Overview of How Digital Remotely Sensed Data are Transformed into Useful Information
EXAMPLES OF MAIN PROGRAMS FOR ENVIRONMENTAL REMOTE SENSING

- TIROS (USA)
- NOAA (USA)
- Nimbus (USA)
- Landsat (USA)
- GOES/METEOSAT (USA/Europe)
- SPOT (France)
- JERS (Japan)
- ERS (European Space Agency)
- IRS (India)
- RADARSAT (Canada)
SATELLITE ORBITS OF REMOTE SENSORS

Equatorial  Polar  Near Polar  Geostationary

Remote Sensing System used for Multispectral and Hyperspectral Data Collection
Two fundamental ways to obtain digital imagery:

1) acquire remotely sensed imagery in an analog format (often referred to as hard-copy) and then convert it to a digital format through the process of digitization, such as aerial photographs

or

2) acquire remotely sensed imagery already in a digital format, such as that obtained by multispectral or hyperspectral sensors.

Digitization

Into an image processing software, like ENVI

ENVI From Images to Information
Relationship between digitizer instantaneous-field-of-view measured in dots per inch or micrometers, and the pixel ground resolution at various scales of photography.

<table>
<thead>
<tr>
<th>Digitizer Detector IFV</th>
<th>Pixel Ground Resolution at Various Scales of Photography (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1:10,000</td>
</tr>
<tr>
<td>100</td>
<td>25.00</td>
</tr>
<tr>
<td>200</td>
<td>12.90</td>
</tr>
<tr>
<td>300</td>
<td>8.67</td>
</tr>
<tr>
<td>400</td>
<td>6.50</td>
</tr>
<tr>
<td>500</td>
<td>5.80</td>
</tr>
<tr>
<td>600</td>
<td>5.00</td>
</tr>
<tr>
<td>700</td>
<td>4.40</td>
</tr>
<tr>
<td>800</td>
<td>3.88</td>
</tr>
<tr>
<td>900</td>
<td>3.45</td>
</tr>
<tr>
<td>1000</td>
<td>3.12</td>
</tr>
<tr>
<td>1200</td>
<td>2.67</td>
</tr>
<tr>
<td>1500</td>
<td>2.14</td>
</tr>
<tr>
<td>2000</td>
<td>1.70</td>
</tr>
<tr>
<td>3000</td>
<td>1.13</td>
</tr>
<tr>
<td>4000</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Useful Scanning Conversions

- Dots per inch (dpi) = \( \frac{P}{1.27} \) micrometers
- Dots per square millimeter (dpi) = \( \frac{P}{1.27} \) micrometers
- Dots per square centimeter (dpi) = \( \frac{P}{1.27} \) micrometers

Conversion of Field/Ground Resolution

\[ P = \frac{F}{S} \]

Useful Examples

- For example, if a 5.100000 scale model is scanned at 500 dpi, the pixel size will be (500000/500000) \( \times 0.000032 \) = 0.03 per pixel.
- If a 1.000000 scale model is scanned at 500 dpi, the pixel size will be (500000/500000) \( \times 0.000032 \) = 0.03 per pixel.

LANDSAT: REMOTE SENSORS

- **Return Beam Vidicon camera (RBV)**: B,G,R
- **Multispectral Scanner (MSS)**: G,R, 2 NIR
- **Thematic Mapper (TM)**: B,G,R, NIR, 2 MIR, FIR
- **Enhanced Thematic Mapper Plus (ETM+)**: B,G,R, NIR, 2 MIR, FIR, PAN
- **Operational Land Imager (OLI)**: B,G,R, NIR, 3MIR, PAN
- **Thermal Infrared Sensor (TIRS)**: 2 Thermal Bands
Landsat Multispectral Scanner (MSS) and Landsat Thematic Mapper (TM) Sensor System Characteristics

