Remote Sensing: An overview
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• Remote Sensing is the collection of information about an object without being in direct physical contact with the object.

• Remote sensing involves the use of instruments or sensors to "capture" the spectral and spatial relations of objects and materials observable at a distance - typically from above them.

• Information acquisition technique for remote sensed data.
Historical review

- Remote sensing began in the 1840s as balloonists took pictures of the Earth's surface using the newly invented photograph camera.
- Aerial photography became a valuable reconnaissance tool during the First World War and came fully into its own during the Second World War due to the improvement of technology in both rockets and antennas.
Current status

• First operational satellites during 70s.
• Non military satellite systems since 1982.
• Airborne or spaceborne systems.
• USA vs EU missions. (GPS vs Galileo)
Remote Sensing Process

- Select Appropriate Logic
  - Inductive
  - Deductive
  - Technological

- Formulate Hypothesis

- In Situ
  - Field
  - Laboratory
  - Collateral data

- Remote Sensing of Biophysical and Hybrid Data
  - Passive analog
    - Camera
    - Videography
  - Passive digital
    - Camera
    - Multispectral scanners
    - Linear and area arrays
    - Spectroradiometers
  - Active
    - Microwave (radar)
    - Laser (Lidar)
    - Sonar

- Analog (Visual) Image Processing
  - Using the “Elements of Image Interpretation”

- Digital Image Processing
  - Pattern recognition
    - Statistical, syntactical
    - Expert systems
    - Using a knowledge base and inference engine
  - Neural networks
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling based on physics of energy/matter interactions

- Scientific Visualization

- Hypothesis Testing
  - Accept or reject hypothesis

- Analog and Digital
  - Images
  - Image maps
  - Orthophotomaps
  - Thematic maps
  - Spatial databases

- Error Report
  - Geometric
  - Thematic

- Image Lineage
  - Genealogy

- Statistics
  - Univariate
  - Multivariate

- Graphs
  - 1d, 2d, 3-dimensions
Remote Sensing and GIS

Real World

- World Model

GIS

- Object Model
- Analysis Model
- Object Extraction

Remote Sensing Image

Image Model

Diagram shows the relationship between the real world, GIS, and remote sensing image through various models and processes.
Applications I

- **Agriculture & Forestry**
  - Discrimination of vegetation types.
  - Determination of soil conditions.
  - Deforestation & Aforestation.
  - Assessment of grass and forest fires damage.

- **Geology and Water**
  - Recognition of rocks and minerals.
  - Mapping recent volcanic surface deposits.
  - In land water.
  - Bathymetry.
  - Water quality assessment.
  - River discharge mapping.
Applications II

• **Surveillance.**
  – Volcanoes and Fires.
  – Technological hazards.
  – Ice mountains.
  – Landslides and soil erosion.
  – Oil spill detection.
  – Surveillance of oceans.
  – Ship detection and monitoring.

ITALSCAR project generates reference Burn Scars Maps (BSM) and the associated catalogue, based on the use of historical Remote Sensing data from European Earth Observation (EO) satellite missions, for supporting the operational Fire Disaster management over Italy at national and at regional level.
Applications III

- **Land Cover/Use**
  - Classification of land uses.
  - Mapping of road networks.
  - Change detection.
  - Digital Elevation Models (DEM).

![Map of Europe with various land cover classes]
Applications IV

- Medical Imaging
  - Electromagnetic radiation
  - Use of different complementary modalities

Computed Tomography (CT)  Magnetic Resonance Image (MRI)
Applications V

- **Cosmology**
  - Space probes with a variety of imaging sensors.
Electromagnetic spectrum

- Most remote sensing data consists of receiving and measuring reflected and/or emitted radiation from different parts of the electromagnetic spectrum.
- Commonly used segments are ultraviolet, visible, reflected infrared, thermal infrared, and microwave.
Electromagnetic spectrum

