CHAPTER 1: REMOTE SENSING OF THE ENVIRONMENT

REFERENCE: Remote Sensing of the Environment
John R. Jensen (2007)
Second Edition
Pearson Prentice Hall
What is Remote Sensing?

Photographic Interpretation – the act of examining photographic images for the purpose of identifying objects and judging their significance (Colwell, 1966).
Remote Sensing – the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study (by the American Society of Photogrammetry and Remote Sensing-ASPRS; in Colwell, 1983).
Photogrammetry and Remote Sensing – are the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representation of energy patterns derived from non-contact sensor systems (adopted by the ASPRS in 1988; in Colwell, 1997).
Spectral Reflectance Measurement using a Spectroradiometer.
To be of greatest value, the original remotely sensed data must usually be:

1) geometrically \((x,y,z)\) and radiometrically \((\text{e.g., to percent reflectance})\) calibrated so that remotely sensed data obtained on different dates can be compared with one another.

2) calibrated (compared) with what is on the ground in terms of biophysical (e.g., leaf-area-index, biomass) or cultural characteristics (e.g., land use/cover, population density).

THEREFORE, Fieldwork is necessary to achieve both of these objectives. Thus, a person who understands how to collect meaningful field data about the phenomena under investigation is much more likely to use the remote sensing science wisely.
GROUNDS TRUTHING

a. Spectroradiometer measurement.

b. Global positioning system (GPS) measurement.
A remote sensing instrument collects information about an object or phenomenon within the instantaneous-field-of-view (IFOV) of the sensor system without being in direct physical contact with it. The remote sensing instrument may be located just a few meters above the ground and/or onboard an aircraft or satellite platform.
A *science* is defined as the broad field of human knowledge concerned with facts held together by *principles* (rules).

Scientists discover and test facts and principles by the scientific method, an orderly system of solving problems.

Scientists generally feel that any subject that humans can study by using the scientific method and other special rules of thinking may be called a science.

The sciences include:

1) *mathematics* and *logic*,
2) the *physical sciences*, such as physics and chemistry,
3) the *biological sciences*, such as botany and zoology, and
4) the *social sciences*, such as geography, sociology, and anthropology.
Is Remote Sensing an Art?

Visual image interpretation brings to bear not only scientific knowledge but all of the *experience* that a person has obtained in a lifetime.

The synergism of combining scientific knowledge with *real-world analyst experience* allows the interpreter to develop heuristic rules of thumb to extract information from the imagery.

Some image analysts are superior to other image analysts because they:

1) understand the scientific principles better,

2) are more widely traveled and have seen many landscape objects and geographic areas, and/or

3) have the ability to synthesize scientific principles and real-world knowledge to reach logical and correct conclusions.

Thus, remote sensing image interpretation is both an *art* and a *science*. 
Remote sensing is a tool or technique similar to mathematics.

Using sensors to measure the amount of electromagnetic radiation (EMR) exiting an object or geographic area from a distance and then extracting valuable information from the data using mathematically and statistically based algorithms is a scientific activity.

It functions in harmony with other spatial data-collection techniques or tools of the mapping sciences, including cartography and geographic information systems (GIS) (Clarke, 2001).
Interaction Model Depicting the Relationships of the Mapping Sciences as they relate to Mathematics and Logic, and the Physical, Biological, and Social Sciences.
MILESTONE IN THE HISTORY OF REMOTE SENSING

- Balloons
- Pigeons
- Airplanes
- Satellites
1609 and 1700s
1887 - Sir Isaac Newton’s Principia summarizes basic laws of mechanics
1886 - Joseph Nicephore Niepce takes first photograph
1887 - Louis M. Dappert invents positive print stereotyping photography
1889 - William Henry Fox Talbot invents Calotype negative-positive process
1895 - James Clerk Maxwell publishes additive color theory
1898 - Gaspard Felix Tournachon takes aerial photograph from a balloon
1900 - James Clerk Maxwell puts forth electromagnetic wave theory

1908 - American Society of Photogrammetry (ASP) founded
1934 - Photogrammetric Engineering (ASEP)
1958 - Photogrammetry (ISP)
1938 - World War II photo-reconnaissance advances
1940 - RADAR invented
1941 - Jet aircraft invented by Germany
1942 - Kodak patent for color negative film
1942 - Launch of German V-2 rocket by Wernher von Braun (Oct 3)

1950s
1950 - Thermal infrared remote sensing invented by military
1953 - Photogrammetric Record (Photogrammetric Society, U.K.)
1954 - Washington, DC develops side-looking airborne radar system
1955 - United States launches Sputnik satellite
1960 - Central Intelligence Agency U-2 reconnaissance program
1957 - Soviet Union launches Sputnik satellite (Oct 4)
1958 - United States launched Explorer 1 satellite

