MODULE – 2 LECTURE NOTES – 2

SPATIAL AND SPECTRAL RESOLUTIONS

1. Introduction

In general, the resolution is the minimum distance between two objects that can be distinguished in the image. Objects closer than the resolution appear as a single object in the image. However, in remote sensing the term resolution is used to represent the resolving power, which includes not only the capability to identify the presence of two objects, but also their properties. In qualitative terms resolution is the amount of details that can be observed in an image. Thus an image that shows finer details is said to be of finer resolution compared to the image that shows coarser details. Four types of resolutions are defined for the remote sensing systems.

- Spatial resolution
- Spectral resolution
- Temporal resolution
- Radiometric resolution

This lecture covers the spatial and spectral resolutions in detail.

2. Spatial resolution

A digital image consists of an array of pixels. Each pixel contains information about a small area on the land surface, which is considered as a single object.

Spatial resolution is a measure of the area or size of the smallest dimension on the Earth’s surface over which an independent measurement can be made by the sensor.

It is expressed by the size of the pixel on the ground in meters. Fig.1 shows the examples of a coarse resolution image and a fine resolution image.

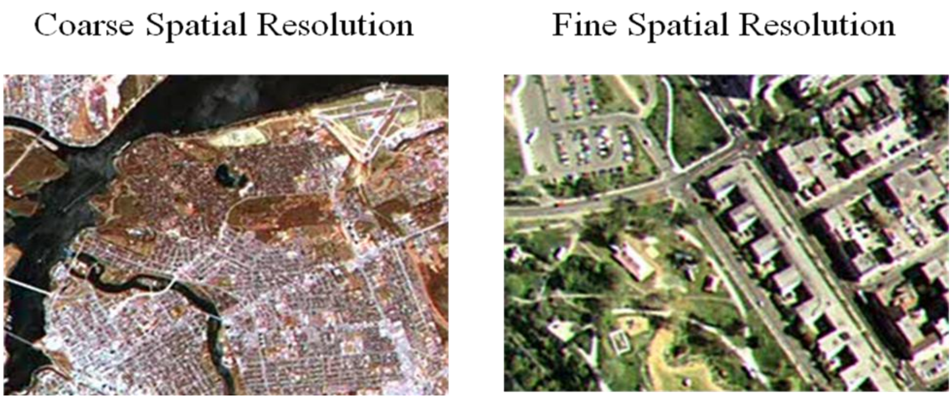


Fig.1 Examples of a coarse resolution and a fine resolution image

A measure of size of pixel is given by the Instantaneous Field of View (IFOV). The IFOV is the angular cone of visibility of the sensor, or the area on the Earth's surface that is seen at one particular moment of time. IFOV is dependent on the altitude of the sensor above the ground level and the viewing angle of the sensor.

A narrow viewing angle produces a smaller IFOV as shown in Fig. 2. It can be seen that viewing angle β being greater than the viewing angle α, $IFOV_\beta$ is greater than $IFOV_\alpha$. IFOV also increases with altitude of the sensor as shown in Fig. 2. $IFOV_\beta$ and $IFOV_\alpha$ of the sensor at smaller altitude are less compared to those of the higher altitude sensor.

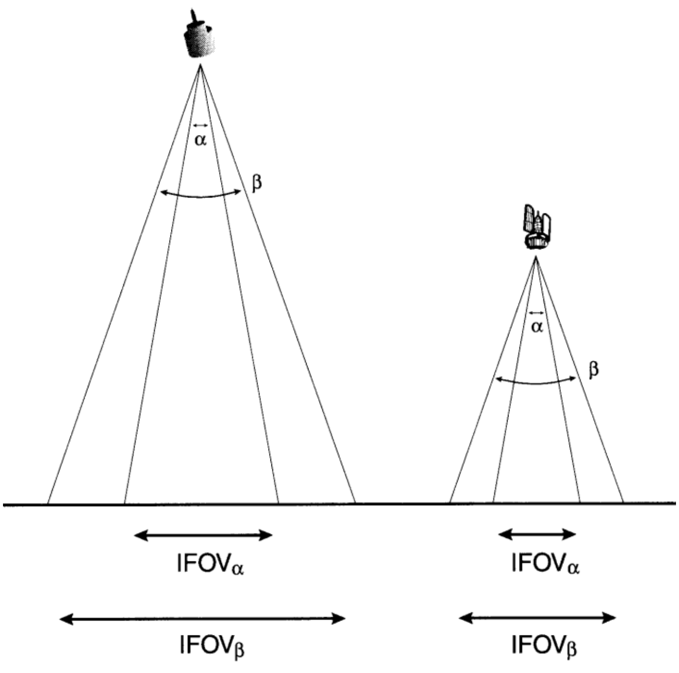


Fig.2. IFOV variation with angle of view and altitude of the sensor

The size of the area viewed on the ground can be obtained by multiplying the IFOV (in radians) by the distance from the ground to the sensor. This area on the ground is called the ground resolution or ground resolution cell. It is also referred as the spatial resolution of the remote sensing system.

For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If more than one feature is present within the IFOV or ground resolution cell, the signal response recorded includes a mixture of the signals from all the features. When the average brightness of all features in that resolution cell is recorded, any one particular feature among them may not be detectable. However, smaller features may sometimes be detectable if their reflectance dominates within a particular resolution cell allowing sub-pixel or resolution cell detection.

Fig. 3 gives an example of how the identification of a feature (a house in this case) varies with spatial resolution. In the example, for the 30m resolution image, the signature from the "house" dominates for the cell and hence the entire cell is classified as "house". On the other hand, in the fine resolution images, the shape and the spatial extent of the feature is better captured. In the 5m resolution image, along the boundary of the feature, some of the cells that are partially covered under the feature are classified as "house" based on the dominance of the signals from the feature. In the very fine resolution image, the feature shape and the spatial extent is more precisely identified.

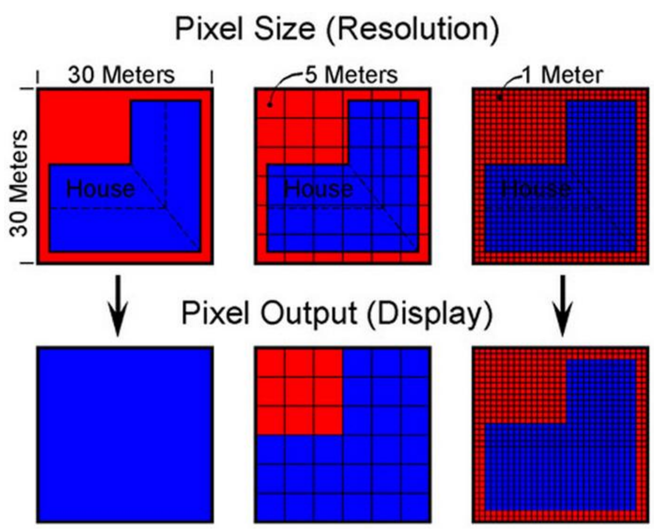


Fig. 3. Schematic representation of feature identification at different spatial resolutions (Source: http://www.satimagingcorp.com/)

Based on the spatial resolution, satellite systems can be classified as follows.

- Low resolution systems
- Medium resolution systems
- High resolution systems
- Very high resolution systems

Remote sensing systems with spatial resolution more than 1km are generally considered as low resolution systems. MODIS and AVHRR are some of the very low resolution sensors used in the satellite remote sensing. When the spatial resolution is 100m – 1km, such systems are considered as moderate resolution systems. IRS WiFS (188m), band 6 i.e., thermal infrared band, of the Landsat TM (120m), and bands 1-7 of MODIS having resolution 250-500m come under this class. Remote sensing systems with spatial resolution approximately in the range 5-100m are classified as high resolution systems. Landsat ETM^+ (30m), IRS LISS-III (23m MSS and 6m Panchromatic) and AWiFS (56-70m), SPOT 5(2.5-5m Panchromatic) are some of the high resolution sensors. Very high resolution systems are those which provide less than 5m spatial resolution. GeoEye (0.45m for Panchromatic and 1.65m for MSS), IKONOS (0.8-1m Panchromatic), and Quickbird (2.4-2.8 m) are examples of very high resolution systems.

Fig. 4 shows how an area looks like in images of different spatial resolution, how much information can be retrieved from each and the scale of application of these images.

