PIE Tech
POLLACHI INSTITUTE OF ENGINEERING AND TECHNOLOGY
(Approved by AICTE and Affiliated to Anna University)
sky is the limit

Department of Electronics and Communication Engineering

Regulation 2021

III Year – VI Semester

CEC348- REMOTE SENSING

UNIT I REMOTE SENSING AND ELECTROMAGNETIC RADIATION
Definition – components of RS – History of Remote Sensing – Merits and demerits of Data Collation between conventional and remote sensing methods - Electromagnetic Spectrum – Radiation principles - Wave theory, Planck's law, Wien's Displacement Law, Stefan's Boltzmann law, Kirchoff's law – Radiation sources: active & passive – Radiation Quantities.

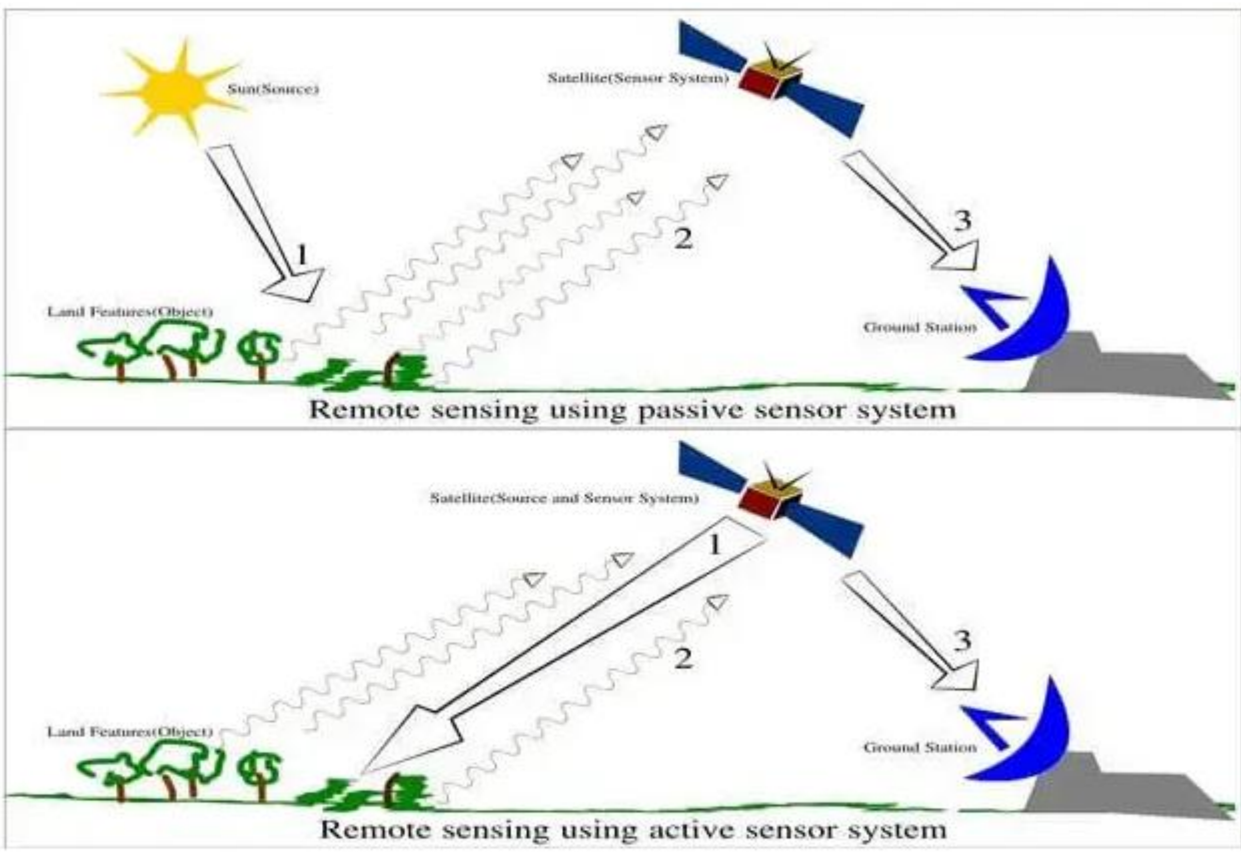
The Components of remote sensing

These are the components involved in remote sensing process

1. Energy Source or Illumination (A)
2. Radiation and the Atmosphere (B)
3. Interaction with the Target (C)
4. Recording of Energy by the Sensor (D)
5. Transmission, Reception, and Processing (E)
6. Interpretation and Analysis (F)
7. Application (G)

1 Energy Source or Illumination (A)

The first requirement for remote sensing is to have an energy source of electromagnetic radiation to illuminate the target. Sensors can use either external Energy source(Sun) or have their own energy source of illumination.



Energy Interactions with Atmosphere (B)

The energy travels from the source to the target, It passes through the earth's atmosphere which contains obstacles such as haze, clouds, smog etc.

3 Interaction with the Target (C)
The electromagnetic Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface.

4 Recording of Energy by the Sensor (D)
When the energy has been scattered by, or emitted from the target, It is collected through a sensor (remote – not in contact with the target) and record the electromagnetic radiation.

5 Transmission, Reception, and Processing(E)
The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

6 Interpretation and Analysis (F)
The processed image is interpreted and analyzed, visually or digitally or electronically, to extract information about the target which was illuminated.

7 Application (G)

- Geology: it is used for geological mapping;
- Hydrology: Used in monitoring wetlands and snow cover;
- Agriculture: Helps in identification of type of crop , crop condition monitoring, soil moisture measurement, and soil tillage and crop residue identification.
- Forestry: Useful clear-cuts and linear features mapping, biomass estimation, species identification and fire scar mapping;
- Oceanography: sea ice identification, coastal wind field measurement, and wave slope measurement.
- Shipping: for ship detection and classification. Coastal Zone: for shoreline detection, substrate mapping, slick detection and general vegetation mapping.
- Military/Security Applications: Helps in detecting or locating metal objects.

Limitations of Remote Sensing

1. Its utility is often oversold.
2. It is not a solution that will provide all the information needed for conducting physical, biological, or a science.
3. It simply provides some spatial, spectral, and temporal information.

The history of remote sensing and development of hardware

Analog tools
Streoscope
Analog Stereoplotter
Digital tools
Digital cameras
Scanners
Digital photogrammetric workstations
1858 - Gasper Felix Tournachon “Nadar" takes the first aerial photograph from a balloon at an altitude of 1,200 feet over Paris.

1860's - Aerial observations, and possible photography, for military purposes were acquired from balloons in the Civil War.
1887 - Germans began experiments with aerial photographs and photogrammetric techniques for measuring features and areas in forests. 1889 - Arthur Batut take the first aerial photograph using a kite of Labruguiere France.
1903 – Use of pigeons to take aerial photos.
1914 – WWI (World War I) provided a boost in the use of aerial photography, but after the war, enthusiasm waned
1940 - World War II brought about more sophisticated techniques in air photo interpretation. 1960 - TIROS-1 (Television IR Observation Satellite, USA) launched as first meteorological satellite. 1964- Nimbus Weather Satellite Program begins with the Launch of Nimbus1.
1972 - Launch of ERTS-1 (the first Earth Resources Technology Satellite ,later renamed Landsat 1). 1972 - Photography from Skylab, America's first space station, was used to produce land use maps. 1975 - Landsat 2 1978 - Landsat 3 1978 - Seasat, the first civil Synthetic Aperture Radar (SAR) satellite.
1981 - Space-Shuttle Imaging Radar (SIR-A) 1982 - Landsat-4 1984 - SIR-B 1984 - Landsat-5 1986 - SPOT-1 1988 - IRS-1A 1990 - SPOT-2 1993 - SPOT-3
1996 - Launch of IRS-P3 1998 - Launch of SPOT-4 1999 - Launch of Landsat 7,IKONOS ,IRS-P4, Terra 2001- Quickbird 2002 - Aqua, SPOT-5
1839: Beginning of practice of photography 1850-1860: Photography from balloons 1873: Theory of electromagnetic energy developed by James Clerk Maxwell 1909: Photography from airplanes 1914-1918: World War 1: aerial reconnaissance 1920-1930: Development & initial application of aerial photography & photogrammetry
2003 – Oceansat 2 2012 – RISAT 1

Remote sensing and electromagnetic radiation.

Remote sensing is the acquiring of information from a distance. NASA observes Earth and other planetary bodies via remote sensors on satellites and aircraft that detect and record reflected or emitted energy. Remote sensors, which provide a global perspective and a wealth of data about Earth systems, enable data-informed decision making based on the current and future state of our planet.

- Orbits
- Observing with the Electromagnetic Spectrum
- Sensors
- Resolution
- Data Processing, Interpretation, and Analysis
- Data Pathfinders

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object, in contrast to in situ or on-site observation. The term is applied especially to acquiring information about Earth and other planets. Remote sensing is used in numerous fields, including geophysics, geography, land surveying and most Earth science disciplines (e.g. exploration geophysics, hydrology, ecology, meteorology, oceanography, glaciology, geology); it also has military, intelligence, commercial, economic, planning, and humanitarian applications, among others.

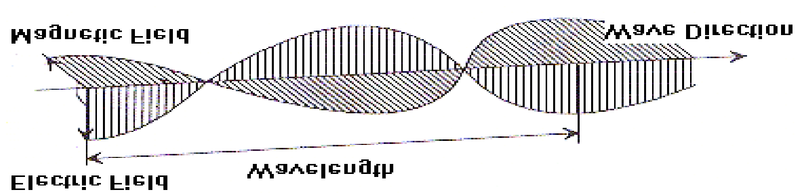
Remote sensing can be divided into two types of methods: Passive remote sensing and Active remote sensing. Passive sensors gather radiation that is emitted or reflected by the object or surrounding areas. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, charge-coupled devices, and radiometers. Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR and LiDAR are examples of active remote sensing where the time delay between emission and return is measured, establishing the location, speed and direction of an object.

The amount of electromagnetic radiation an object emits depends primarily on its temperature. The higher the temperature of an object, the faster its electrons vibrate and the shorter its peak wavelength of emitted radiation. Conversely, the lower the temperature of an object, the slower its electrons vibrate, and the longer its peak wavelength of emitted radiation. This concept can be shown by gripping the end of a long rope and shaking it. Rapidly shaking the rope (high temperature) results in a series of short waves travelling along it, while shaking it slowly (low temperature) results in a series of longer waves.

The fundamental unit of electromagnetic phenomena is the photon, the smallest possible amount of electromagnetic energy of a particular wavelength. Photons, which are without mass, move at the speed of light—300,000 km/sec (186,000 miles/sec) in the form of waves analogous to the way waves propagate through the oceans. The energy of a photon determines the frequency (and wavelength) of light that is associated with it. The greater the energy of the photon, the greater the frequency of light and vice versa.

Electromagnetic wave and electromagnetic spectrum

Electromagnetic Waves



Electromagnetic waves are energy transported through space in the form of periodic disturbances of electric and magnetic fields. All electromagnetic waves travel through space at the same speed, c = 2.99792458 x 108 m/s, commonly known as the speed of light. An electromagnetic wave is characterized by a frequency and a wavelength. These two quantities are related to the speed of light by the equation,

speed of light = frequency x wavelength

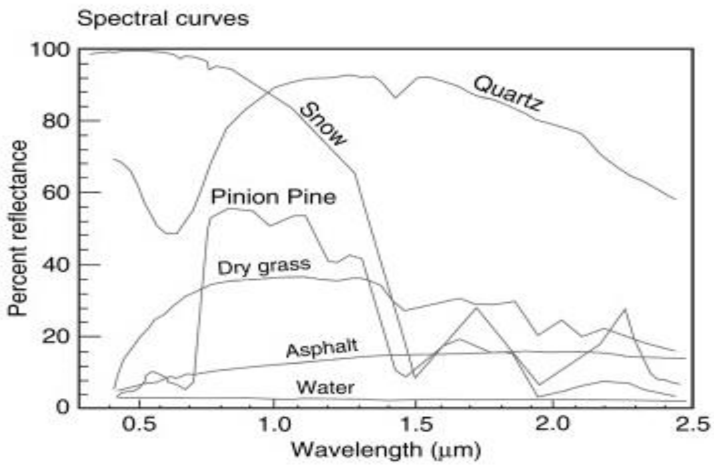
The frequency (and hence, the wavelength) of an electromagnetic wave depends on its source. There is a wide range of frequency encountered in our physical world, ranging from the low frequency of the electric waves generated by the power transmission lines to the very high frequency of the gamma rays originating from the atomic nuclei. This wide frequency range of electromagnetic waves constitute the Electromagnetic Spectrum.

