A Remote Sensing Overview: Principles and Fundamentals

Marvin Bauer
Remote Sensing and Geospatial Analysis Laboratory
College of Natural Resources
University of Minnesota

Remote Sensing for GIS Users Workshop, June 24, 2004

Outline

• Remote Sensing
  • Introduction: Need, History, Advantages
  • How it works
    • Physical basis
    • Sensors, data acquisition and analysis

• Applications
  • Examples of mapping and monitoring Minnesota land and water resources

• Future Perspectives
Challenges....

- Feeding the world's population
  Now 6 billion plus
  Urbanization, soil erosion and salinization,… have reduced the amount of cropland
- Tropical deforestation
- Global warming and climate change
- Ozone depletion
- Toxic chemicals in the environment
- Loss of biodiversity and habitat
- 
- 

Environmental and Natural Resources Issues in Minnesota

- Forest fragmentation
- Loss of wetlands
- Loss of farmland
- Soil erosion
- Ground water contamination
- Lake water quality
- Flooding
- Urban sprawl
- Climate change
- 
- 
-
• Demand for **accurate, timely** information on environment and natural resources, including **spatial relationships** and **temporal changes and trends**, is increasing at all levels, **local to global**.

...provides opportunity and need for remote sensing and geospatial analysis

“Man must rise above the Earth to the top of the universe and beyond, for only then will fully understand the world in which he lives.”

• Socrates, 500 BC
Advantages of Remote Sensing

1. Improved vantage point, synoptic view
2. Broadened spectral sensitivity
3. Increased spatial resolution
4. 3-D perspective
5. Capability to stop action
6. Historical record
7. Comparability of data
8. Rapid data collection
9. Quantitative analysis
10. Ability to extend ground observations
11. Cost savings
Uses of Remotely Sensed Images

• Base on which other information can be portrayed
• Delineate patterns
• Determine extent and areas of different cover types and conditions
• Quantitative measurement of landscape properties

Applications of Remote Sensing
a few of many…

• Agriculture, Forestry and Range
  Identify crop, forest and rangeland types
  Measure area
  Assess condition and estimate yields
  Monitor changes

• Water Resources
  Lake water quality monitoring
  Inventory and mapping of wetlands

• Urban Dynamics
  Monitor land use and change
History of Remote Sensing

• 1839      Photographic image formed
• 1850’s   Photography from balloons
• 1909     First photography from airplane
• 1920’s   Initial development of photogrammetry and applications of aerial photography
• 1940’s   Initial development of infrared and radar sensing
• 1956     Research on crop disease detection with infrared photography
History of Remote Sensing, cont.

- 1960 “Remote Sensing” term first used
- 1960 TIROS weather satellite launched
- 1965 Airborne multispectral scanner data becomes available for civilian research
- 1972 Launch of Landsat 1
- 1982 Landsat-4 w/ Thematic Mapper launched
- 1986 SPOT satellite launched
- 1999 First U.S. high resolution commercial satellite successfully launched
- 1999 Launches of Landsat-7 and Earth Observing System (Terra satellite)

Definition of Remote Sensing

- Obtaining information about Earth’s surface from measurements by aircraft or satellite sensors of radiated energy
Overview of Remote Sensing

Energy Source → Sensor

Atmospheric Absorption and Scattering → Reflectance

Landscape

Interpretation and Analysis

Information – maps and statistics – for Applications

Major Objective of Remote Sensing

Detect, measure, record and analyze energy radiated in selected wavelengths of the electromagnetic spectrum

<table>
<thead>
<tr>
<th>Gamma Rays</th>
<th>X-Rays</th>
<th>UV</th>
<th>Visible</th>
<th>Reflective Infrared</th>
<th>Thermal Infrared</th>
<th>Microwave</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Color spectrum:
- V: Visible
- B: Blue
- G: Green
- Y: Yellow
- O: Orange
- R: Red
- Near IR
- Middle IR
Physical Basis of Remote Sensing

The distinctive character of electromagnetic radiation reflected or emitted from natural and human-made objects and scenes.