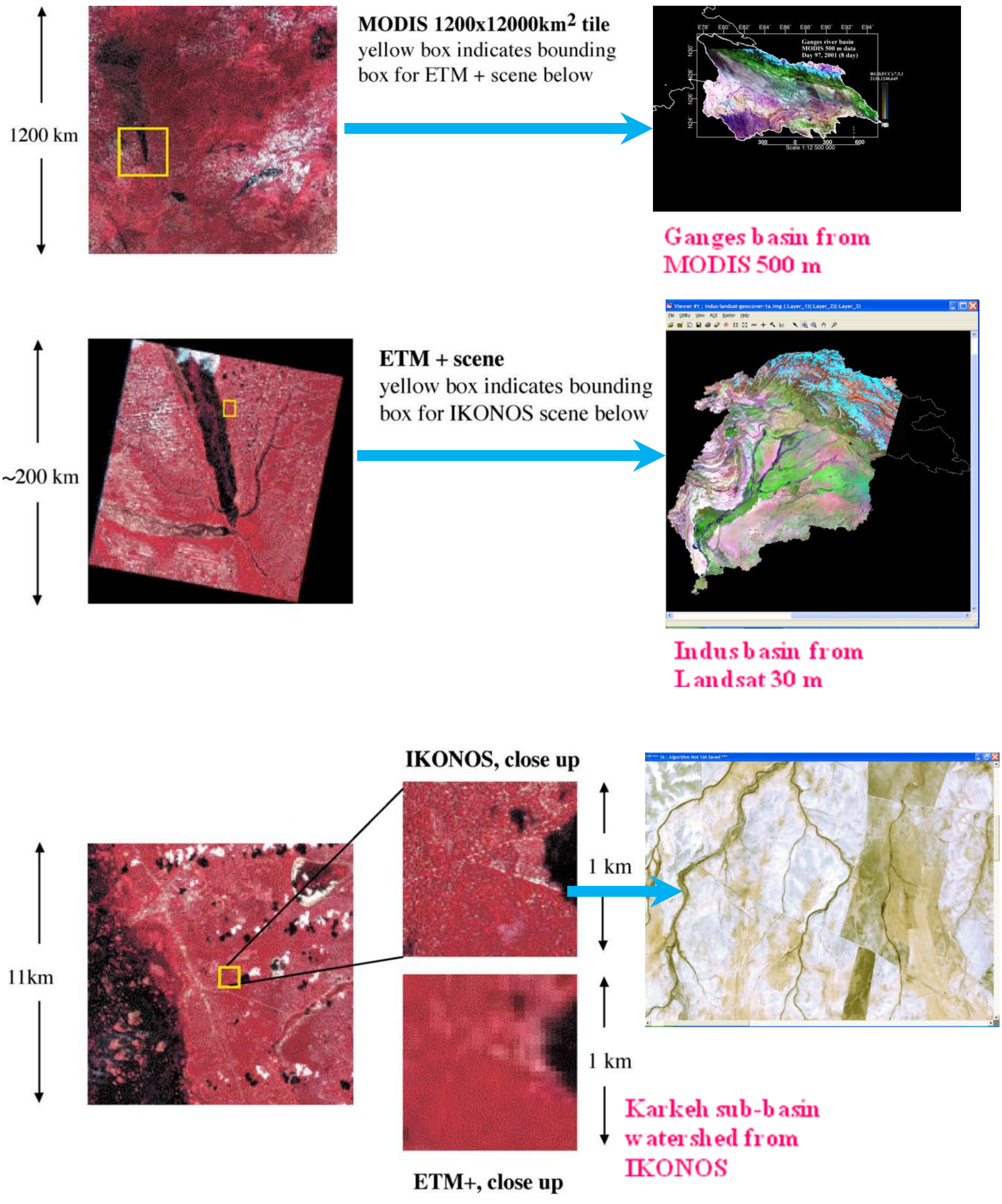


Fig.4. False color composite image (red = 850 nm, blue = 650 nm, blue = 555 nm) of MODIS, ETM+ and IKONOS imagery (Courtesy: Morisette et al., 2002)

The ratio of distance on an image or map, to actual ground distance is referred to as scale.

If we have a map with a scale of 1:100,000, an object of 1cm length on the map would actually be an object 100,000cm (1km) long on the ground. Maps or images with small "map-to-ground ratios" are referred to as small scale (e.g. 1:100,000), and those with larger ratios (e.g. 1:5,000) are called large scale. Thus, large scale maps/images provide finer spatial resolution compared to small scale maps/images.

3. Spectral resolution

Spectral resolution represents the spectral band width of the filter and the sensitiveness of the detector. The spectral resolution may be defined as the ability of a sensor to define fine wavelength intervals or the ability of a sensor to resolve the energy received in a spectral bandwidth to characterize different constituents of earth surface. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

Many remote sensing systems are multi-spectral, that record energy over separate wavelength ranges at various spectral resolutions. For example IRS LISS-III uses 4 bands: 0.52-0.59 (green), 0.62-0.68 (red), 0.77-0.86 (near IR) and 1.55-1.70 (mid-IR). The Aqua/Terra MODIS instruments use 36 spectral bands, including three in the visible spectrum. Recent development is the hyper-spectral sensors, which detect hundreds of very narrow spectral bands. Figure 5 shows the hypothetical representation of remote sensing systems with different spectral resolution. The first representation shows the DN values obtained over 9 pixels using imagery captured in a single band. Similarly, the second and third representations depict the DN values obtained in 3 and 6 bands using the respective sensors. If the area imaged is say A km^2, the same area is being viewed using 1, 3 and 6 number of bands.

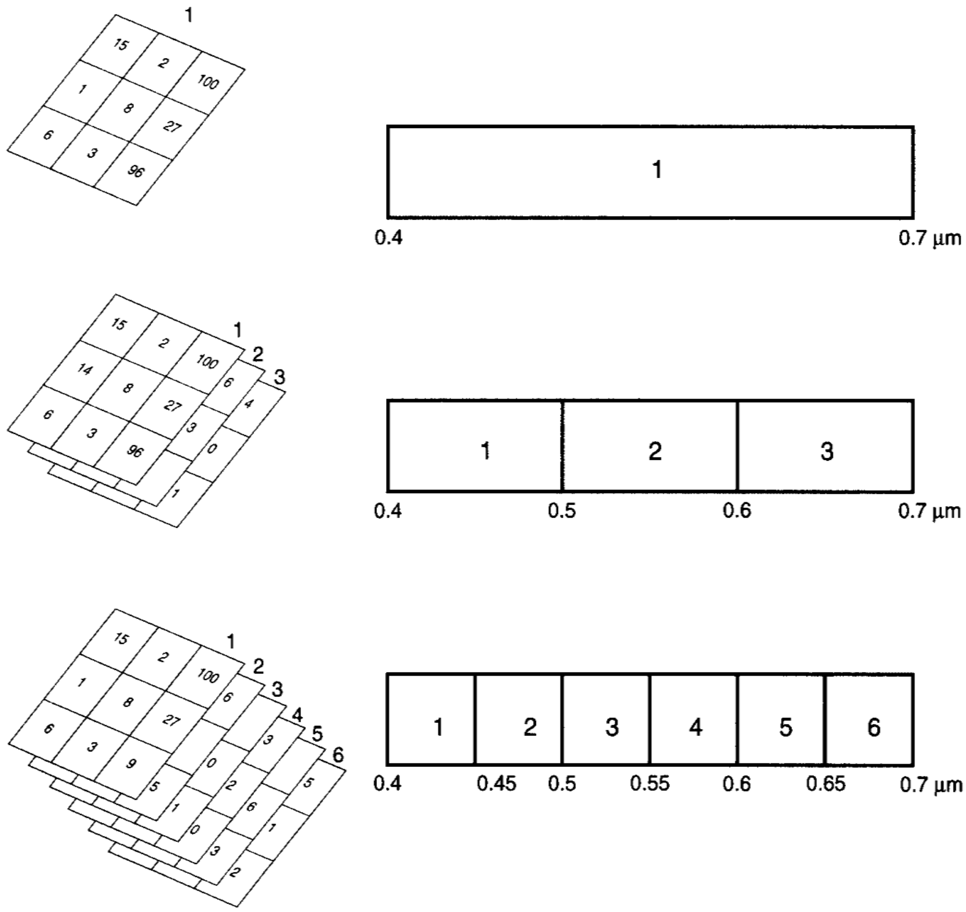


Fig. 5. Hypothetical representation of remote sensing systems with different spectral resolution (Source: Gibson, 2000)

Generally surface features can be better distinguished from multiple narrow bands, than from a single wide band.

For example, in Fig. 6, using the broad wavelength band 1, the features A and B cannot be differentiated. However, the spectral reflectance values of the two features are different in the narrow bands 2 and 3. Thus, a multi-spectral image involving bands 2 and 3 can be used to differentiate the features A and B.

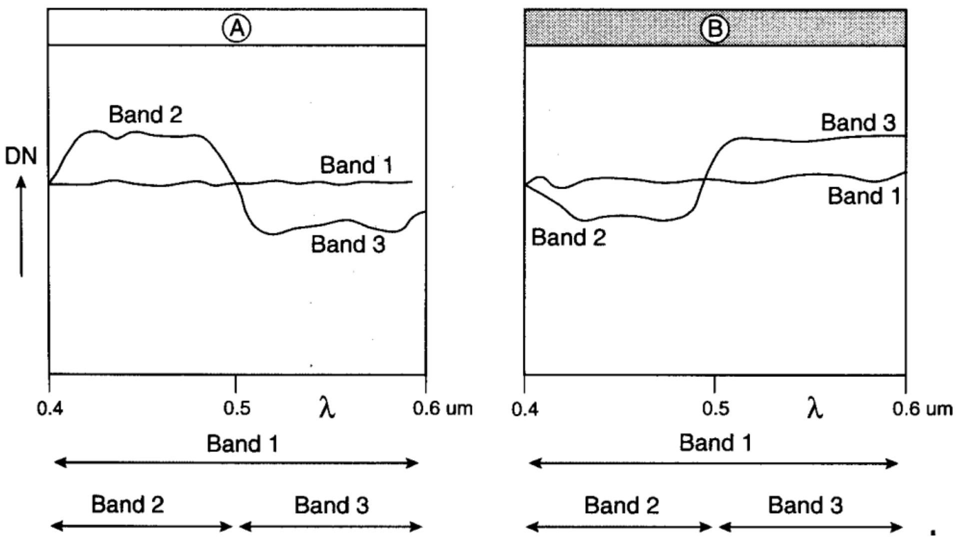


Fig.6. Two different surfaces (A and B) are indistinguishable on a single band but can be differentiated in 2 narrow bands

In remote sensing, different features are identified from the image by comparing their responses over different distinct spectral bands. Broad classes, such as water and vegetation, can be easily separated using very broad wavelength ranges like visible and near-infrared. However, for more specific classes viz., vegetation type, rock classification etc, much finer wavelength ranges and hence finer spectral resolution are required. For example, Fig. 7 shows the difference in the spectral responses of an area in different bands of the Landsat TM image.