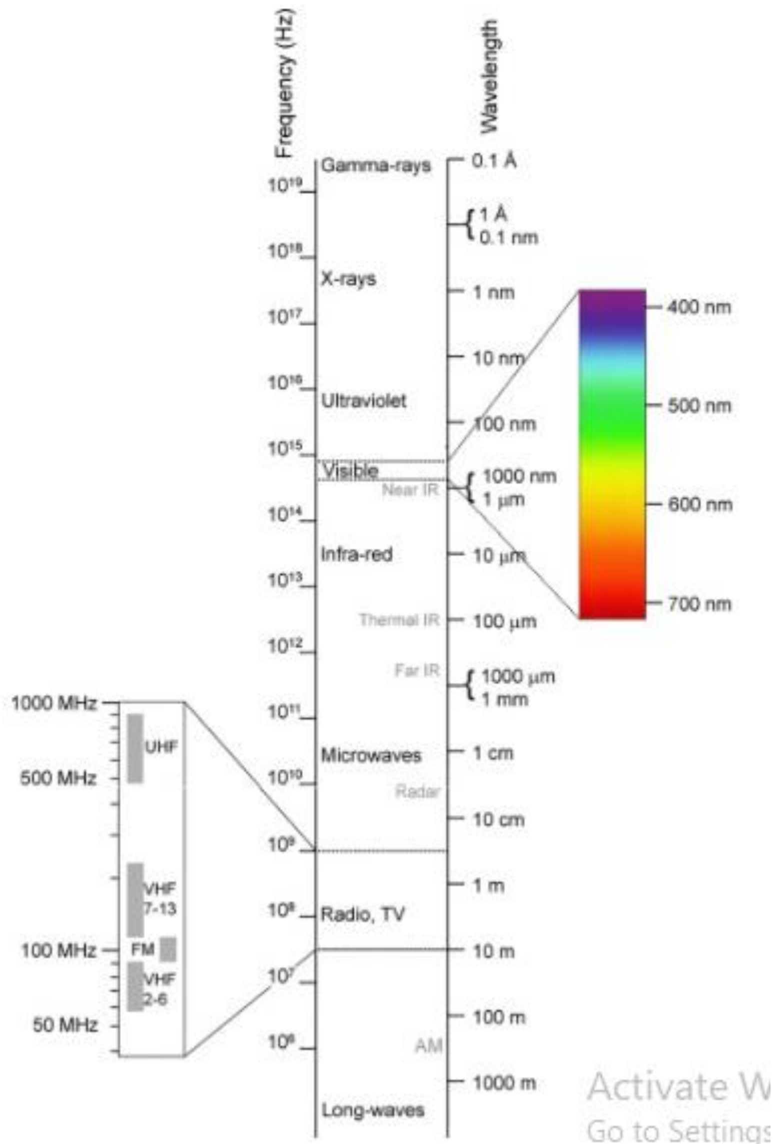
Electromagnetic Spectrum

The electromagnetic spectrum (EMS) includes wavelengths of electromagnetic radiation ranging from short wavelength (high frequency) gamma rays to long-wavelength (low frequency) radio waves. We will focus on the region of the spectrum starting in the ultraviolet and continuing through the microwave wavelengths. Optical sensors are used to measure ultraviolet, visible, and infrared wavelengths and microwave sensors are used for the microwave portion of the EMS.

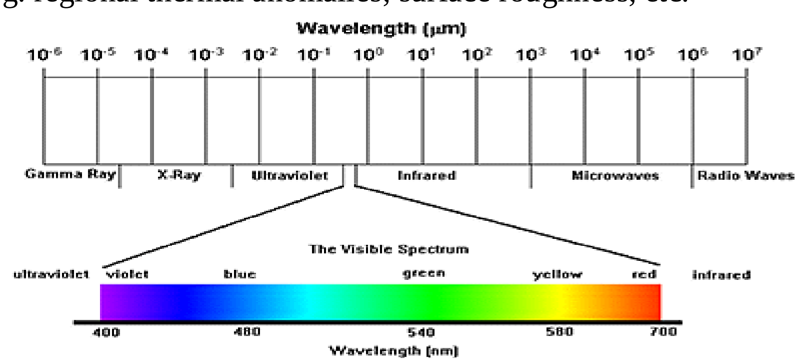
A fundamental physical principal that remote sensing relies on is that different features on the Earth's surface interact with specific wavelengths of the EMS in different ways. When working with optical sensors the most important property used to identify features on the Earth's surface is spectral reflectance; the ratio of the intensity of light reflected from a surface divided by the intensity of incident light. Different features have different spectral reflectance properties and we can use this information to identify individual features. For example, white sand reflects most visible and near-infrared light whereas green vegetation absorbs most red wavelengths and reflects most near-infrared wavelengths.

Figure 1 illustrates the spectral properties of different materials.





The electromagnetic spectrum is the term used to describe the entire range of light that exists (Fig. 1). For geological applications, shorter wavelengths are generally useful for site characterization down to the mineralogical scale, while longer wavelengths reveal larger scale surface information, e.g. regional thermal anomalies, surface roughness, etc.



The electromagnetic spectrum can be divided into several wavelength (frequency) regions, among which only a narrow band from about 400 to 700 nm is visible to the human eyes. Note that there is no sharp boundary between these regions. The boundaries shown in the above figures are approximate and there are overlaps between two adjacent regions.

Wavelength units: 1 mm = 1000 µm; 1 µm = 1000 nm.

- Radio Waves: 10 cm to 10 km wavelength.
- Microwaves: 1 mm to 1 m wavelength. The microwaves are further divided into different frequency (wavelength) bands: (1 GHz = 109 Hz)
  - P band: 0.3 - 1 GHz (30 - 100 cm)
  - L band: 1 - 2 GHz (15 - 30 cm)
  - S band: 2 - 4 GHz (7.5 - 15 cm)
  - C band: 4 - 8 GHz (3.8 - 7.5 cm)
  - X band: 8 - 12.5 GHz (2.4 - 3.8 cm)
  - Ku band: 12.5 - 18 GHz (1.7 - 2.4 cm)
  - K band: 18 - 26.5 GHz (1.1 - 1.7 cm)
  - Ka band: 26.5 - 40 GHz (0.75 - 1.1 cm)

Infrared: 0.7 to 300 µm wavelength. This region is further divided into the following bands:

- Near Infrared (NIR): 0.7 to 1.5 µm.
- Short Wavelength Infrared (SWIR): 1.5 to 3 µm.
- Mid Wavelength Infrared (MWIR): 3 to 8 µm.
- Long Wanelength Infrared (LWIR): 8 to 15 µm.
- Far Infrared (FIR): longer than 15 µm.

The NIR and SWIR are also known as the Reflected Infrared, referring to the main infrared component of the solar radiation reflected from the earth's surface. The MWIR and LWIR are the Thermal Infrared.

Visible Light: This narrow band of electromagnetic radiation extends from about 400 nm (violet) to about 700 nm (red). The various colour components of the visible spectrum fall roughly within the following wavelength regions:

- Red: 610 - 700 nm
- Orange: 590 - 610 nm
- Yellow: 570 - 590 nm
- Green: 500 - 570 nm
- Blue: 450 - 500 nm
- Indigo: 430 - 450 nm
- Violet: 400 - 430 nm
- Ultraviolet: 3 to 400 nm
- X-Rays and Gamma Rays

Photons

According to quantum physics, the energy of an electromagnetic wave is quantized, i.e. it can only exist in discrete amount. The basic unit of energy for an electromagnetic wave is called a photon.

The energy E of a photon is proportional to the wave frequency f,

$$E = h f$$

where the constant of proportionality h is the Planck's Constant,

$$h = 6.626 \times 10^{-34} \text{ J s}.$$

Conventional Technique and Remote sensing

There are various technique used in remote sensing but we can broadly categorized the technique into namely:

•Conventional technique
•Modern technique

Conventional technique:

This technique use traditional method such as field survey, field equipment, manual recording, field work and aerial photography. we sense our surroundings with out eye-brain system we are determining the size, shape, and color of objects from a distance by collecting and analyzing reflected visible light. This technique uses visible rage of radiation. This survey is done when there is need of detailed and exact information of particular area is required.

Modern technique:

This technique uses modern remote sensing equipment such as satellite, radar etc. to get the generalize information of an area. In this technique visible and non visible range of radiation are studied.

Conventional Technique

•It comprise of field work, aerial photography and visible range of radiation.
•Most of the works are manual.
•Provides detailed information about an area.
•This is useful for survey of small area.
•It requires lots of time for collecting data.
•The process is very slow and requires huge amount of human inputs and finance.
•The information we get is limited to an area so we cannot generalize the information over the large area.
•Its requires lots of mathematical method to analyze the data.
•It doesn’t work in bad weather condition.

Remote sensing

•It comprise of visible range and non visible range of radiation.
•Most of the work are done through computer and satellite.
•Provides genearal information about an area.
•This is useful for survey of larger area.
•It requires less amount of time for collecting data.
•The process is very fast and requires huge finance at the start but provide information for long time and at regular intervals.
•Its requires interpretation of data and little of mathematical method to analyze the data.
•It work in all weather condition.
•This technique works well in all areas.
•These technique is far better than conventional technique.

Aerial Photography.

FLIR.
Geodetic Survey.
Hyperspectral Imaging.
Long-Wave Infrared.
Multispectral Imaging.
Near Infrared Surveys.
Oblique Aerial & Ground Visible Band & Thermographic Imaging.

Black Body Radiation and radiation laws

Black Body Radiation

To stay in thermal equilibrium, a black body must emit radiation at the same rate as it absorbs, so it must also be a good emitter of radiation, emitting electromagnetic waves of as many frequencies as it can absorb, i.e. all the frequencies. The radiation emitted by the blackbody is known as blackbody radiation.

Characteristics of Blackbody Radiation

The characteristics of the blackbody radiation are explained with the help of the following laws:

Wien's displacement law
Planck's law
Stefan-Boltzmann law

Wien's Displacement Law

Wien's displacement law states that

The blackbody radiation curve for different temperature peaks at a wavelength is inversely proportional to the temperature.

Wien's Law Formula

Wien's Law Formula	$\lambda_{max} = \frac{b}{T}$	• T is the temperature in kelvins • b is the Wien's displacement constant = 2.8977*10^{3} m.K

Planck's Law

Using Planck's law of blackbody radiation, the spectral density of the emission is determined for each wavelength at a particular temperature.

Planck's law	$E_\lambda = \frac{8\pi hc}{\lambda^5 (e^{\frac{hc}{\lambda KT}} - 1)}$	• E_λ is the wavelength • T is the absolute temperature

Stefan-Boltzmann Law

The Stefan-Boltzmann law explains the relationship between total energy emitted and the absolute temperature.

Stefan-Boltzmann Law Formula

Stefan-Boltzmann Law	$E \propto T^4$	• E is the total energy emitted • T is the absolute temperature

Wien's Displacement Law Example

- We can easily deduce that a wood fire approximately 1500 K hot gives out peak radiation at 2000 nm. This means that the majority of the radiation from the wood fire is beyond the human eye's visibility. This is why a campfire is an excellent source of warmth but a very poor source of light.
- The temperature of the sun's surface is 5700 K. Using Wien's displacement law, we can calculate the peak radiation output at a wavelength of 500 nm. This lies in the green portion of the visible light spectrum. It turns out that our eyes are highly sensitive to this particular wavelength of visible light. We really should be appreciative that a rather unusually large portion of the sun's radiation falls in a fairly small visible spectrum.
- When a piece of metal is heated, it first becomes 'red hot'. This is the longest visible wavelength. On further heating, it moves from red to orange and then yellow. At its hottest, the metal will be seen to be glowing white. These are the shorter wavelengths dominating the radiation.

Application,advantages and disadvantages of remote sensing

1. Military applications
•Surveillance
•Combat support
•Target monitoring
•National security
•UAV (unmanned aerialvehicle) imagery processing
2. Local governments
•Imagery as the backgroundof city and county maps
•Data for environmentalassessment
•Planning and developmentsupport
•Engineering project support
•Change monitoring
3. State and federal institutions
• Natural resources management
•Change monitoring
•Social infrastructure management
•Physical environment monitoring
•Transportation
•Mapping
4. Private sector applications
•Energy
•Electricity
•Water
•Engineering
•Business support
•Agriculture
Advantages of remote sensing :-
1. Large area coverage: Remote sensing allows coverage of very large areas which enables regional surveys on a variety of themes and identification of extremely large features.
2. Remote sensing allows repetitive coverage which comes in handy when collecting data on dynamic themes such as water, agricultural fields and so on.

3. Remote sensing allows for easy collection of data over a variety of scales and resolutions.
4. A single image captured through remote sensing can be analyzed and interpreted for use in various applications and purposes. There is no limitation on the extent of information that can be gathered from a single remotely sensed image.
5. Remotely sensed data can easily be processed and analyzed fast using a computer and the data utilized for various purposes.

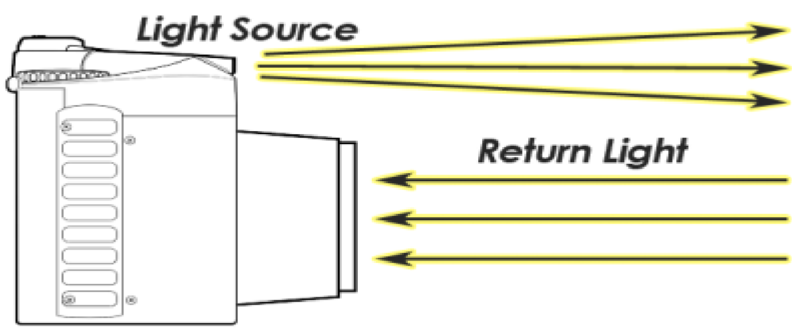
Disadvantages of remote sensing :-

1. Remote sensing is a fairly expensive method of analysis especially when measuring or analyzing smaller areas.
2. Remote sensing requires a special kind of training to analyze the images. It is therefore expensive in the long run to use remote sensing technology since extra training must be accorded to the users of the technology.
3. It is expensive to analyze repetitive photographs if there is need to analyze different aspects of the photography features.
4. It is humans who select what sensor needs to be used to collect the data, specify the resolution of the data and calibration of the sensor, select the platform that will carry the sensor and determine when the data will be collected. Because of this, it is easier to introduce human error in this kind of analysis.
5. Powerful active remote sensing systems such as radars that emit their own electromagnetic radiation can be intrusive and affect the phenomenon being investigated.

The radiation sources

- **Active sensors** have their own source of light or illumination. In particular, it actively sends a pulse and measures the backscatter reflected to the sensor.
- But **passive sensors** measure reflected sunlight emitted from the sun. When the sun shines, passive sensors measure this energy. More on this later.
- **Active sensors**
- When you take a picture with the flash turned on, the camera **sends its own source of light**. After it illuminates the target, the camera captures the reflected light back to the camera lens.
- So, cameras are ***active sensors*** when the **photographer uses flash**. It illuminates its target and measures the reflected energy back to the camera.