<table>
<thead>
<tr>
<th>Band</th>
<th>Spectral Resolution (µm)</th>
<th>Radiometric Sensitivity (NEE/EPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.5 – 0.6</td>
<td>0.57</td>
</tr>
<tr>
<td>5</td>
<td>0.6 – 1.1</td>
<td>0.55</td>
</tr>
<tr>
<td>6</td>
<td>0.7 – 0.8</td>
<td>0.60</td>
</tr>
<tr>
<td>7</td>
<td>0.8 – 1.3</td>
<td>0.70</td>
</tr>
<tr>
<td>8</td>
<td>1.4 – 2.4</td>
<td>1.64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band</th>
<th>Spectral Resolution (µm)</th>
<th>Radiometric Sensitivity (NEE/EPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.51 – 0.52</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>0.52 – 0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>0.60 – 0.69</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>0.76 – 0.90</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>1.53 – 1.75</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>10.40 – 12.5</td>
<td>0.5 (NEE/EPM)</td>
</tr>
<tr>
<td>7</td>
<td>2.00 – 2.35</td>
<td>2.4</td>
</tr>
</tbody>
</table>

- HFOV at nadir: 70 x 70 m for bands 1 through 7; 240 x 240 m for band 8
- Data rate: 35 Mbps
- Quantization levels: 6 bit (values from 0 to 63) or 8 bit (values from 0 to 255)
- Earth coverage: 18 days (bands 1, 2, 3); 16 days (bands 4, 5, 6)
- Altitude: 919 km
- swath width: 185 km
- Inclination: 99°

*The radiometric sensitivities are the noise-equivalent reflectance differences for the reflective channels expressed as percentages (NEE/EPM) and in microvolts for the thermal infrared bands (NET/EPM).

**Band 8, Band 9, and Band 10 are used for atmospheric correction purposes and are not available for normal use.

Landsat Multispectral Scanning System (MSS)
Inclination of the Landsat Orbit to Maintain A Sun-synchronous Orbit

Landsat Multispectral Scanning System (MSS) Orbit
Orbit Tracks of Landsat 1, 2, or 3 During A Single Day of Coverage

Components of the Landsat Multispectral Scanner (MSS) System on Landsat 1 Through 5
Landsat Multispectral Scanner Bandwidths

MSS Image from Western PR
Landsat 4 and 5 Thematic Mappers

High-gain antenna

Global positioning system (GPS) antenna

Attitude control module

Power module

Multispectral Scanner (MSS)

Thematic Mapper (TM)

Solar array panel

Solar array

Global positioning system antenna

Attitude control module

Propulsion module

Power module

High-gain antenna

Landsat 4 and 5 Platform with Associated Sensor and Telecommunication Systems
Components of the Landsat 4 and 5 Thematic Mapper
Seven Bands of Landsat Thematic Mapper Data of Charleston, SC, Obtained on February 3, 1994

Reflectance of the Upper Surface of A Sycamore Leaf at Different Moisture Contents

[Graph showing reflectance of a sycamore leaf at different moisture conditions]
ETM+ BANDS

<table>
<thead>
<tr>
<th>Band</th>
<th>Micrometers</th>
<th>Resolution (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.45 to .515</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>.525 to .605</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>.63 to .690</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>.75 to .90</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>1.55 to 1.75</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>10.40 to 12.5</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>2.09 to 2.35</td>
<td>30</td>
</tr>
<tr>
<td>Pan</td>
<td>.52 to .90</td>
<td>15</td>
</tr>
</tbody>
</table>

ETM+ TECHNICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Type</th>
<th>opto-mechanical scanner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial resolution</td>
<td>15/30/60 m</td>
</tr>
<tr>
<td>Spectral range</td>
<td>0.45-12.5 µm</td>
</tr>
<tr>
<td>Number of bands</td>
<td>8</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>16 days</td>
</tr>
<tr>
<td>Size of image</td>
<td>183 x 170 km</td>
</tr>
<tr>
<td>Swath</td>
<td>183 km</td>
</tr>
<tr>
<td>Stereo</td>
<td>n</td>
</tr>
<tr>
<td>Programmable</td>
<td>y</td>
</tr>
</tbody>
</table>

Landsat 7 Imagery
ETM+
13-NOV-2000

LANDSAT-8
Launch: February 11, 2013
Operational Land Imager (OLI)
Thermal Infrared Sensor (TIRS)

OLI and TIRS band designations:

<table>
<thead>
<tr>
<th>Spectral bands</th>
<th>Wavelength (micrometers)</th>
<th>Resolution (meters)</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1-coastal aerosol</td>
<td>0.43–0.45</td>
<td>30</td>
<td>Increased coastal zone observations.</td>
</tr>
<tr>
<td>Band 2-blue</td>
<td>0.45–0.51</td>
<td>30</td>
<td>Bidirectional mapping; distinguishes soil from vegetation; deciduous from coniferous vegetation.</td>
</tr>
<tr>
<td>Band 3-green</td>
<td>0.55–0.59</td>
<td>30</td>
<td>Emphasizes peak vegetation, which is useful for assessing plant vigor.</td>
</tr>
<tr>
<td>Band 4-red</td>
<td>0.64–0.67</td>
<td>30</td>
<td>Emphasizes vegetation slopes.</td>
</tr>
<tr>
<td>Band 5-near IR</td>
<td>0.85–0.88</td>
<td>30</td>
<td>Emphasizes vegetation boundary between land and water, and landcovers.</td>
</tr>
<tr>
<td>Band 6-SWIR 1</td>
<td>1.57–1.65</td>
<td>30</td>
<td>Used in detecting plant drought stress and delineating burned areas and fire-affected vegetation, and is also sensitive to the thermal radiation emitted by intense fires; can be used to detect active fires, especially during nighttime when the background interference from SWIR is reflected sunlight is absent.</td>
</tr>
<tr>
<td>Band 7-SWIR 1</td>
<td>2.11–2.29</td>
<td>30</td>
<td>Used in detecting drought stress, burned and fire-affected areas, and can be used to detect active fires, especially at nighttime.</td>
</tr>
<tr>
<td>Band 8-panchromatic</td>
<td>0.50–0.68</td>
<td>15</td>
<td>Useful in &quot;sharpening&quot; multi-spectral images.</td>
</tr>
<tr>
<td>Band 9-cirrus</td>
<td>1.36–1.38</td>
<td>30</td>
<td>Useful in detecting cirrus clouds.</td>
</tr>
<tr>
<td>Band 10-TIRS 1</td>
<td>10.60–11.19</td>
<td>100</td>
<td>Useful for mapping thermal differences in water currents, monitoring fires and other night studies, and estimating soil moisture.</td>
</tr>
<tr>
<td>Band 11-TIRS 2</td>
<td>11.50–12.51</td>
<td>100</td>
<td>Same as band 10.</td>
</tr>
</tbody>
</table>

Resolutions of OLI:

Spatial = 30 m, 15 pan
Spectral = 8 bands
Radiometric = 12 bits
Temporal = 16 days

http://glovis.usgs.gov
http://edcsns17.cr.usgs.gov/EarthExplorer
GOES East and West Coverage

Useful GOES coverage
Communication range

GOES Imager Optical Elements

GOES Imager Optical Elements

Visible detectors (8)
0.52 – 0.72 μm
Spectral balance filter
Visible bandpass filter
Depolarizer
Dichroic beamsplitter
Primary mirror
Secondary mirror
Radiant flux (6) from the terrain
GOES East and West Coverage

Chronological Launch History of the SPOT Satellites

Launch Dates
SPOT 1 - February 21, 1986
SPOT 2 - January 22, 1990
SPOT 3 - September 25, 1993
SPOT 4 - March 24, 1998
SPOT 5 - May 3, 2002
SPOT Satellite System Components
Geographic Coverage of the SPOT HRV and Landsat Thematic Mapper Remote Sensing Systems

Comparison of the Detail of 30 x 30 m Landsat TM Band 3 Data and SPOT 10 x 10 m Panchromatic Data of Charleston, SC
SPOT/LANDSAT TM

NEW SENSORS WITH HIGH SPATIAL RESOLUTION

IKONOS
IKONOS SENSOR

IKONOS is derived from the Greek word for "image." The IKONOS satellite is the world’s first commercial satellite to collect black-and-white images with 1-meter resolution and multispectral imagery with 4-meter resolution. IKONOS and was launched on September 24, 1999 from Space Launch Complex 6 (SLC-6) at Vandenberg Air Force Base in California.

