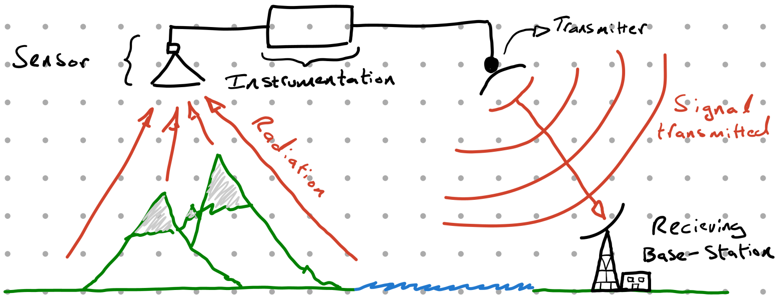
Image Data Analysis - IDA

Lesson One : Sources and Characteristics of Remote sensing Data - RSDA 2: Electromagnetic Boogaloo

Intro to Image Data Sources

Remote Sensing Measures energy that radiated from the Earth or an object using sensors mounted on satellites, aircraft, etc. We use these measurements to construct images.

A simple, illustrative diagram:



Generally there are two types of sensors used to perform these measurements:

- Passive Sensors, which measure energy that comes from the sun or ambient energy that comes from the object's temperature (Blackbody rad.)
- Active Sensors, which use an $\overbrace{\text{artificial source}}^{\text{eg. a laser / RADAR}}$ to illuminate the Earth/objects then measure the reflected energy

The Products of Remote sensing Data are generally:

- Image Maps (Visual representation of data)
- Parametric Maps (Ratioed or interval scaling of the data, usually projected on another map)
- Labelled / Thematic maps (Nominally scaled / rounded, same projection as above)

Wavelengths of Interest, Active, and Passive Systems

The most important parameter involved in remote sensing is, ultimately, the wavelength of the radiation.

For Passive sensors: $\lambda = 0.4\mu m \rightarrow 12\mu m$ (visible/IR)

$\lambda = 30m \rightarrow 300mm$ (microwave)

For active sensors:

$\left.\begin{array}{l}\text{Excitation, } \lambda \approx 355nm \ (\approx UV) \\ \text{Measurement, } \lambda = 0.4\mu m \rightarrow 12\mu m \ (\text{visible/IR})\end{array}\right\}$ Laser Fluorosensors

$\left.\begin{array}{l}\text{SAR (Synthetic Aperture Radar)} \\ \text{/SLAR (Side Looking Airbourne Radar)}\end{array}\right\}$ $\lambda = \{Ka, K, Ku, X, C, S, L \text{ Bands}\}$ Radar Sensors

These are only theoretical ranges in practice the wavelengths are more restricted.

More details regarding Spectral ranges:

VNIR (Visible and Near InfraRed) $\simeq$ 0.4μm → 4~8μm

Mostly utilised to measure:
- Pigmentation
- Moisture content / cellular structure of vegetation
- Mineral and moisture content of Soil
- Sedimentation level of water

IR $\simeq$ 8μm → 12~15μm Measures: - Heat Capacity / thermal properties of the Surface

Lower microwave range ~30mm → ~300mm (1 GHz → 10 GHz), Measures:
- Roughness of Surface
- Electrical properties of the Surface

Higher microwave frequencies $\simeq$ 20 GHz → 60 GHz Measures some atmospheric

Note that, of course, in other fields even more frequencies and collection techniques can be used (eg. X-rays in biomedical imaging).

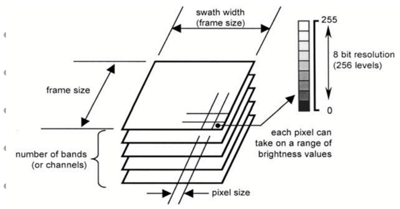
Additionally, even if we do not know what material we might find in an area by using multiple spectral measurements we can infer what material is in an area.