Spectral Reflectance of Basic Cover Types

What Information Can Be Remotely Sensed?

Fundamental Variables

- Planimetric (x,y) location and dimensions
- Topographic (z) location
- Color (spectral reflectance)
- Surface temperature
- Texture
- Surface roughness
- Moisture content
- Vegetation biomass
Sources of Information

Variations in electromagnetic fields that can be used to identify and characterize objects:

- Spectral-radiometric (color, temperature)
- Spatial (pattern, size, shape, texture, ...)
- Temporal (time 1, time 2, ...)

Active and Passive Sensors

- Passive Sensors
  - depend on external energy source, i.e. Sun
  - Photographic
  - Multispectral
  - Thermal infrared
  - Hyperspectral
  - Passive microwave
- Active Sensors
  - energy is transmitted from sensor system to object or surface
  - Radar
  - Lidar
## Major Types of Sensor Systems

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Typical Sensor, Analysis</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pictorial</td>
<td>Camera, Photo Interpreter</td>
<td>Resolution</td>
<td>Spectral range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Familiarity</td>
<td>Data volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>Numerical</td>
<td>Multispectral Scanner, Computer-aided</td>
<td>Spectral range</td>
<td>Complexity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiometric resolution</td>
<td>Familiarity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Digital analysis</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GIS compatible</td>
<td></td>
</tr>
</tbody>
</table>

### Cameras and Films

- **9-inch metric camera**
- **Small format cameras**

### Film Types

- **Black and white**
  - Panchromatic
  - Black and white infrared
- **Color**
  - Color
  - Color infrared
Color Infrared Aerial Photo

Illustrating photo interpretation elements: color, texture, shape, …

How a Multispectral Scanner Works
"Digital Camera" System

Sensor Input and Output

Surface Radiance, \( L = \frac{1}{\pi} \rho E T + L_p \)
Comparison of Color IR Photo and Multispectral Scanner Image

Components of Digital Images

<table>
<thead>
<tr>
<th>Rows (i)</th>
<th>Columns (j)</th>
<th>Digital Numbers</th>
<th>Bands (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 33 29 45 48 50 70 35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>42 46 49 52 68 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>39 49 53 61 74 55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>45 50 56 85 77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>38 53 66 76 80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Advantages and Disadvantages of Electronic/Digital Sensors

• Advantages
  - Spectral range
  - Radiometric resolution
  - Digital analysis
  - GIS compatible

• Disadvantages
  - Complexity, maybe but becoming less complex and more user friendly
  - Familiarity, perhaps, but this, too, is changing
  - Cost, maybe higher, but depends on the sensor system, and all are decreasing
The two types of systems should not be viewed as being in competition with one another; each has different capabilities and is useful in different circumstances

- Photographic systems, typically aerial, have been best suited for intensive mapping or monitoring where high spatial detail is needed.
- Digital systems, typically satellite-borne, have been more appropriate for large area (extensive) surveys.
- However, recently high-resolution multispectral satellite imagery has become available, AND aerial photography (imagery) is increasingly digital.

Examples of Remote Sensing Imagery

- Aerial photography

- Digital imagery
  - Satellite
  - Aerial
Large scale B&W aerial photo

Color Infrared Aerial Photo
High Altitude Color Infrared Aerial Photo

National Agricultural Imagery Program (NAIP) Digital Orthorectified Images

1-meter resolution
Color images
Summer 2003
Cost -- Free
Perhaps the most familiar satellite remote sensing: GOES imagery of weather systems

NOAA AVHRR Imagery

– another weather satellite
NOAA AVHRR NDVI Image

Midwest Drought, 1988

Global Biosphere: Land, Ocean Productivity
Mosaic of Minnesota Landsat images

Landsat TM Image of 7-County Twin Cities Metropolitan Area
IKONOS, high-resolution (4-meter) false color image of northeast Woodbury

