Remote Sensing

Reconnaissance from a distance vs. in situ sensing (by contrast)

Remote Sensing means Measuring electromagnetic energy

Electromagnetic Energy

The oscillation of acceleration of an electrical charge

at 0 Kelvin (K) = -273°C or -460°F: all random molecular movement stops

Ground-based remote sensing

Air Photo:

color film, airplane, 1-2 m detail
Timothy Lake, OR

Landsat 30 m

Mt. St. Helens
Mt. Adams

Columbia River

Portland

AVHRR 1 km

UV, Visible, Near IR Sensors

Thermal IR, Microwave Sensors

Active Sensors radar, lasers...

5880 K emitted

300 K

emitted

reflected
**Satellite remote sensing of earth**

SeaWiFS Land-Ocean Chlorophyll
September 1997 to present …

**MODIS Land Reflectance and Sea Surface Temperature**

**Important questions to answer**

Remote Sensing Systems

How do we discuss and categorize remote sensing?

“the resolutions”

Spatial Resolution -- what size we can resolve
Spectral Resolution -- what wavelengths do we use
Radiometric Resolution -- degree of detail observed
Temporal Resolution -- how often do we observe

**Where else could life begin?**

Liquid Water

Water = Life

**Multistage Remote Sensing**
Basic Interactions between Electromagnetic Energy and the Earth’s Surface

• Remote sensing uses the radiant energy that is reflected and emitted from Earth at various “wavelengths” of the electromagnetic spectrum
• Our eyes are only sensitive to the “visible light” portion of the EM spectrum
• Why do we use nonvisible wavelengths?

The Electromagnetic Spectrum

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The Electromagnetic Spectrum

Visible Spectrum

\[ c = \text{frequency} \times \lambda \]

Visible Spectrum

0.4 0.5 0.6 0.7

Wavelength (µm)

<table>
<thead>
<tr>
<th>Wave</th>
<th>Visible</th>
<th>Ultraviolet</th>
<th>X-ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>E(λ)</td>
<td>E(λ) = E_R(λ) + E_A(λ) + E_T(λ)</td>
<td></td>
</tr>
</tbody>
</table>

Visible Spectrum

\[ c = \text{speed of light} = \lambda \times \text{frequency} \]

Visible Spectrum

\[ \lambda_{\text{max}} = \frac{2\pi\nu}{E_\lambda} \]

known as Wien’s displacement law, where
\[ \lambda_{\text{max}} = \text{wavelength of maximum radiance} \]
\[ T = \text{temperature (K)} \]

From blackbody radiation, the emitted radiation follows Planck’s law:

\[ I_\lambda = \frac{2\pi\nu^3}{\lambda^5} \exp \left( \frac{hc}{\lambda kT} \right) - 1 \]

Stefan-Boltzmann Law

Stefan-Boltzmann constant

\[ \sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \]

Stefan-Boltzmann constant

\[ \sigma = \frac{c}{3} \]
Total Energy Flux: $M = \sigma T^4$

$\sigma = 5.67 \times 10^{-8} \text{ w/m}^2\text{K}^4$

Wavenumber = $1/\lambda$ (# $\lambda$s per unit distance)

Energy per photon:

$E_p = h \times$ frequency

$E_p = h \times c/\lambda$

$E_p = 6.6 \times 10^{-34} \text{ J sec } \times 3 \times 10^8 \text{ m sec}^{-1}$

Ergo: X-rays and $\gamma$-rays are energetic!

Perfect radiator = perfect absorber = black body

Spectral Radiant Exitances for Blackbody, Graybody, & Selective Radiators
Solar Irradiance $\lambda$ at Earth’s Surface

Exoatmospheric Solar Irradiance $\lambda$

atmospheric limb

Rayleigh Scattering: why the sky is blue

Rays from the sun

Earth

Liquid Water

Water = Life

Remote Sensing Systems: the Human Eye

• Spectral Resolution: 0.4-0.7 $\mu$m
• Spatial Resolution: ~1-3 cm @ 20 m
• Radiometric Resolution: ~16-32 shades B/W or ~100 colors

Invertebrate remote sensing

Insects have remote sensing capabilities quite different from vertebrates and the octopus
Key Milestones in Remote Sensing of the Environment

- 1826 – Joseph Niepce takes first photograph
- 1858 – Gaspard Tournachon takes first aerial photograph from a balloon
- 1913 – First aerial photograph collected from an airplane
- 1935 – Radar invented
- 1942 – Kodak patents color infrared film
- 1950s – First airborne thermal scanner
- 1957 – First high resolution synthetic aperture radar
- 1962 – Corona satellite series (camera systems) initiated by the Intelligence community
- 1962 – First airborne multispectral scanner
- 1972 – ERTS-1 Launched – First Landsat satellite

Remote Sensing Systems

- **Thaddeus Lowe’s Balloon**
- **Corona System**
- **Electro-optical systems** (Landsat, Terra, AVHRR, SeaWiFS, GOES, VCL, etc.)