1960s
1960 - Emphasis primarily on visual image processing
1960 - Manned Willow Run Laboratory
1961 - First International Symposium on Remote Sensing of Environment at Ann Arbor, MI
1962 - Paul data laboratory for agricultural remote sensing (LARS) active
1964 - Forestry Remote Sensing Lab at U.C. Berkeley (Robert Colwell)
1967 - Delft initiates photogrammetric education for foreign students
1966 - Digital image processing initiated at LARS, Berkeley, Kansas, ERIM
1967 - Declasification of radar and thermal infrared sensor systems
1967 - United States CORONA spy satellite program
1969 - Air Force Photoreconnaissance (ASP)
1970 - Remotely sensed image introduced by Evelyn Pratt and other U.S. Office of Naval Research personnel
1971 - Yuri Gagarin becomes first human to travel in space
1973 - Columbia Missle Crisis - U-2 photo-reconnaissance shown to public
1984 - SR-71 discussed at President Ronald Reagan press briefing
1963 - Hungarian space program
1965 - ISPERS Journal of Photogrammetry & Remote Sensing
1969 - Remote Sensing of Environment (Elsevier)
Remote sensing is *unobtrusive* if the sensor *passively* records the EMR reflected or emitted by the object of interest. Passive remote sensing does not disturb the object or area of interest.
Advantages of Remote Sensing

Remote sensing devices may be programmed to collect data systematically, such as within a $9 \times 9$ in. frame of vertical aerial photography. This systematic data collection can remove the sampling bias introduced in some *in situ* investigations.
Advantages of Remote Sensing

Under controlled conditions, remote sensing can provide fundamental biophysical information, including $x,y$ location, $z$ elevation or depth, biomass, temperature, and moisture content.
Advantages of Remote Sensing

Remote sensing–derived information is now critical to the successful modeling of numerous natural (e.g., water-supply estimation; eutrophication studies; nonpoint source pollution) and cultural (e.g., land-use conversion at the urban fringe; water-demand estimation; population estimation) processes.
The greatest limitation is that it is often *oversold*. Remote sensing is *not a panacea* that provides all the information needed to conduct physical, biological, or social science research. It provides some spatial, spectral, and temporal *information* of value in a manner that we hope is efficient and economical.

**WorldView-2**

WorldView-2, launched October 2009, is the first high-resolution 8-band multispectral commercial satellite. Operating at an altitude of 770 kilometers, WorldView-2 provides 46 cm* panchromatic resolution and 1.84 meter* multispectral resolution. WorldView-2 has an average revisit time of 1.1 days and is capable of collecting up to 975,000 square kilometers (376,000 square miles) per day**, more than tripling the DigitalGlobe multispectral collection capacity for more rapid and reliable collection.

The WorldView-2 system, offering incredible accuracy, agility, capacity and spectral diversity, allows DigitalGlobe to substantially expand its imagery product offerings to both commercial and government customers.
Limitations of Remote Sensing

*Human beings* select the appropriate remote sensing system to collect the data, specify the various resolutions of the remote sensor data, calibrate the sensor, select the platform that will carry the sensor, determine when the data will be collected, and specify how the data are processed. *Human method-produced error* may be introduced as the remote sensing instrument and mission parameters are specified.
Powerful active remote sensor systems that emit their own electromagnetic radiation (LIDAR, RADAR, SONAR) can be intrusive and affect the phenomenon being investigated. Additional research is required to determine how intrusive these active sensors can be.
Remote sensing instruments may become *uncalibrated*, resulting in uncalibrated remote sensor data.
Remote sensor data may be expensive to collect and analyze. Hopefully, the information extracted from the remote sensor data justifies the expense.
The remote sensing data-collection and analysis procedures used for Earth resource applications are often implemented in a systematic fashion referred to as the *remote sensing process*. 

**The Remote Sensing Process**

The remote sensing data-collection and analysis procedures used for Earth resource applications are often implemented in a systematic fashion referred to as the *remote sensing process*. 

