Hyperspectral Imaging or Imaging Spectroscopy: An Overview

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Information in Remote Sensing of the Earth

- Information about the earth can be derived from
  - Electromagnetic fields
    - Spatial
    - Spectral
    - Temporal
  - Gravitational fields

- To extract the information of interest one must
  - Measure variations of those fields → Sensors
  - Relate them to the desired information → Modeling

Apollo 17, 1972
Key Concepts

• SPATIAL DIFFERENTIATION - Every sensor is limited in respect to the size of the smallest area that can be separately recorded as an entity on an image. Object shapes and spatial relations are

• SPECTRAL DIFFERENTIATION - Remote sensing depends upon observed differences in the energy reflected or emitted from features of interest.

• RADIOMETRIC DIFFERENTIATION – Examination of any image acquired by remote sensing ultimately depends upon detection of differences in the brightness of objects and the features.
Spectral vs Spatial Resolution
Reflected vs. Emitted Energy

- Earth Reflectance (100%)
- Earth Emission (100%)

Assumes no atmosphere
Interaction of energy and objects

Energy Balance Equation: $E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$
Three Dimensions for RS

Spatial Resolution
- IKONOS, Quickbird
- SPOT
- Landsat

Spectral
- Hyperion
- Hyperspectral
- Multi-spectral

Temporal
- Geosynchronous Weather
- Missile Warning
Sampling the Spectrum

LOW  Panchromatic: one very wide band

MED  Multispectral: several to tens of bands

HIGH Hyperspectral: hundreds of narrow bands
The Spectral Cube
The image cube is a 3-dimensional data set. We have two spatial dimensions and a third spectral dimension that is usually put vertical.

It is important to remember that the spectral dimension is fundamentally different, and the 3-D spatial analogy can only go so far…

How do the various sensors assemble this image cube?
Building up the Image Cube

Most spectral imagers* build up the image cube by scanning through it. The conventional methods are whiskbroom (a), filter/Fourier transform (b), pushbroom (c).

*We will also discuss the CTIS snapshot hyperspectral imager

Descour, et al., Applied Optics 34 1995
1D Array Usage in Imaging Spectrometer

1D Array  Diffraction Grating  Focusing Optics  Slit  X-Dimension Scanning Mechanism  Focusing Optics
Whiskbroom Sensor Accumulation (AVIRIS, AVHRR/MODIS, LANDSAT)

Image for single spectrum (i.e. fixed $\lambda$)

$x$, the first spatial dimension is obtained by scanning orthogonal to the direction of sensor motion.

$y$, the second spatial dimension, is obtained in time as sensor is moved across the scene.
2D Array Usage in Imaging Spectrometer

Focal Plane Array
Diffraction Grating
Focusing Optics
Slit
Focusing Optics
Scene FOV
Push-broom Sensor Accumulation
(HYDICE, NVIS, Hyperion)

Image for single spectrum (i.e. fixed $\lambda$)

$y$, the second spatial dimension, is obtained in time as sensor is moved across the scene. Sensor can also acquire data using a whiskbroom scan procedure to increase FOV.
Linear Array CCD

Area Array CCD
Landsat ETM Focal Plane Array

![Diagram of Landsat ETM Focal Plane Array]
## Landsat Sensors
### Thematic Mapper (TM)

<table>
<thead>
<tr>
<th>Spectral bands (micro meters)</th>
<th>IFOV (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. .45-.52 (blue)</td>
<td>30x30</td>
</tr>
<tr>
<td>2. .52-.60 (green)</td>
<td>30x30</td>
</tr>
<tr>
<td>3. .63-.69 (red)</td>
<td>30x30</td>
</tr>
<tr>
<td>4. .76-.90 (near IR)</td>
<td>30x30</td>
</tr>
<tr>
<td>5. 1.55-1.75 (mid IR)</td>
<td>30x30</td>
</tr>
<tr>
<td>6. 2.08-2.35 (mid IR)</td>
<td>30x30</td>
</tr>
<tr>
<td>6. 10.4-12.5 (thermal)</td>
<td>120x120</td>
</tr>
</tbody>
</table>
LANDSAT TM Simulator, Añasco/Mayaguez, PR
Landsat TM Color Composites
Landsat TM SW Puerto Rico
Landsat: Color IR image from SW Puerto Rico

- Example: color infrared (CIR)
  - red channel assigned to near IR sensor band
  - green channel assigned to red sensor band
  - blue channel assigned to green sensor band
- vegetation appears red, soil appears yellow - grey, water appears blue - black
Landsat Simulated Normal Color of PR
IKONOS PAN Sharpened
Old San Juan Bay
Hyperspectral Imagery, also referred to as Imaging Spectrometry, combines:
(i) conventional imaging,
(ii) spectroscopy, and
(iii) radiometry to produce images for which a spectral signature is associated with each spatial resolution element (pixel).

