HYPERSPECTRAL IMAGING

Lecture 9
The term hyperspectral usually refers to an instrument whose spectral bands are constrained to the region of solar illumination, i.e., visible through shortwave infrared, and in the remote sensing context have an observing platform that is either airborne or spaceborne. The data collected are often termed an "image cube" where the two spatial dimensions are joined by the third spectral dimension.
Hyperspectral images are sometimes referred to as “image cubes” because they have a large spectral dimension as well as the two spatial dimensions. This cube shows an AVIRIS hyperspectral image of the Leadville mining district in Colorado.
Hyperspectral Imaging

- Hyperspectral images find many applications in resource management, agriculture, mineral exploration, and environmental monitoring.
- The effective use of hyperspectral images requires an understanding of the nature and limitations of the data and of various strategies for processing and interpreting it.
- An introduction to the fundamental concepts in the field of hyperspectral imaging.
Multispectral remote sensors such as the Landsat Thematic Mapper and SPOT XS produce images with a few relatively broad wavelength bands.

Hyperspectral remote sensors, on the other hand, collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands.

These measurements make it possible to derive a continuous spectrum for each image cell.
Hyperspectral Imaging

Images acquired simultaneously in many narrow, adjacent wavelength bands.

Set of brightness values for a single raster cell position in the hyperspectral image.

A plot of the brightness values versus wavelength shows the continuous spectrum for the image cell, which can be used to identify surface materials.
Hyperspectral images are produced by instruments called imaging spectrometers.

The development of these complex sensors has involved the convergence of two related but distinct technologies: spectroscopy and the remote imaging of Earth and planetary surfaces.

Spectroscopy is the study of light that is emitted by or reflected from materials and its variation in energy with wavelength.

As applied to the field of optical remote sensing, spectroscopy deals with the spectrum of sunlight that is diffusely reflected (scattered) by materials at the Earth's surface.
Instruments called spectrometers (or spectroradiometers) are used to make ground-based or laboratory measurements of the light reflected from a test material.

An optical dispersing element such as a grating or prism in the spectrometer splits this light into many narrow, adjacent wavelength bands and the energy in each band is measured by a separate detector.

By using hundreds or even thousands of detectors, spectrometers can make spectral measurements of bands as narrow as 0.01 micrometers over a wide wavelength range, typically at least 0.4 to 2.4 micrometers (visible through middle infrared wavelength ranges).
## List of Imaging Spectrometers

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Organization</th>
<th>Country</th>
<th>Number of Bands</th>
<th>Wavelength Range (µm)</th>
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</thead>
<tbody>
<tr>
<td>AVIRIS</td>
<td>NASA</td>
<td>United States</td>
<td>224</td>
<td>0.4 - 2.5</td>
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<td>AISA</td>
<td>Spectral Imaging Ltd.</td>
<td>Finland</td>
<td>286</td>
<td>0.45 - 0.9</td>
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<td>CASI</td>
<td>Itres Research</td>
<td>Canada</td>
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<td>0.43 - 0.87</td>
</tr>
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<td>DAIS 2115</td>
<td>GER Corp.</td>
<td>United States</td>
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<td>0.4 - 12.0</td>
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<tr>
<td>HYMAP</td>
<td>Integrated Spectronics Pty Ltd</td>
<td>Australia</td>
<td>128</td>
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<tr>
<td>PROBE-1</td>
<td>Earth Search Sciences Inc.</td>
<td>United States</td>
<td>128</td>
<td>0.4 - 2.45</td>
</tr>
</tbody>
</table>

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Spectral reflectance

- In reflected-light spectroscopy the fundamental property that we want to obtain is spectral reflectance: the ratio of reflected energy to incident energy as a function of wavelength.

- Reflectance varies with wavelength for most materials because energy at certain wavelengths is scattered or absorbed to different degrees.

- The reflectance variations are evident when we compare spectral reflectance curves (plots of reflectance versus wavelength) for different materials.
The overall shape of a spectral curve and the position and strength of absorption bands in many cases can be used to identify and discriminate different materials.