Technical characteristics of Digital Image Data

When handling image data the most important technical values of sensors are:

- The number, placement, and shape of the spectral bands / channels / measurements.
- The spatial resolution as it relates to pixel size
- The radiometric resolution (number of possible intensity values)
- The total frame size in ground km (determined by the swath width and frame size of the system)

Generally the combination of these values results in the total data volume to be processed in each image.



Blackbody Radiation

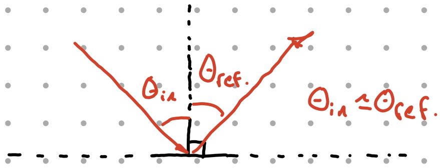
This is covered in more detail in RSDA with Proffesor Modotto, basically we can use the radiation curves of black bodys to infer where we will see the maximum radiance of a given object at a given temperature, eg's:
- Earth surface temp. $\simeq$ 300 Kelvin => $\lambda_{max} \simeq$ 10 → 12μm
- Bushfire temp. $\simeq$ 800 Kelvin => $\lambda_{max} \simeq$ 3 → 5μm

Electromagnetic Radiation Scattering

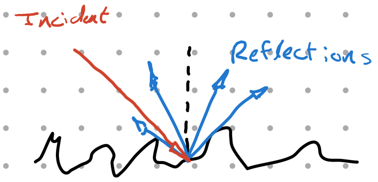
In Microwave based Sensing systems image data is obtained by first transmitting some waves then measuring the reflected wave.

This is affected primarily by the Surface's Scattering Coefficient which is a function of surface roughness and the complex permittivity of the material under study.
There are generally 4 types of reflector found on Earth:

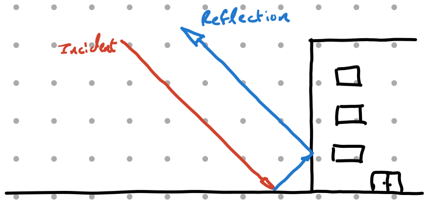
1. Smooth Surfaces (specular reflectors, mirror-like)
   These will reflect waves away from the sensing plat. and thus appear black or dark. Eg's:
   Calm water, flat concrete, etc.



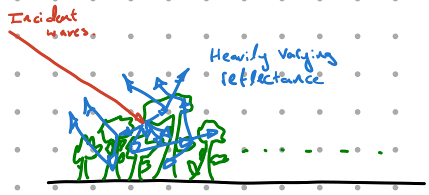
2. Rough Surfaces (diffuse reflectors) Scatter energy in many directions including back to the sensing platform. eg.s: mountainous terrain, desert, etc.



3. Corner Reflectors particularly associated with manufactured features like buildings. This will usually result in heavy reflection.



4. Volume Scattering reflectors usually due to vegetation, sea ice, etc. and results in heavy scattering from a number of places meaning reflectance in a tonal appearance.



Of course this isn't the whole picture and different M.W. wavelengths can be partially, fully, or not at all absorbed or attenuated different material types.

Remote Sensing Platforms

Different types of platforms and their general use cases:

1. Aircraft-based Sensing platforms → eg's: Airplanes, ballons, blimps, etc.

2. Satellite-based platforms → a. Geostationary Orbits ≃ 35,000Km → 45,000Km
   → b. Low Earth Orbits (LEO) ≃ 150Km → 2,000 Km

TODO: FINISH LECTURE ONE MAYBE??

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Lecture Two: Image Errors, Correction, and Registration (resolving known ground features with available image data)

Broad Strokes:

- Two categories of image data errors: 1. Radiometric (error in the measured brightness of a pixel)
  2. Geometric (distortion in image data from actual scene)

- Two general approaches to correcting radiometric errors caused by atmospheric effects:
  i.) Detailed (per-pixel) Correction
  ii.) Bulk (approximate) Correction → Also used to correct for radiometric, instrumentation errors.

- Two approaches to correcting geometric errors:
  i.) Numerical modelling of the error followed by bulk correction based on this model, this involves the use of Ground Control Points (GCPs) which must be appropriately chosen.
  ii.) Mathematical modelling of well known geometric errors followed by correction.