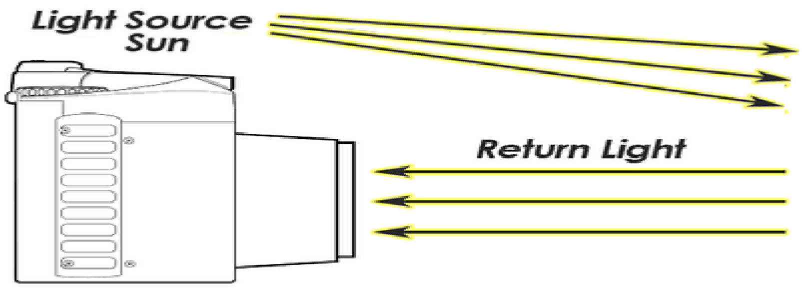
But active remote sensing comes in many forms. For example, they can be satellites orbiting the Earth, helicopters in the air, or anything on the ground too. Just as long as it has an active sensor.



Passive sensors

Cameras are ***passive sensors*** when the photographer does not use the flash. Because the camera is not sending the source of light, it uses naturally emitted light from the sun.

Passive sensors use naturally emitted light from the sun. Without the sun, there wouldn't be passive remote sensing.



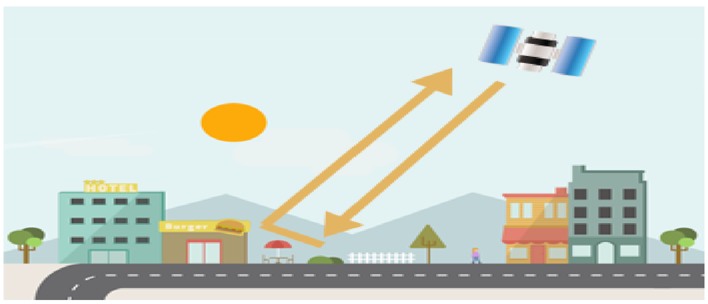
Examples of remote sensing

Now that we have a clear understanding of passive and active remote sensing, let's see it in action for satellite sensors. In this diagram, you can see how the sun emits light.

First, light passes through the atmospheric window. Then, it reflects off Earth to a satellite sensor orbiting Earth.

Whereas active sensors **illuminate their target**. In this example, it's a side-looking sensor that sends its own pulse to the Earth's surface. First, it bounces off the ground.

Then, it bounces again off a building. Finally, it returns to the sensor again. Actually, this type of backscatter is called *double bounce backscatter*. More on this later.



Active remote sensing example

If you ever have a chance to see a synthetic aperture radar image, it will look speckled like this:

For the untrained eye, it's just a bunch of black and white pixels. But the reality is that there's more than meets the eye. For example, the 3 main types of backscatter are:

- Specular reflection
- Double-bounce
- Diffuse scattering

SPECULAR REFLECTION: Specular reflection is where dark spots are in the image. In this case, it's the smooth surfaces like the east-west flowing river and paved surfaces.

DOUBLE-BOUNCE: The bright white in the center is double-bounce backscatter at work. As shown in the schematic above, it's an urban feature like a building but it's not entirely clear at this scale.

DIFFUSE SCATTERING: Finally, the majority of the radar image is rough surface and diffuse scattering. This may be from the growing vegetation in the agricultural areas.

Passive remote sensing example

Really, passive remote sensing can be very similar to how our eyes interpret the world. For example, here are the Rocky Mountains in true color.

But the power of passive remote sensing is to see light in the whole electromagnetic spectrum. For example, this multispectral image can have different band combinations like color infrared.

What's important to realize is how it emphasizes healthy vegetation in bright red. To say the least, there is a lot of it in this scene. While the bright white is built-up areas, the darkest shade is water. In the east, this could be a transmission line right-of-way because of how it's constantly the same width.

Finally, you can see the world much sharper using the panchromatic band. If you want to pan-sharpen an image, this is the spectral band that you use. Here's a list of the band combinations for Landsat 8 to see the world in a whole new way.

Active and passive sensors in remote sensing

- **Active sensors** have their own source of light or illumination. In particular, it actively sends a pulse and measures the backscatter reflected to the sensor.
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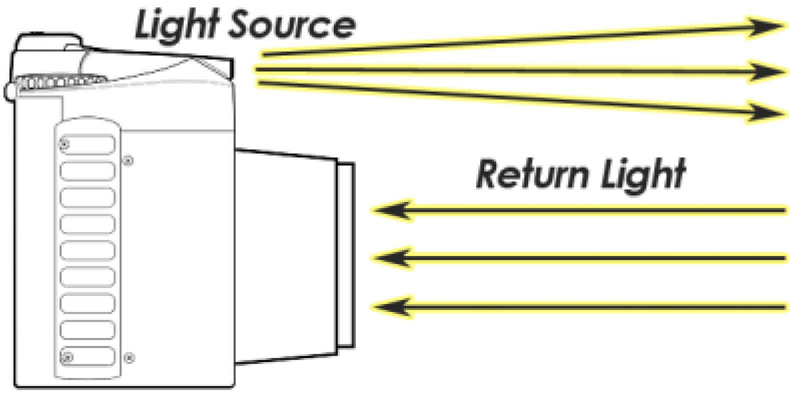

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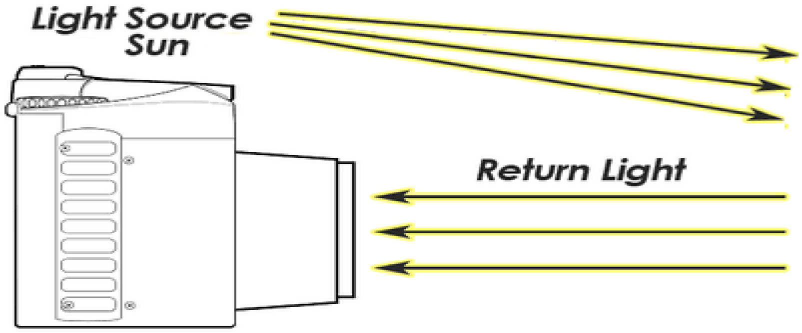
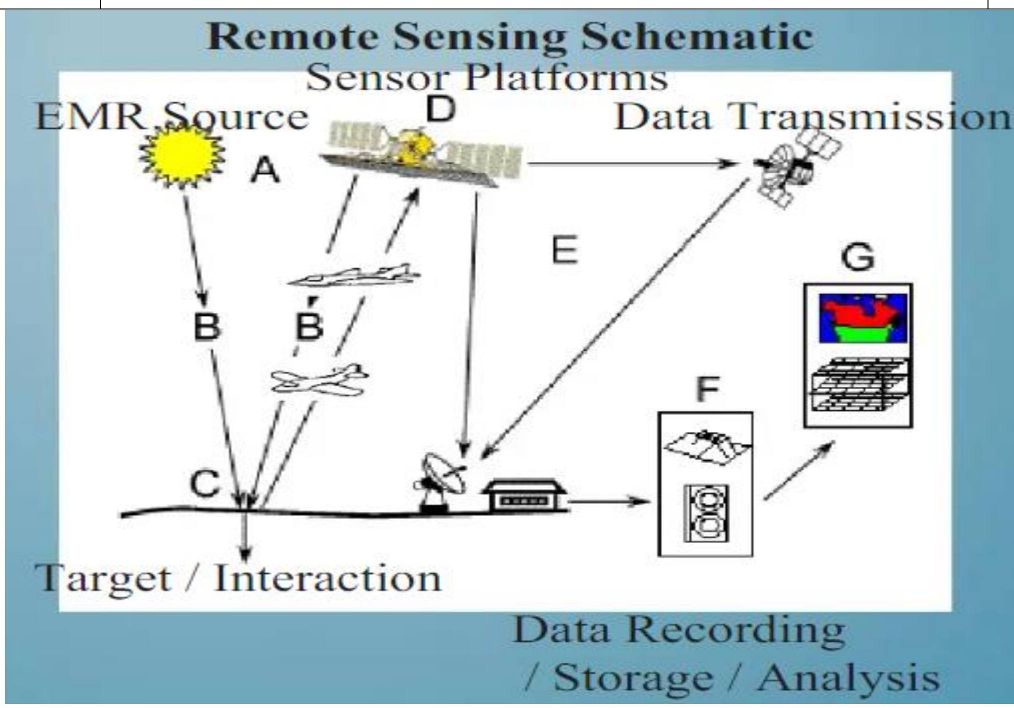


11	With neat sketch explain the process of remote sensing.	CO1	



Electro-magnetic radiation which is **reflected** or **emitted** from an object is the usual sourceof remote sensing data. However any media such as gravity or magnetic fields can beutilized in remote sensing.

Energy Source or Illumination (A)

The first requirement for remote sensing is to have an energy source of electromagnetic radiation to illuminate the target. Sensors can use either external Energy source(Sun) or have their own energy source of illumination.

Energy Interactions with Atmosphere (B)

The energy travels from the source to the target, It passes through the earth's atmosphere which contains obstacles such as haze, clouds, smog etc.

3 Interaction with the Target (C)

The electromagnetic Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface.

4 Recording of Energy by the Sensor (D)
When the energy has been scattered by, or emitted from the target, It is collected through a sensor (remote – not in contact with the target) and record the electromagnetic radiation.

5 Transmission, Reception, and Processing(E)
The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

6 Interpretation and Analysis (F)
The processed image is interpreted and analyzed, visually or digitally or electronically, to extract information about the target which was illuminated.

7 Application (G)

- Geology: it is used for geological mapping;
- Hydrology: Used in monitoring wetlands and snow cover;

The Wien and Stefan-Boltzmann Laws

The behaviour of blackbody radiation is described by the Planck's law. From the Planck's law, one can derive two other radiation laws i.e. the *Stefan-Boltzmann law* and the *Wien's displacement law*. These two laws illustrated below are very important in remote sensing to understand characteristics of EMR:

Stefan-Boltzmann law defines relationship between total emitted radiation (E) and temperature and is expressed as:

$$E = \sigma T^4 \quad \text{......} \quad (3)$$

where,

E = radiant energy per surface unit measured in Watts m^{-2} leaving a blackbody

$\acute{o}$ = 5.6697×10^{-5} (Watts m^{-2} k^{-4} is the Stefan-Boltzmann constant, and

T = absolute temperature of the blackbody in Kelvin (K).

The *Wien's displacement law* defines the relationship between the wavelength of the radiation emitted and the temperature of the object and is expressed as:

$ë_{max}$ – .... (4)

where,

$ë_{max}$ is the wavelength at which radiance is maximum (unit of the ë is in Angstroms), and

T is the absolute temperature in Kelvin (K).

The Wien's Displacement law gives the wavelength of the peak of the radiation distribution, while the Stefan-Boltzmann law gives the total energy being emitted at all wavelengths by the blackbody (which is the area under the Planck's law curve). Thus, the Wien's law explains the shift of the peak to shorter wavelengths as the temperature increases, while the Stefan-Boltzmann law explains the growth in the height of the curve as the temperature increases. Notice that this growth is very large, since it varies as the fourth power of the temperature.

UNIT II EMR INTERACTION WITH ATMOSPHERE AND EARTH MATERIAL

Standard atmospheric profile – main atmospheric regions and its characteristics – interaction of radiation with atmosphere – Scattering, absorption and refraction – Atmospheric windows – Energy balance equation – Specular and diffuse reflectors – Spectral reflectance & emittance– Spectroradiometer – Spectral Signature concepts – Typical spectral reflectance curves for vegetation, soil and water – solid surface scattering in microwave region.

Standard atmospheric profile

The atmosphere temperature profile of Earth demonstrates the temperature as it changes in the atmosphere. It displays changes in temperature as the altitude above sea-level changes.

The standard atmospheric profile is a model that represents the vertical distribution of atmospheric properties such as temperature, pressure, and density as a function of altitude. This model provides a baseline reference for atmospheric conditions under standard circumstances. The most commonly used standard atmospheric model is the International Standard Atmosphere (ISA). Below are key parameters of the ISA at sea level:

Altitude: 0 meters (sea level)
Temperature: 288.15 K (15°C or 59°F)
Pressure: 101325 Pa (101.325 kPa or 1013.25 hPa)
Density: 1.225 kg/m³
Gravity: 9.80665 m/s²
Molar mass of air: 28.9644 g/mol
Gas constant for dry air: 287.05 J/(kg·K)

As you ascend in the atmosphere, these parameters change according to certain lapse rates. The standard atmospheric lapse rates are as follows:

Temperature Lapse Rate: The temperature decreases at a rate of approximately 6.5°C per kilometer up to an altitude of 11 kilometers. This portion of the atmosphere is known as the troposphere.
Tropopause: At an altitude of approximately 11 kilometers, the troposphere transitions into the stratosphere. In the tropopause, the temperature stops decreasing with altitude.
Stratosphere: In the stratosphere, the temperature starts to increase with altitude due to the presence of the ozone layer.
Pressure Lapse Rate: The pressure decreases exponentially with altitude.
Density Lapse Rate: The density decreases with altitude.
Scale Height: The scale height of the atmosphere is the vertical distance over which the pressure decreases by a factor of e (approximately 2.718).

Main atmospheric regions and its characteristics.

The Earth's atmosphere is divided into several main regions, each characterized by distinct properties such as temperature, composition, and behavior. These regions, from the surface of the

Earth outward, include the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. Here are the main atmospheric regions and their key characteristics:

Troposphere:

- Altitude Range: 0 to approximately 8-15 kilometers.
- Temperature: Generally decreases with altitude.
- Composition: Contains the majority of the Earth's atmospheric mass and nearly all weather phenomena.
- Weather: Most weather events occur in this layer, including clouds, precipitation, and storms.