Sensor Characteristics

The IKONOS satellite weighs about 1600 pounds. It orbits the Earth every 98 minutes at an altitude of approximately 680 kilometers or 423 miles. IKONOS was launched into a sun-synchronous orbit, passing a given longitude at about the same local time (10:30 A.M.) daily. IKONOS can produce 1-meter imagery of the same geography every 3 days.

Spectral Range

1-meter black-and-white (panchromatic) 0.45 - 0.90 mm.

4-meter multispectral
Blue: 0.45 - 0.52 mm
Green: 0.51 - 0.60 mm
Red: 0.63 - 0.70 mm
Near IR: 0.76 - 0.85 mm

1 meter – B/W
1 meter – True Color
4 meter – False Color
4 meter – True Color
La Parguera

Bahia Mosquito, Vieques
Characteristics of the Daedalus Airborne Multispectral Scanner (AMS)

Aircraft Multispectral Scanner Data of Fiver Mile Creek Delta in South Carolina

- b. Color-infrared composite (RGB = bands 30, 6, 4).
- b. Color-infrared composite (RGB = bands 30, 6, 4).
Advanced Thermal and Land Applications Sensor (ATLAS)
DIGITAL IMAGE CLASSIFICATION

REFERENCE: Introduction to Remote Sensing, Chapter 11
James B. Campbell (2007)
The Guilford Press
DEFINITION

It is the process of assigning pixels to classes. Usually each pixel is treated as an individual unit composed of values in several spectral bands.

FIGURE 11.1. Numeric image and classified image. The classified image (right) is defined by examining the numeric image, then grouping together those pixels that have similar spectral values. Here class "A" is formed from bright pixels (values of 6, 7, 8, and 9), and class "B" is formed from dark pixels (values of 0, 1, 2, and 3). Usually there are many more classes and at least three or four spectral bands.
FIGURE 11.2. Point classifiers operate upon each pixel as a single set of spectral values considered in isolation from its neighbors.

INFORMATIONAL CLASSES AND SPECTRAL CLASSES

INFORMATIONAL CLASS "FOREST"

SPECTRAL SUBCLASSES ARISING FROM VARIATIONS IN ILLUMINATION
- SHADOWED FOREST
- DIRECTLY LIT FOREST

SPECTRAL SUBCLASSES ARISING FROM VARIATIONS IN SPECIES COMPOSITION
- 10% PINE 90% OAK
- 50% PINE 50% OAK

SPECTRAL SUBCLASSES ARISING FROM VARIATIONS IN DENSITY
- SPARSE FOREST
- DENSE FOREST

FIGURE 11.4. Spectral subclasses.
UNSUPERVISED CLASSIFICATION

It can be defined as the identification of natural groups, or structures, within multispectral data.

ADVANTAGES OF THE UNSUPERVISED CLASSIFICATION

- No extensive prior knowledge of the region is required.
- The opportunity for human error is minimized.
- Unique classes are recognized as distinct units.
DISADVANTAGES OF THE UNSUPERVISED CLASSIFICATION

- Identifies spectrally homogeneous classes that do not necessarily correspond to the categories that are of interests to the analyst.

- The analyst has limited control over the menu of classes and their identities.

- Spectral properties of specific classes will change over time.
FIGURE 11.7. Sketch illustrating multidimensional scatter diagrams. Here three bands of data are shown.

FIGURE 11.8. Scatter diagram. Data from two Landsat MSS bands illustrate the general form of the relationship between spectral measurements in contiguous regions of the spectrum. This diagram shows several hundred points; when so many values are shown, the distinct clusters visible in Figure 11.6 are not visible. The groups may still be present, but they can only be detected by application of classification algorithms that can simultaneously consider values in many spectral bands. From Todd et al. (1980, p. 511) Copyright 1980 by the American Society for Photogrammetry and Remote Sensing. Reproduced with permission.
SUPERVISED CLASSIFICATION

It can be defined as the process of using samples (training data) of known identity to classify pixels of unknown identity.

