Deep Learning with Satellite Imagery

Satellite Imagery
Overview

- Satellite orbits.
- Satellite resolution.
- Satellite collection.
- Color spaces.
- Satellite spectral bands.
- Satellite imagery processing:
  - Demosaicing.
  - Georeferencing.
  - Atmospheric correction.
  - Pansharpening.
  - Orthorectification.
  - Dynamic range adjustment.
- NIRS scale.
Orbits

- **GeoSynchronous Orbit (GSO):**
  - An orbit with an orbital period matching Earth’s rotation.
  - GSO is at 35,786 km above Earth’s surface.
  - **GeoStationary Orbit:** A special type of GSO with 0 angle of inclination.
  - Application: Communication (radio, tv, etc).

**Angle of inclination:**
Angle between the orbit and the equatorial plane.
Orbits

- **Low Earth Orbit (LEO):**
  - An orbit with an orbital period between 84 and 127 minutes.
  - LEO is within 2,000 km from Earth’s surface.
  - **Polar Orbit**: Orbit passes by both poles.
    - **Sun Synchronous Orbit**: Satellite passes over region at roughly the same local solar time.
  - **Inclined Orbit**: Orbit with an angle of inclination between 0 and 90 degrees.
  - Application: Remote sensing.
Satellite Ground Sample Distance (GSD)

- **GSD**: The distance between pixel centers measured on the ground.
- Inversely proportional to resolution.
- Higher orbits tend* to increase GSD and increase field of view.
- Lower orbits decrease GSD and decrease field of view.

*Top: Low resolution. Bottom: High resolution.*
Low Resolution Satellite Imagery

- Mapping missions.
- Crop monitoring
- Natural disaster assessment.
High Resolution Satellite Imagery

- Supply chain monitoring.
- Military surveillance.
- Construction monitoring.
Visible Spectrum

- Part of the electromagnetic spectrum.
- Visible to the human eye.
- Wavelengths range from 380 - 740 nm.

How we perceive colors:
1. Sunlight illuminates an object.
2. Object absorbs certain bands and reflects others.
3. The eye associates the reflected bands as the object’s color.
Satellite Bands: Active and Passive Remote Sensing

- Passive: Measures natural energy.
  - Multispectral (e.g. RGB+SWIR).
  - Infrared (near, short-wave, thermal).
  - Panchromatic.
  - Hyperspectral.

- Active: Provides own energy.
  - Light Detection and Ranging (LIDAR).
  - Synthetic Aperture Radar (SAR).
Why do we use the RGB color space?

- What do we get when mixing red and green paint?

- What do we get by combining red and green pixels?
Why do we use the RGB color space?

- What do we get when mixing red and green paint?
- What do we get by combining red and green pixels?

- **Additive space**: Colors are created from light, e.g. computers.
- **Subtractive space**: Colors act as filters to natural light, e.g. paint.
More Color Spaces

- **Hue** (H): Related to wavelength of color.
- **Saturation** (S): Pureness of color.
- **Value** (V): Brightness of color.
- **Luminance** (Y): Brightness of color.
- **Chrominance** (C): Color information.
- Cb: C - Blue. Cr: C - Red.
- U: B - Y. V: R - Y

**Color Spaces:** HSV (bottom), YUV (middle), YCbCr (right).
RGB Imagery:

- Visible imagery.
- Blue wavelength: 450 - 490 nm.
- Green wavelength: 520 - 560 nm.
- Red wavelength: 640 - 700 nm.
False Color Images

Images depict an object in colors that differ from those in the visible range.

Near Infrared (NIR) Imagery:

- Essential for crop monitoring.
- High contrast between water and land.
- Penetrate through light fog, haze, smoke
- Wavelength range from 700 - 1400 nm.
- **False color**: NIR, Red, Green to RGB.

**Left**: Visual. **Right**: NIR, R, G.
Short-Wave Infrared (SWIR) Imagery:
- Detects moisture in soil and vegetation.
- High contrast between water and snow.
- Penetrate through thin clouds, light fog, haze, smoke.
- Provide day and night collection.
- Wavelength range from 1400 - 3000 nm.
- **False color:** varies.