Fig.8 shows a panchromatic image and Fig.9 and 10 show Landsat TM images taken in different spectral bands. The figures clearly indicate how different bands and their combinations help to extract different information.

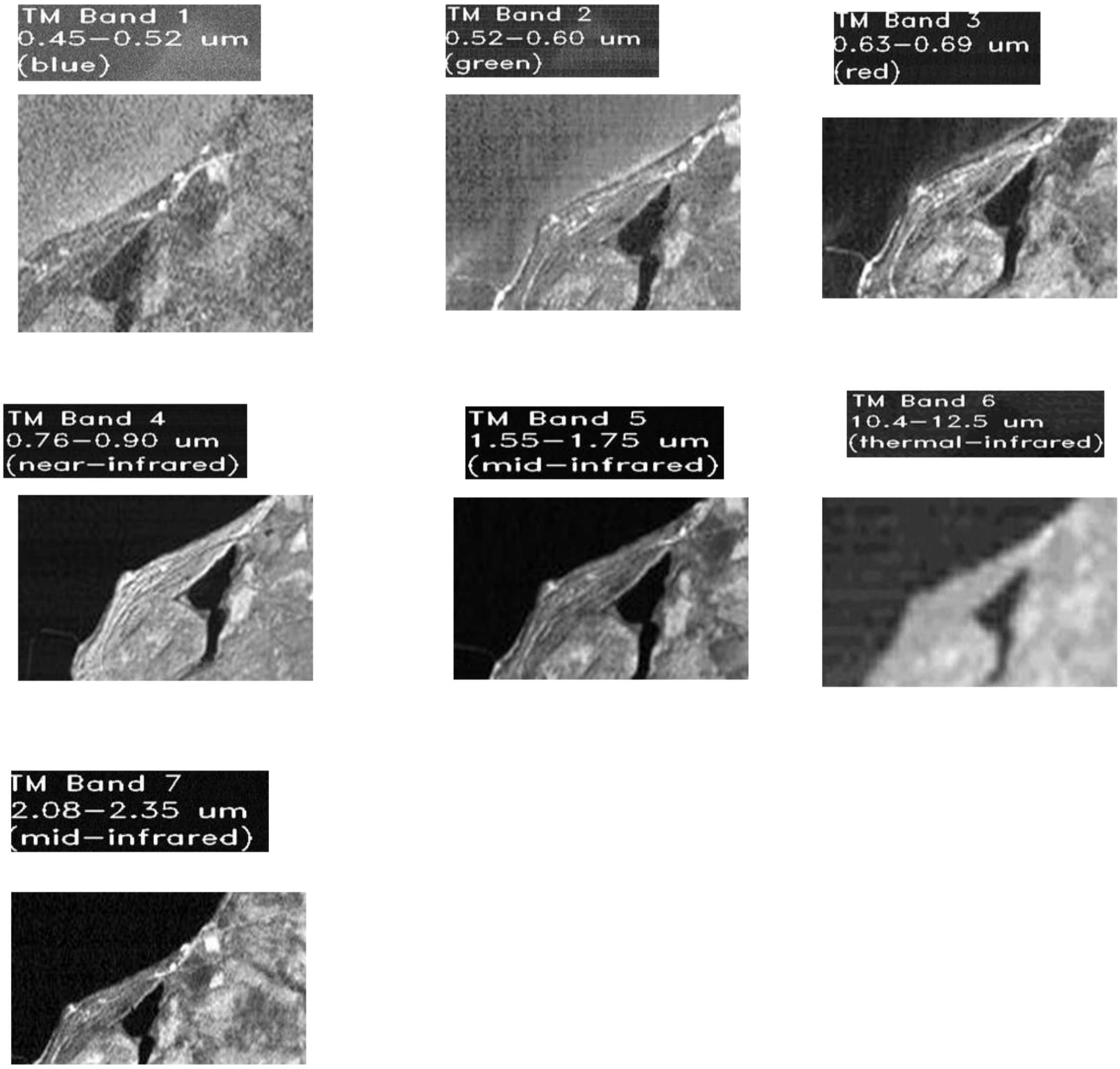


Fig.7 Landsat TM images of an area recorded in different spectral bands

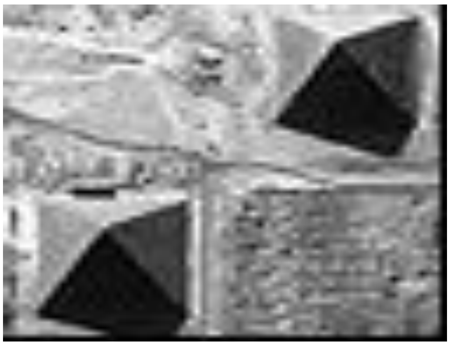


Fig.8. A coarse resolution panchromatic image- Minimum information is visible from the image

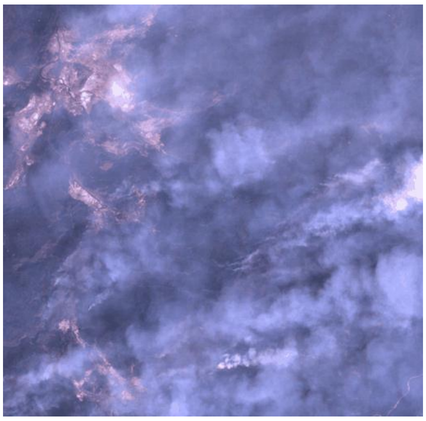


Fig. 9. Landsat TM (321) showing forest fire in Yellowstone NP- The smoke cover obstructs the ground view

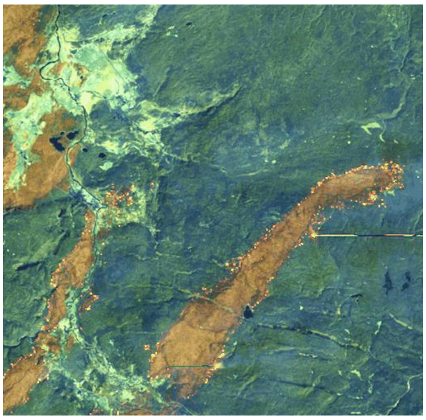


Fig. 10. Landsat TM (754) showing forest fire in Yellowstone NP

Bibliography / Further Reading

1. Gibson P.J (2000) “Introductory Remote Sensing- Principles and Concepts” Routledge, London.
2. Morisette, J.T, Privette, J. L, Justice, C. O [2002], A framework for the validation of MODIS Land products. Remote Sensing of Environment, 83 (2-Jan), 77-96.

MODULE – 2 LECTURE NOTES – 3

RADIOMETRIC AND TEMPORAL RESOLUTIONS

1. Introduction

In remote sensing the term resolution is used to represent the resolving power, which includes not only the capability to identify the presence of two objects, but also their properties. In qualitative terms the resolution is the amount of details that can be observed in an image. Four types of resolutions are defined for the remote sensing systems.

- Spatial resolution
- Spectral resolution
- Temporal resolution
- Radiometric resolution

The previous lecture covered the details of the spatial and spectral resolution. This lecture covers the radiometric and temporal resolutions, in detail.

2. Radiometric resolution

Radiometric resolution of a sensor is a measure of how many grey levels are measured between pure black (no reflectance) to pure white. In other words, radiometric resolution represents the sensitivity of the sensor to the magnitude of the electromagnetic energy.

The finer the radiometric resolution of a sensor the more sensitive it is to detecting small differences in reflected or emitted energy or in other words the system can measure more number of grey levels.

Radiometric resolution is measured in bits.

Each bit records an exponent of power 2 (e.g. 1 bit = 2^1 = 2). The maximum number of brightness levels available depends on the number of bits used in representing the recorded energy. For example, Table 1 shows the radiometric resolution and the corresponding brightness levels available.

Table 1. Radiometric resolution and the corresponding brightness levels

Radiometric resolution	Number of levels	Example
1 bit	2^1 – 2 levels	
7 bit	2^7 – 128 levels	IRS 1A & 1B
8 bit	2^8 – 256 levels	Landsat TM
11 bit	2^{11} – 2048 levels	NOAA-AVHRR

Thus, if a sensor used 11 bits to record the data, there would be 2^{11}=2048 digital values available, ranging from 0 to 2047. However, if only 8 bits were used, then only 2^8=256 values ranging from 0 to 255 would be available. Thus, the radiometric resolution would be much less.

Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data). By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions. In an 8 bit system, black is measured as 0 and white is measured as 255. The variation between black to white is scaled into 256 classes ranging from 0 to 255. Similarly, 2048 levels are used in an 11 bit system as shown in Fig.1.