**DATA ACQUISITION**

- a) Sources of energy
- b) Propagation through the atmosphere
- c) Earth surface features
- d) Re-transmission through the atmosphere
- e) Sensing systems

**DATA ANALYSIS**

**Pre-processing**

**Analysis**
The Remote Sensing Process

- **Statement of the Problem**
  - Formulate Hypothesis (if appropriate)
- **Select Appropriate Logic**
  - Inductive and/or
  - Deductive
  - Technological
- **Select Appropriate Model**
  - Deterministic
  - Empirical
  - Knowledge-based
  - Process-based
  - Stochastic

### Data Collection
- **In Situ Measurements**
  - Field (e.g., x,y,z from GPS, biomass, reflectance)
  - Laboratory (e.g., reflectance, leaf area index)
- **Collateral Data**
  - Digital elevation models
  - Soil maps
  - Surficial geology maps
  - Population density, etc.
- **Remote Sensing**
  - Passive analog
    - Frame camera
    - Videography
  - Passive digital
    - Frame camera
    - Scanners
      - Multispectral
      - Hyperspectral
    - Linear and area arrays
      - Multispectral
      - Hyperspectral
  - Active
    - Microwave (RADAR)
    - Laser (LIDAR)
    - Acoustic (SONAR)

### Data-to-Information Conversion
- **Analog (Visual) Image Processing**
  - Using the *Elements of Image Interpretation*
- **Digital Image Processing**
  - Preprocessing
    - Radiometric Correction
    - Geometric Correction
  - Enhancement
  - Photogrammetric analysis
  - Parametric, such as
    - Maximum likelihood
  - Nonparametric, such as
    - Artificial neural networks
  - Nonmetric, such as
    - Expert systems
    - Decision-tree classifiers
    - Machine learning
  - Hyperspectral analysis
  - Change detection
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling
    - Scientific geovisualization
      - 1, 2, 3, and n dimensions
- **Hypothesis Testing**
  - Accept or reject hypothesis

### Information Presentation
- **Image Metadata**
  - Sources
  - Processing lineage
- **Accuracy Assessment**
  - Geometric
  - Radiometric
  - Thematic
  - Change detection
- **Analog and Digital**
  - Images
    - Unrectified
    - Orthoimages
    - Orthophotomaps
    - Thematic maps
    - GIS databases
    - Animations
    - Simulations
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1, 2, and 3 dimensions
The amount of electromagnetic radiance, $L$ (watts m$^{-2}$ sr$^{-1}$; watts per meter squared per steradian) recorded within the IFOV of an optical remote sensing system (e.g., a picture element in a digital image) is a function of:

$$L = f(\lambda, S_{x,y,z}, t, \theta, P, \Omega)$$

where,

- $\lambda$ = wavelength
- $S$ = location and pixel size
- $t$ = temporal information
- $\theta$ = geometric angles
- $P$ = polarization
- $\Omega$ = radiometric resolution
Remote Sensor Resolution

- **Spatial** - the size of the field-of-view, e.g. 10 x 10 m.

- **Spectral** - the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared thermal infrared, microwave (radar).

- **Temporal** - how often the sensor acquires data, e.g. every 30 days.

- **Radiometric** - the sensitivity of detectors to small differences in electromagnetic energy.
Spectral Resolution


b. Precise bandpass measurement of a detector based on Full Width at Half Maximum (FWHM) criteria

blue band (450 – 515 nm)
green band (525 – 605 nm)
red band (640 – 690 nm)
near-infrared (750 – 900 nm)
d. Multispectral remote sensing
Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan’s Island Obtained on October 26, 1998

Color-infrared color composite on top of the datacube was created using three of the 224 bands at 10 nm nominal bandwidth.
**Spatial Resolution**

<table>
<thead>
<tr>
<th>IMAGE ROWS</th>
<th>IMAGE COLUMNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
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<tr>
<td>C</td>
<td>3</td>
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<tr>
<td>D</td>
<td>4</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
</tr>
</tbody>
</table>

![Image Grid]

**Pixel**

[Image of a grid with shaded pixels]
Spatial Resolution

Imagery of residential housing in Mechanicsville, New York, obtained on June 1, 1998, at a nominal spatial resolution of 0.3 x 0.3 m (approximately 1 x 1 ft.) using a digital camera.
Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions

Spatial Resolution

a. 0.5 x 0.5 m.
b. 1 x 1 m.
c. 2.5 x 2.5 m.
d. 5 x 5 m.
e. 10 x 10 m.
f. 20 x 20 m.
g. 40 x 40 m.
h. 80 x 80 m.

Nominal Spatial Resolution (enlarged view)
SAME SCENE-DIFFERENT PIXEL SIZE

Satellite
Pour l'Observation
de la Terre

SPOT – 20 m

Compact
Airborne
Spectrographic
Imager

CASI – 5 m
Temporal Resolution

Remote Sensor Data Acquisition

June 1, 2006       June 17, 2006       July 3, 2006

16 days
There are spatial and temporal resolution considerations that must be made for certain remote sensing applications.
Radiometric Resolution

7-bit
(0 - 127)

8-bit
(0 - 255)

9-bit
(0 - 511)

