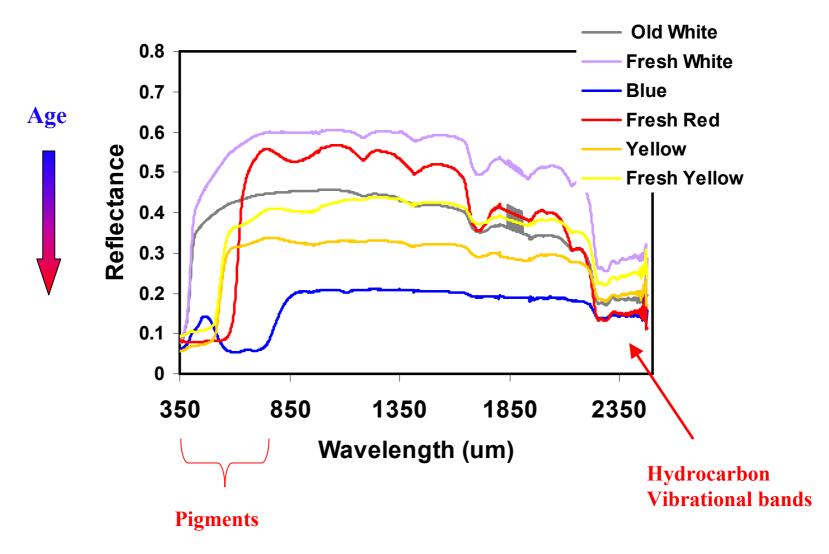
Wavelength (um)

Road Surface Modification



Transportation surfaces change Asphalt roads generally become lighter as they age Cracking, patching and oil generally darken road surfaces

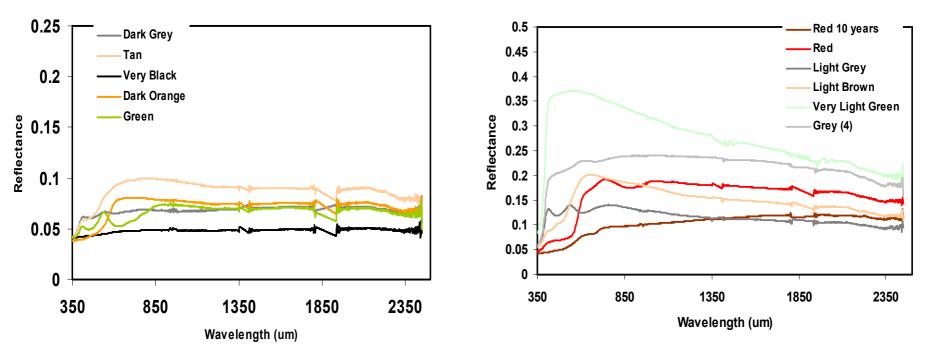
Street Paints



Composite Shingles

Dark Composite Shingle

Light Composite Shingle

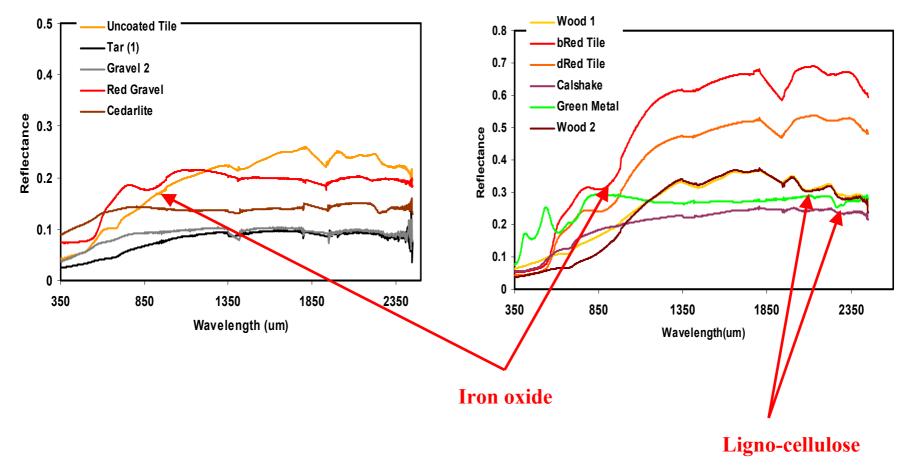


Generally comprised of asphalt with minerals imbedded in the surface for color Vary depending upon age, mix of materials that provide color Highly variable – these show only a selection of those present in the region