- Numerical modelling tech. for geometric errors can involve:
  - Image-to-Image registration (mapping one image onto another)
  - Rectification / geo-referencing (alignment of an image to a map.)

- Modern techniques for image correction, registration, and the selection of GCPs are often automated (feature based methods, SIFT, RANSAC)

Lecture Three: PCA (Principle Component Analysis) OR How I learned to stop worrying and Extract Useful Information from Hyperspectral Data

Broad Strokes:

- It is generally very useful to peform spectral transformations to image data to generate new images
- These new images usually provide new information and aid with classification techniques (next chapter), they can also lower the amount of data in an image without lossing essential information and allow for a colour rep. of image data without colour.
- Whilst a specialised Remote Sensing transform exists, we will look at a simpler one called the Principle Components Transform or Principle Components Analysis - PCA
- PCA involves:

Construct a new vector space with as many axes as there are channels → Plot each pixel in this space with the vector to its position corresponding to the pixels brightness. → Using a co-variance matrix the spread or scatter of the image pixels can be measured.

SOMETHING SOMETHING, I'M A BIT CONFUSED

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Lecture Four: Image Interpretation - Rise of the Machine (((Learning)))

Broad Strokes

- Two general approaches to image data interpretation:
  - Qualitative photointerpretation (humans) → Good spatial reasoning and feature assessment but quantitive spectral analysis is very difficult meaning information can be missed, dependent on operator training.
  - Quantitative analysis (computer) → Can be performed without humans but often will req. human intervention, it is possible to assess every single pixel (highly accurate), poor spatial reasoning unless deep learning is employed, dependent on good info.

A combination of the two is often employed for a "best of both worlds" result.

- Non-machine learning techniques can classify pixels individually using a number of techniques:
  - Using Pattern/multispectral space
  - Using object-wise or feature-wise detection

  } Both these techniques require good spectral seperation of classes and pre-defined spectral values of the classes in the image. This is often not trivial.

- Machine learning classification: Supervised vs Unsupervised:
  - Unsupervised learning generally involves clustering but there are other techniques. Without any input it will resolve the image data into a set of classes which the user will then label appropriately. This technique can be used as part of a "pipeline" which also has supervised learning for very accurate classification

	Supervised	Unsupervised	Reinforcement
Training data	Data and correct output	Data	States, actions, and rewards
Learning target	Data-output relationship	Patterns in data	Policy
Evaluation	Statistics	Fitness	Reward value
Typical application	Classifiers	Clustering	Controllers

Lecture Five: Statistical, Supervised classification - How to lose ~~a guy~~ *your mind* in ~~10~~ *less than a* day~~s~~

Lecture Six: Supervised, non-parametric (geometrical) classification - ♫ Anything statistical learning can do I can do better ♫

Lecture Seven: Unsupervised classification - ~~eat, pray, love~~ Cluster, Classify, Cry (then quit)

Lesson Eight: Deep ~~Impact~~ *Neural Networks* - Is it a bird?! Is it a plane?! Answer the Capcha so the robots can tell that it is in fact Superman.

Lesson Nine: Convolutional Neural Nets or "r/ kids are ~~f****** stupid~~ *really smart actually*"

Lesson Ten: AI and D.L. for Medical Imaging - Grandma was not run over by a reindeer, she was hallucinating due to this large tumor the doctors missed

Image Data Sources in the Microwave Region

Side Looking Airbourne Radar - SLAR
Synthetic Aperture Radar - SAR

Spatial Data Sources in General

Types of Spatial Data
Data Formats
Use of Colour in Remote Sensing Images
Multispectral Raster Image Formats

Lesson Two - Error Correction and Registration of Image Data

Error Correction and Registration of Image Data

Image Data Acquisition
Sources of Error in the (data-driven) Image Analysis Pipeline
Sources of Error in the Remote Sensing Data