According to Steffan-Boltzman law the amount of energy emitted by an object such as the Sun or the Earth is a function of its temperature. Its dominant wavelength ($\lambda_{max}$) can be computed as:

$$\lambda_{max} = \frac{k}{T}$$

where $k$ is a constant equaling 2898 $\mu$m °K, and $T$ is temperature in degrees Kelvin. The Sun produces a continuous spectrum of electromagnetic radiation ranging from very short, extremely high frequency gamma and cosmic waves to long, very low frequency radio waves.
Data types

- Panchromatic data.
- Multispectral data.
- Hyperspectral data.
- Microwave (Synthetic Aperture Radar).
Interaction with Atmosphere

• **Scattering** occurs when particles interact with and cause the electromagnetic radiation to be redirected from its original path.

• **Absorption** is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. This phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.
Rayleigh scattering occurs when the diameter of the matter (usually air molecules) are many times smaller than the incident electromagnetic radiation. Rayleigh scattering is responsible for the blue sky. The short violet and blue wavelengths are more efficiently scattered than the longer orange and red wavelengths. When we look up on cloudless day and admire the blue sky, we witness the preferential scattering of the short wavelength sunlight.
Atmospheric Absorption

- **Ozone** serves to absorb the harmful (to most living things) ultraviolet radiation from the sun.
- **Carbon dioxide** is referred to as a greenhouse gas. This is because it tends to absorb radiation strongly in the far infrared portion of the spectrum - that area associated with thermal heating - which serves to trap this heat inside the atmosphere.
- Those areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors, are called **atmospheric windows**.
Atmospheric windows

• Here is a generalized diagram showing relative atmospheric radiation transmission of different wavelengths.

Blue zones mark minimal passage of incoming and/or outgoing radiation, whereas, white areas denote atmospheric windows.
Atmospheric windows

The Sun approximates a 6,000 K blackbody with a dominant wavelength of 0.5 μm (green light). Earth approximates a 300 K blackbody with a dominant wavelength of 9.7 μm. The 6,000 K Sun produces 41% of its energy in the visible region from 0.4 - 0.7 μm (blue, green, and red light). The other 59% of the energy is in wavelengths shorter than blue light (<0.4 μm) and longer than red light (>0.7 μm). Eyes are only sensitive to light from the 0.4 to 0.7 μm. Remote sensor detectors can be made sensitive to energy in the non-visible regions of the spectrum.
Geostationary satellites

- Same speed with Earth.
- Altitude \(~36000\text{Km}\).
Orbital Satellites

- Flight height ~ 800-900 km.
- Period ~ 95-105 min about 14 full circles in 24 hours.
Multispectral Scanners Characteristics

- Spatial resolution.
- Instantaneous field of view (IFOV).
- Pixel size.
- Spectral resolution.
- Radiometric resolution (bits).
- Temporal resolution.
Multispectral Scanners Characteristics

- Spatial resolution – the size of the field-of-view, e.g. 10x10 m.
- Spectral resolution – the number and size of spectral regions that the sensor records data, e.g. 7 bands covering visible and near infrared.
- Temporal resolution – how often the sensor acquires data, e.g. every 3 days.
- Radiometric resolution – the sensitivity of detectors to small differences in electromagnetic energy.
Across-track scanners

- Across-track scanners scan the Earth in a series of lines using a rotating mirror (A) and a bank of internal detectors (B).
- The reflected or emitted radiation is separated into several spectral components that are detected independently.
- The IFOV (C) and the altitude determine the ground resolution cell viewed (D), and thus the spatial resolution.
- The angular field of view (E) determines the width of the imaged swath (F).
Along-track scanners

- Along-track scanners, instead of a scanning mirror, they use a linear array of detectors (A) located at the focal plane of the image (B) formed by lens systems (C), which are "pushed" along in the flight track direction. (pushbroom scanners)
- Each individual detector measures the energy for a single ground resolution cell (D) and thus the size and IFOV of the detectors determines the spatial resolution of the system.