Stratosphere:

- Altitude Range: 15 to 50 kilometers.
- Temperature: Generally increases with altitude due to the presence of the ozone layer.
- Composition: Contains the ozone layer, which absorbs and scatters ultraviolet solar radiation.
- Aircraft Flight: Commercial jet aircraft often fly in the lower stratosphere for smoother air travel.

Mesosphere:

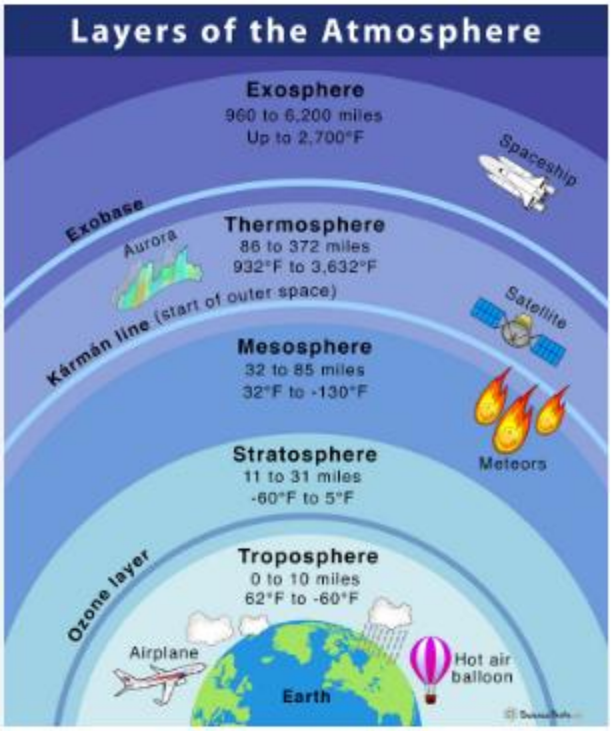
- Altitude Range: 50 to 85 kilometers.
- Temperature: Decreases with altitude.
- Composition: Characterized by a decrease in temperature with altitude, reaching extremely low temperatures.
- Thermosphere:
- Altitude Range: 85 to 600 kilometers (approximately).
- Temperature: Increases significantly with altitude due to absorption of high-energy solar radiation.
- Composition: Sparse gas molecules; primarily oxygen and nitrogen.
- Auroras: The thermosphere is where auroras (northern and southern lights) occur due to interactions with charged particles from the Sun.

Thermosphere:

- Altitude Range: 85 to 600 kilometers (approximately).
- Temperature: Increases significantly with altitude due to absorption of high-energy solar radiation.
- Composition: Sparse gas molecules; primarily oxygen and nitrogen.
- Auroras: The thermosphere is where auroras (northern and southern lights) occur due to interactions with charged particles from the Sun.

Exosphere:

- Altitude Range: Beyond 600 kilometers.
- Temperature: Extremely low temperatures.
- Composition: Very thin atmosphere; mainly hydrogen and helium.
- Transition to Space: The exosphere gradually transitions into outer space, and atmospheric particles are sparse.



Interaction of radiation with atmosphere

Scattering:

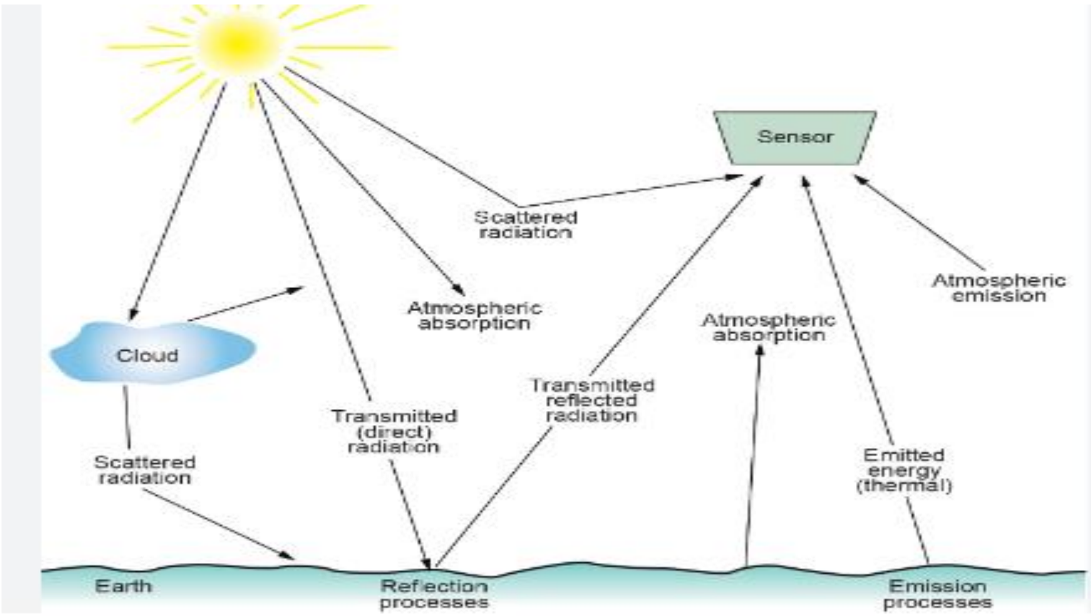
- Definition: Scattering is the process by which EMR is redirected in different directions as it interacts with particles or gas molecules in the atmosphere.
- Types of Scattering:
  - *Rayleigh Scattering:* Occurs when the size of atmospheric particles is much smaller than the wavelength of the incident radiation. Rayleigh scattering is more effective for shorter wavelengths, leading to the blue color of the sky.
  - *Mie Scattering:* Involves larger particles that are comparable in size to the wavelength of the incident radiation. Mie scattering is less wavelength-dependent and can result in scattered light of various colors.
  - *Non-selective Scattering:* This occurs when particles are much larger than the wavelength of light, and scattering is relatively uniform across the spectrum.
- Effects: Scattering contributes to the color of the sky, the visibility of celestial bodies, and the quality of remote sensing data.

Absorption:

- Definition: Absorption occurs when certain molecules in the atmosphere absorb specific wavelengths of EMR, transferring the energy to the absorbing molecules.
- Selective Absorption: Different atmospheric components absorb specific wavelengths of light. For example, water vapor, carbon dioxide, and ozone absorb specific infrared wavelengths.
- Effects: Absorption influences the spectral composition of sunlight reaching the Earth's surface and is essential for processes like photosynthesis. It also affects the behavior of different wavelengths in remote sensing applications.

Refraction:

- Definition: Refraction is the bending of light as it passes from one medium to another with a different refractive index.
- Effects: Refraction causes changes in the apparent position of celestial objects, such as the Sun and stars, especially when they are near the horizon. This effect is responsible for phenomena like sunsets and the twinkling of stars.
- Atmospheric Lensing: Refraction acts as a natural lens, affecting the visibility of objects on the horizon and enabling the observation of celestial bodies that are below the geometric horizon.



Atmospheric window

In the context of Earth's atmosphere and remote sensing, the term "atmospheric windows" refers to specific wavelength ranges within the electromagnetic spectrum where the Earth's atmosphere allows certain types of electromagnetic radiation to pass through with minimal absorption. These regions are critical for observational purposes because they enable the collection of data from the Earth's surface or outer space without significant interference from atmospheric constituents. Here are some key atmospheric windows:

Visible Spectrum:

- Wavelength Range: Approximately 400 to 700 nanometers.
- Importance: The visible spectrum is a crucial atmospheric window for optical observations. It corresponds to the colors of light visible to the human eye. Solar radiation in this range is not heavily absorbed by atmospheric gases, allowing it to reach the Earth's surface.

Near-Infrared (NIR) Window:

- Wavelength Range: Around 700 to 1,300 nanometers.
- Importance: The near-infrared window is valuable for remote sensing applications. In this range, solar radiation can penetrate the atmosphere and interact with the Earth's surface. NIR radiation is used in various Earth observation techniques, such as vegetation monitoring and land cover analysis.

Shortwave Infrared (SWIR) Window:

- Wavelength Range: Approximately 1,300 to 2,500 nanometers.
- Importance: The shortwave infrared window is another region where certain wavelengths can pass through the atmosphere relatively unaffected. It is utilized for applications like mineral identification and water content assessment.

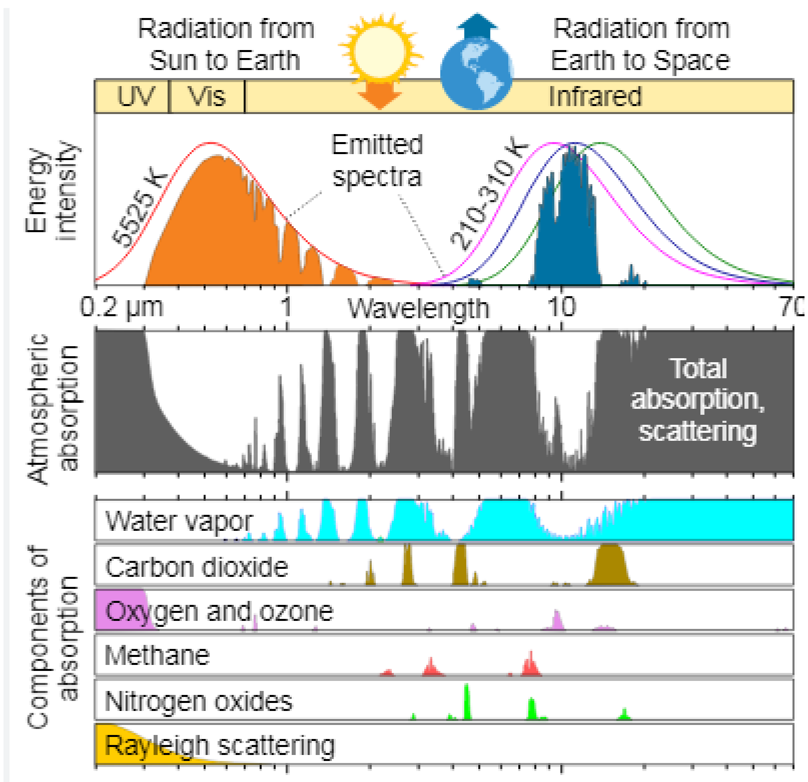
Thermal Infrared (TIR) Windows:

- Wavelength Range: There are multiple TIR windows, such as 3-5 µm, 8-14 µm, and others.
- Importance: These windows are critical for studying the thermal emission of the Earth's surface. In these ranges, the atmosphere is less effective at absorbing and re-emitting thermal radiation, allowing for measurements of surface temperature and heat distribution.

Microwave Windows:

- Wavelength Range: In the microwave portion of the spectrum (1 millimeter to 1 meter).
- Importance: Microwaves at specific frequencies can penetrate the atmosphere, allowing for observations of the Earth's surface regardless of cloud cover. This is particularly useful in radar and passive microwave remote sensing.

Scientists and remote sensing practitioners take advantage of these atmospheric windows when designing and interpreting observations. By selecting appropriate wavelength ranges, they can minimize the impact of atmospheric interference, leading to more accurate and valuable data for applications such as weather monitoring, climate studies, and Earth observation.



Energy balance equation

The energy balance equation represents the balance between incoming and outgoing energy in a system. It is commonly used in the context of Earth's energy balance to understand and quantify the exchanges of energy between the Earth and space. The equation can be expressed as follows:

Incoming Solar Radiation (Insolation)=Outgoing Infrared Radiation (Heat Emission)+Sensible Heat +Latent HeatIncoming Solar Radiation (Insolation)=Outgoing Infrared Radiation (Heat Emission)+Sensible Heat+Latent Heat

In more detail:

Incoming Solar Radiation (Insolation):

- Represents the solar energy received by the Earth from the Sun.
- This energy is in the form of shortwave radiation (mainly visible light and some ultraviolet and infrared radiation).

Outgoing Infrared Radiation (Heat Emission):

- Represents the thermal radiation emitted by the Earth back into space.
- This is longwave radiation in the form of infrared radiation.

Sensible Heat:

- Represents the heat transfer associated with temperature changes in the atmosphere and at the Earth's surface.
- It includes the warming or cooling of the air and the Earth's surface.

