HYPERSPECTRAL IMAGE PROCESSING

Pattern Recognition Module
Supplement Lecture
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Overview

- What is Remote Sensing?
- Imaging Types: MSI and HSI
- Sensors
- Applications
- Image Analysis Software
- Feature Extraction
- Information Extraction
- Post Processing
Mini Quiz?

- Some use for ultraviolet spectrum?
- Which type of radiation have the shortest wavelength?
- Why we are not damaged by x-ray from the sun?
- Name a Multispectral Sensor? Hyperspectral?
- Remote Sensing Applications?
- Types of Classification?
Remote Sensing

- **Science and art of identifying, observing and measuring an object without coming into direct contact with it.**

- **RS instruments** measures reflected and/or emitted electromagnetic radiation.

- **RS systems**
  - Passive
  - Active
The Electromagnetic Spectrum is the range of all possible Electromagnetic radiation which has an electric and magnetic field component which oscillate in phase perpendicular to each other and to the direction of energy propagation.
Spectral Resolution

- **Number and dimension** of specific wavelength intervals, referred to as bands or channels.

### Examples:

- **LOW**
  - **Panchromatic**: one very wide band

- **MED**
  - **Multispectral**: several to tens of bands

- **HIGH**
  - **Hyperspectral**: hundreds of narrow bands
Electromagnetic Radiations Types

- Radio frequency
- Microwaves
- Terahertz radiation
- Infrared radiation
- Visible radiation
- Ultraviolet light
- X-rays
- Gamma rays
Example
Domains of RS and its Applications

- **Gamma rays**: nuclear medicine.

- **Ultraviolet**: security, sterilization, disinfecting water.

- **Green**: 515..520-590..600 nm, used for imaging of vegetation and deep water structures.

- **Near infrared**: 750-900 nm, primarily for imaging of vegetation.

- **Mid-infrared**: 2080-2350 nm, for imaging soil, moisture, geological features and fires.

- **Radar**: related technologies, useful for mapping terrain and for detecting various objects.
Light Interaction

- Satellite
- Sun
- Incident Solar Radiation
- Atmosphere
- Reflected Solar Radiation
- Forest
- Water
- Grass
- Bare Soil
- Paved Road
- Built-up Area
Atmospheric Electromagnetic Transmittance

- Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
- Visible Light observable from Earth, with some atmospheric distortion.
- Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
- Radio Waves observable from Earth.
- Long-wavelength Radio Waves blocked.
Sensor

- Multispectral
  - Landsat
  - QuickBird
  - IKONOS
  - Spot
- Hyperspectral
  - AVIRIS
  - Hyperion
  - AISA
Sensor

- **Radar**
  - Monopulse radar
  - Bistatic radar
  - Doppler radar
  - Continuous-wave radar

- **Sonar**
  - Sonograms
  - Underwater sonar: LIMIS and LUIS
Imaging Modalities

- **Panchromatic**
  - The sensor is a single channel detector sensitive to radiation within a broad wavelength range.

- **Multispectral**
  - The sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band.

- **Hyperspectral**
  - The sensor contains hundred of detector acquiring hundred of contiguous images in the electromagnetic spectrum.
Spatial Resolution

- Spatial detail in an image.
- How much of the Earth’s surface a single pixel covers.
- Depends primarily on the instantaneous field of view (IFOV)

\[
\text{Size}_{\text{Area}} = IFOV \cdot H
\]
Spatial Resolution

Multispectral Image
IKONOS 1m

Hyperspectral Image
Hyperion 30m
Spatial Resolution

Same scene – Different spatial resolution
Enrique Reef at Lajas P.R.

SAME SCENE-DIFFERENT RESOLUTION

CASI
5 m

IKONOS
1 m
Multispectral Sample Data
Hyperspectral Sample Data
Hyperspectral Images

- Large amounts of data taken at narrow and contiguous spectral bands.
- Helps to discriminate better between different objects.

Frequently used
- Land cover classification
- Detection and target recognition
- Search and rescue operations
- Biomedical applications
Example of Hyperspectral Image

AVIRIS data-224 spectral Bands 0.4-2.4 µm with 20m spatial resolution
Hyperspectral Sensors

SOC-700 Hyperspectral Imager

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spectral Resolution</th>
<th>Spatial Resolution</th>
<th>No. of Bands</th>
<th>Spectral range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC-700</td>
<td>4 nm</td>
<td>high</td>
<td>120</td>
<td>400-900 nm</td>
</tr>
<tr>
<td>HYDICE</td>
<td>10 nm</td>
<td>1-4 m</td>
<td>210</td>
<td>400-2500 nm</td>
</tr>
</tbody>
</table>

*a Depends on the IFOV of the sensor system and on the distance from the ground to the sensor (H). The IFOV of the SOC-700 is 0.0078125. Size$_{AREA}$ = IFOV x H*
Spectral Resolution

- **Number and dimension** of specific wavelength intervals, referred to as bands or channels.

![Diagram showing spectral resolution with labels for low, medium, and high]

- **Low**
  - **Panchromatic**: one very wide band

- **Medium**
  - **Multispectral**: several to tens of bands

- **High**
  - **Hyperspectral**: hundreds of narrow bands
Spectral Resolution

![Graphs showing spectral profiles with wavelength on the x-axis and value on the y-axis. The graphs compare #1 Spectral Profile: EnriqueReef.bsq with #2 Spectral Profile: Memory1.](image-url)
Spectral and Spatial Trade of

- Sensor aperture
- Sensor altitude
- Observed area
Multispectral vs Hyperspectral

- **HSI images**
  - High spectral resolution
  - The measured spectra is the contribution of the spectral signatures of the objects in the field of view of the sensor.