Improved radiometric resolution. Smaller IFOV resulting in improved spatial and spectral resolution.
Multispectral Space

• A multispectral vector space has as many dimensions as the spectral bands.
• The pixels tend to form groups or clusters of pixels corresponding to different ground or cover types.
• In many cases the information classes of interest do not form distinct clusters or groups.
Spectral Signature

- Measuring the energy that is reflected by targets on the Earth's surface over a variety of different wavelengths, we can build up a **spectral signature** for that object.
Spectral Signature

- By comparing the response patterns of different features we may be able to distinguish between them, where we might not be able to, if we only compared them at one wavelength.
- In the figure the spectral signatures of alunite (red), buddingtonite (green) and kaolinite (blue) are presented.
Examples of different ground or spatial resolution.
LandSat 7 ETM

- The series started at 1972 for military purposes.
- Very successful commercially.
- 5 year design life (may be expendable for 6 years).
- Collect and transmit up to 532 scenes/day.
- Launched April 1999.
- Repeat coverage is 16 days.
LandSat 7 ETM

Highly correlated complementary information.

Features that are not perceived by the human eye can be found in multispectral data.

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Spectral Range (microns)</th>
<th>Ground Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.45 to .515</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>.525 to .605</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>.63 to .690</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>.75 to .90</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>1.55 to 1.75</td>
<td>30</td>
</tr>
<tr>
<td>6 (thermal)</td>
<td>10.40 to 12.50</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>2.09 to 2.35</td>
<td>30</td>
</tr>
<tr>
<td>Pan</td>
<td>.52 to .90</td>
<td>15</td>
</tr>
</tbody>
</table>
Panchromatic data

- These data cover only the visible region of the electromagnetic spectrum.
- The information is exactly the same with that perceived by the human eye.
- Improved spatial resolution (15m for Landsat).
IKONOS

• Revisit time 1 day
• Spatial resolution 4 m for multispectral data.
• It can be improved to 1 m.
• Blue: 0.45-0.52 μm
  Green: 0.51-0.60 μm
  Red: 0.63-0.70 μm
  Near IR: 0.76-0.85 μm

IKONOS, Manhattan.
IKONOS

Frankfurt Airport, Germany
MERIS

- The Medium Resolution Imaging Spectrometer (MERIS) is one of ten sensors onboard Envisat.
- Operates in the visible and near-infrared region of the EM spectrum (400-900nm).
- It provides 15 wavebands of either 1200 or 300 metres spatial resolution.
- MERIS data are used to obtain information about oceans, coastal zones, land surfaces and atmosphere.
MERIS
The Airborne Visible Infrared Imaging Spectrometer (AVIRIS) is one of the first airborne systems operated by NASA/JPL.

Each data set contains 224 bands with wavelengths ranging from 370 to 2500 nm.

The instantaneous field of view (IFOV) is about 1 mrad so that in the operating height of 20 Km, the ground spatial resolution is about 20m.

The radiometric resolution is 16 bits.
AVIRIS

- A pushbroom sensor collects information along the scan line. (a)
- Successive scan lines are stacked to obtain a three-dimensional hyperspectral data cube. (b)
- The spatial information of a scene is represented by the $x$ and $y$ dimensions of the cube, while the amplitude spectra of the pixels are projected into the $z$ dimension. (c).
- The spectral samples can be plotted for each pixel or for each class of material in the hyperspectral cube. (d)
Vegetation Indices

• The near-infrared (NIR) to red simple ratio (SR) is the first true vegetation index:
  
  \[ \text{SR} = \frac{\text{NIR}}{\text{red}} \]

  It takes advantage of the inverse relationship between chlorophyll absorption of red radiant energy and increased reflectance of near-infrared energy for healthy plant canopies.