Information Extraction Algorithms for HSI should take advantage of spatial, spatial and temporal variability in the data.
Hyperspectral versus Multispectral
The Spectrum is the Fundamental Datum of HSI RS
Higher Discriminability

Spectral Response vs. Wavelength

Soybeans

Corn
Goals of Spectral Sensing & Imaging
Estimation, Detection, Classification, or Understanding

**Estimate:** probed spectral signature \( \{ \alpha(x,y,\lambda) \} \)
physical parameter to be estimated \( \{ \beta(x,y,\lambda) \} \)

**Examples of** \( \beta \)
- Land cover type
- Crop health
- Chemical composition, pH, CO\(_2\)
- Metabolic information
- Ion concentration
- Physiological changes (e.g., oxygenation)
- Extrinsic markers (dyes, chemical tags)

**Detect:** presence of a target characterized by its spectral features \( \alpha \) or \( \beta \)

**Classify:** objects based on features exhibited in \( \alpha \) or \( \beta \).

**Or Understand:** object information, e.g., spectral signature, shape or other features based on \( \alpha \) or \( \beta \).
Examples of Classification Maps Derived from Different Feature Sets

PCA

SVDSS

OIDPP

IDSS

AVIRIS KSC Image

C-means with covariance Unsupervised Classification 2 features 7 clusters

<table>
<thead>
<tr>
<th>Method</th>
<th>Minimum Bhattacharyya Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCA</td>
<td>0.85</td>
</tr>
<tr>
<td>OIDPP</td>
<td>1.56</td>
</tr>
<tr>
<td>SVDSS</td>
<td>0.44</td>
</tr>
<tr>
<td>IDSS</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Spectral Mixing

Linear

Nonlinear
HSI Abundance Estimation

Reef Flat

Sea Grass

Carbonate Sand
Estimate:

\[ \{ \alpha, \beta \} \]
- Atmospheric constituents
- Aquatic optical properties
- Aquatic constituents
- Benthic composition
- Bathymetry (water depth)

Detect:
- Healthy/unhealthy coral
- Unexploded ordinance
- Human induced changes

Classify:
- Coral distribution
- Seagrass density
- Benthic habitat maps

Understand:
- Environmental stressors
- Seasonal/annual changes
- System productivity

Detectors at different wavelengths, \( Y_i \)

Airborne or Satellite Multi/Hyperspectral

Upwelling Photons measured as At-Sensor Radiance

Broadband Probe, \( P \)

The Sun
Analysis Procedure

**Input Parameters**
- Absorption Properties
- Bottom Reflectance

**Field Spectra**

**Spectral Endmembers**
- Reef, Algae, Sand

**Atmospheric Correction**
- Tafkaa
- Glint Removal

**Inversion Model**
- Semi-Analytical

**Forward Model**
- Semi-Analytical

**Linear Unmixing Model**

**AVIRIS**

**Inversion Output**
- Water Constituent Properties
- Bottom Albedo (550 nm)
- Bathymetry
- RMSE

**Unmixing Output**
- Reef, Algae, Sand Distribution
- RMSE
AVIRIS Derived Bathymetry

AVIRIS Color Composite

8/19/2004 9:36 am W-E

8/19/2004 10:18 am E-W

Bathymetry

8/19/2004 9:36 am W-E

8/19/2004 10:18 am E-W

0 meters

5

10

15

20

SAB Visit 2005
Endmembers

- Sand
- Algae
- Coral
Final Remarks

• Hyperspectral remote sensing is a powerful technology for quantitative remote sensing.

• It is becoming more widely available
  – Commercial providers
    • ITRES, Galileo, etc

• Satellite platforms in plan
  – Hyperion – only available
  – ARTEMIS and others coming!
Any Questions