For example, vegetation has higher reflectance in the near infrared range and lower reflectance of red light than soils.
Several libraries of reflectance spectra of natural and man-made materials are available for public use. These libraries provide a source of reference spectra that can aid the interpretation of hyperspectral and multispectral images.

- The ASTER spectral library currently contains nearly 2000 spectra, including minerals, rocks, soils, man-made materials, water, and snow. Many of the spectra cover the entire wavelength region from 0.4 to 14 μm. The library is accessible interactively via the Worldwide Web at http://speclib.jpl.nasa.gov.

- USGS Spectral Library (The United States Geological Survey) Spectroscopy Lab in Denver, Colorado has compiled a library of about 500 reflectance spectra of minerals and a few plants over the wavelength range from 0.2 to 3.0 μm. This library is accessible online at http://speclab.cr.usgs.gov/spectral.lib04/spectral-lib04.html.
Spectral plots are an important tool to use when you explore a hyperspectral image.

A reflectance spectrum consists of a set of reflectance values, one for each spectral channel (band).

Each of these channels can be considered as one dimension in a hypothetical n-dimensional spectral space, where n is the number of spectral channels.
A simple two-band example is shown. The designated point can also be treated mathematically as the end point of a vector that begins at the origin of the coordinate system.

Spectra with the same shape but differing in overall reflectance plot as vectors with the same orientation but with endpoints at different distances from the origin.

Shorter spectral vectors represent darker spectra and longer vectors represent brighter spectra.
It may be difficult to visualize such a plot for an image involving more than three wavelength bands, but it is mathematically possible to construct a hyper-dimensional spectral space defined by dozens or hundreds of mutually-perpendicular coordinate axes.

Each spectrum being considered, occupies a position in this n-dimensional spectral space.

Similarity between spectra can be judged by the relative closeness of these positions (spectral distance) or by how small the angle is between the spectral vectors.
An imaging spectrometer makes spectral measurements of many small patches of the Earth’s surface, each of which is represented as a pixel in the hyperspectral image.

The size of the ground area represented by a single set of spectral measurements defines the spatial resolution of the image and depends on the sensor design and the height of the sensor above the surface.

NASA’s Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), for example, has a spatial resolution of 20 meters when flown at its typical altitude of 20 kilometers, but a 4-meter resolution when flown at an altitude of 4 kilometers.
When the size of the ground resolution cell is large, it is more likely that more than one material contributes to an individual spectrum measured by the sensor.

The result is a composite or mixed spectrum, and the "pure" spectra that contribute to the mixture are called endmember spectra.
Linear and Non-linear mixing

- **Linear spectral mixing:**
  - Each reflected photon interacts with only one surface material.
  - The energy reflected from the materials combines additively, so that each material’s contribution to the composite spectrum is directly proportional to its area within the pixel.

- **Non-linear mixing:**
  - In an intimate mixture, such as the microscopic mixture of mineral particles found in soils, a single photon interacts with more than one material. Such mixtures are nonlinear in character and therefore more difficult to unravel.
Spectral radiance characteristics

- Apart from surface reflectance, the spectral radiance measured by a remote sensor depends on:
  - The spectrum of the input solar energy
  - Interactions of this energy during its downward and upward passages through the atmosphere
  - The geometry of illumination for individual areas on the ground
  - Characteristics of the sensor system.

- Effects:
  - These factors not only affect our ability to retrieve accurate spectral reflectance values for ground features
  - Introduce additional within-scene variability which hampers comparisons between individual image cells.

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The difference in spectral information between two adjacent wavelength bands is typically very small and their grayscale images therefore appear nearly identical.

Much of the data in a scene therefore would seem to be redundant, but embedded in it is critical information that often can be used to identify the ground surface materials.

Dimension reduction methodologies:
- Principle Component Analysis (PCA)
- Kernel Principle Component Analysis (K-PCA)
- Independent Component Analysis (ICA)
- Projection Pursuit

Gaussian distributed data

Non-Gaussian distributed data