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?

See YouTube Video
**Photogrammetry** – the art or science of obtaining reliable measurement by means of photography (American Society of Photogrammetry, 1952, 1966).

**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 (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.
GROUND 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.
Observations About Remote Sensing

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 PLATFORMS

Balloons → Pigeons → Airplanes → Satellites → Dromes
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>1990</td>
<td>Digital ortho-photography becomes commonplace</td>
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<tr>
<td>1990s</td>
<td>University degree programs in remote sensing available</td>
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<tr>
<td>1990s</td>
<td>Electric Vehicles and Spacecraft (EVECS) concept of space mission</td>
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<tr>
<td>1995</td>
<td>NASA announces commercial remote sensing (Commercial Space Imaging)</td>
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<td>1995</td>
<td>Increased use of hyperspectral and LIDAR sensors</td>
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Check the book with More details of Major Milestones in Remote Sensing
Advantages of Remote Sensing

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 and cultural processes.

NATURAL:
- water-supply estimation
- eutrophication studies
- nonpoint source pollution

CULTURAL:
- land-use conversion at the urban fringe
- water-demand estimation
- population estimation
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.
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.
Limitations of Remote Sensing

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*. 

Diagram: 
- **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
      - Multi-spectral
      - Hyperspectral
    - Linear and area arrays
      - Multi-spectral
      - 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
    - Non-parametric, such as
      - Artificial neural networks
    - Nonmetric, such as
      - Expert systems
      - Decision-tree classifiers
      - Machine learning
  - Hyperspectral analysis
  - Change detection
  - Modelling
    - Spatial modeling using GIS data
    - Scene modeling
  - Scientific geovisualization
    - 1, 2, 3, and n dimensions

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

- Hypothesis Testing
  - Accept or reject hypothesis
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
- $s_{x,y,z}$ = location and pixel size
- $t$ = temporal information
- $\theta$ = geometric angles
- $P$ = polarization resolution
- $\Omega$ = 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

- FWHM = 0.7 – 0.8 μm
  = 700 – 800 nm
  = 100 nm bandwidth

b. Single band of ADAR 5500 data

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.
Image Resolution

Picture Elements

PIXELS
Spatial Resolution

IMAGE COLUMNS
1 2 3 4 5 6 7 8

IMAGE ROWS
A B C D E

PIXEL
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
Temporal Resolution

MODIS Leaf Area Index
Composite March 24 - April 8, 2000

University of Montana
Science Compute Facility
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
SAME SCENE-DIFFERENT RESOLUTION

CASI
5 m

IKONOS
1 m
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

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

Data collection → Information Delivery System

Information consumer (User)

Knowledge gap

Analog (visual) and/or digital image processing → Information

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

$ Cost

Easy to use

Difficult to understand

Equilibrium

Platform and sensors

Radiant energy (photons)
TOPICS SCHEDULE FOR SPRING 2019
(Same as last year)

January 16: Introduction
January 18: Chapter 1-Remote Sensing of the Environment
January 20: Chapter 2: Electromagnetic Radiation Principles
January 22: Lab 2: Field Radiometric Measurements
January 25: Chapters 3, 4, and 6: Aerial Photography
February 1: Lab 3: Analysis of Aerial Photography
February 6: Chapter 5: Elements of Visual Image Interpretation
February 8: Lab 4: Principles of Image Processing

February 13: Papers Presentation

February 15: First Partial Exam
February 20: Chapter 7: Multispectral Remote Sensing System
February 22: Lab 5: Multispectral Classification
February 27: Chapter 8: Thermal Infrared Remote Sensing
March 1: Lab 6: Processing of Infrared Images
March 6: Chapters 9 and 10: Microwave and LIDAR Remote Sensing
March 8: Lab 7: Basic SAR Processing and Analysis

March 13 and 15: Proposal Presentations

March 20: Second Partial Exam
March 27: Chapter 11: Remote Sensing of Vegetation
March 29: Lab 8: Estimation of Vegetation Indices
April 3: Chapter 12: Remote Sensing of Water
April 5: Lab 9: Processing of Ocean Color
April 10: Chapter 13: Remote Sensing the Urban Landscape
April 12: Lab 10: Introduction to ArcGIS
April 16: Chapter 14: Remote Sensing of Soils, Minerals, and Geomorphology
April 17: Lab 11: Processing of Hyperspectral Data

April 24: Practical Laboratory Exam

May 3 and 7: Research Projects Presentations

May 9 (Period of Finals Exams): Final Exam