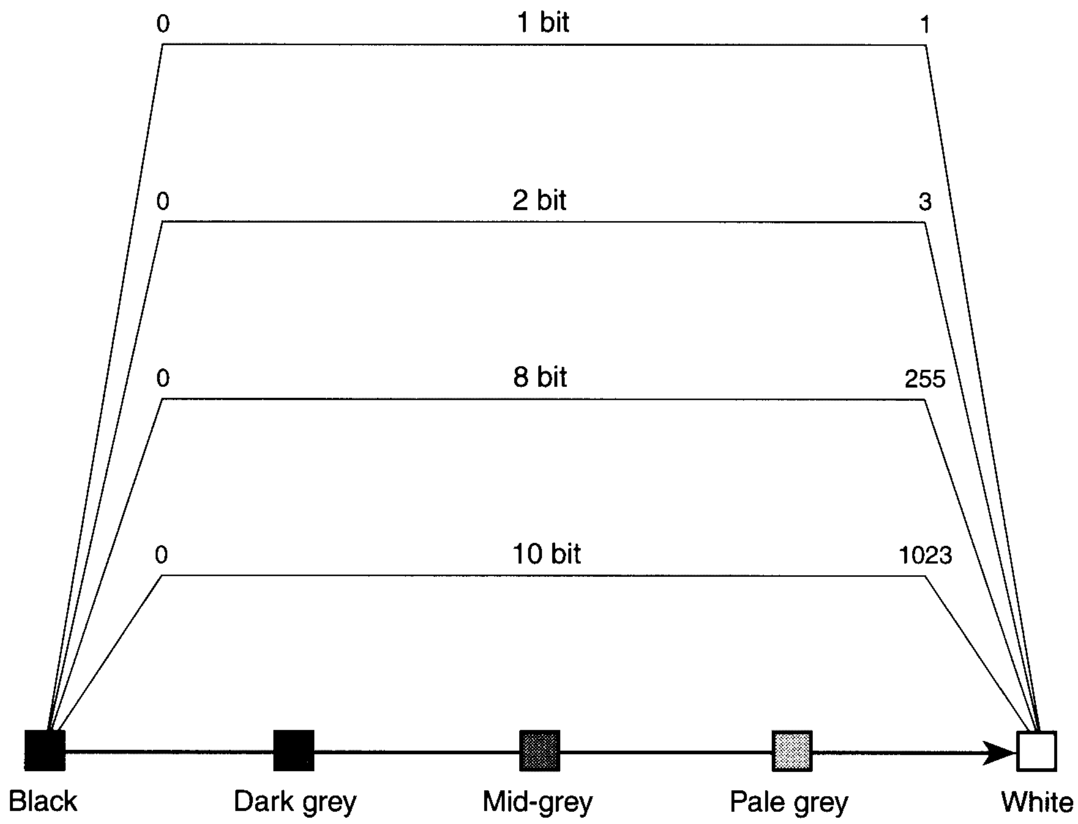


Fig.1 Variation in the brightness levels recorded at different radiometric resolution

(Source: Gibson 2000)

Finer the radiometric resolution, more the number of grey levels that the system can record and hence more details can be captured in the image.

Fig.2 shows the comparison of a 2-bit image (coarse resolution) with an 8-bit image (fine resolution), from which a large difference in the level of details is apparent depending on their radiometric resolutions.

As radiometric resolution increases, the degree of details and precision available will also increase. However, increased radiometric resolution may increase the data storage requirements.

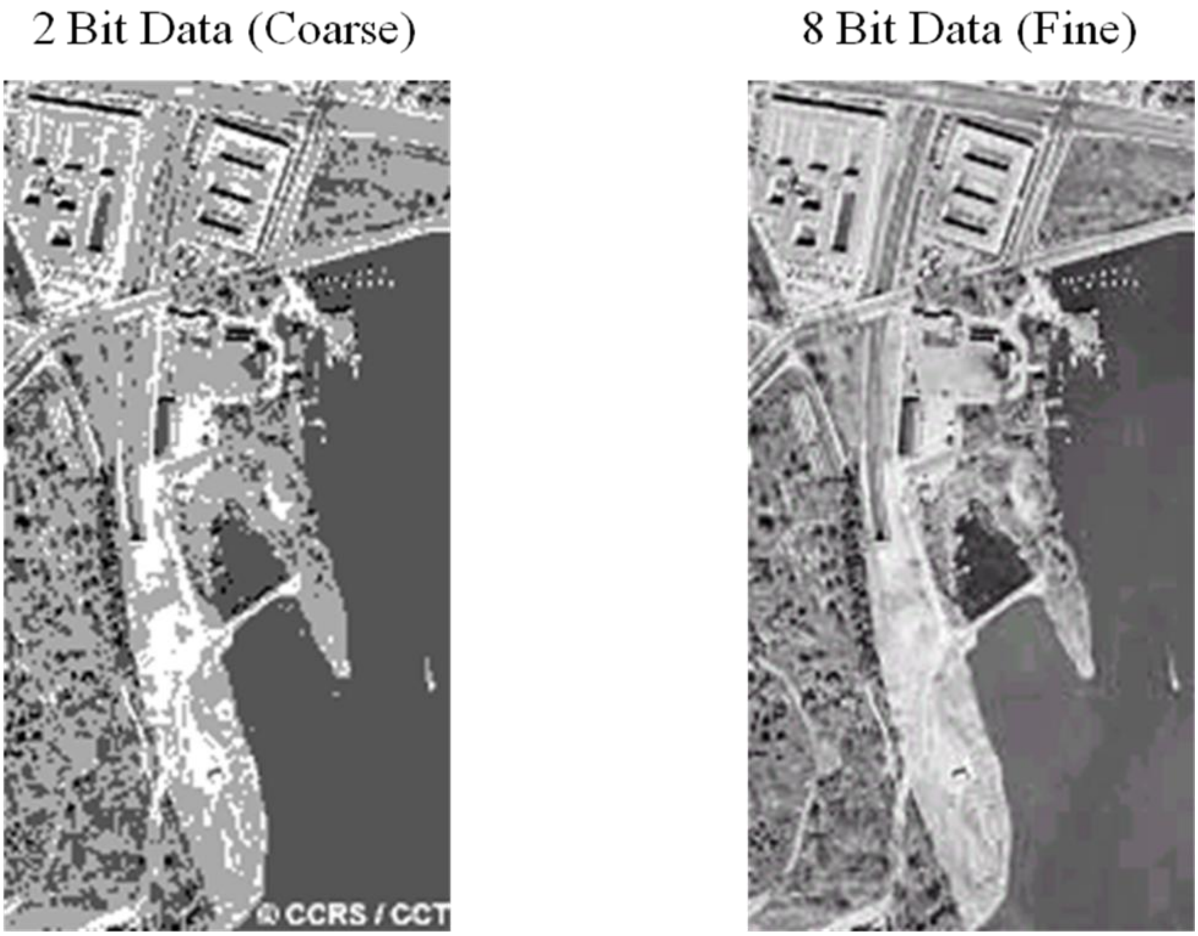


Fig.2 Comparison of a coarse resolution 2-bit image with a fine resolution 8-bit image

In an image, the energy received is recoded and represented using Digital Number (DN). The DN in an image may vary from 0 to a maximum value, depending up on the number of gray levels that the system can identify i.e., the radiometric resolution. Thus, in addition to the energy received, the DN for any pixel varies with the radiometric resolution. For the same amount of energy received, in a coarse resolution image (that can record less number of energy level) a lower value is assigned to the pixel compared to a fine resolution image (that can record more number of energy level). This is explained with the help of an example below.

Example: A RS system with a radiometric resolution of 6 bits assigns a DN of 28, 45 and 48 to three surfaces. What would be the equivalent DNs for the same surfaces if the measurements were taken with a 3 bit system?

The DNs recorded by the 3-bit system range from 0 to 7 and this range is equivalent to 0-63 for the 6 bit system.

0	1	2	3	4	5	6	7	(3 bit)
0	9	18	27	36	45	54	63	(6 bit)

Therefore a DN of 28 on the 6-bit system will be recorded as 3 in the 3-bit system. A 6-bit system could record the difference in the energy at levels 45 and 47, whereas in a 3-bit system both will be recorded as 5.

Therefore when two images are to be compared, they must be of same radiometric resolution.

3. Temporal Resolution

Temporal resolution describes the number of times an object is sampled or how often data are obtained for the same area

The absolute temporal resolution of a remote sensing system to image the same area at the same viewing angle a second time is equal to the **repeat cycle** of a satellite.

The repeat cycle of a near polar orbiting satellite is usually several days, eg., for IRS-1C and Resourcesat-2 it is 24 days, and for Landsat it is 18 days. However due to the off-nadir viewing capabilities of the sensors and the sidelap of the satellite swaths in the adjacent orbits the actual revisit period is in general less than the repeat cycle.

The actual temporal resolution of a sensor therefore depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude.

Because of some degree of overlap in the imaging swaths of the adjacent orbits, more frequent imaging of some of the areas is possible. Fig. 3 shows the schematic of the image swath sidelap in a typical near polar orbital satellite.