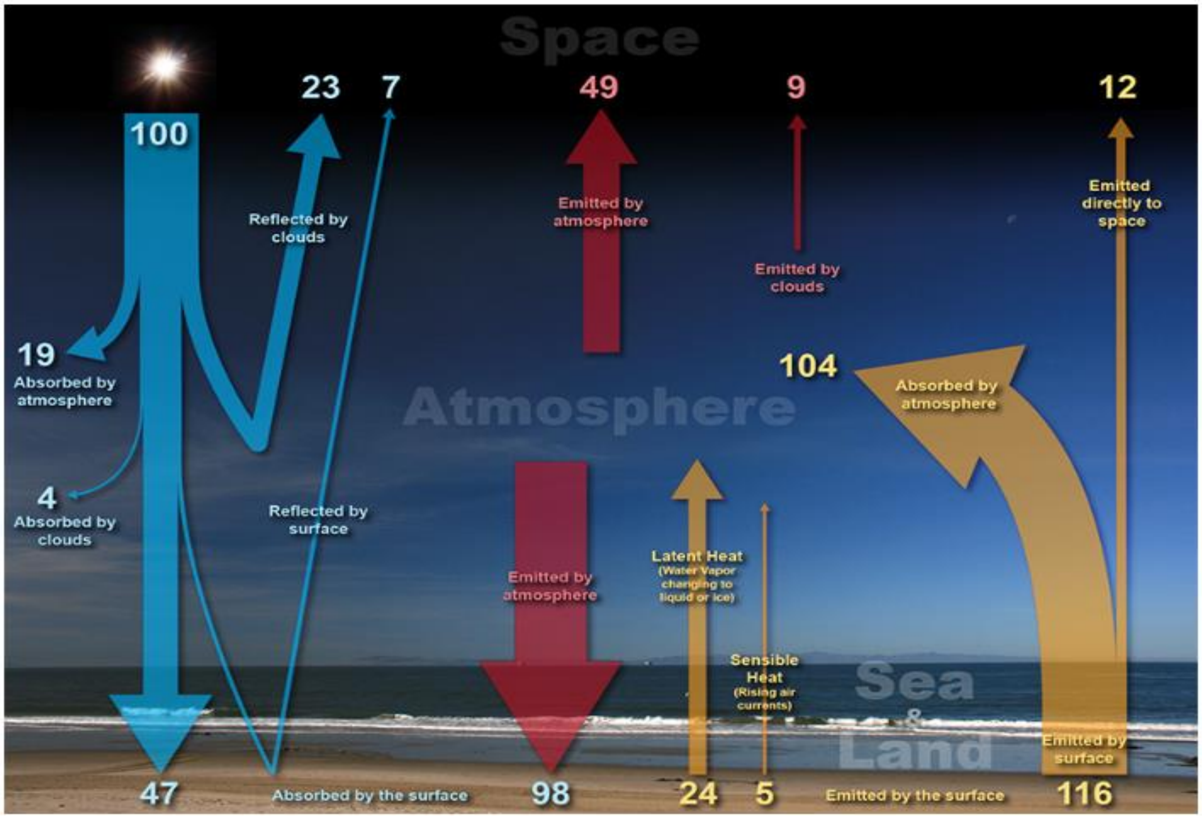
Latent Heat:

- Represents the heat energy associated with phase changes, such as evaporation and condensation.
- It accounts for the energy absorbed or released during processes like the conversion of liquid water to water vapor (evaporation) or the condensation of water vapor into liquid water.

The energy balance equation is essential for understanding the factors that influence the Earth's temperature and climate. When the system is in equilibrium, the incoming solar radiation is balanced by the outgoing infrared radiation, and the Earth's temperature remains relatively constant. Changes in any of the components, such as alterations in greenhouse gas concentrations or changes in surface properties, can lead to imbalances and contribute to climate variability.

It's important to note that this energy balance equation is a simplification, and various factors, including greenhouse gases, clouds, and albedo, contribute to the complexity of Earth's energy balance. Models and observations are used to study and quantify these interactions for a more comprehensive understanding of the Earth's climate system.

The earth-atmosphere energy balance is the balance between incoming energy from the Sun and outgoing energy from the Earth. Energy released from the Sun is emitted as shortwave light and ultraviolet energy. When it reaches the Earth, some is reflected back to space by clouds, some is absorbed by the atmosphere, and some is absorbed at the Earth's surface.



INCOMING ENERGY		OUTGOING ENERGY	
UNITS	SOURCE	UNITS	SOURCE
+100	Shortwave radiation from the sun.	-23	Shortwave radiation reflected back to space by clouds.
		-7	Shortwave radiation reflected to space by the earth's surface.
		-49	Longwave radiation from the atmosphere into space.
		-9	Longwave radiation from clouds into space.
		-12	Longwave radiation from the earth's surface into space.
+100	Total Incoming	-100	Total Outgoing

Specular and diffuse reflectors

Specular and diffuse reflection are two distinct types of interactions that occur when electromagnetic radiation, such as light, interacts with a surface.

Specular Reflection:

- Definition: Specular reflection refers to the reflection of light or other forms of electromagnetic radiation off a smooth surface in a single, well-defined direction.
- Surface Characteristics: Specular reflectors have smooth and polished surfaces that maintain the incident angle of light upon reflection.
- Result: The reflected light retains its original intensity and forms a clear, sharp reflection.
- Examples: Mirrors, smooth metal surfaces, and still water surfaces exhibit specular reflection.

Diffuse Reflection:

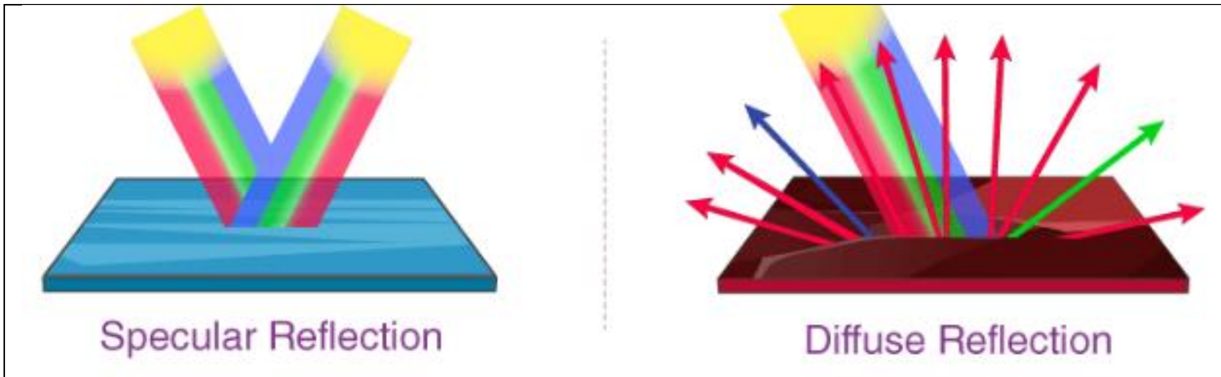
- Definition: Diffuse reflection occurs when light or electromagnetic radiation strikes a rough or irregular surface, scattering in multiple directions.
- Surface Characteristics: Diffuse reflectors have irregular surfaces that cause incoming light to be scattered in various directions.
- Result: The reflected light is scattered, and there is no clear reflection angle. The intensity of the reflected light is generally lower than that of the incident light.
- Examples: Most non-metallic surfaces, such as paper, wood, and rough walls, exhibit diffuse reflection.

In summary:

Specular Reflection: Occurs on smooth, polished surfaces, and the reflected light maintains a well-defined angle.
Diffuse Reflection: Occurs on rough or irregular surfaces, and the reflected light scatters in multiple directions.

Real-world surfaces often exhibit a combination of specular and diffuse reflection. For instance, a glossy magazine cover may show both specular highlights (due to smooth, shiny ink) and diffuse reflection (due to the underlying paper fibers).

Understanding the nature of reflection is crucial in various fields, including computer graphics, computer vision, optics, and material science, where it impacts the appearance and behavior of surfaces in different lighting conditions.



Most things that we encounter every day do not themselves emit visible light but reflect incident natural sunlight and artificial light. A tomato appears red because it has a relatively smooth surface that reflects red light and absorbs other non-red wavelengths of light. Reflection of light can be categorized into two types as specular reflection and diffuse reflection. Reflection of light from smooth surfaces such as mirrors or a calm body of water leads to specular reflection while reflection off of rough surfaces such as clothing, or paper, leads to diffuse reflection. The roughness and smoothness of the surface have a tremendous impact on the reflection of a beam of light. In this article, let us discuss in brief specular and diffuse reflection.

Applications of Specular and Diffuse Reflection

There are several interesting applications of diffuse reflection and specular reflection. However, here we shall discuss two of the most noteworthy applications.

- Most of us are aware of the fact that driving at night on a wet road is difficult because of the glare caused due to the oncoming headlights. The glare is the result of the specular reflection of the beam of the light of the oncoming vehicle. Normally, the rough surfaces of the road cause diffuse reflection, but if the surface is wet, water fills up the crevices and smoothen the surface. The rays of light hit this surface and undergo specular reflection.
- The second application pertains to the field of photography. Most of us have seen a photograph of a beautiful nature scene captured by a photographer with a calm body of water in the foreground. We can witness the specular reflection of light from the subject of the photograph if the water is calm. Light from the subject can reach the camera lens directly or it can take a longer path in which it reflects off the water before traveling to the lens. Since the light reflecting off the water undergoes specular reflection, the incident rays remain concentrated (instead of diffusing). The light is thus able to travel together to the lens of the camera and produce an image (an exact replica) of the subject which is strong enough to perceive in the photograph.

Spectral reflectance & emittance.

Spectral reflectance and emittance are two important concepts in remote sensing and the study of electromagnetic radiation interactions with materials. They describe how objects or surfaces interact with and emit electromagnetic radiation at different wavelengths.

Spectral Reflectance:

- Definition: Spectral reflectance refers to the ratio of the amount of electromagnetic radiation reflected by a surface at a specific wavelength to the amount of incident radiation at that wavelength.
- Mathematically: Reflectance=Reflected RadianceIncident RadianceReflectance=Incident RadianceReflected Radiance
- Representation: Spectral reflectance is often expressed as a function of wavelength, resulting in a spectral reflectance curve or spectrum.
- Application: Spectral reflectance is crucial in remote sensing for identifying and characterizing materials based on their unique spectral signatures. Different materials have distinct reflectance patterns across the electromagnetic spectrum, allowing for their discrimination and analysis.

Emittance:

- Definition: Emittance, specifically thermal emittance or thermal emissivity, refers to the ability of a material to emit thermal radiation. It represents the ratio of the emitted thermal radiation by a material to the radiation emitted by a perfect black body at the same temperature.
- Mathematically: Emittance=Emitted Thermal Radiation by MaterialEmitted Thermal Radiation by Black BodyEmittance=Emitted Thermal Radiation by Black BodyEmitted Thermal Radiation by Material
- Values: Emittance values range from 0 to 1, with a black body having an emittance of 1.
- Application: Emittance is particularly relevant in thermal infrared remote sensing, where it helps in understanding the thermal behavior of surfaces. Different materials emit thermal radiation differently, and emissivity values are used to quantify this property for various surfaces.

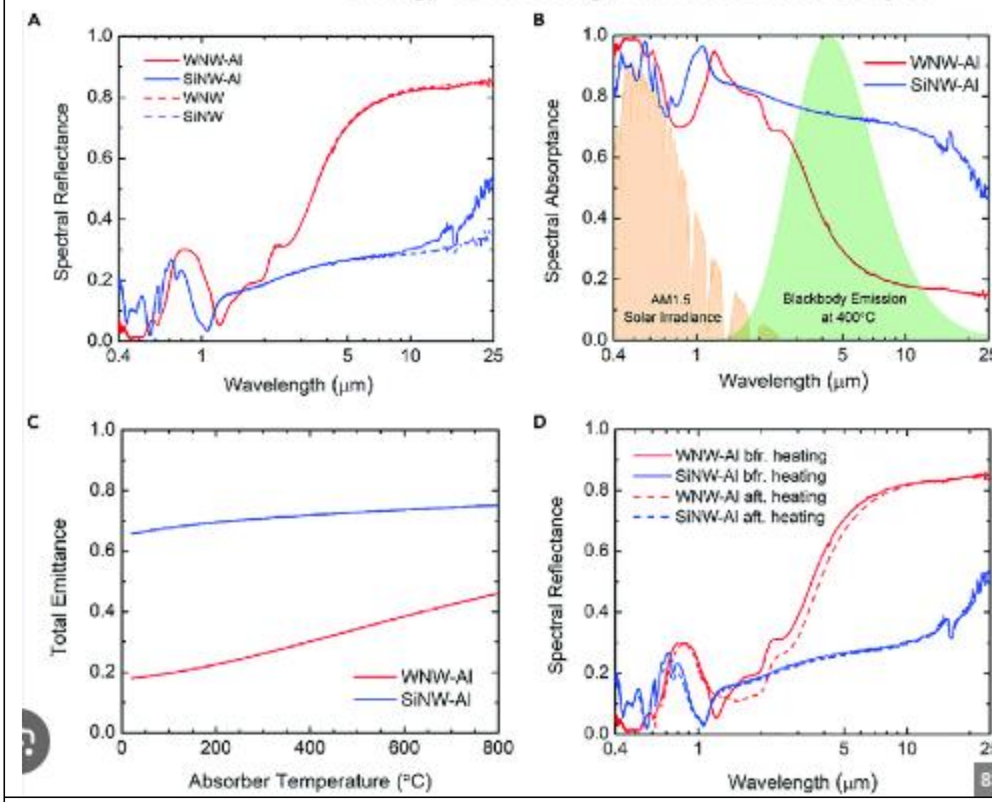
In summary:

Spectral Reflectance: Describes how much light is reflected at different wavelengths across the electromagnetic spectrum. It is crucial for identifying and characterizing materials in remote sensing applications.
Emittance: Specifically thermal emittance, refers to the ability of a material to emit thermal radiation. It is important for understanding the thermal behavior of surfaces, especially in the thermal infrared part of the spectrum.

Both spectral reflectance and emittance play significant roles in remote sensing applications, helping scientists and researchers analyze and interpret data gathered from satellite or airborne sensors. They contribute to the understanding of Earth's surface properties and processes.