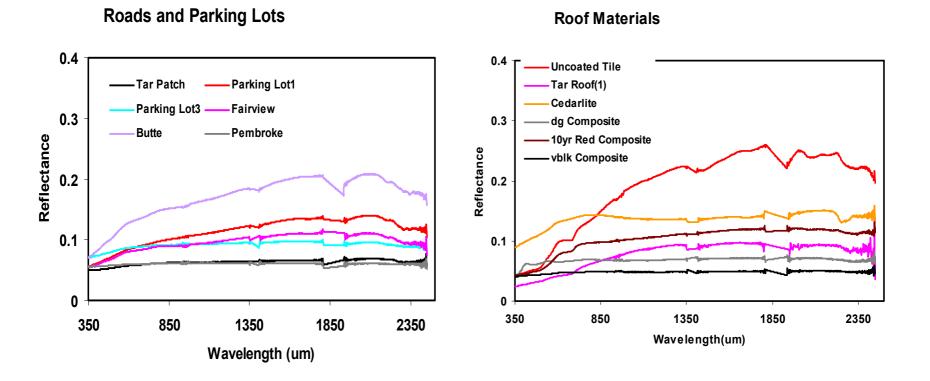
Other Roof Materials

Dark Roofs





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?

VIS: 660/550/470 nm VIS/NIR: 810/660/550 nm Full range: 2180/810/470 nm IKONOS 55 55 2) 50 ASD/AVIRIS 50 45 45 40 40 % 35 35 30 30 Reflect 25 25 20 20 15 6) 2200 2.100 400 Wavelength [nm] Wavelength [nm] 1) Tan composite shingle roof 2) Red tile roof 3) Wood shingle roof 4) Asphalt road 5) Concrete road 6) Parking lot - 7) Green vegetation (grassland) - 8) Bare soil (construction site)

From Herold and Roberts, 2006 *Int. J. Geoinformatics* 2(1) 1-14 Figure 3: Representation of different urban surface types in different AVIRIS color composites compared to ground spectral measurements convolved to AVIRIS spectral configurations. The VIS and VIS/NIR composites would be similar to measurements taken by the IKONOS satellite. Spectra 1-3 represent roofs, spectra 4 - 6 transportation surfaces, spectra 7 green vegetation and spectra 8 bare soil to refer these spectra to land cover classes used in the classification

Urban Classification Schemes

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3.3 Bare Rock 4 Water bodies		3.2 Beach		
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bodies	4 Water	4.1 Natural/quasi-natural		
	bodies	4.2 Swimming Pools		

Anderson Classification: Hierarchical classification scheme

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

Herold et al., 2003

Spectral Separability Measures: Bhattacharrya Distance

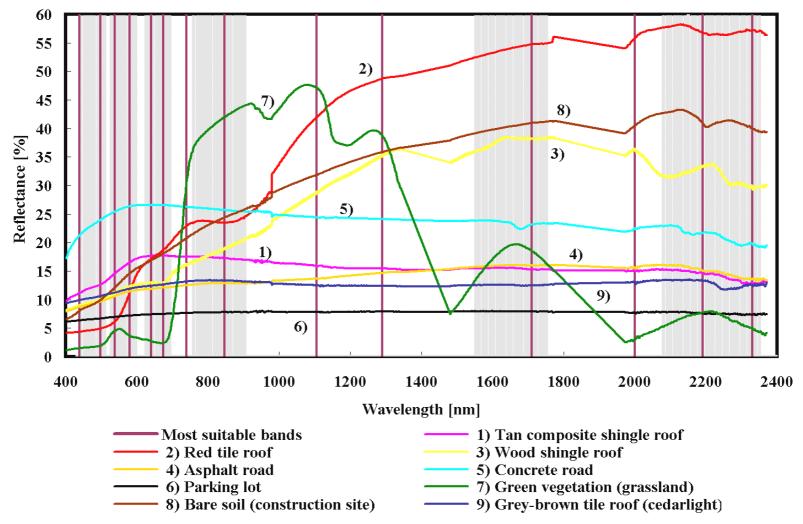
- Screening of spectral characteristics of urban targets
- Separability measures Bhattacharyya distance:

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

(μ - mean value | Σ - Covariance)

• Maximum Likelihood based image classification

Most suitable spectral bands Top 14 selected based on Bhattacharyya -distance



From: Herold M., Roberts D., Gardner M. and P. Dennison 2004. Spectrometry for urban area remote sensing - Development and analysis of a spectral library from 350 to 2400 nm, Remote Sens. Environ, Vol 91 (3-4) 304-319.

Spectral Separability Matrix

Table 2

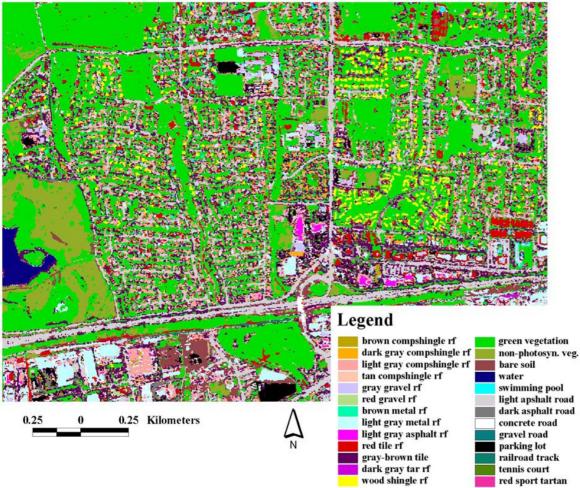
Average and minimum spectral separability (B-distance) for different land cover types

2.53	142	0.010		1.1.1			A. A. A. A.							
	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:	14:
	Com_sh	Grav_rf	Tar_rf	Gr_tile	Rd_tile	Wd_sh	Asp_rd	Concr	Grav_rd	P_lot	Gr_veg	NPV	Soil_dk	Soil_b
1: Composite shingle		56	19	14	75	61	8	18	106	13	80	70	133	285
2: Gravel roof	405		36	46	109	189	51	17	88	84	97	52	184	480
3: Tar roof	190	599		30	69	127	17	20	135	26	66	58	145	285
4: Gray tile roof	92	178	67		34	32	35	16	61	31	59	31	99	237
5: Red tile roof	549	581	559	375		84	90	52	147	130	92	59	248	748
5: Wood shingle roof	315	359	171	172	197		218	31	152	249	119	10	378	899
7: Asphalt road	244	693	119	99	1331	351		28	68	7	97	64	48	91
3: Concrete road	687	735	1325	423	1247	977	1151		29	11	59	42	27	20
: Gravel road	2533	2514	1733	2460	927	4370	3047	1799		117	79	105	485	632
0: Parking lot	194	700	98	81	1499	436	194	897	3832		53	171	104	278
1: Green veg.	992	1066	1023	779	609	426	1614	1589	1106	588		88	64	144
2: Non-photos. veg.	585	646	439	366	511	156	880	887	2288	953	1266		72	84
3: Bare soil (dark)	438	627	330	230	652	542	542	840	2196	801	638	731		218
4: Bare soil (beach)	1152	780	1145	477	1568	1073	1413	1035	1249	1614	889	881	354	
Coding of values:	Bold: Av	verage ser	arability	(lower le	eft part of	matrix) /	Italic: Mi	nimum se	parability()	upper rig	htpart of m	atrix)		
Coding of	Average	value ≤1	50 / Mini	imum val	ue ≤20			$151 \le A$	verage val	$ue \le 300$	$/21 \leq Min$	imum va	lue ≤ 40	
background:														

- 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

From: Herold M., Roberts D., Gardner M. and P. Dennison 2004. Spectrometry for urban area remote sensing - Development and analysis of a spectral library from 350 to 2400 nm, Remote Sens. Environ, Vol 91 (3-4) 304-319.