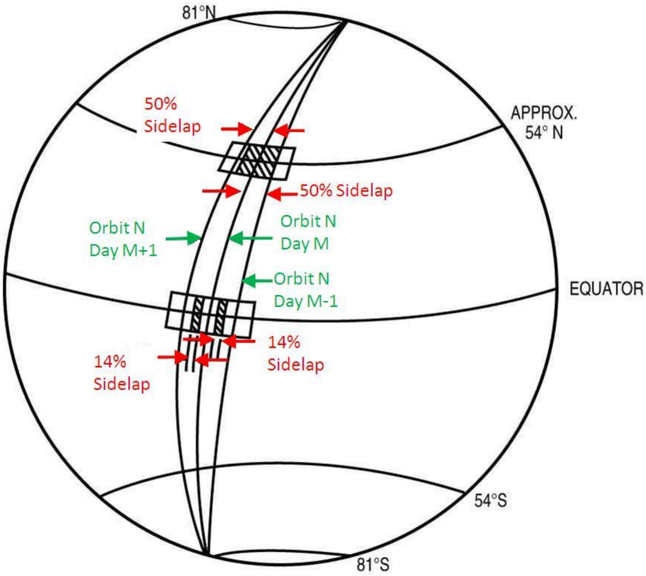


Fig.3 Sidelap in a typical near polar satellite orbit (Source: http://eros.usgs.gov/)

From Fig.3 it can be seen that the sidelap increases with latitude. Towards the polar region, satellite orbits come closer to each other compared to the equatorial regions. Therefore for the polar region the sidelap is more. Therefore more frequent images are available for the polar region. Fig. 4 shows the path of a typical near-polar satellite.

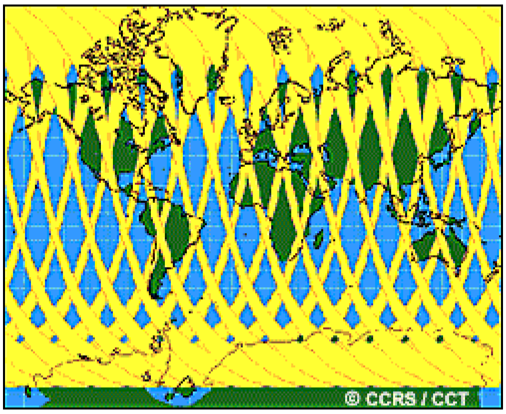


Fig.4. Orbit of a typical near-polar satellite (Source: http://www.nrcan.gc.ca/earth-sciences)

In addition to the sidelap, more frequent imaging of any particular area of interest is achieved in some of the satellites by pointing their sensors to image the area of interest between different satellite passes. This is referred as the off-nadir viewing capability.

For example: using pointable optics, sampling frequency as high as once in 1-3 days are achieved for IKONOS, whereas the repeat cycle of the satellite is 14 days.

Images of the same area of the Earth's surface at different periods of time show the variation in the spectral characteristics of different features or areas over time. Such multi-temporal data is essential for the following studies.

- Land use/ land cove classification
- Temporal variation in land use / land cover
- Monitoring of a dynamic event like
  - Cyclone
  - Flood
  - Volcano
  - Earthquake

Flood studies: Satellite images before and after the flood event help to identify the aerial extent of the flood during the progress and recession of a flood event. The Great Flood of 1993 or otherwise known as the Great Mississippi and Missouri Rivers Flood of 1993, occurred from April and October 1993 along the Mississippi and Missouri rivers and their tributaries. The flood was devastating affecting around $15 billion and was one of the worst such disasters occurring in United States. Fig.5 shows the landsat TM images taken during a normal period and during the great flood of 1993. Comparison of the two images helps to identify the inundated areas during the flood.

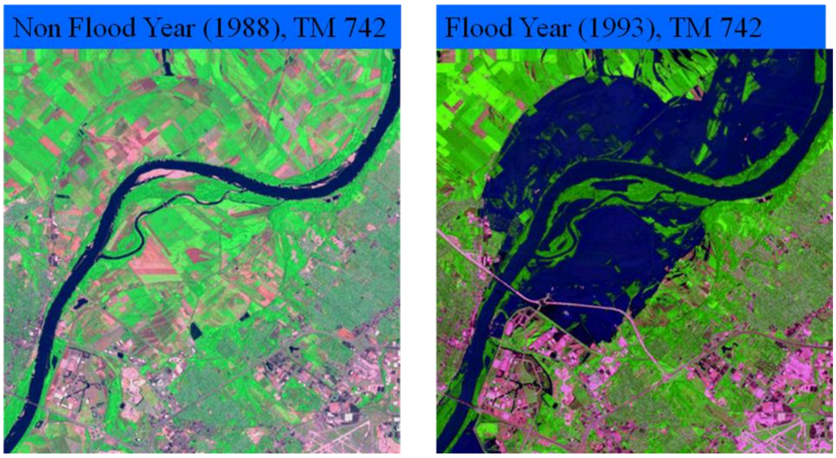


Fig.5 Landsat TM images of the Mississipi River during non-flood period and during the great flood of 1993

Land use/ land cover classification: Temporal variation in the spectral signature is valuable in land use/ land cover classification. Comparing multi-temporal images, the presence of features over time can be identified, and this is widely adopted for classifying various types of crops / vegetation. For example, during the growing season, the vegetation characteristics change continuously. Using multi-temporal images it is possible to monitor such changes and thus the crop duration and crop growth stage can be identified, which can be used to classify the crop types viz., perennial crops, long or short duration crops.

Fig. 6 shows the MODIS data product for the Krishna River Basin in different months in 2001. Images of different months of the year help to differentiate the forest areas, perennial crops and short duration crops.

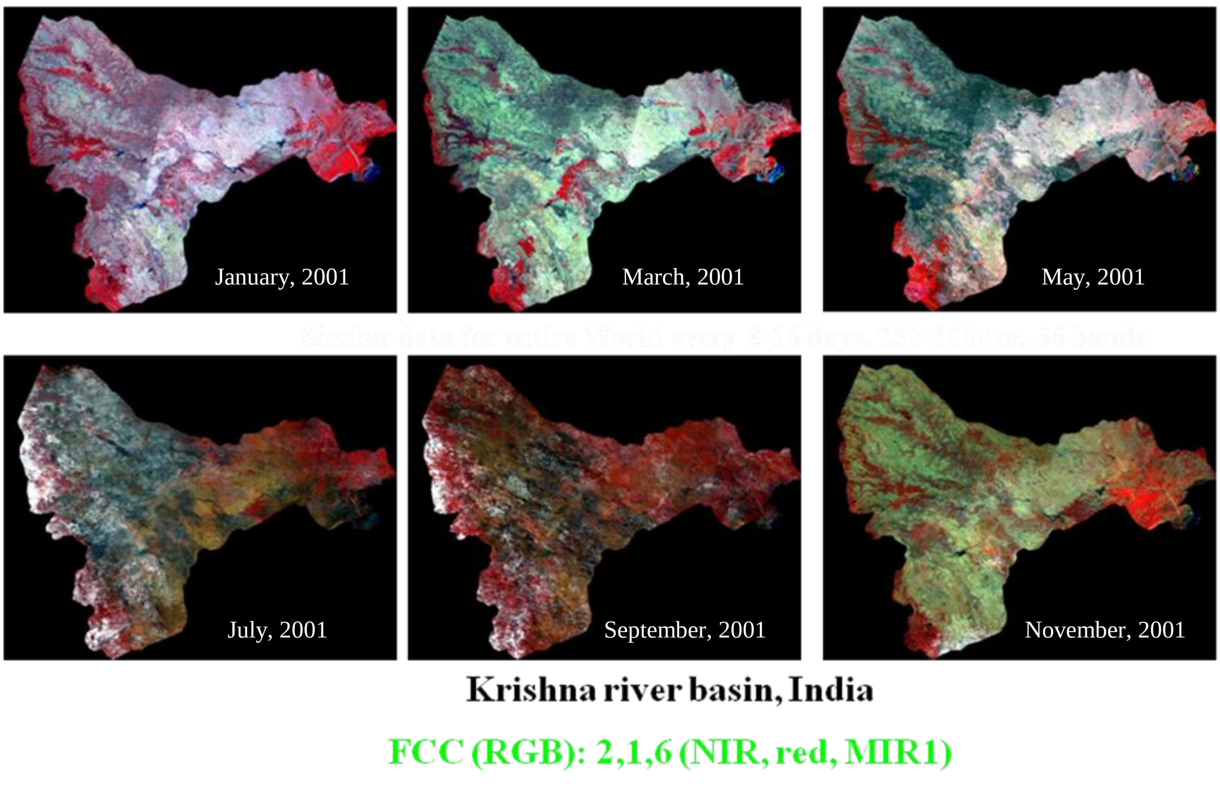


Fig.6 False Color Composites (FCC) of the Krishna River Basin generated from the MODIS data for different months in 2001.

The figure represents False Color Composites (FCC) of the river basin. The concepts regarding color composites have been explained in module 4.

4. Signal-to-Noise Ratio

The data recorded on a sensor are composed of the signal (say reflectance) and noise (from aberrations in the electronics, moving parts or defects in the scanning system as they degrade over time). If the signal-to-noise ratio (SNR) is high, it becomes easy to differentiate the noise from the actual signals. SNR depends on strength of signal available and the noise of the system.

Increasing the spectral and spatial resolution reduces the energy received or the strength of the signal. Consequently, the SNR decreases. Also, finer radiometric resolution results in larger number of grey levels and if the difference in the energy level between the two levels is less than the noise, reliability of the recorded grey level diminishes.