10-bit
(0 - 1023)
SAME SCENE WITH TWO DIFFERENT RADIOMETRIC RESOLUTIONS
TOWARD A NEW CENTURY WITH HIGHER RESOLUTION

IKONOS
1 METER

HYPERION
220 BANDS
Remote Sensing Of Earth System Science
Analog (Visual) and Digital Image Processing of Remote Sensor Data

**Fundamental Image Analysis Tasks**
- Detect, Identify, Measure
- Solve problems

Application of the *Multi* concept
- Multispectral - Multifrequency - Multipolarization
- Multitemporal - Multiscale - Multidisciplinary

Use of *Collateral Information*
- Literature - Laboratory spectra - Dichotomous keys - Prior probabilities
- Field training sites - Field test sites - Soil maps - Surficial geology maps

<table>
<thead>
<tr>
<th>Analog (Visual) Image Processing</th>
<th>Digital Image Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elements of Image Interpretation</strong></td>
<td><strong>How the Elements of Image Interpretation Are Extracted or Used in Digital Image Processing</strong></td>
</tr>
<tr>
<td>• Grayscale tone (black to white)</td>
<td>• 8- to 12-bit brightness values or scaled to surface reflectance or emittance</td>
</tr>
<tr>
<td>• Color (RGB = red, green, blue)</td>
<td>• 24-bit color look-up table display</td>
</tr>
<tr>
<td>• Height (elevation) and depth</td>
<td>• Multiband RGB color composites</td>
</tr>
<tr>
<td>• Size (length, area, perimeter, volume)</td>
<td>• Transforms (e.g., intensity, hue, saturation)</td>
</tr>
<tr>
<td>• Shape</td>
<td>• Soft-copy photogrammetry, radargrammetry, RADAR interferometry, LIDAR, SONAR</td>
</tr>
<tr>
<td>• Texture</td>
<td>• Soft-copy photogrammetry, radargrammetry, RADAR interferometry</td>
</tr>
<tr>
<td>• Pattern</td>
<td>• Soft-copy photogrammetry, radargrammetry, interferometry, landscape ecology metrics, object-oriented image segmentation</td>
</tr>
<tr>
<td>• Shadow</td>
<td>• Texture transforms, geostatistical analysis, landscape ecology metrics, fractal analysis</td>
</tr>
<tr>
<td>• Site</td>
<td>• Autocorrelation, geostatistical analysis, landscape ecology metrics, fractal analysis</td>
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<tr>
<td>• Association</td>
<td>• Soft-copy photogrammetry, radargrammetry, measurement from rectified images</td>
</tr>
<tr>
<td>• Arrangement</td>
<td>• Contextual, expert system, neural network analysis</td>
</tr>
</tbody>
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Remote Sensing Earth Observation Economics

Platform and sensors
Radiant energy (photons)

Data collection
Raw data

Information Delivery System

Analog (visual) and/or digital image processing

Knowledge gap

Information

Information consumer (User)

Perceived economic, social, strategic, environmental, or political value

Equilibrium

$ Cost
Easy to use
Difficult to understand

low high
GEOL 6225: Advanced Geological Remote Sensing

TOPICS SCHEDULE FOR FALL 2015
(Subject to Change)

August 17: Introduction; Chapter 1-Remote Sensing of the Environment
August 19: Introduction to ENVI
August 24: Chapter 2-Electromagnetic Radiation Principles
August 26: Lab 2-Field Radiometric Measurements
August 31: Chapters 3, 4, and 6-Aerial Photography
September 2: Lab 3-Working with Aerial Photos
September 9: Chapter 5-Elements of Visual Image Interpretation
September 10: Lab 4-Principles of Image Processing

September 14: First Partial Exam

September 16: Chapter 7-Multispectral Remote Sensing System
September 21: Lab 5-Multispectral Classification
September 25: Independent Work with Research Projects
September 28: Chapter 8-Thermal Infrared Remote Sensing
September 30: Lab 6-Processing of Infrared Images
October 5: Chapters 9 and 10-Microwave and LIDAR Remote Sensing
October 7: Lab 7-Basic SAR Processing and Analysis

October 14: Second Partial Exam

October 19 and 21: Proposal Presentations

October 26: Chapter 11-Remote Sensing of Vegetation
October 28: Lab 8-Estimation of Vegetation Indices
November 2: Chapter 12-Remote Sensing of Water
November 4: Lab 9-Processing of Ocean Color
November 9: Chapter 13-Remote Sensing the Urban Landscape
November 10: Lab 10-Introduction to ArcGIS
November 16: Chapter 14-Remote Sensing of Soils, Minerals, and Geomorphology
November 23: Lab 11-Processing of Hyperspectral Data

November 25: Practical Laboratory Exam

November 30 and December 2: Research Projects Presentations

December ? (Period of Finals Exams): Final Exam