Land Cover Mapping



14 most suitable bands

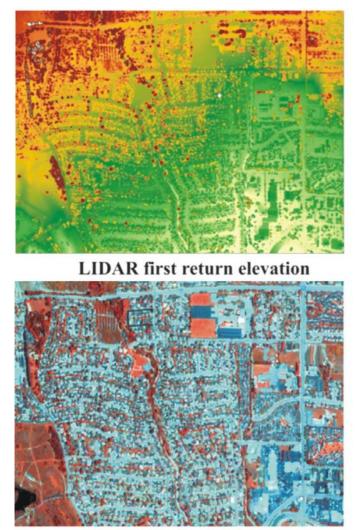
- 26 land cover classes
- 22 built up classes
- Inter-class confusion confirms sep. analysis
- **Spectral limitations:**
 - # and location of bands
 - Narrow vs. broadband

Overall Accuracy										
	Mean	Карра	Area weighted	Bu						
	accuracy	coefficient	accuracy	a						

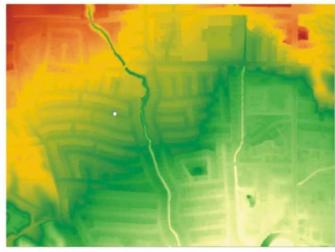
uilt classes accuracy cenicient accurac IKONOS (4 bands) 61.8 % 60.2 % 66.6 % 37.7 % Landsat TM (6 bands) 68.9 % 67.7 % 75.8 % 53.9 % AVIRIS (14 bands) 73.5 % 72.5 % 82.0 % 66.6 %

From: Herold M., Gardner M. and Roberts D. 2003. Spectral **Resolution Requirements for Mapping Urban Areas, IEEE** Transactions on Geoscience and Remote Sensing, 41, 9, pp. 1907-1919

Small-footprint LIDAR



IKONOS 4/2/1

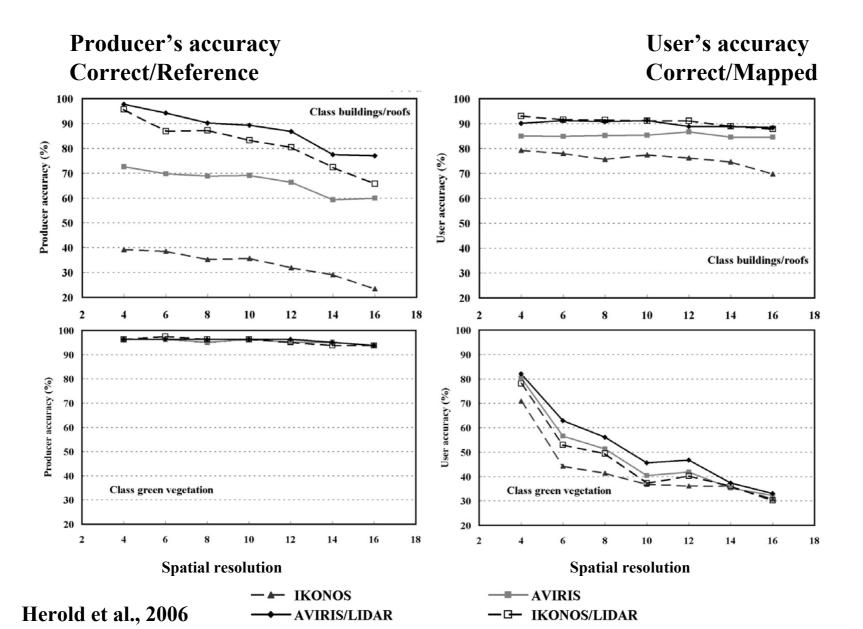


LIDAR last return elevation



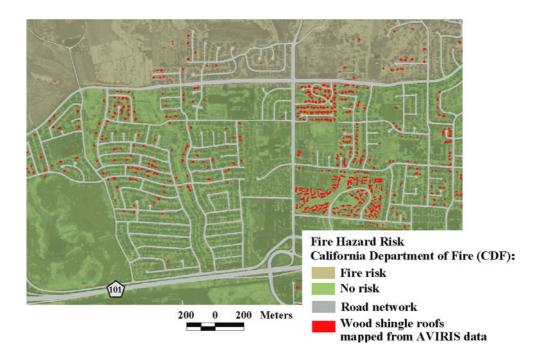
Elevation difference first/last (m)