5. Trade-offs between spatial, spectral and radiometric resolution

In remote sensing, energy recorded at the sensor depends on the spatial and spectral resolution of the sensor.

Radiometric resolution of the sensor varies with the amount of energy received at the sensor. Fine spatial resolution requires a small IFOV. Smaller the IFOV, smaller would be the area of the ground resolution cell and hence less energy is received from that area. When the energy received is less, lesser would be the ability of the sensor to detect the fine energy differences, thereby leading to poor radiometric resolution.

Use of narrow spectral bands increases the spectral resolution, whereas it reduces the energy received at the sensor in the particular band. A wider band increases the reflected energy. To increase the amount of energy received and hence to improve the radiometric resolution without reducing the spatial resolution, broader wavelength band can be used. However, this would reduce the spectral resolution of the sensor.

Thus, there are trade-offs between spatial, spectral, and radiometric resolution. These three types of resolution must be balanced against the desired capabilities and objectives of the sensor.

Thus, finer spatial, spectral and radiometric resolutions of a system may decrease the SNR to such an extent that the data may not be reliable.

Bibliography / Further Reading

1. Gibson P.J (2000) “Introductory Remote Sensing- Principles and Concepts” Routledge, London.

MODULE – 2 LECTURE NOTES – 4

MULTISPECTRAL, THERMAL AND HYPERSPECTEAL REMOTE SENSING

1. Introduction

Multi-band imaging employs the selective sensing of the energy reflected in multiple wavelength bands in the range 0.3 to 0.9 μm. Generally broad bands are used in multi-band imaging. Multi-spectral scanners operate using the same principle, however using more number of narrower bands in a wider range varying from 0.3 to approximately 14 μm. Thus multi-spectral scanners operate in visible, near infrared (NIR), mid-infrared (MIR) and thermal infrared regions of the electro-magnetic radiation (EMR) spectrum.

Thermal scanners are special types of multi-spectral scanners that operate only in the thermal portion of the EMR spectrum. Hyperspectral sensing is the recent development in the multi-spectral scanning, where hundreds of very narrow, contiguous spectral bands of the visible, NIR, MIR portions of the EMR spectrum are employed.

This lecture gives a brief description of the multispectral remote sensing. Different types of multispectral scanners and their operation principles are covered in this lecture. The lecture also gives brief overview of the thermal and hyperspectral remote sensing.

2. Multispectral scanners

A Multispectral scanner (MSS) simultaneously acquires images in multiple bands of the EMR spectrum. It is the most commonly used scanning system in remote sensing.

For example the MSS onboard the first five Landsat missions were operational in 4 bands: 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 μm. Similarly, IRS LISS-III sensors operate in four bands (0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70 μm) three in the visible and NIR regions and one in the MIR region of the EMR spectrum.

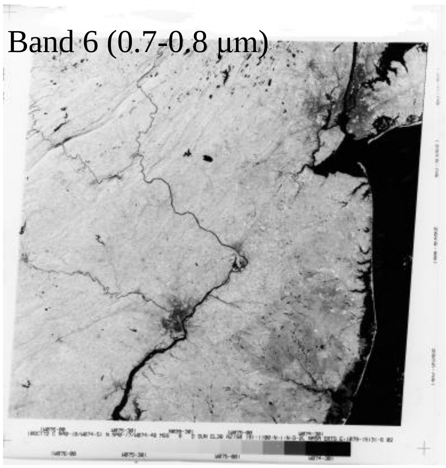
Spectral reflectance of the features differs in different wavelength bands. Features are identified from the image by comparing their responses over different distinct spectral bands. Broad classes, such as water and vegetation, can be easily separated using very broad wavelength ranges like visible and near-infrared. However, for more specific classes viz., vegetation type, rock classification etc, much finer wavelength ranges and hence finer spectral resolution are required.

Fig.1 shows the bands 4, 5, 6 and 7 obtained from Lansdat1 MSS and the standard FCC.

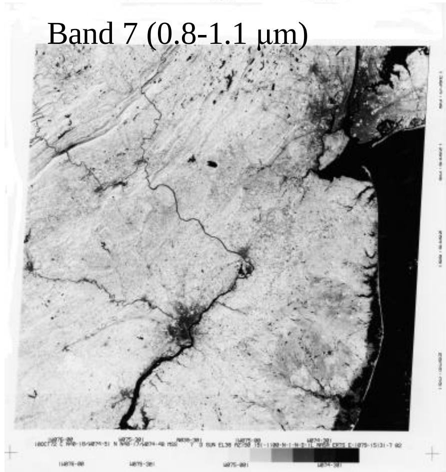
Band 4 (0.5-0.6 μm)

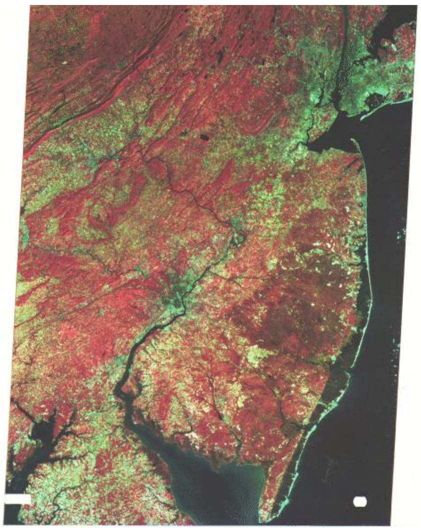
Band 5 (0.6-0.7 μm)

Band 6 (0.7-0.8 μm)



Band 7 (0.8-1.1 μm)





Bands 456, Standard FCC

Fig.1. Landsat-1 MSS images of an area obtained in different spectral bands and the standard FCC (source: http://www.fas.org/)

The figure clearly displays how water, vegetation and other features are displayed in different bands, and how the combination of different bands helps the feature identification.

Airborne or space-borne MSS systems generate two-dimensional images of the terrain beneath the aircraft. Two different approaches are adopted for this: Across-track (whiskbroom) scanning and Along-track (push broom) scanning.

2.1 Across-track scanning

Across-track scanner is also known as whisk-broom scanner. In across track scanner, rotating or oscillating mirrors are used to scan the terrain in a series of lines, called scan lines, which are at right angles to the flight line. As the aircraft or the platform moves forward, successive lines are scanned giving a series of contiguous narrow strips. Schematic representation of the operational principle of a whisk-broom scanner is shown in Fig.2.

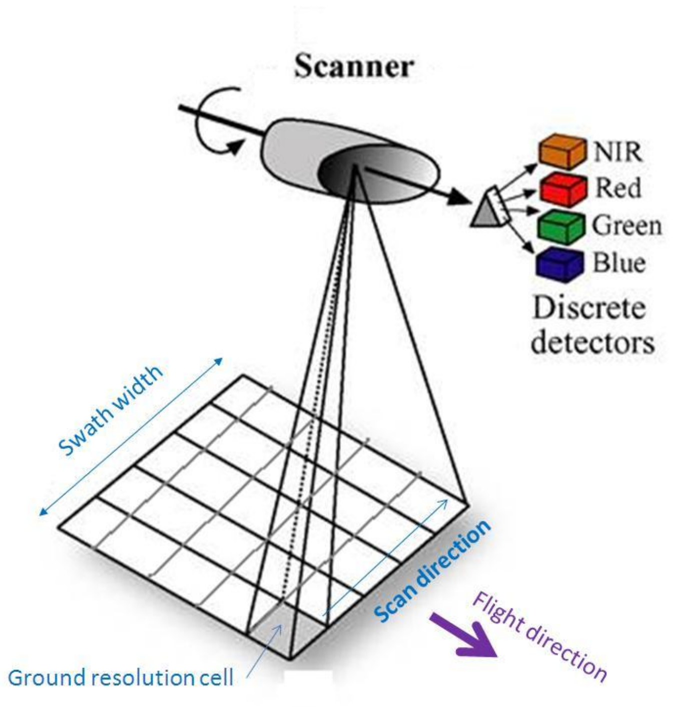


Fig.2 Operational principle of a whisk-broom scanner (Source: www.e-education.psu.edu)

The scanner thus continuously measures the energy from one side to the other side of the platform and thus a two-dimensional image is generated.

The incoming reflected or emitted radiation is separated into several thermal and non-thermal wavelength components using a dichroic grating and a prism. An array of electro-optical detectors, each having peak spectral sensitivity in a specific wavelength band, is used to measure each wavelength band separately.

2.2 Along-track scanning

Along-track scanner is also known as push-broom scanner.

Along-track scanners also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction. However, along-track scanner does not use any scanning mirrors, instead a linear array of detectors is used to simultaneously record the energy received from multiple ground resolution cells along the scan line. This linear array typically consists of numerous charged coupled devices (CCDs). A single array may contain more than 10,000 individual detectors. Each detector element is dedicated to record the energy in a single column as shown in Fig. 3. Also, for each spectral band, a separate linear array of detectors is used. The arrays of detectors are arranged in the focal plane of the scanner in such a way that the each scan line is viewed simultaneously by all the arrays. The array of detectors are pushed along the flight direction to scan the successive scan lines, and hence the name push-broom scanner. A two-dimensional image is created by recording successive scan lines as the aircraft moves forward.