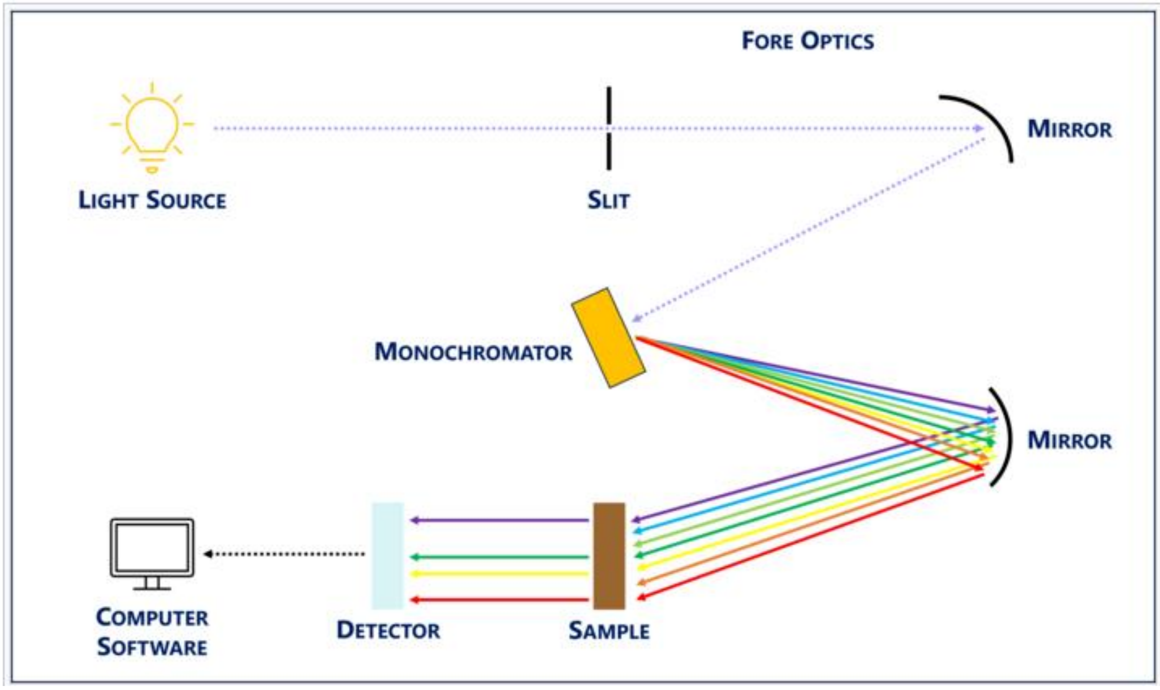
$$\text{Spectral reflectance} = \frac{ER(\lambda)}{EI(\lambda)}$$

$$= \frac{\text{Energy of wavelength } \lambda \text{ reflected from the object}}{\text{Energy of wavelength } \lambda \text{ incident on the object}} \times 100$$



Working principle of spectroradiometer in remote sensing.

Spectroradiometry is a technique in Earth and planetary remote sensing, which makes use of light behaviour, specifically how light energy is reflected, emitted, and scattered by substances, to explore their properties in the electromagnetic (light) spectrum and identify or differentiate between them.



Spatial resolution evaluates the quality of an image captured by imaging spectroradiometers. It describes the extent of spatial detail the sensors can record, i.e., the smallest feature detected, based on pixel and grid sizes of the captured digital imagery.A sensor with fine *spatial resolution* would capture an image with small grid cells, thus recording more spatial details and image pixels.

A visualization of radiometric resolution. The area bounded by the curve represents the magnitude of electromagnetic radiation reflected by a given material at various wavelengths. Devices with high radiometric resolution can precisely measure and detect relatively small differences in the values of reflectance for a given material.

Radiometric resolution deals with the sensitivity of a sensor towards measuring the magnitude of electromagnetic radiation and light intensity. A sensor with high *radiometric resolution* can detect and discriminate subtle variations in brightness and radiation magnitudes. In the context of multispectral imaging, the greater the number of data bits per pixel (bit depth) of the image recorded, the better the quality and interpretability of the image, thus the finer the *radiometric resolution*.

Temporal resolution is the frequency or the repeat cycle of a sensor, most commonly referring to sensors on imaging spectroradiometers, to capture images and acquire spectral information. An imaging spectroradiometer with high *temporal resolution* typically requires less time to complete spectral measurements of an image.

Key components and features of a spectroradiometer

Wavelength Resolution:

- Spectroradiometers are designed to provide high wavelength resolution. They can measure the intensity of light at numerous discrete wavelengths across a specified range.

Detector Array:

- Spectroradiometers typically employ a detector array, such as a charge-coupled device (CCD) or a complementary metal-oxide-semiconductor (CMOS) sensor, to capture the spectral information.

Grating or Prism:

- A component like a diffraction grating or prism disperses incoming light into its spectral components, allowing the spectroradiometer to measure the intensity of light at different wavelengths.

Calibration Source:

- Calibration is crucial for ensuring accurate measurements. Spectroradiometers often include a calibration source, such as a known light source, to calibrate the instrument and establish a reliable reference for measurements.

Optical System:

- The optical system of a spectroradiometer is designed to efficiently direct and focus light onto the detector. It may include lenses, mirrors, and other components to enhance the instrument's sensitivity and precision.

Data Output:

- Spectroradiometers provide detailed spectral data, and the output may be in the form of a spectral radiance or irradiance curve. The data can be stored digitally for further analysis.

Applications:

- Spectroradiometers are used in various applications, including:
    - Remote Sensing: Studying Earth's surface properties and composition from satellite or airborne platforms.
    - Environmental Monitoring: Measuring atmospheric parameters, analyzing water quality, and studying vegetation health.
    - Astronomy: Observing and analyzing the spectra of celestial objects to gather information about their composition and temperature.
    - Material Science: Characterizing the spectral properties of materials for research and quality control.

Spectroradiometers are valuable tools for scientists and researchers who require detailed spectral information to understand and analyze the properties of light and the objects it interacts with in different fields of study.

Spectral signature concepts

Spectral signature is a fundamental concept in remote sensing that refers to the unique pattern of electromagnetic energy (radiation) reflected or emitted by different surfaces on the Earth's surface at various wavelengths. Each material has a distinct spectral signature, allowing remote sensing instruments to identify and differentiate between different features or objects based on their spectral characteristics. Here are key concepts related to spectral signatures in remote sensing:

Electromagnetic Spectrum: The electromagnetic spectrum encompasses a range of wavelengths of electromagnetic radiation. Remote sensing instruments operate in different regions of this spectrum, including the visible, near-infrared, shortwave infrared, thermal infrared, and microwave.

Reflectance and Emissivity: Reflectance is the measure of the amount of incoming solar radiation that is reflected by the Earth's surface. Emissivity refers to the ability of a material to emit thermal radiation. Both reflectance and emissivity contribute to the spectral signature.

Wavelengths and Bands: Remote sensing instruments are designed to capture data in specific wavelength bands. These bands are selected to highlight the spectral characteristics of features of interest. For example, vegetation strongly reflects in the near-infrared portion of the spectrum.

Feature Discrimination: Different materials absorb, transmit, or reflect energy differently at different wavelengths. This differential behavior allows remote sensing systems to discriminate between various land cover types, such as water bodies, vegetation, urban areas, and bare soil.

Signature Variability: Spectral signatures can vary based on factors like time of day, season, and environmental conditions. Understanding this variability is crucial for accurate interpretation and classification of remote sensing data.

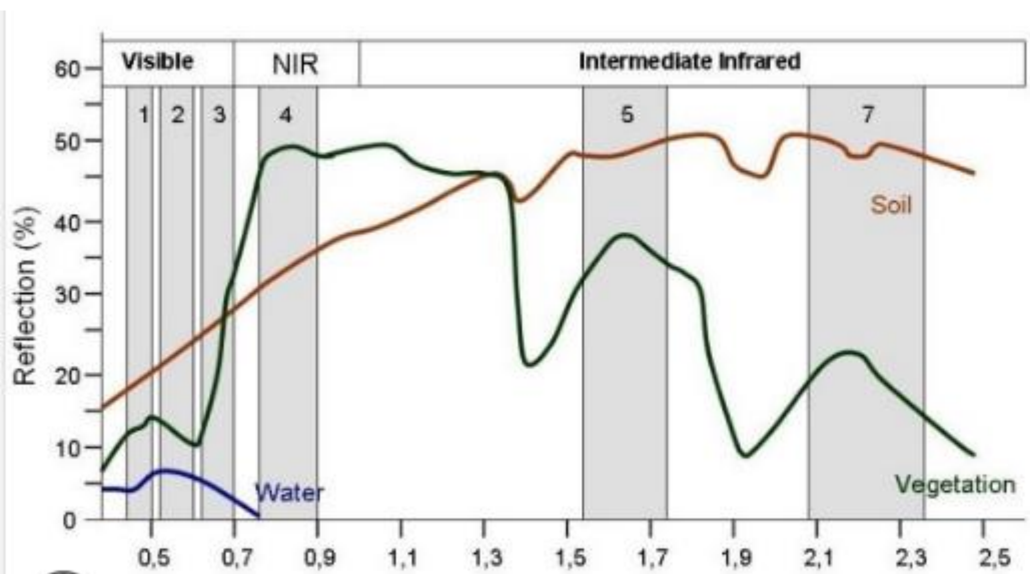
Signature Libraries: Researchers and remote sensing practitioners compile spectral signature libraries, which are databases containing the spectral characteristics of various materials. These libraries serve as references for interpreting remote sensing data and classifying land cover.

Vegetation Indices: Indices like the Normalized Difference Vegetation Index (NDVI) leverage specific bands to quantify the health and density of vegetation, providing valuable information for agricultural monitoring, ecosystem health assessments, and land cover classification.

Mineral Identification: In geological remote sensing, spectral signatures are used for mineral identification. Different minerals exhibit unique absorption features in the infrared region, aiding in the mapping of geological formations.

Understanding spectral signatures is essential for the interpretation of remote sensing data and the extraction of meaningful information about the Earth's surface, making it a foundational concept in the field of remote sensing

Spectral signatures are the specific combination of reflected, absorbed and transmitted or emitted EMR by objects at varying wavelengths, which can uniquely identify an object. It is important because this forms the basis of image interpretation.



Spectral reflectance curves for vegetation, soil and water.

The spectral reflectance curves for vegetation, soil, and water in remote sensing exhibit distinct patterns across different wavelengths. Here's a general overview of the typical spectral reflectance curves for these three types of surfaces:

Vegetation:

- Visible Spectrum (400-700 nm): Vegetation generally has high reflectance in the near-infrared (NIR) portion of the spectrum (around 700 nm) and lower reflectance in the visible range.
- Red Edge (700-750 nm): There is a characteristic "red edge" where reflectance increases sharply between the red and NIR wavelengths.
- Shortwave Infrared (SWIR) Region (around 1000-2500 nm): Reflectance in the SWIR region tends to be lower for healthy vegetation, with specific absorption features related to water content.

Soil:

- Visible Spectrum: Soil typically has moderate to low reflectance in the visible range.
- Near-Infrared (NIR) Region: Similar to vegetation, soil reflects more strongly in the NIR region, but the reflectance is generally lower compared to healthy vegetation.
- Mid-Infrared (MIR) Region: Soil can exhibit variations in reflectance in the MIR range due to factors such as mineral composition.

Water:

- Visible Spectrum: Water absorbs most of the sunlight in the visible range, resulting in low reflectance.
- Near-Infrared (NIR) Region: Water shows higher reflectance in the NIR region compared to the visible spectrum.
- Shortwave Infrared (SWIR) Region: In the SWIR region, water absorbs radiation due to molecular vibrations, leading to low reflectance.

These spectral reflectance characteristics are the basis for developing vegetation indices like NDVI (Normalized Difference Vegetation Index) and other remote sensing applications such as land cover classification and environmental monitoring. It's important to note that the specific reflectance values can vary depending on factors such as vegetation health, soil type, and water composition. Researchers and remote sensing practitioners use these characteristic patterns to interpret satellite or airborne sensor data and distinguish between different land cover and surface types.

The solid surface scattering in microwave region

Solid surface scattering in the microwave region refers to the interaction of microwave radiation with the Earth's surface, particularly with solid materials like soil, rocks, and artificial structures. Microwave remote sensing is commonly used in various applications, such as agriculture, forestry, soil moisture monitoring, and geological studies. The interaction of microwaves with solid surfaces involves several key mechanisms:

Specular Reflection: In the microwave region, smooth surfaces can exhibit specular reflection, where incoming microwaves are reflected at the same angle as the incident angle. This phenomenon is particularly relevant for flat surfaces, such as calm water bodies and certain types of artificial structures.

Diffuse Scattering: Surfaces that are rough at the scale of the microwave wavelength can cause diffuse scattering, where microwaves are scattered in multiple directions. This is common for natural surfaces like soil and rocks. The degree of roughness influences the scattering behavior, with rougher surfaces leading to increased diffuse scattering.

Rough Surface Scattering Models: Various models have been developed to describe the scattering behavior of rough surfaces in the microwave region. The most well-known model is the Kirchhoff approximation, which assumes that the surface is a collection of small facets, each acting as a scattering center. The small-scale variations in surface elevation contribute to the overall scattering response.

Polarization Dependence: The polarization of microwaves (horizontal, vertical, or other polarizations) also influences the scattering characteristics of solid surfaces. Different polarizations may interact differently with surface features, leading to variations in the observed backscattering.

Dielectric Properties: The dielectric properties of materials play a crucial role in microwave interactions. The complex permittivity of a material determines how much microwave energy is absorbed and scattered. For solid surfaces, the dielectric constant and loss factor are essential parameters.

Understanding the microwave interaction with solid surfaces is vital for interpreting remote sensing data acquired by microwave sensors, such as synthetic aperture radar (SAR). SAR systems operate in the microwave region and utilize the backscattered signals to extract information about the Earth's surface, including topography, vegetation, and soil moisture content. Researchers often use empirical models and theoretical scattering models to simulate and analyze microwave interactions with different types of solid surfaces for a variety of applications in Earth observation and environmental monitoring.

Scattering, absorption and refraction

Scattering:

- Definition: Scattering is the process by which EMR is redirected in different directions as it interacts with particles or gas molecules in the atmosphere.
- Types of Scattering:
  - *Rayleigh Scattering:* Occurs when the size of atmospheric particles is much smaller than the wavelength of the incident radiation. Rayleigh scattering is more effective for shorter wavelengths, leading to the blue color of the sky.
  - *Mie Scattering:* Involves larger particles that are comparable in size to the wavelength of the incident radiation. Mie scattering is less wavelength-dependent and can result in scattered light of various colors.
  - *Non-selective Scattering:* This occurs when particles are much larger than the wavelength of light, and scattering is relatively uniform across the spectrum.
- Effects: Scattering contributes to the color of the sky, the visibility of celestial bodies, and the quality of remote sensing data.