Spatial-spectral tradeoffs



Matched Filter Analysis

Wood shingle roof a) Asphalt road c) Matched filter score: 70 - 106roads



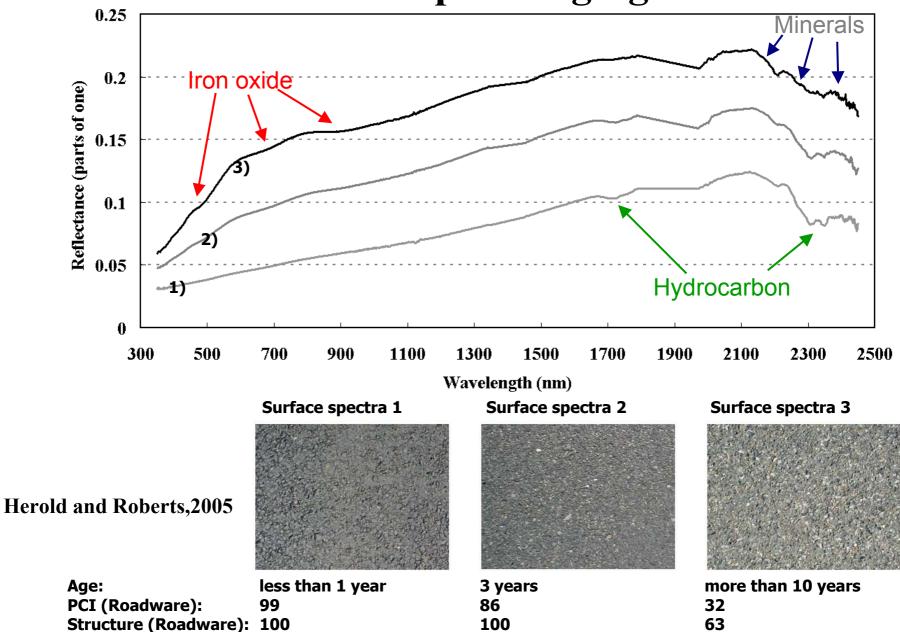
Confusion is minimal between wood shingle and other materials Considerable error occurs between Roads and composite shingle roofs

Roberts and Herold, 2004

Pavement Quality

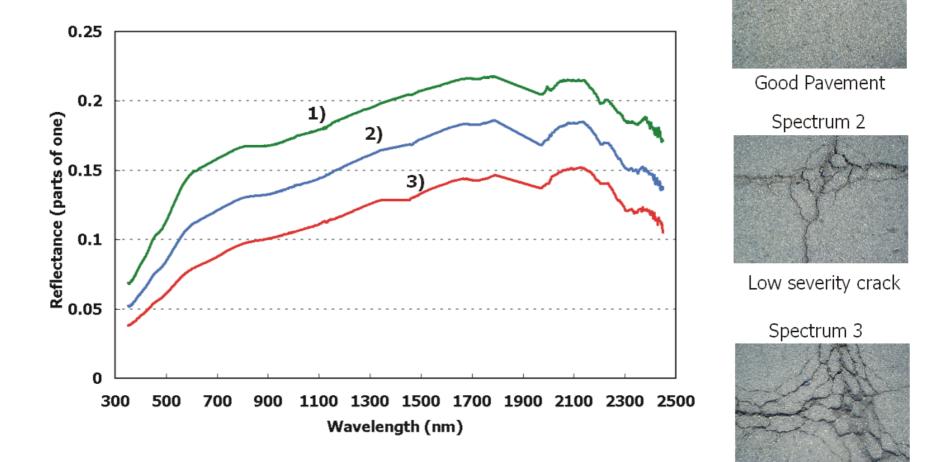
- Two aspects are of interest
 - How old is a road?
 - What is its condition?
 - Cracks, patches
- Data Sources
 - Field spectra
 - High spatial resolution imagery