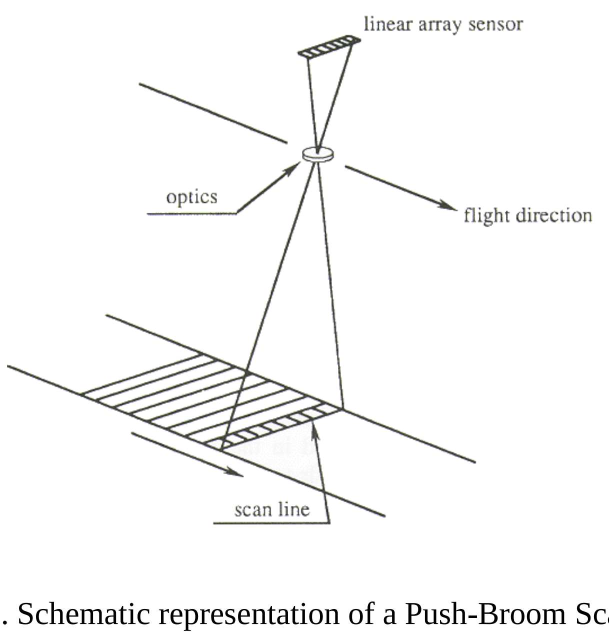


Fig. 3. Schematic representation of a Push-Broom Scanner

(Source: http://stlab.iis.u-tokyo.ac.jp/)

The linear array of detectors provides longer dwell time over each ground resolution cell, which increases the signal strength. This also increases the radiometric resolution. In a push-broom scanner, size of the ground resolution cell is determined by the IFOV of a single detector. Thus, finer spatial and spectral resolution can be achieved without impacting radiometric resolution.

2.3 Thematic Mapper

Thematic Mapper (TM) is an advanced multispectral scanner designed to achieve higher spatial, spectral and radiometric accuracy. It was introduced by NASA during the Landsat-4 mission. The TM used in the Landsat mission was operational in 7 bands. These bands are more refined compared to the MSS and are designated for some potential application. Principal applications of each of the Landsat TM bands are shown in Table below.

Table 1. Landsat TM spectral bands and their potential applications
(Source: http://www.fas.org)

Band	Spectral range (μm)	Principal application
1	0.45-0.52	Coastal water mapping, soil-vegetation differentiation, deciduous-coniferous differentiation
2	0.52-0.6	Green reflectance by healthy vegetation
3	0.63-0.69	Chlorophyl absorption for plant species differentiation
4	0.76-0.90	Biomass surveys, water body delineation
5	1.55-1.72	Vegetation moisture measurement, snow-cloud differentiation
6	10.4-12.5	Plant heat stress measurement, other thermal mapping
7	2.08-2.35	Hydrothermal mapping

3. Thermal scanner

Thermal scanner is a special kind of across track multispectral scanner which senses the energy in the thermal wavelength range of the EMR spectrum. Thermal infrared radiation refers to electromagnetic waves with wavelength 3-14 μm. The atmosphere absorbs much of the energy in the wavelength ranging from 5-8 μm. Due to the atmospheric effects, thermal scanners are generally restricted to 3-5 μm and 8-14 μm wavelength ranges.

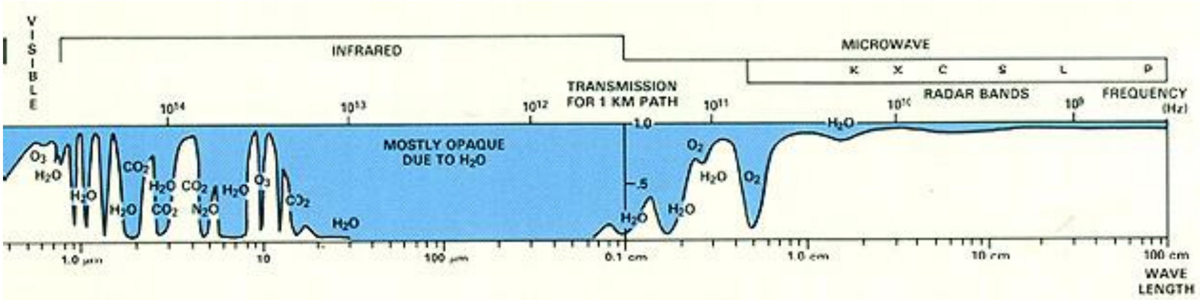


Fig.4. EMR spectrum showing the atmospheric absorption regions
(Source: http://www.geog.ucsb.edu/~jeff/115a/remote_sensing/thermal/thermalirinfo.html)

Fig. 5 shows a day time thermal image if the San-Francisco region recorded using 8.5-13.0 μm thermal wavelength region. The runway of the airport appears in light tone as the thermal emission from the runway is more in the day time.

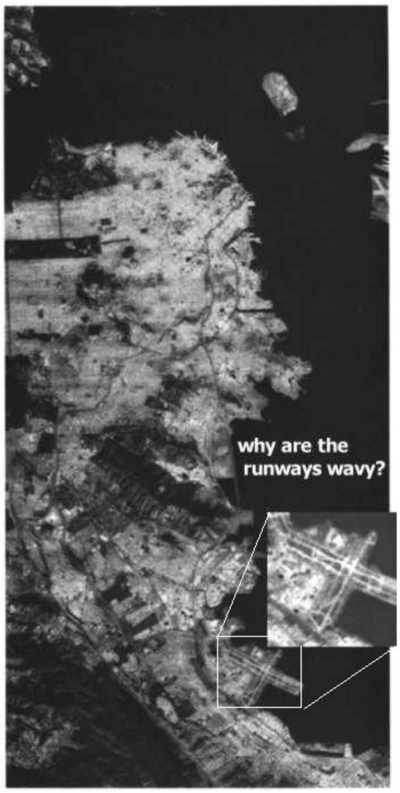


Fig. 5. Day time thermal image (8.5-13 μm) of San Francisco
(Source :
http://www.geog.ucsb.edu/~jeff/115a/remote_sensing/thermal/fig6_12daytimirofsf_airport.jpg)

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard Terra, TIMS developed jointly by NASA JPL and the Daedalus Corporation are some of the examples. ASTER data is used to create detailed maps of land surface temperature, reflectance, and elevation. TIMS is used as an airborne geologic remote sensing tool to acquire mineral signatures to discriminate minerals like silicate and carbonate. It uses 6 wavelength channels as shown in Table 2.

Table 2. Spectral bands of the TIMS
(Source: http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/tims.html)

Channel	Wavelength μm
1	8.2-8.6
2	8.6-9.0
3	9.0-9.4
4	9.4-10.2
5	10.2-11.2
6	11.2-12.2

Since the energy received at the sensor decreases as the wavelength increases, larger IFOVs are generally used in thermal sensors to ensure that enough energy reaches the detector for a reliable measurement. Therefore the spatial resolution of thermal sensors is usually fairly coarse, relative to the spatial resolution possible in the visible and reflected infrared. However, due to the relatively long wavelength, atmospheric scattering is minimal in thermal scanning. Also since the reflected solar radiation is not measured in thermal scanning, it can be operated in both day and night times.

3.1 Principle involved in the thermal sensing

In thermal scanning the energy radiated from the land surface is measured using thermal sensors. The thermal emission is the portion of internal energy of surface that is transformed into radiation energy.

Radiation from a blackbody and real materials

A blackbody is a hypothetical, ideal radiator that totally absorbs and re-emits all energy incident upon it. Emissivity (ε) is the factor used to represent the radiant exitance of a material compared to that of a blackbody. Thus

$$\varepsilon = \frac{\text{radiant exitance of an object at a given temperature}}{\text{radiant exitance of a blackbody at the same temperature}}$$

An ideal blackbody (the body which transforms all internal energy into radiation energy) has emissivity equal to 1. The emissivity of real surfaces ranges from 0 to 1.

Emissivity of a material varies with the wavelength, viewing angle and temperature. If the emissivity of a material varies with wavelength, it is called a selective radiator. If a material has constant emissivity, which is less than 1, in all the wavelengths it is called a grey body.

In the thermal scanning, the radiant energy from the surface is measured.

According to the Stefan-Bolzmann law, the radiant exitance (M) from a black body is given by

$$M = \sigma T^4$$

Where, σ is the Stefan-Boltzmann's constant = 5.6697x10^{-8} W m^{-2} K^{-4}, T is the temperature of the black body (K)

For a real material, it can be extended as

$$M = \varepsilon \sigma T^4$$

The thermal sensors record the radiant energy M from the surface. Thus if we know the emissivity ε, we can determine the real surface temperature. But in general, in satellite remote sensing the target features are unknown and hence are their emissivities. In such cases, the brightness temperature of the surface is determined, which is the surface temperature if that were a blackbody.

Thermal imaging

For the thermal energy sensing, typically quantum or photon detectors containing electrical charge carriers are used. The principle behind the thermal scanning is the direct relationship between the photons of radiation falling on the detector and the energy levels of the electrical charge carriers.