**Left:** Visual. **Right:** SWIR, NIR, R. **Top:** NIR, R, G. **Bottom:** SWIR, NIR, G.
Thermal Infrared (TIR):

- Measures water and land temperatures.
- Penetrate through clouds, smoke, haze, and fog.
- Provide day and night collection.
- Wavelength range from 8000 - 15000 nm.
Multispectral (MSI) Imagery:

- Generally refers to 3 - 10 bands.
- RGB*.
- Detects geological and materials spectral signature.
- Reduces influence of clouds, smoke, haze, and fog.
- Provide day and night* collection.
- Wavelengths from visible and IR parts of spectrum.
Hyperspectral (HSI) Imagery:

- Hundreds of narrow bands.
- Detects materials by their unique spectral signature.
- Wavelengths from visible and IR parts of spectrum.
- Also known as imaging spectroscopy.
Panchromatic (PAN) Imagery:

- PAN uses the visible and IR parts of the EM spectrum.
- One wide wavelength: 250 - 900 nm.
- Lower GSD than multispectral imagery.
- PAN sharpening: Increase spatial resolution of multispectral image.
PAN Sharpening Methods:

Brovey transform:

\[ R_{\text{new}} = \frac{R}{(R + G + B)} \times PAN \]

\[ G_{\text{new}} = \frac{G}{(R + G + B)} \times PAN \]

\[ B_{\text{new}} = \frac{B}{(R + G + B)} \times PAN \]

Simple-Mean transform:

\[ R_{\text{new}} = \frac{R + PAN}{2} \]

\[ G_{\text{new}} = \frac{G + PAN}{2} \]

\[ B_{\text{new}} = \frac{B + PAN}{2} \]

Color Map Substitution:
- Convert to HSV, YUV, or YCbCR and replace intensity (V or Y) by PAN channel.
## Multispectral Satellites: Examples

### KOMPSAT-3 Satellite Sensor Specifications

**Spectral bands**
- 450-900 nm Pan (Panchromatic)
- 450-520 nm MS1 (Multispectral), blue
- 520-600 nm MS2, green
- 630-690 nm MS3, red
- 760-900 nm MS4, NIR (Near Infrared)

### Multispectral Scanner (MSS)

<table>
<thead>
<tr>
<th>Landsat 1-5</th>
<th>Landsat 1-3</th>
<th>Landsat 4-5</th>
<th>Wavelength (micrometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 4 - Green</td>
<td>Band 1 - Green</td>
<td>Band 4 - Near Infrared (NIR)</td>
<td>0.5-0.6</td>
</tr>
<tr>
<td>Band 5 - Red</td>
<td>Band 2 - Red</td>
<td>Band 3 - Near Infrared (NIR)</td>
<td>0.6-0.7</td>
</tr>
<tr>
<td>Band 6 - Near Infrared (NIR)</td>
<td>Band 7 - Near Infrared (NIR)</td>
<td>0.7-0.8</td>
<td></td>
</tr>
<tr>
<td>Band 7 - Near Infrared (NIR)</td>
<td>Band 4 - Near Infrared (NIR)</td>
<td>0.8-1.1</td>
<td></td>
</tr>
</tbody>
</table>

### Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

<table>
<thead>
<tr>
<th>Bands</th>
<th>Wavelength (micrometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1 - Blue</td>
<td>0.45-0.52</td>
</tr>
<tr>
<td>Band 2 - Green</td>
<td>0.52-0.60</td>
</tr>
<tr>
<td>Band 3 - Red</td>
<td>0.63-0.69</td>
</tr>
<tr>
<td>Band 4 - Near Infrared (NIR)</td>
<td>0.77-0.90</td>
</tr>
<tr>
<td>Band 5 - Shortwave Infrared (SWIR) 1</td>
<td>1.55-1.75</td>
</tr>
<tr>
<td>Band 6 - Thermal</td>
<td>10.40-12.50</td>
</tr>
<tr>
<td>Band 7 - Shortwave Infrared (SWIR) 2</td>
<td>2.09-2.35</td>
</tr>
<tr>
<td>Band 8 - Panchromatic</td>
<td>.52-.90</td>
</tr>
</tbody>
</table>
Light Detection and Ranging (LIDAR) Imagery:

- Emits laser pulses in the visible and IR portions of the spectrum onto the Earth's surface.
- Measures time it takes for the energy to return.
- Highlights distances and heights.
- Develops 3D models of objects.
- Provides day and night collection.
- Cannot penetrate clouds or smoke.
Synthetic Aperture Radar (SAR) Imagery:

- Emits pulses of radio waves onto the Earth’s surface.
- Measures time it takes for the energy to return.
- Signal processing is needed to process (complex-valued) frequencies.
- Highlights distances and heights.
- Develops 3D models of objects.
- Provides day and night collection.
- Penetrates through clouds, fog, smoke, and haze.
Demosaicing: Bayer Color Filter Pattern

- A color filter array for arranging RGB on a grid.
- Pattern repeats every 2x2 block.
- Filter pattern (mosaic) is 50% green, 25% blue and 25% red.
- More green filters due to human’s eye sensitivity to green light.
Demoscicing: Interpolation Approach

Interpolation Schemes:

- 1D nearest-neighbour
- Linear
- Cubic
- 2D nearest-neighbour
- Bilinear
- Bicubic
Demosaicing: YCbCr Approach

- Luminance (Y): Brightness of color.
- Chrominance (C): Color information.
- Cb: C - Blue. Cr: C - Red.