IKONOS, high-resolution (4-meter) color image of northeast Woodbury
QuickBird Image
2.4 meter resolution
Band 4,3,2 false color composite
August 18, 2003

QuickBird Panchromatic Image
0.6 meter resolution
August 18, 2003
Scale

- Refers to the geographic coverage of an image
  ratio of image distance to ground distance

![Large scale image](image1)

![Very small scale imagery](image2)

Resolution

- **Spatial** -- measure of smallest angular or linear separation between two objects that can be resolved
- **Spectral** -- number and width of wavelength intervals (spectral bands)
- **Radiometric** -- sensitivity to differences in radiance; number of brightness levels
- **Temporal** -- time interval between data acquisitions
Comparison of Spatial Resolutions

40 meters

13.5 meters

4.5 meters

1.5 meters

• Low

Spectral Resolution

• High
Radiometric Resolution

- Measured in “bits”
- 6-bit = 64 gray levels
- 8-bit = 256 levels, or approx. 0.25% reflectance
- 10-bit = 1024 levels, or approx. 0.10% reflectance
Some further thoughts on sensors…

• Until recently, digital systems, typically satellite-borne, have been thought of as more appropriate for large area (extensive) surveys.
• But, today we have high-resolution satellite data
  • As high as 0.6 meters
• Meanwhile, aerial digital remote sensing systems are becoming common
• There are a wide variety (and growing number) of data acquisition and analysis approaches available
• Successful remote sensing matches information requirements to sensor characteristics
  • no single sensor or analysis procedure is appropriate for all applications

Multispectral Concept

<table>
<thead>
<tr>
<th></th>
<th>Visible</th>
<th>Near Infrared</th>
<th>Thermal Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.4 – 0.7 µm</td>
<td>0.7 – 0.9 µm</td>
<td>4.5 – 5.5 µm</td>
</tr>
<tr>
<td>Corn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stubble</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare Soil</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example of Multispectral Imagery

Band 1: Blue

Band 2: Green

Band 3: Red

Band 4: Near-Infrared
Color: bands 3, 2, 1  4-meter

False Color: bands 4, 3, 2  4-meter
NDVI Transformation: bands 4 - 2 / 4 + 2

Multispectral Analysis

Spectral Response

Band 1 Reflectance vs. Wavelength

Feature Space

Band 2 Reflectance vs. Band 1 Reflectance
A typical approach to training and classification will take one of two forms:

- Supervised training
- Unsupervised training
Applications of Remote Sensing

1. Land Cover Classification and Change Detection
Twin Cities Landsat Imagery

1975
1981
1986
1991
1998
2000

Overall accuracy: 95.2%
Kappa: 94%

1986

Overall accuracy: 95.2%
Kappa: 94%
Comparison of Landsat and NRI Area Estimates

- **Developed**:
  - Landsat – 1991
  - NRI survey – 1992
  - Landsat – 1998
  - NRI survey – 1997

- **Rural**:
  - Landsat – 1991
  - NRI survey – 1992
  - Landsat – 1998
  - NRI survey – 1997

- **Agriculture**:
  - Landsat – 1991
  - NRI survey – 1992
  - Landsat – 1998
  - NRI survey – 1997

- **Water**:
  - Landsat – 1991
  - NRI survey – 1992
  - Landsat – 1998
  - NRI survey – 1997
Comparison of Classifications

- Two dates are classified separately
- Classification map of Date 2 is then subtracted from the map of Date 1