Asphalt Aging



Asphalt Condition

Asphalt ASD ground spectra - cracking

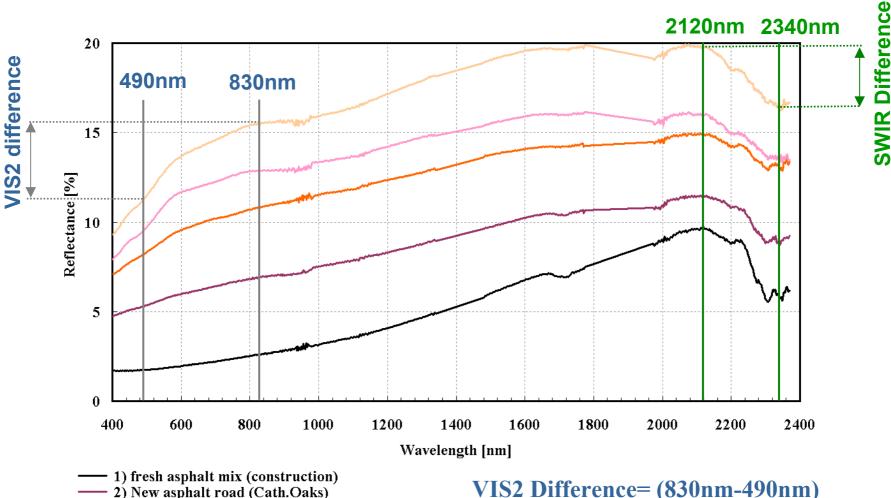


Herold and Roberts,2005

Severe alligator crack

Spectrum 1

Band Differences for RS data analysis



- 4) Old asphalt road, fair condition (Calle real)
- ----- 5) Old asphalt road, very poor condition (Berkeley)

VIS2 Difference= (830nm-490nm) SWIR Difference = (2120nm-2340nm)

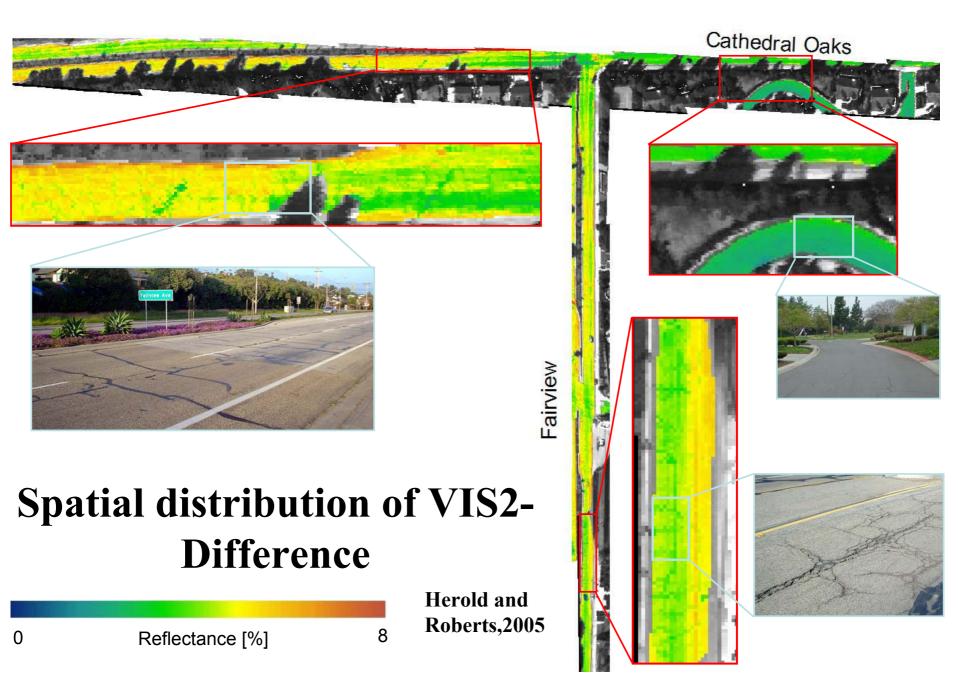
Herold and Roberts,2005

HyperSpectir (HSI) data Ultra-fine spatial resolution is needed for mapping road quality