Top: Visible. Middle: Y. Middle: Cb. Bottom: Cr.

Majority of Luminance from Green pixels

Bayer Color Filter Pattern

Chrominance from Red, Green, and Blue pixels

Final RGB Image
Demosaicing: TrueSense Color Filter Pattern

- Similar to Bayer filter.
- Pattern repeats every 4x4 block.
- Filter pattern is 50% pan, 25% green, 12.5% blue, and 12.5% red.
- More PAN filters to sharpen RGB image.
Demosaicing: Bayer vs. TrueSense

- PAN channel provides higher light absorption.
- PAN pixels create luminance from higher resolution.
- Fewer RGB pixels for chrominance.
Georeferencing

- Satellite imagery presents geolocation error after collection.
- **Georeferencing** reduces error and prepares imagery ready for mapping.

**Algorithm:**

1. Features are identified in satellite imagery.
2. Corresponding features are found in basemap (Top).
3. Each pair forms a tie point (Left).
4. Minimize distance of each tie point (Right).
5. Outlier tie points are discarded.
6. Repeat 4, 5 until convergence.
7. Apply transformation to all pixels.
Off-Nadir Collection

**Bottom left**: at-nadir collection.
**Bottom right**: off-nadir collection.
**Top right**: very off-nadir collection.
Orthorectification

- **Orthorectification** removes perspective (off-nadir) effects and terrain (elevation) effects.
- Model uses elevation data.
- Reduces geolocation error arising from features with high elevation.
- Hidden pixels are created by sampling neighbors.
- **Algorithm**: Rational polynomial coefficients (RPC).
Orthorectification: Rational Polynomial Coefficients (RPC)

1) Sets up a transformation from satellite image \((X, Y, Z)\) to orthorectified image \((x, y)\) with cubic polynomials.

\[
\begin{align*}
    x &= \frac{P_1(X, Y, Z)}{P_2(X, Y, Z)} \\
    y &= \frac{P_3(X, Y, Z)}{P_4(X, Y, Z)}
\end{align*}
\]

2) Rewrite system to solve for errors.

\[
\begin{align*}
    F_x &= P_1(X, Y, Z) - xP_2(X, Y, Z) \\
    F_y &= P_3(X, Y, Z) - yP_4(X, Y, Z)
\end{align*}
\]

3) Linearized system, set up iterative scheme, and solve using least squares.

\[
V = BX - L
\]

\[
B = \begin{bmatrix}
    \frac{\partial F_x}{\partial a_i} & \frac{\partial F_x}{\partial b_i} & \frac{\partial F_x}{\partial c_i} & \frac{\partial F_x}{\partial d_i} \\
    \frac{\partial F_y}{\partial a_i} & \frac{\partial F_y}{\partial b_i} & \frac{\partial F_y}{\partial c_i} & \frac{\partial F_y}{\partial d_i}
\end{bmatrix}
\]

\[
L = \begin{bmatrix} x \\ y \end{bmatrix}^T
\]

\[
X = [a_i \ b_i \ c_i \ d_i]^T
\]
Atmospheric Correction

- **Atmosphere correction** removes atmospheric effects from imagery.
- Atmosphere scatters colors with smaller wavelengths.
- Blue has the smallest wavelength in the spectrum.
- **Simple Algorithm**: Subtract darkest pixel from each channel.
- **Complex Algorithm**: Use a model of the atmosphere and reverse the scattering process.
Dynamic Range Adjustment (DRA)

- Dynamic range adjustment (DRA) automatically adjusts contrast and brightness of satellite imagery.
- DRA is prone to fail in certain cases.
- In such cases, a manual adjustment yields better results.
National Image Interpretability Range Scale (NIIRS)

- Rates quality of imagery.
- Ranges from 0 (worst quality) to 9 (best quality).
- Score depends on the tasks achieved with imagery.
- Uses General Image Quality Equation 5 (GIQE5):

\[
NIIRI_S = c_0 + c_1 \log_{10} GSD + c_2 \left( 1 - e^{\frac{c_3}{SNR}} \right) \log_{10} RER_0 + c_4 (\log_{10} RER_0)^4 + \frac{c_5}{SNR} + c_6 smear
\]

- GSD: ground sample distance.
- SNR: signal to noise ratio.
- RER: relative edge response.
- Smear: quality degradation during integration time.
Next Time: Classical Computer Vision Methods

Thank you.