- **MSI**
  - High spatial resolution
  - Low spectral profile
  - Specifically derived applications
Remote Sensing Applications

- Multispectral
  - Mapping
  - Forestry
  - Resource management
  - Oceanography

- Hyperspectral
  - Geology
  - Mining
  - Mapping
  - Ecology
  - Surveillance
State of the Art in HSI Software Tools

**ENVI**
by Research Systems Inc., a ITT subsidiary.

**MultiSpec**
developed at Purdue University by Dr. David Landgrebe and the Remote Sensing research group in Purdue’s LARS
Hyperspectral Image Analysis

MATLAB Toolbox

Hardware Implementation in FPGA/DSP and GPUs
Laboratory #1

Basic image analysis and applications

- Introduction to ENVI
- Learning to use the basic operations
- Image Manipulation
  - Loading images
  - Displaying different bands
  - Displaying pixel information
  - Merging data sets
Data Reduction

- HSI contains hundreds of bands.
- High Dimensionality in HSI.
  - Curse of dimensionality.
- High Computational time.
Data Projection

Feature Extraction as a Linear Projection

- \( x \) original data space
- \( A \) projection matrix
- \( y \) reduced data by means of

\[
Y = \Lambda^T X
\]

High Dimensional Space
- \( d \)-dimensional
  - (AVIRIS 224 Channels)

Lower Dimensional Subspace
- \( p \)-dimensional (\( p \ll d \))
Feature Extraction

- Principal Component Analysis
- Discriminant Analysis
- Projection Pursuit
PCA Definition

- PCA is mathematically defined as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on.

\[ Y = XW = VU \]

- Where \( VUW \) is the singular value decomposition of \( X \)
PCA Example

HSI Data

HSI data using PCA
Information Extraction

- Classification
  - Supervised
  - Unsupervised

- Unmixing
  - Abundance Estimation
  - Full Unmixing
Image Classification

- Process of assigning all pixels in a digital image to particular classes according to their characteristics.

- Result: Thematic Map

- Main Classification Schemes
  - Unsupervised
  - Supervised
  - Semi-Supervised
Classification of hyperspectral image

Hyperspectral dataset

Preprocessing

Atmospheric and radiometric correction: reduce distortion and enhance dataset

Feature extraction

Reduce bands using principal components reduce data dimensionality

Classification

Use feature image (reduced bands) pixels to perform classification using distance classifiers (supervised or unsupervised): identify pixels
Supervised Classification

- Uses samples of known identity - **Training data** - to classify pixels of unknown identity.

- **Testing samples** are used to evaluate the accuracy of the classifier.

- **Different Supervised Classification Methods**
  - Maximum Likelihood
  - Minimum Distance
  - Mahalanobis Distance
  - Neural Networks
  - Support Vector Machines (SVMs)
Supervised Classification

- Analyst identifies in the imagery homogeneous representative samples of the different surface cover types or classes of interest.

- These samples data are referred to as **training areas**. The analyst is "supervising" the categorization of a sets of specific classes.

- The numerical information in all spectral bands for the pixels comprising these areas are used to "train" the algorithms to recognize spectrally similar areas for each class.

- Once the algorithms has determined the statistics for each class, each pixel in the image is compared each class statistics and labeled as the class it most closely "resembles" to create a **Class Map**.
Unsupervised Classification

- Identification of natural groups
- Based only on the dataset statistics
  - No previous knowledge about the classes
- User inputs the number of classes
  - User must then name each class
- Main unsupervised classification methods
  - K-Means
  - Isodata (Iterative Self-Organizing Data Analysis Technique)
Unsupervised Classification

- **Clusters** (similar as classes), group similar pixels based on the natural data statistics.

- Different measurement create different clusters.

- The analyst specifies how many groups or clusters are to be looked for in the data.

- Analyst also specify parameters related to the separation distance among the clusters and the variation within each cluster.

- The final result is a **Cluster Map or Class Map**.
Classified Image
Classifications of IKONOS image (La Parguera)

4 bands
- R, Near IR, G, B

Total features = 4
(Band R spectral value and 3 Statistical features)
8x8 regions
Accuracy (testing) = 99%

Maximum likelihood classification using 4 bands of spectral values
Coastal classification
IKONOS image

Coral/algae
Seagrass
Sand
Water
Mangroves

4 bands – R, NIR, G and B
Resolution -1mt.

Class map – using spectral and gray level statistical features -3x3 regions
Total features = 5 (NIR band and 4 statistical features)
Accuracy (testing samples) = 95.0745%
Laboratory # 2
Feature Extraction and Information Extraction

- Use of different feature extraction technique
- Comparison of images projected
- Basic Classifier
  - Supervised
- Class Map comparison and accuracy
Unmixing

- **Spectral unmixing** is the processing is to decompose the mixed pixels into the materials that contribute to the pixel, *endmember and a set of corresponding fractions* of the spectral signature in the pixel, *abundances.*
Mixed pixels are an important problem in information extraction from remote sensed imagery.

Low spatial resolution sensors

Mixed Pixel constituent by three object spectra

\[ x = \sum_{i=1}^{3} a_i s_i + w = Sa + w \]

PSF effects

Boundaries among classes
Post Processing

- Techniques for class map enhancement
  - Base on contextual information of the image classes
  - Using spatial and spectral information of pixel neighborhood to enhance the final map
- Common use is for removing class map anomalies
- In addition, for class smoothness
Laboratory #3
Post processing & Unmixing

- Use of basic post processing algorithms for class map improvement.
- Class map comparison.
- Accuracy of the different maps.
- Using Unmixing Algorithms for Information Extraction