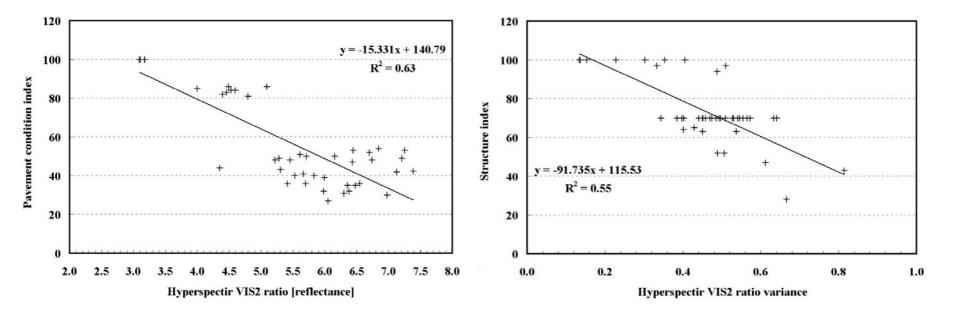


- Goleta, CA
- www.spectir.com
- HSI-1 data
- spatial res. ++
- 0.5 m / 40 m swath
- spectral cal. --
- Only VIS/VNIR use
- Improv. sensor now

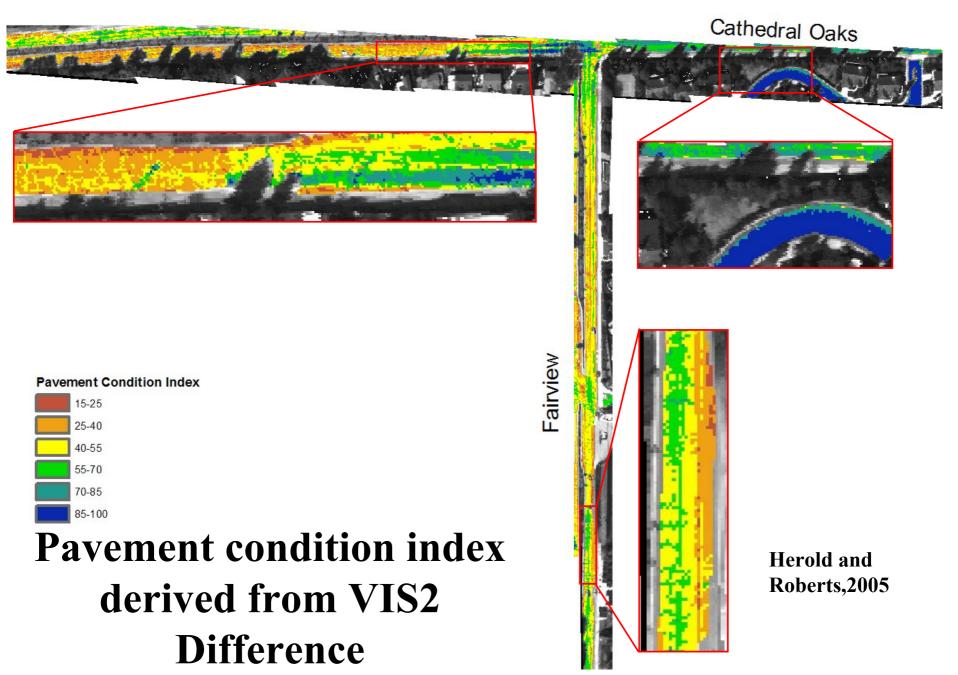
Herold and Roberts,2005



HSI signal versus Roadware data



Herold and Roberts,2005

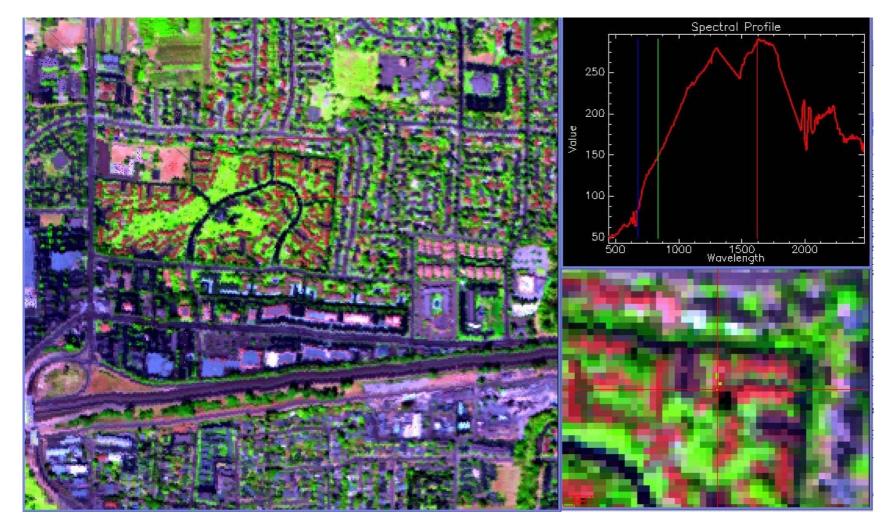


Mapping Impervious Surfaces and Vegetation Cover in an Urban area using MESMA



- 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

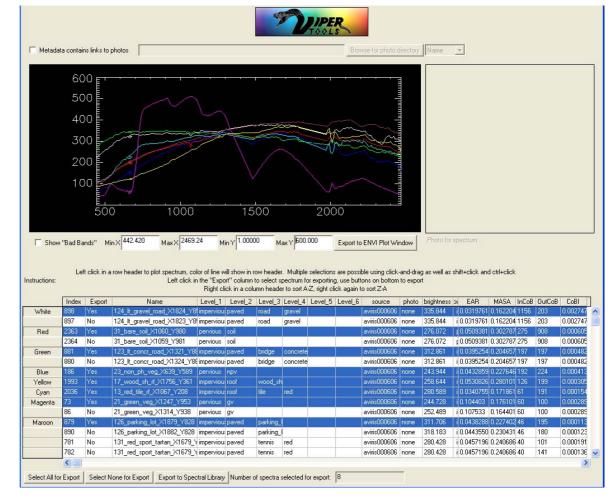


000606, 1650, 830, 645 nm RGB