Change Map
## Land Cover Changes from 1991 to 2002

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (000 ha)</td>
<td>%</td>
<td>Area (000 ha)</td>
<td>%</td>
<td>Area (000 ha)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>365</td>
<td>47.5</td>
<td>342</td>
<td>44.4</td>
<td>316</td>
</tr>
<tr>
<td>Urban</td>
<td>183</td>
<td>23.8</td>
<td>202</td>
<td>26.3</td>
<td>235</td>
</tr>
<tr>
<td>Forest</td>
<td>112</td>
<td>14.6</td>
<td>111</td>
<td>14.4</td>
<td>106</td>
</tr>
<tr>
<td>Wetland</td>
<td>58</td>
<td>7.5</td>
<td>60</td>
<td>7.8</td>
<td>56</td>
</tr>
<tr>
<td>Water</td>
<td>42</td>
<td>5.5</td>
<td>46</td>
<td>6.0</td>
<td>46</td>
</tr>
<tr>
<td>Cult. Grass</td>
<td>7.2</td>
<td>0.9</td>
<td>6.4</td>
<td>0.8</td>
<td>7.7</td>
</tr>
<tr>
<td>Extraction</td>
<td>1.9</td>
<td>0.2</td>
<td>2.4</td>
<td>0.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

- Multitemporal data, typically at different times of the year, can be used to increase classification accuracy and specificity but does require acquiring and processing additional dates of data
- Data acquired over different years can be used to detect and classify changes in land cover and use
2. Impervious surface classification and mapping

Basic Theory for Satellite Mapping of ISA

Greenness is sensitive to amount of green vegetation and inversely related to amount of impervious surface
Relationship of Landsat TM Greenness and Percent Impervious Surface Area

\[ y = -0.0079x^2 + 0.5015x + 119.51 \]
\[ R^2 = 0.91 \]

Comparison of measured and Landsat estimates of impervious surface area

\[ y = 0.9059x + 4.1558 \]
\[ R^2 = 0.96 \]
Landsat classification of TCMA Impervious Surface Area

Landsat classification of Eagan land cover and % impervious surface area
Change in Impervious Surface Area, 1986 - 2000

Change in Percent Impervious Surface Area, 1986 – 2000, by County
A strong relationship between impervious area and Landsat greenness enables percent impervious surface area to mapped at the pixel level.

Landsat classification provides GIS-ready, accurate and consistent maps and estimates at 30-meter resolution over city to county to regional size areas.
3. Vegetation Condition Assessment

Temporal Series of MODIS NDVI Images

Spring
4 April ‘02
Temporal Series of MODIS NDVI Images

Summer
7 July '02

Temporal Series of MODIS NDVI Images

Fall
9 September '02
Temporal Profile Parameters

1. start of green-up
2. rate of growth
3. maximum "greenness"
4. date of maximum "greenness"
5. duration of "greenness"
6. rate of senescence
7. end of growing season
8. total seasonal accumulation (area under the curve)

Examples of Temporal Profiles for several Minnesota cover types
4. Use of Landsat Data for Synoptic Assessment of Lake Water Clarity

M. Bauer, L. Olmanšon, P. Brezonik, S. Kloiber
Remote Sensing Laboratory and Water Resources Center
University of Minnesota
St. Paul, Minnesota, USA
Basic Method

\[ y = -15.583x + 4.6742 \]

\[ R^2 = 0.84 \]

![Graph showing a linear relationship between TM3/TM1 and log(SDT) -- meters.]

Landsat Classification of Lake Water Clarity, 1998

Landsat Classification of Lake Water Clarity, 1998

<table>
<thead>
<tr>
<th>TSI(SDT)</th>
<th>SDT (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>8</td>
</tr>
<tr>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>70</td>
<td>0.5</td>
</tr>
<tr>
<td>80</td>
<td>0.25</td>
</tr>
<tr>
<td>90</td>
<td>0.125</td>
</tr>
</tbody>
</table>

7-county Twin Cities Metropolitan Area
Agreement between Landsat Estimates and Lake Measurements

![Graph showing the relationship between observed Secchi depth and Landsat estimates. The graph includes a 1:1 line and an R^2 value of 0.87.]

Landsat Estimation of Lake Water Clarity

- ~1990 and ~2000 Assessments are complete and
- ~1975, ~1985, ~1995 Landsat images have been acquired
- Over 10,000 Lakes Classified
- All lakes 20 acres or larger are included

![Maps showing water clarity for ~1990 and ~2000. The maps use color coding to represent different water clarity ranges.]
• Landsat data can be effectively used to monitor lake water clarity (quality) over time and large geographic areas.