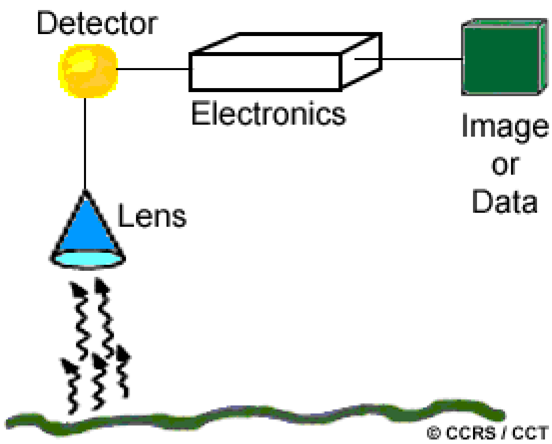


Fig.6. Schematic representation of a thermal sensor operational principle
(Source: http://www.nrcan.gc.ca/)

Some of the commonly used detectors are mercury-doped germanium (sensitive in the range 3-14 μm), indium antimonide (sensitive in the region 3-5 μm) and mercury cadmium telluride (sensitive in the region 8-14 μm).

A thermal scanner image, also known as thermogram, is a pictorial representation of the detector's response on a line-by-line basis. Thus areas having higher radiant/brightness temperature are displayed as lighter tomes in the image. Most of the thermal scanning operations in geologic and water resources studies are qualitative in nature, wherein only the relative difference in the radiant temperature are obtained.

Information about the temperature extremes, heating and the cooling rates are used to interpret the type and condition of the object, For example, water reaches maximum temperature slower than rocks or soils and therefore, terrain temperatures are normally higher than the water temperature during the day time and lower during the night.

Some of the important applications of thermal remote sensing image are the following.

- Geological studies: determining rock type and structures
- Soil mapping

- Soil moisture studies
- Study of evapotranspiration in vegetation
- Detection of heat looses in buildings
- Detection of damages of steam pipelines and caliducts
- Detection of subsurface fires(e.g. coal seams)

4. Hyperspectral Sensors

Hyperspectral sensors (also known as imaging spectrometers) are instruments that acquire images in several, narrow, contiguous spectral bands in the visible, NIR, MIR, and thermal infrared regions of the EMR spectrum. Hyperspectral sensors may be along-track or across-track.

A typical hyperspectral scanner records more than 100 bands and thus enables the construction of a continuous reflectance spectrum for each pixel.

For example, the Hyperion sensor onboard NASA's EO-1 satellite images the earth's surface in 220 contiguous spectral bands, covering the region from 400 nm to 2.5 μm, at a ground resolution of 30 m. The AVIRIS sensor developed by the JPL contains four spectrometers with a total of 224 individual CCD detectors (channels), each with a spectral resolution of 10 nanometers and a spatial resolution of 20 meters.

Fig. 7 shows the schematic representation of the hyperspectral imaging process.

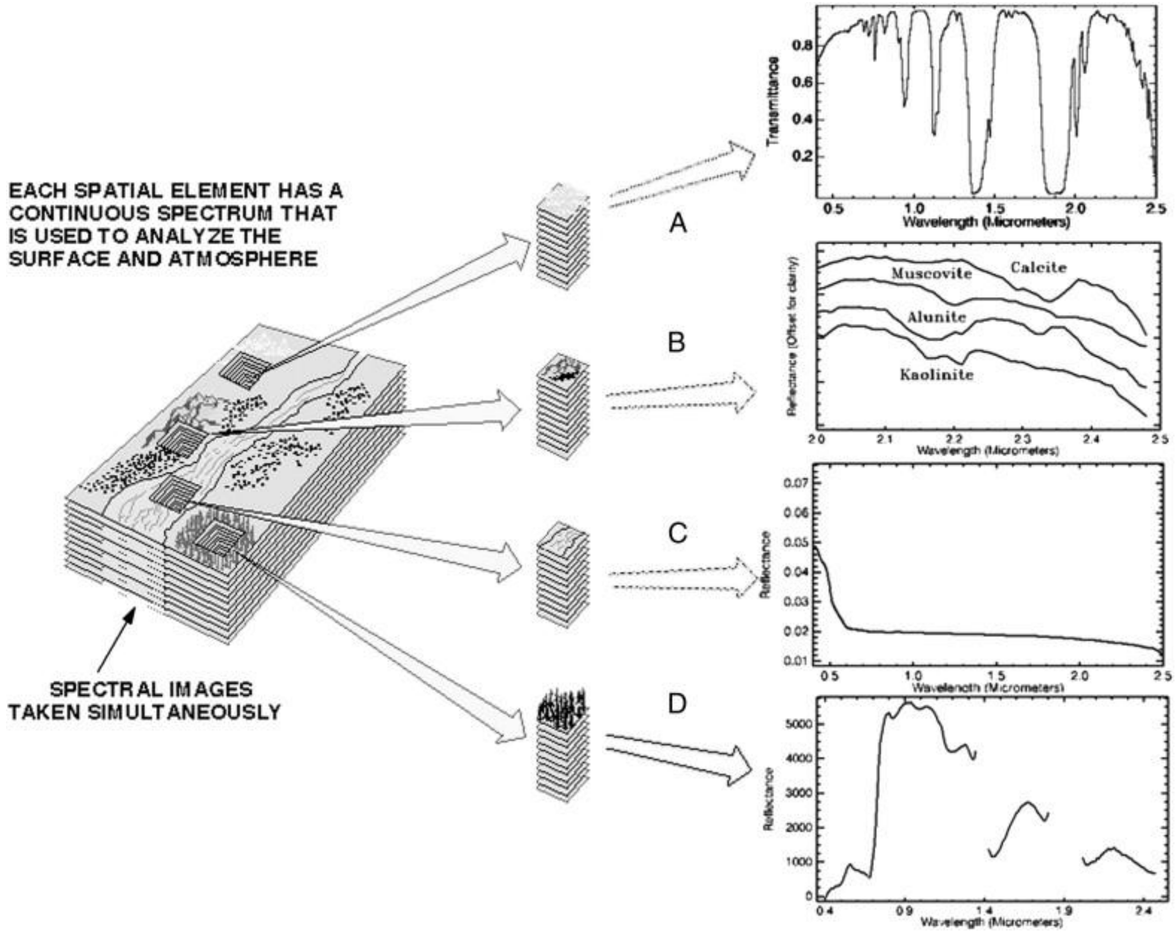


Fig. 7. Schematic representation of the hyperspectral imaging (Source: Kruse, 2012)

From the data acquired in multiple, contiguous bands, the spectral curve for any pixel can be calculated that may correspond to an extended ground feature.

Depending on whether the pixel is a pure feature class or the composition of more than one feature class, the resulting plot will be either a definitive curve of a "pure" feature or a composite curve containing contributions from the several features present. Spectral curves of the pixels are compared with the existing spectral library to identify the targets. All pixels whose spectra match the target spectrum to a specified level of confidence are marked as potential targets.

Hyperspectral AVIRIS image of the San Juan Valley of Colorado is shown below. Fig.8 below shows the spectral curves for different crop classes generated using the reflectance from multiple bands of the AVIRIS image. Spectral curves generated from the image are used to identify the vegetation or crop type in the circular fields and are verified with the ground data.

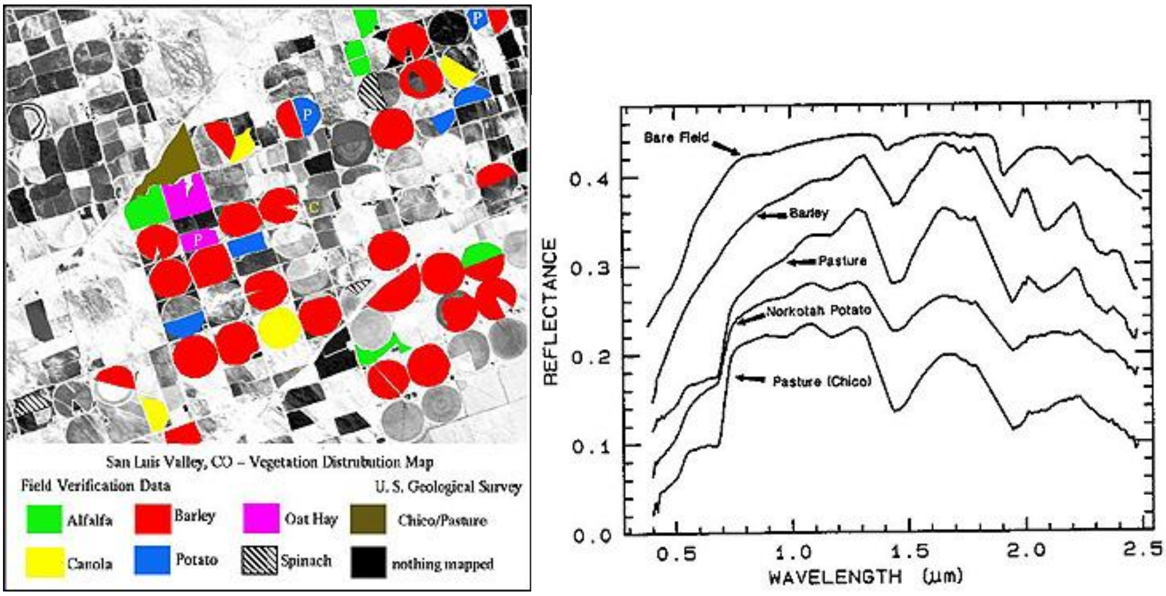


Fig.8. Hyperspectral AVIRIS image of the San Juan Valley of Colorado and the spectral signature curves generated for different fields
(Source : http://geoinfo.amu.edu.pl/wpk/rst/rst/Intro/Part2_24.html)

Hyperspectral imaging has wide ranging applications in mining, geology, forestry, agriculture, and environmental management.

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