Sources of Radiometric Distortion in Remote Sensing Data

Types of Radiometric Distortion
The Effect of Atmosphere on Radiation
Radiometric Quantity Definitions
Absorption and Scattering by the Atmosphere
The Effect of Atmosphere on Radiation Cont..
Further Radiometric Quantity Definitions
Atmospheric Effects on Remote Sensing Imagery
Instrumentation Errors
Striping (or Banding) Artifacts (Along Swath Direction)

Correction of Radiometric Distortion

Correction of Atmospheric Effects
Correction of Instrumentation Errors

Sources of Geometric Distortion in Remote Sensing Data

Sources of Geometric Distortion
Basic Image Formation Geometry
Earth Rotation Effects
Panoramic Distortion
Earth Curvature
Scan Time Skew
Variations in Platform Altitude, Velocity, and Attitude
Aspect Ratio Distortion
Sensor Scan Non-Linearities
Non-Systemic and Systematic Distortions

Correction of Geometric Distortion

General Aspects
Use of Mapping Polynomials for Image Correction
- Mapping Polynomials and Ground Control Points
- Resampling
- Interpolation
- Choice of Control Points
- Eg.: Map-Landsat MSS Registration

Mathematical Modelling
- Aspect Ratio Correction
- Earth Rotation Skew Correction
- Image Orientation to North-South
- Correction of Panoramic Effects
- Combining the corrections

Image Registration

Georeferencing and Geocoding
Image to Image Registration
Control Point Localisation by Windowed Image Correlation
Example of Im.-Im. Registration (Manual GCP Selection - SSDA)
Image to Image (Affine) Registration in the Frequency Domain
Control Point Registration by Automated Feature Extraction and Matching
Example of Im.-Im. Registration (Automated Feature Based)

Lesson Three - Multispectral Transformations of Image Data

Introduction

The Principle Components Transformation

The Mean Vector and Covariance Matrix
An example
A Zero Correlation, Rotational Transform
An example (cont...)
Practical Considerations
Real Example
A Second Real Example
A Third Real Example: Landsat Thematic Mapper
Remarks about the Principle Components Transform
The Effects of an Origin Shift
Applications of Principal Components in Image Enhancement and Display
The Taylor Method of Contrast Enhancement (Decorrelation Stretch)
Decorrelation Stretch Example One
Decorrelation Stretch Example Two
Other Applications of Principle Components Analysis

Lecture Four - The Interpretation of Digital Image Data

Approaches to Interpretation
The Classic View of Complementarity
Pixel-Wise Classification
Pixel-Wise Classification in the Pattern Space
Multi-Spectral Pattern Space: Information vs Spectral Classes

Object-Wise Detection / Classification
The Current "Interpretability" Perspective

Definition and Types of Machine Learning
Machine Learning Overview
Applications of Machine Learning
Imaging and Beyond
Classification and Beyond

Image Interpretation Domains: Beyond Remote Sensing
UnSupervised Classification
Supervised Classification
Steps in Supervised Classification
Measuring the Success and Performance for Classification
Typical Issues in Machine Learning
Overfitting and Underfitting
Generalisation and Capacity
Model Capacity
Bias and Variance
Overall Picture

Lesson Five - Supervised (Statistical) Classification Techniques

Maximum Likelihood Classification

Bayes' Classification
The Maximum Likelihood Decision Rule
Multivariate Normal Class Models
Decision Surfaces
Thresholds
Number of Training Pixels Required for Each Class
A Simple Illustration

Gaussian Mixture Models

Minimum Distance and Parallel-Piped Classification

The Case of Limited Training Data
Minimum Distance Classifier: The Discriminant Function
Remarks on Minimum Distance Classification
Decision Surfaces - Example
Remarks on Minimum Distance Classification
Parallel-Piped Classification
Classification Time Comparison of the Classifiers

Context Classification

The Concept of Spatial Context
Context Classification by Image Pre-Processing
Post Classification Filtering
Probabilistic Label Relaxation
- The Basic Algorithm
- The Neighbourhood Function
- Determining the Compatibility Coefficients
- The Final Step
  - Stopping the Process
  - Propagation Control
- Example One
- Example Two