Wood Shingle Roof

Selecting Impervious and Pervious Spectra Count Based Endmember Selection

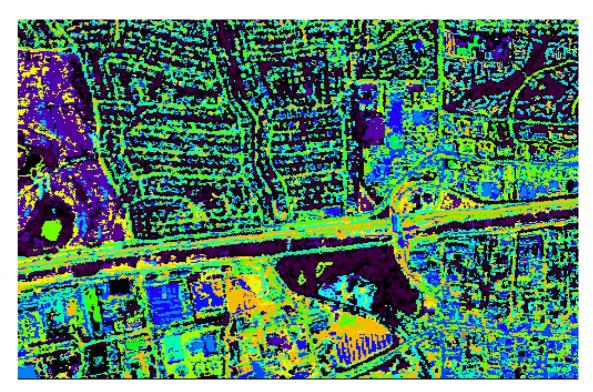
- Objective
 - Identify spectra that best discriminate pervious and impervious surfaces
- Spectra sorted by two categories
- Optimum spectra selected from each category using CoB
- 51 spectra selected
 - 20 pervious
 - 4 GV
 - 4 NPV
 - 5 soils
 - 7 water
 - 31 impervious
 - 21 roofs
 - 10 roads



Model Selection: Two Endmembers

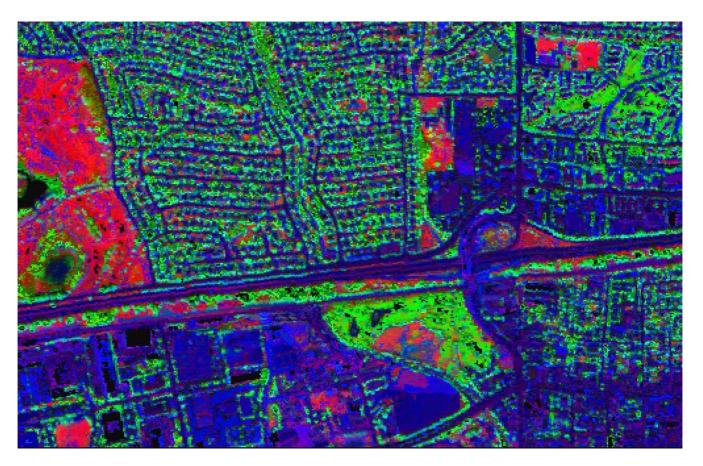
• Legend

- 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