Absorption:

- Definition: Absorption occurs when certain molecules in the atmosphere absorb specific wavelengths of EMR, transferring the energy to the absorbing molecules.

- Selective Absorption: Different atmospheric components absorb specific wavelengths of light. For example, water vapor, carbon dioxide, and ozone absorb specific infrared wavelengths.
- Effects: Absorption influences the spectral composition of sunlight reaching the Earth's surface and is essential for processes like photosynthesis. It also affects the behavior of different wavelengths in remote sensing applications.

. Refraction:

- Definition: Refraction is the bending of light as it passes from one medium to another with a different refractive index.
- Effects: Refraction causes changes in the apparent position of celestial objects, such as the Sun and stars, especially when they are near the horizon. This effect is responsible for phenomena like sunsets and the twinkling of stars.
- Atmospheric Lensing: Refraction acts as a natural lens, affecting the visibility of objects on the horizon and enabling the observation of celestial bodies that are below the geometric horizon.

Atmospheric windows

Visible Spectrum:

- Wavelength Range: Approximately 400 to 700 nanometers.
- Importance: The visible spectrum is a crucial atmospheric window for optical observations. It corresponds to the colors of light visible to the human eye. Solar radiation in this range is not heavily absorbed by atmospheric gases, allowing it to reach the Earth's surface.

Near-Infrared (NIR) Window:

- Wavelength Range: Around 700 to 1,300 nanometers.
- Importance: The near-infrared window is valuable for remote sensing applications. In this range, solar radiation can penetrate the atmosphere and interact with the Earth's surface. NIR radiation is used in various Earth observation techniques, such as vegetation monitoring and land cover analysis.

. Shortwave Infrared (SWIR) Window:

- Wavelength Range: Approximately 1,300 to 2,500 nanometers.
- Importance: The shortwave infrared window is another region where certain wavelengths can pass through the atmosphere relatively unaffected. It is utilized for applications like mineral identification and water content assessment.

. Thermal Infrared (TIR) Windows:

- Wavelength Range: There are multiple TIR windows, such as 3-5 µm, 8-14 µm, and others.
- Importance: These windows are critical for studying the thermal emission of the Earth's surface. In these ranges, the atmosphere is less effective at absorbing and re-emitting thermal radiation, allowing for measurements of surface temperature and heat distribution.

. Microwave Windows:

- Wavelength Range: In the microwave portion of the spectrum (1 millimeter to 1 meter).
- Importance: Microwaves at specific frequencies can penetrate the atmosphere, allowing for observations of the Earth's surface regardless of cloud cover. This is particularly useful in radar and passive microwave remote sensing.

EMR interaction with atmosphere and earth material.

Electromagnetic radiation (EMR) interacts with the atmosphere and Earth materials in various ways, depending on the wavelength of the radiation and the properties of the substances it encounters. The interaction between EMR and the atmosphere and Earth materials plays a crucial role in remote sensing, climate studies, and geological observations. Here are some key interactions:

Reflection: When EMR encounters a surface, it can be reflected. The amount of reflection depends on the nature of the surface. Smooth and shiny surfaces tend to reflect more radiation than rough and dull surfaces. In remote sensing, the reflected radiation is often measured to extract information about the Earth's surface.

Absorption: Certain materials absorb specific wavelengths of EMR. For example, water absorbs infrared radiation, which is why thermal infrared imagery is used to study ocean temperatures. Different minerals and compounds have characteristic absorption bands, allowing scientists to identify and analyze Earth materials based on their spectral signatures.

Transmission: Some EMR passes through the atmosphere and Earth materials without being significantly absorbed or reflected. This is common in certain parts of the electromagnetic spectrum, such as visible light. The ability of a material to transmit certain wavelengths is crucial for various applications, including satellite imaging and communication.

Scattering: The interaction of EMR with small particles or gas molecules in the atmosphere can cause scattering. Rayleigh scattering occurs when particles are much smaller than the wavelength of the incident radiation, leading to a greater scattering of shorter wavelengths (blue light) compared to longer wavelengths (red light). Mie scattering involves larger particles and is more uniform across different wavelengths. Scattering contributes to the color of the sky and affects the quality of remote sensing data.

Emission: Materials, especially at high temperatures, can emit radiation. This is particularly relevant in the thermal infrared portion of the spectrum. The emitted radiation can be detected and used to study surface temperatures and heat distribution.

Refraction: EMR may change direction when it passes through different media with varying refractive indices. This phenomenon is particularly noticeable during sunrise and sunset when the Sun's light is refracted as it passes through the Earth's atmosphere, causing changes in the apparent position of the Sun.

UNIT III ORBITS AND PLATFORMS

Motions of planets and satellites – Newton ‘s law of gravitation – Gravitational field and potential - Escape velocity - Kepler ‘s law of planetary motion - Orbit elements and types – Orbital perturbations and maneuvers – Types of remote sensing platforms - Ground based, Air borne platforms and Space borne platforms – Classification of satellites – Sun synchronous and Geosynchronous satellites – Legrange Orbit

Concept of motions of planets and satellites

Earth and Its Satellite

Consider a satellite of mass m revolving in a circular orbit around the Earth, which is located at the centre of its orbit. If the satellite is at a height h above the Earth's surface, the radius of its orbit r = Re + h, where Re is the radius of the Earth. The gravitational force between Me & m provides the centripetal force necessary for circular motion, i.e.,

$GMem/(Re+h)2 \quad = \quad mv2/(Re+h)$

Or $v2 = GMe/(Re+h)$ or $v = \sqrt{}GMe/(Re+h)$

Hence orbital velocity depends on the height of the satellite above Earth's surface. Time period T of the satellite is the time taken to complete one revolution.

Therefore, $T = 2\Pi r/v = 2\Pi(Re + h)\sqrt{}(Re+h)/GMe$

or $T2 = 4\Pi 2(Re+h)3/GMe$ where $r = Re + h$

If time period of a satellite is 24 hrs. Then,

$r = [GMeT2/4\Pi 2]1/3 = 42400$ km and $h = 36000$ km.

This gives the height of a satellite above the Earth's surface whose time period is same as that of Earth's. Such a satellite appears to be stationary when observed from the Earth's surface and is hence known as Geostationary satellite.

For a satellite very close to the surface of Earth i.e. $h << Re$ then

$r \approx Re$

$v_{orbital} = \sqrt{}GMe/Re = \sqrt{}gRe$

$$V_O = \sqrt{\frac{GM_e}{R_e}} = \sqrt{gR_e}$$

Simulation for Kepler Laws of Motion

Satellite in circular orbit:-

For different velocities, the trajectory of the satellite would be different. Let us consider these cases. If v is the velocity given to a satellite and v_O represents the velocity of a circular orbit and v_e the escape velocity.
i.e. $v_0 = \sqrt{GM_e/(R_e+h)}$

$$V_O = \sqrt{\frac{GM_e}{R_e + h}}$$

$$V_e = \sqrt{\frac{2GM_e}{R_e + h}}$$

$v_e = \sqrt{2GM_e/(R_e+h)}$

Where, h is the distance of the satellite from the surface of the Earth.

- When, $v < v_0$, the satellite follows an elliptical path with center of the Earth as the further focus. In this case, if satellite is projected from near surface of the Earth, it will hit the Earth's surface without completing the orbit.
- If $v = v_0$, obviously the satellite follows a circular orbit with center of Earth as the center of the orbit.
- If $v_0 < v < v_e$, then the satellite follows an elliptical orbit with center of the Earth as the nearer focus.
- If $v = v_e$, the satellite escapes the gravitational field of the Earth along a parabolic trajectory.
- If $v > v_e$, the satellite escapes the gravitational field of Earth along a hyperbolic trajectory

What should be the energy required to shift a satellite orbiting around the Earth to infinity?

At infinity the Potential Energy of the satellite would be zero and if we want to supply minimum Energy then its kinetic energy would also be zero. Let us first find the total Energy of the satellite.

Total Energy = Kinetic Energy + Potential Energy

= 1/2 mv2 + (-GMem/r)

= 1/2 m (GMe/r) - GMem/r

= -GMem/2r

Now, Binding Energy would be equal to - (Total Energy) as it is the energy needed to shift the satellite from its orbit to infinity.

So, the energy required = GMem/2r.

Here, r = Re + h.

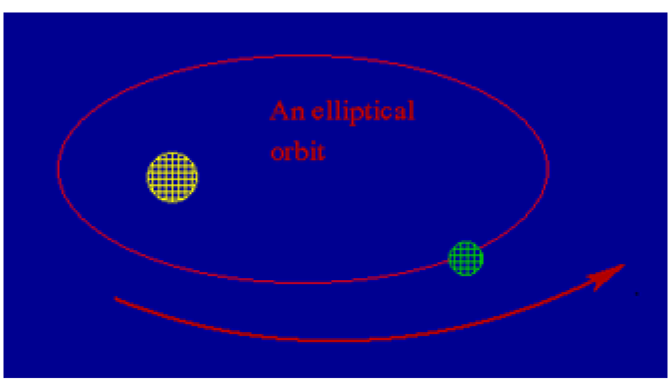
If we see a satellite from Earth, how long will it take for one revolution?

Let us consider a satellite in circular orbit with a time period Ts. The Earth also rotates with the time period Te = 24 hrs. If an observer on Earth sees this satellite, the angular velocity of the satellite will be $\omega \vec{_{SE}} = \omega \vec{_S} - \omega \vec{_e}$. Hence, the time period of revolution will seem different from Ts and will be observed as TSE.

Two cases arise for calculation of TSE:-

(i) If the satellite and Earth are revolving and rotating respectively in the same direction.
Hence, 2Π/TSE = |2Π/Ts - 2Π/Te|
=> TSE = TsTe/|Te - Ts|
(ii) If the satellite and Earth are revolving and rotating respectively in the opposite direction.
Hence,2Π/TSE = 2Π/Ts + 2Π/Te
or TSE = TsTe/|Ts - Te|.

Kepler's Laws- Elliptical Motion of Planets and Satellites



One of the greatest ideas proposed in human history is the fact that the earth is a planet, among the other planets, that orbits the sun. The precise determination of these planetary orbits was carried out by Jhannes Kepler, using the data compiled by his teacher, the astronomer Tycho Brahe. Johannes Kelper discovered three empirical laws by using the data on planetary motion.

(a) Each planet moves in an elliptical orbit, with the sun at one foci of the ellipse.

(b) A line from the sun to a given planet sweeps out equal areas in equal intervals of time.

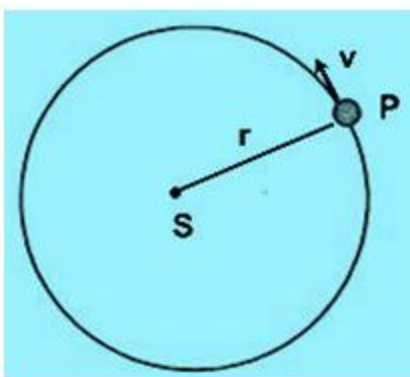
(c) The square of the periods of the planets are proportional to cube of their mean distance (or semi-major axis) from the sun.

These laws go by the name 'Kepler's laws of planetary motion'. It was in order to explain the origin of these laws, among other phenomena, that Newton proposed the theory of gravitation.

In our discussion, we are not going to derive the complete laws of planetary motion from Newton's law of gravitation. Since most of the planets actually revolve in near circular orbits, we're going to assume that the planets revolve in circular orbits.

Consider a planet of mass m rotating around the sun (mass M >> m) in a circular orbit of radius r with velocity v. Then, by applying Newton's law of gravitation and the second law of motion, we can write

Gravitational force = mass × centripetal acceleration



i.e. GMm/r2 = m(v2/r) ... (1)

or, v2 = GMm/r ... (2)

As the moment of the gravitational force about S is zero, the angular momentum of the planet about the sun remains constant. This is the meaning of Kepler's 2nd law of motion, as will be shown later.

The time period of rotation, T, of the planet around the sun is given by,

T = 2Πr/v = -2Πr/√GM/r = 2Π/√GM r3/2 ... (3)

Squaring both sides,

T2 = (4Π2/GM)r3 ... (4)

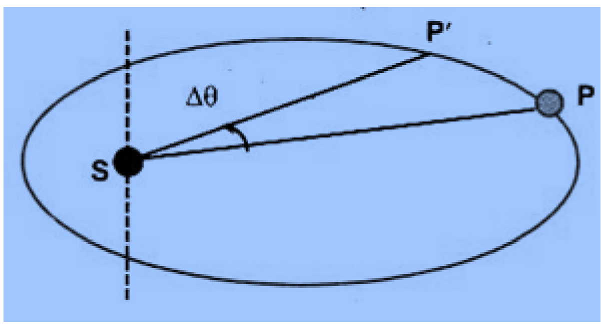
$$T^2 = \left[\frac{4\pi^2}{GM}\right] r^3$$

which is Kepler's 3rd law of motion.

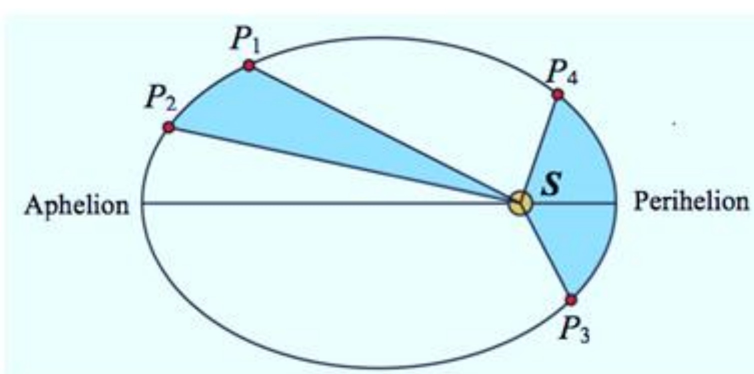
Kepler's Laws are also valid for the motion satellites around the earth.