Results can be used to improve lake management and policy, and to develop a better understanding of lake systems on a regional scale.

Internet Delivery of Information:
Lake Browser    http://water.umn.edu/
5. Aquatic Vegetation Mapping

IKONOS High Resolution (4-meter) Satellite Imagery

Swan Lake, MN

IKONOS Classification of Aquatic Vegetation

Emergent Vegetation
- Cattail & Arrowhead
- Sedge
- Bulrush
- Water Lily & Floating-leaf Pandan
- Mud Flat with Dead Sedge or Cattail

Submerged Aquatic Vegetation
- Vegetation Below Surface (Thin or Dispersed)
- Vegetation Below Surface
- Vegetation at Surface
- Vegetation at Surface (Thick)

Cloud-Covered Area
Future Perspectives

Numerous sources of digital imagery

- Landsat…will continue to be the ‘workhorse’ of satellite RS
- Earth Observing System = suite of sensors and long term observations on Terra and Aqua satellites
- Commercial satellites with high spatial resolution IKONOS, QuickBird, ORBIMAGE
- Satellites operated by other countries SPOT, EnviSat, RadarSat, ….
- Hyperspectral (50-300 spectral bands, spectroscopic analysis), lidar and radar
- Airborne systems -- yes, airplanes will continue to fly and collect data
Recent Satellite Launches

- Landsat-7, 1999
- IKONOS, 1999
- QuickBird, 2001
- ORBIMAGE-3, 2003
- EOS / Terra, 1999
- EOS / Aqua, 2002
- EnviSat, 2002
- SPOT-5, 2002
- NOAA-17, 2002

By the end of 2004 there will be over 25 Earth observation satellites in orbit

Improvements and Advancements in Technology and Capability

- Increasing use of digital imagery
- “Hypermedia” --- no single source
- Increasingly sophisticated software and hardware that anyone can use
- More “customizable” products
- Software adapted to standards e.g., open GIS
- Greater awareness of the public TerraServer, imagery on CNN, etc.
Benefits from Other Technologies

- GIS and image processing -- more sophisticated and well integrated
- Improved process models that use RS inputs
- Computers
  more powerful, less expensive
- Telecommunications and the Internet
  will simplify and speed data and information delivery
- Global Positioning System
  improved navigation and location information will be commonplace

Some concluding thoughts

- Aerial photography has been in use for 75 years and will continue to play a key role in mapping and monitoring.
- Satellite remote sensing, a much younger technology, has blossomed in recent years and we are now realizing the long-expected benefits of routine Earth observations from space.
- In the next few years we will see even more multi-source, multi-scale remote sensing data
  Hyperspectral, high-resolution, microwave, lidar,…
- Quantitative measurements of biophysical properties of land, vegetation, water, and atmosphere are rapidly developing.
- These new data and measurements are finding their way into spatial models of environment and natural resources.
New era: “The image information age”

• “The map of the future will be an ‘intelligent’ image,” Lawrie Jordan, President, ERDAS

Some of the things that will enhance the acquisition, analysis and applications of remote sensing and spatial data

• Continued improvements in sensors.
• Improvements in computing capacity, Internet, and analysis and visualization tools.
• Use of spatial data will increase as access to data and tools for analysis improve (spatial literacy will increase).
• Data integration – spatial data will become increasingly common in the digital environment.
• Time lag between data acquisition and generation of information will decrease.

Adapted from The Future of Spatial Data and Society (Nat’l. Academy of Sciences, 1997)
The most familiar remote sensing: Satellite image of today’s weather systems

Perhaps in a few years remote sensing of natural resources and environment will be equally familiar.

“The Nature of the Universe,”
Sir Fred Hoyle, 1950.
Thank you

Questions….

Copies of presentation slides can be found at:
http://rsl.gis.umn.edu/rs101.html