• The generic normalized difference vegetation index (NDVI):

  \[ \text{NDVI} = \frac{(\text{NIR} - \text{red})}{(\text{NIR} + \text{red})} \]

  has provided a method of estimating net primary production over varying biome types, identifying ecoregions, monitoring phenological patterns of the earth’s vegetative surface, and of assessing the length of the growing season and dry-down periods.
Applications of hyperspectral data
Hyperspectral image processing
Spectral unmixing

• Spectral unmixing is the decomposition of a mixed pixel into a collection of distinct spectra, or endmembers, and a set abundance fractions that indicate the percentage of each endmember.

• Dimensionality reduction is achieved by means of PCA, ICA, PP, Wavelet transform.
Microwave region ~ 1mm to 1m

- **Ka, K, Ku bands** → short wavelengths used in early airborne radar systems
- **X-band** → used on airborne systems for military and terrain mapping
- **C-band** → common on airborne / spaceborne systems (e.g. ERS-1 and 2 and RADARSAT)
- **S-band** → used on-board by ALMAZ
- **L-band** → used on-board by SEASAT and JERS-1 and NASA airborne system
- **P-band** → used on NASA experimental airborne research system
SAR polarization

Like-polarized

- HH – horizontal transmit, horizontal receive
- VV – vertical transmit, vertical receive

Cross-polarized

- HV – horizontal transmit, vertical receive
- VH – vertical transmit, horizontal receive

RADAR systems can have:

- single polarized → HH or VV (or possibly HV or VH)
- dual polarized → HH and HV, VV and VH, or HH and VV
- alternating polarized → HH and HV, alternating with VV and VH
- polarimetric → HH, VV, HV, and VH
Polarization

C-band images

Composite

C-HV

C-HH

C-VV
Two bands - SAR

→ C-band radar

→ L-band radar
SAR missions – current & future

Current SAR missions
- ERS-2
- RADARSAT-1
- ENVISAT
- JERS
- ALOS
- METEOR-3M N1

Future SAR missions
- RADARSAT-2
- COSMO-SKYMED
- RISAT
- SAR-Lupe
- TerraSAR-L
- TerraSAR-X
- HJ-1C (CAST)
- SAOCOM
- SSR-2
- NPOESS
- METEOR-3M N2
- MicroSAR

Airborne radar systems
- Convair-580 C/X SAR
- STAR
- AirSAR / TopSAR
**RADARSAT-1 (CSA)**

**SAR Characteristics**

<table>
<thead>
<tr>
<th>Frequency / Wavelength</th>
<th>5.3GHz/C-band 5.6 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Bandwidth</td>
<td>11.6, 17.3 or 30.0 Mhz</td>
</tr>
<tr>
<td>Transmitter Power (peak)</td>
<td>5 kW</td>
</tr>
<tr>
<td>Transmitter Power (average)</td>
<td>300 W</td>
</tr>
<tr>
<td>Maximum Data Rate</td>
<td>85 Mb/s (recorded) - 105 Mb/s (R/T)</td>
</tr>
<tr>
<td>Antenna Size</td>
<td>15m x 1.5m</td>
</tr>
<tr>
<td>Antenna Polarization</td>
<td>HH</td>
</tr>
</tbody>
</table>

- image swaths from 45 to 500 kilometres in width
- resolutions from 8 to 100 metres
- incidence angles from 10 to 60 degrees.

**RADARSAT-1 (CSA)**

| Currently being flown | 04 Nov 95 | 31 Dec 05 | Environmental monitoring, physical oceanography, ice and snow, land surface | RADARSAT DTT, RADARSAT TTC, SAR (RADARSAT) | Type: Sun-synchronous Altitude: 798 km Period: 100.7 mins Inclination: 98.594 deg Repeat cycle: 24 days LST: 1800 Longitude (if geo): Asc/desc: Ascending |
### Coverage and Frequency Using Maximum Swath Width