FIGURE 11.12. Assignment of spectral categories to image categories. Unsupervised classification defines the clusters defined schematically on the scatter diagram. The analyst must decide which, if any, match to the list of informational categories that form the object of the analysis.
ADVANTAGES OF THE SUPERVISED CLASSIFICATION

- The analyst has control of a selected menu of informational categories tailored to a specific purpose and geographic region.
- It is tied to specific areas of known identity, called training areas.
- It is not necessary to match the spectral categories with the informational categories of interest.
- The operator may be able to detect serious errors in classification by examining how training data have been classified.

DISADVANTAGES OF THE SUPERVISED CLASSIFICATION

- The analyst imposes a classification structure upon the data.
- Training data are often defined primarily with reference to informational category.
- Training data selected by the analyst may not be representative of conditions encountered throughout the image.
- Selection of training data can be time-consuming, expensive, and tedious.
- It may not be able to recognize and represent special or unique categories not represented in the training data.
KEY CHARACTERISTICS OF TRAINING AREAS

1. Number of Pixels
2. Size
3. Shape
4. Location
5. Number
6. Placement
7. Uniformity

FIGURE 11.13. Training fields and training data. Training fields, each composed of many pixels, sample the spectral characteristics of informational categories. Here the shaded figures represent training fields, each positioned carefully to estimate the spectral properties of each class, as represented by the histograms. This information provides the basis for classification of the remaining pixels not within the training fields.
FIGURE 11.14. Location of training fields with reference to landmarks. Training fields must be positioned with reference to features easily recognizable on the ground, on maps and aerial photographs, and on the digital imagery.

FIGURE 11.15. Positioning training fields. Here the irregular line represents the edge of a parcel visible on a digital image. The inner rectangle represents the training field surrounded by a "buffer" of pixels within the parcel, but not included in the training data. These unused pixels help ensure that mixed pixels at the edge of the parcel are not included within the training field. (Remember that the analyst may not have absolute confidence in his or her ability to match map or photo information to the digital image.)
IDEALIZED SEQUENCE FOR SELECTING TRAINING DATA

1. Assemble information
2. Field studies
3. Carefully plan collection of field observations.
4. Preliminary examination of the digital scene.
5. Identify prospective training areas.
6. Display digital image and identify training areas.
7. Display and inspect histograms of all spectral bands.
8. Modify boundaries of the training fields to eliminate bimodality.
9. Incorporate training data information into the classification procedure.

FIGURE 11.16. Uniform and heterogeneous training data. On the left, the histogram of the training data has a single peak, indicating a degree of spectral homogeneity. Data from such training fields form a suitable basis for image classification. On the right, a second set of training data displays a bimodal histogram that reveals that this area encompasses two, rather than one, spectral classes. This training area is not satisfactory for image classification and must be discarded or redefined.
FIGURE 11.17. Parallelepiped classification. Ranges of values within training data (Table 11.4) define decision boundaries. Here only two bands are shown, but the principle extends to several spectral bands. Other pixels, not from the training fields, are classified as a given category if their positions fall within the polygons defined by the training data.
FIGURE 11.18. Minimum distance classifier. Here small dots represent pixels from training fields and crosses indicate the large unclassified pixels from elsewhere in the image; each of these pixels is assigned to the class with the closest centroid, as measured using the distance measures discussed in the text.

FIGURE 11.19. Maximum likelihood classification. These frequency distributions represent pixels from two training fields; the zone of overlap depicts pixel values common to both categories. The relations of the values within the overlap region to the overall frequency distribution for each class forms the basis for assigning pixels to classes.
FIGURE 11.21. Membership functions for fuzzy clustering. This example illustrates membership functions for the simple instance of three classes considered for a single band, although the method is typically applied to multiple bands. The horizontal axis represents pixel brightness; the vertical axis represents degree of membership, from low near the bottom to high at the top. The class "Water" consists of pixels darker than brightness 20, although only pixels darker than 8 are likely to be completely occupied by open water. The class "Agriculture" can include pixels as dark as 22 and as bright as 33, although pure "Agriculture" pixels are found only in the range 24 to 28. A pixel of brightness 24, for example, can only be "Agriculture," although a pixel of brightness 24 could be partially forested, partially in agriculture. Unlabeled areas on this diagram are not occupied by any of the classes in this classification.

FIGURE 11.22. Artificial neural net.