Handling Spatial Context by Markov Random Fields
Comparative Example

Lesson Six - Supervised Non-Parametric Classification: Geometric Approaches

Introduction

The kNN (Nearest Neighbour) Classifier

Non-Parametric Methods from a Geometric Basis: Linear Discrimination

Concept of a Weight Vector
Testing Class Membership
Training a Linear Classifier in the Weight Space
Setting the Correction Increment

Support Vector Classifiers

Linearly Seperable Classes
Overlapping Classes - The Use of Slack Variables
Linear Inseparability
The use of Kernel Functions
Example
Popular Kernels

Binary vs Multicategory Classification

Binary Classification - The Threshold Logic Unit
Multi category Classification
Networks of Classifiers - Solutions of Non-Linear Problems
SVM Application: Kernel Selection and Multicategory Stategy
SVM Application: Examples

Networks of Classifiers: The Neural Network Approach

The Neural Network Approach
The Processing Element
Training the Neural Networks - Backpropagation
Choosing the Network Parameters

Committees of Classifiers: Ensemble Classification

Problem Statement and Decision Logics
Bagging
Boosting: AdaBoost

Committees of Classifiers: Random Forests

The Idea of Ensembling Multistage Classifiers
Decision Tree Classifiers
CART - Classification And Regression Trees
Random Forests

Lesson Seven - Clustering and Unsupervised Classification

Back to the General Problem of Delineation of Spectral Classes

Similarity Metrics and Clustering Criteria

How many Clusters? - Similarity Metrics and Clustering Criteria

The Iterative Optimisation (Migrating Means, k-Means) Clustering Algorithm

The Basic Algorithm
Isodata - Mergings, Deletions, and Splitting Elongated Clusters
Choice of Initial Cluster Centres
Clustering Cost

Unsupervised Classification and Cluster Maps - Examples

Unsupervised Classification and Cluster Maps
Clustering Example

A Single Pass Clustering Technique

Single Pass Algorithm
Advantages and Limitations
Skip Generation Parameter
Variations on the Single Pass Algorithm
Example

Agglomerative Hierarchical Clustering

Clustering by Histogram Peak Selection

Lesson Eight - From Shallow to Deep Neural Networks

Main Resources & Related Courses

Knowledge Base vs Representation Learning

Feed-Forward Neural Networks...
The Mammalian Visual Cortex is Hierarchical
Multilayer Perceptron (MLP)
Representation (Feature) Learning Perspective of MLP
Activation (Non-Linear) Functions, g()
Training an MLP (and a Function)
MLP Expressiveness
Number of Neurons
Example One: Expressiveness
Example Two: Binary Case and Complexity

Universal Approximation Theorems
Approximation Capability (Expressiveness): The Width or Depth Dilemma

Outputs and Loss Functions

Loss Function
Task Dependency of Output and Loss Functions
Image Classification
Binary Classification - Bernoulli Distribution - BCE
Multiclass Classification - Categorical Distribution - CE Loss
Multiclass Classification - Categorical Distribution - Softmax Output
Summary: Classification Deep Neural Networks

Activation Functions

Sigmoid
Tanh
Rectified Linear Unit (ReLU)
Leaky ReLU
Exponential Linear Units (ELU)
Maxout

Lesson Nine - Convolutional Neural Networks

Introduction
Notation
Fully Connected vs Convolutional Layers
Downsampling
  Pooling
  Strided Convolution
Receptive Field Algorithm
Fully Connected Layers
Convolutional Network Example
Upsampling
Max Unpooling
Dilated Convolution
  Gridding Effects
  Architectures
Some Remarks about CNNs

Lesson Ten - AI and Deep Learning for Medical Image Analysis

Intro - Main Issues/Challenges
Data Driven Approach
Evaluation Metrics
Applications and Case Studies
  Medical Image Classification
  Medical Image Segmentation and Detection
  Higher Dimensionality Data
Interpretability, Fairness, Ethics