Platform, sensing device, data transmission

Thaddeus Lowe, circa 1861-1865 remote sensing for military purposes. Then, as now, newest developments are always in the military sphere

Remote sensing in the airplane era

1914 to 1960
CIA’s Corona Program
1960-1972 >100 missions
Followed after U-2s…
Platform: Spacecraft
Sensor: Camera
Data System: Film Drop
Started: August 1960
Coverage: 7.6 Bil mi²
Spatial Resolution: early missions @ 13 m, later missions @ 2 m
Spectral Resolution: visible and visible-near infrared (both film)
Radiometric Resolution: equivalent 2² to 2⁵ (4 to 6 bits)

CIA’s Corona Program
reentry with air capture

CIA’s Corona Program
Washington Monument 1967

Basic Interactions between Electromagnetic Energy and the Earth’s Surface

Leaf Optical Properties

Leaf Spectral Reflectance
Reflectance = 1.0 - Absorption.
Where else could life begin?

**Liquid Water**

Water = Life

**True Color Photography or Imaging**

- True Color
- False Color
- IR Photography or Imaging

**False Color IR Photography or Imaging**

- Reflectance of objects in original scene
- Mix after exposure
- Yellow dye layer
- Red dye layer
- Blue dye layer
- Resulting color when viewed

**True Color & False Color Imaging**

- Less atmospheric scattering & more near-IR veg. info.

**True & False Color Ikonos Satellite Data**

Beltville Agricultural Research Center
More green leaves affect visible & near-ir reflectances

Signals from Eye Processed in Brain

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120 M rods, 5 M cones, & 1 M optic axons

Cones—color sensitive, form sharp images, require many photons

Rods are intensity, but not color, sensitive & form blurred images

Birds—big eyes, more cones, “faster” eye muscles, more support, and best vision (8x)

Nocturnal animals have big eyes & more rods/fewer cones

Human Eye and Retina

Retina Rods & Cones: our visible detectors
Retinal structure

Rods and Cones at 10,000x

Our vision is optimized for receiving spectral radiance from our star. Evolution?

Human Vision

Eye Function

Human Vision -- could be better

Not optimum design—lots of nerve cells in optical pathway (give us a few more million years without a major extinction event…)

To brain
Insect Vision -- Compound Eyes

combine: $\Delta \phi = \frac{D}{R}$ and $2\Delta \phi = \frac{\lambda}{D}$, eliminate $D$; thus $R = \frac{\lambda}{2(\Delta \phi)}$. $\Delta \phi$ for us is $1$ arc min or $0.0003$ radians; Do the algebra: $R_{\text{hs}} = 6$ m at fovea & $1$ m off-fovea.

Insect Vision -- Compound Eyes

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Insect visual simulation at 2-3 m

You be the judge

Albert Einstein

Image projected onto compound eye

Insect views AE

The “Intelligent Design” ‘eye’ argument: God is a Bird of Prey?

Raptors can see clearly a rabbit at 1500 m

Raptors have 6x-8x better vision than humans

High degree of binocularity--greatest overlap of eyes

Have 2nd fovea (greatest # of rods & cones/unit area)

Very large eyes for their head size--bird brain/bird eye

Well-developed pecten to supply nutrients and O₂: reduces blood vessels, reduces obstructions in front of rods & cones

All alone in our neighborhood of space

Apollo 12’s Classic Earth Rise from Moon

Image/Photographic Interpretation

- size
- shape
- patterns
- textures
- contrast
- shadow
- volume orientation
- association(s)
- scale--representative fraction
- black/white imagery: 16-32 tones or gray levels by human eye
- color imagery: ~100 color bands by human eye
- brightness/contrast/intensity--chroma
- hue--wavelength--"color"