<table>
<thead>
<tr>
<th>Area</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>North of 70 degrees N</td>
<td>Daily</td>
</tr>
<tr>
<td>North of 48 degrees N</td>
<td>Every 4 days</td>
</tr>
<tr>
<td>The Earth (except the centre of Antarctica - 80 degrees S and 90 degrees S)</td>
<td>Every 6 days</td>
</tr>
</tbody>
</table>
**ENVISAT (ESA)**

- **Instrument**: C-band
- **Polarization**: HH, VV, HV or VH
- **Spatial resolution**: 30 m
- **Swath width**: up to 100 km
- **Incidence angles**: 15° – 45° (7 swath positions)

| Envisat (ESA) | Currently being flown | 01 Mar 02 | 01 Mar 07 | Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles | AATSR, ASAR, ASAR (image mode), ASAR (wave mode), DORIS-NG, ENVISAT Comms, GOMOS, MERIS, MIPAS, MWR (BNSC), RA-2, SCIAMACHY | Type: Sun-synchronous Altitude: 782 km Period: 100.5 mins Inclination: 98.52 deg Repeat cycle: 35 days LST: 1030 Longitude (if geo): Asc/desc: Descending |

Alternating Polarization is similar, but will provide simultaneous dual-polarised images; either both VV & HH polarization images, or one of two combinations of plane polarised and cross polarized images (VV&VH or HH & HV). Wide Swath Mode (150 m resolution) and Global Monitoring Mode (1000 m resolution) provide images covering a 400 km swath, in either HH or VV polarization. Finally, in Wave Mode, images of 5 km by (5 to 10 km) will be acquired, spaced 100 km along track and alternating between 2 of 7 across track positions, in either VV or HH polarization.
**ENVISAT (ESA)**

Synthetic Radar Aperture (SAR) vs. Advanced Synthetic Radar Aperture (ASAR)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>10 to 100 metres</td>
<td>30 to 1000 metres</td>
<td>3 to 100 metres</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>HH</td>
<td>HH, VV, HV or VH</td>
<td>HH, HV, VV and VH</td>
</tr>
<tr>
<td><strong>Look direction</strong></td>
<td>Right-looking (Left-</td>
<td>Routine left- and right-looking operation</td>
<td>Routine left- and right-looking operation</td>
</tr>
<tr>
<td></td>
<td>looking for Antarctic missions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Onboard recording device</strong></td>
<td>Analogue recorders</td>
<td>Solid-state recorders</td>
<td>Solid-state recorders</td>
</tr>
<tr>
<td><strong>Location Accuracy Device</strong></td>
<td>None</td>
<td>Three instruments for corrections and precise orbit provision (MWR, DORIS, and LRR)</td>
<td>GPS receivers onboard</td>
</tr>
<tr>
<td><strong>Yaw-steering</strong></td>
<td>None</td>
<td>Yes</td>
<td>Yaw-steering for zero Doppler shift at beam centre</td>
</tr>
<tr>
<td><strong>Polarimetry</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Main difference between RADARSAT-1, ENVISAT and RADARSAT-2

**Signal polarization**

- **RADARSAT-1** provided single HH polarization data, providing HH products.

- The **ASAR** sensor on **ENVISAT** has multi-polarization capability. It will provide:
  - 2 choices of selective single polarization (HH or VV); or
  - 3 choices of dual-polarized data products (HH/VV or HH/HV or VV/VH). The dual-polarized products are delivered as an image with 2 layers of information.

- **RADARSAT-2** will have complete polarimetric capability. It will provide:
  - 2 choices of selective single polarization (HH or VV);
  - 2 choices of dual-polarized data (HH/HV or VV/VH). The dual-polarized products are delivered as an image with 2 layers of information; or
  - Complete set of quad-polarized data (HH/VV/HV/VH). The polarimetric data are measured coherently (i.e. the quad-polarized data are not only a four-layer image). This product is delivered in a matrix format that gives full information of the received signal (amplitude and relative phase). This opens up the possibility of extracting unique information in the image in a way that is not possible with other civilian SAR sensors.