Kepler's Second Law

Consider a planet P that moves in an elliptical orbit around the sun, and let P and P' be the positions of the planet at time t and t + Δt (where Δt is a very small time interval). If the angular displacement of the planet is Δθ, then the are swept out by the line joining the planet and sun (SP) in time Δt is:



ΔA = area of the section SPP'
= 1/2 r2.Δθ; where r = the length SP.
The area velocity, vA = ΔA/Δt = 1/2r2Δθ/Δt = 1/2r2ω = constant .... (5)
In other words,
m × (2vA) = constant as well (m = mass of the planet)
Areal velocity = dA/dt = L/2m ... (6)
This is the expression for the angular momentum of the planet,
L = Iω = mr2ω
= mr2 (dθ/dt) perpendicular to the plane of its orbit.



The gravitational force,

$\vec{F}$ = -GMm/r2 $\hat{r}$ is centripetal, and the torque on the planet is zero,
So,

$$\vec{r} \times \vec{F} = \vec{r} \times (-\frac{GMm}{r^2}\hat{r}) = 0.(7)$$

Hence, the angular momentum of the planet does not vary, i.e. the areal velocity of the planet remains constant. At its aphelion (farthest point from the sun, r is large), the planet moves slowly and at its perihelion (nearest point from the sun, r is small) the planet moves fastest.

Newton ‘s law of gravitation

Newton's first law

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force. This law is often called "the law of inertia".

Newton's second law

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

Newton's Third law

For every action there is an equal and opposite re-action. This means that for every force there is a reaction force that is equal in size, but opposite in direction. That is to say that whenever an object pushes another object it gets pushed back in the opposite direction equally hard.

Newton’s Law of Universal Gravitation states that every particle attracts every other particle in the universe with force directly proportional to the product of the masses and inversely proportional to the square of the distance between them.

The universal gravitation equation thus takes the form

$$F \propto \frac{m_1 m_2}{r^2}$$
$$\Rightarrow F = G\frac{m_1 m_2}{r^2}$$

Universal Gravitation Equation

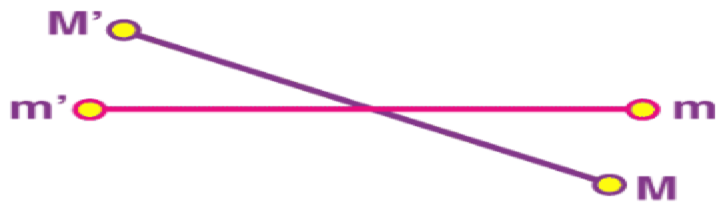
Newton’s conclusion about the magnitude of gravitational force is summarized symbolically as

$$F \propto \frac{m_1 m_2}{r^2}$$
$$\Rightarrow F = G\frac{m_1 m_2}{r^2}$$

where, F is the gravitational force between bodies, m1 and m2 are the masses of the bodies, r is the distance between the centres of two bodies, G is the universal gravitational constant.

The constant proportionality (G) in the above equation is known as the universal gravitation constant. Henry Cavendish experimentally determined the precise value of G. The value of G is found to be G = 6.673 x 10-11 N m2/kg2.

The Universal Gravitational Law can explain almost anything, right from how an apple falls from a tree to why the moon revolves around the earth. Watch the video and understand the beauty of the law of universal gravitation.



Newton's Law of Gravitation

Sir Isaac Newton was the first person to lay down a law which would help calculate the force of gravity between any two bodies. Newton discovered the law of universal gravitation in 1687. It states that every particle in the cosmos is attracted to every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance from one another. Mathematically, this law can be given as:

$$F \propto \frac{M_1 M_2}{R^2}$$

$$F = G\frac{M_1 M_2}{R^2}$$

Here, M_1 and M_2 are the masses of two objects and R is the distance between those objects. G is the universal gravitational constant and its value is 6.674×10^{-11} Nm^2kg^{-2}.

This law is valid for all the bodies in the universe and is one of the most fundamental laws in physics. This law can explain everything from the motion of planets around the sun, the tides, the motion of satellites to why objects fall to the surface of the earth.

Gravitational Field and Potential

Gravitational Field

A gravitational field in layman's terms can be defined as the region around any object in which when another body is placed, the gravitational force is exerted on that object. More precisely, we can say that a massive body's effects on the surrounding area, which result in a force on another massive body, are described by a gravitational field. It is just a physical model similar to the electric field around charges. The gravitational field is defined as:

$$E = \frac{F}{m}$$

Here, E is the gravitational field, F is the gravitational force and m is the mass of the body on which the force is acting.

Suppose the body which has this field has mass M, then the force it exerts on the body of mass m will be:

$$F = \frac{GMm}{R^2}$$

R is the distance between their center of masses.
The expression for the gravitational field will then be:

$$E = \frac{\left(\frac{GMm}{R^2}\right)}{m}$$

$$E = \frac{GM}{R^2}$$

The SI unit of the gravitational field is Nkg^{-1}.

The gravitational field is a vector quantity since force is a vector quantity.

Potential

Suppose we have a particle of mass m which is taken from a point X to Y, and all the other masses are kept fixed. If U_X and U_Y are the potential energies at X and Y respectively, then the change in potential between two points will be:

$$V_Y - V_X = \frac{U_Y - U_X}{m}$$

If we take X to be the reference point such that the potential at X is 0, then we have:

$$V_Y = \frac{U_Y - U_X}{m}$$

Using the above equation, we can define gravitational potential at a point to be equal to the change in potential energy per unit mass, when the mass is brought from the reference point to the given point. The reference point is taken as infinity.

Relationship between Gravitational Field and Gravitational Potential

Using the expression of gravitational field we can write:

F=mE

Suppose, now we move the particle from point r to r+dr, then the work done will be equal to:

$$dW = F \cdot dr$$

$$dW = mE \cdot dr$$

We also know that for a conservative force:

dU=-dW

We know that gravity is a conservative force because the work done by gravity to go from point A and then back to point A is zero. So we can write:

$$dU = -mE \cdot dr$$

We also know that:

$$dV = \frac{dU}{m}$$

So we get:

Escape Velocity Formula

Escape velocity refers to the minimum velocity which is needed to leave a planet or moon. For instance, for any rocket or some other object to leave a planet, it has to overcome the pull of gravity.

The formula for escape velocity comprises of a constant, G, which we refer to as the universal gravitational constant. The value of it is = 6.673 × 10-11 N . m2 / kg2. The unit for escape velocity is meters per second (m/s).

Escape velocity = $\sqrt{\frac{2(gravitationalconstant)(massoftheplanetofmoon)}{radiusoftheplanetormoon}}$

v escape = $\sqrt{\frac{2GM}{R}}$

Over here:
v escape refers to the escape velocity (m/s)
G is the universal gravitational constant (6.673 × 10-11 N . m2 / kg2)
M refers to the mass of the planet or moon (kg)
R is the radius of the planet or moon (m)

The escape velocity is the minimum velocity that an object should acquire to overcome the gravitational field of earth and fly to infinity without ever falling back. It purely depends on the distance of the object from the massive body and the mass of the massive body.

Escape speed is the minimum speed required to escape a planet's gravitational pull.

A spacecraft leaving the earth's surface should be going at a speed of about 11 kilometres (7 miles) per second to enter the outer orbit. Here, in this article, let us dig deeper into the concept of escape speed.

Escape speed is the minimum speed with which a mass should be projected from the Earth's surface in order to escape Earth's gravitation field. Escape speed, also known as escape velocity is defined as:

The minimum speed that is required for an object to free itself from the gravitational force exerted by a massive object.
For example, if we consider earth as a massive body. The escape velocity is the minimum velocity that an object should acquire to overcome the gravitational field of earth and fly to infinity without ever falling back. It purely depends on the distance of the object from the massive body and the mass of the massive body. More the mass it will be higher, similarly, the closer distance, higher will be the escape velocity.

For any massive bodies such as planets, stars which are spherically symmetric in nature, **the escape speed for any given distance is mathematically expressed as:**

$$v_e = \sqrt{\frac{2GM}{r}}$$

Where,

- ve is the escape speed
- G is the universal gravitational constant (G≅6.67×10-11 m3kg-1s-2)
- M is the mass of the massive body(the body from which the object is to be escaped from)
- r is the distance from the centre of the massive body to the object

Here we can notice that the above-mentioned relation is independent of the mass of the object which will be escaping from the massive body.

Kepler's First Law

Kepler's first law states that the path followed by a satellite around the primary will be an ellipse. An ellipse hast Two focal points shown as $F1$ and $F2$in Fig. The center of mass of the two-body system, termed the *bary center,* is always center of the foci.

The semi major axis of the ellipse is denoted by a, and the semi minor axis, by b. The eccentricity e is given by

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

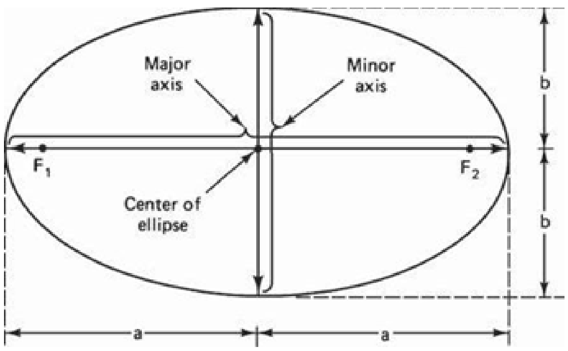


Figure The foci $F1$ and $F2$, the semi major axis a, and the semi minor axis b of an ellipse.

Kepler's Second Law

Kepler's second law states that, for equal time intervals, a satellite will sweep out equal areas in its orbital plane, focused at the barycenter. Referring to Fig. assuming the satellite travels distances $S1$ and $S2$ meters in 1 s, then the areas $A1$ and $A2$ will be equal. The average velocity in each case is $S1$ and $S2$ m/s, and because of the equal area law, it follows that the velocity at $S2$ is less than that at $S1$.

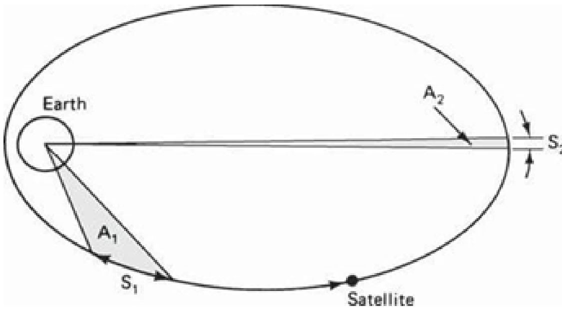


Figure Kepler's second law. The areas $A1$ and $A2$ swept out in unit time are equal.

Kepler's Third Law

Kepler's third law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies. The mean distance is equal to the semi major axis *a*.

For the artificial satellites orbiting the earth, Kepler's third law can be written in the form

$$a^3 = \mu/n^2$$

o e sa

Where n is the mean motion f the satellite in radians per second and is the earth's geocentric gravitational constant μ=3.986005 X 1014m3/s2

Orbit elements and its types

Orbital elements are the parameters required to uniquely identify a specific orbit. In celestial mechanics these elements are considered in two-body systems using a Kepler orbit. There are many different ways to mathematically describe the same orbit, but certain schemes, each consisting of a set of six parameters, are commonly used in astronomy and orbital mechanics.

A real orbit and its elements change over time due to gravitational perturbations by other objects and the effects of general relativity. A Kepler orbit is an idealized, mathematical approximation of the orbit at a particular time.

Apogee: A point for a satellite farthest from the Earth. It is denoted as ha.
Perigee: A point for a satellite closest from the Earth. It is denoted as hp.
Line of Apsides: Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this line‟s length is the semi-major axis equivalents to satellite‟s mean distance from the Earth.
Ascending Node: The point where the orbit crosses the equatorial plane going from north to south.

Descending Node: The point where the orbit crosses the equatorial plane going from south to north.

Inclination: the angle between the orbital plane and the Earth‟s equatorial plane. Its measured at the ascending node from the equator to the orbit, going from East to North. Also, this angle is commonly denoted as i.

Line of Nodes: the line joining the ascending and descending nodes through the centre of Earth.

Prograde Orbit: an orbit in which satellite moves in the same direction as the Earth‟s rotation. Its inclination is always between 00 to 900. Many satellites follow this path as Earth‟s velocity makes it easier to lunch these satellites.

Retrograde Orbit: an orbit in which satellite moves in the same direction counter to the Earth‟s rotation.

Argument of Perigee: An angle from the point of perigee measure in the orbital plane at the Earth‟s centre, in the direction of the satellite motion.

Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node is used.For absolute measurement, a fixed reference point in space is required.

It could also be defined as "right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object".

Mean anamoly: It gives the average value to the angular position of the satellite with reference to the perigee.

True anamoly: It is the angle from point of measure at the Earth‟s centre.

Orbital Perturbations and station keeping

Theoretically, an orbit described by Kepler is ideal as Earth is considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth.

In reality, other forces also play an important role and affect the motion of the satellite. These forces are the gravitational forces of Sun and Moon along with the atmospheric drag.

Effect of Sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.

Effects of non-Spherical Earth

As the shape of Earth is not a perfect sphere, it causes some variations in the path followed by the satellites around the primary. As the Earth is bulging from the equatorial belt, and keeping in mind that an orbit is not a physical entity, and it is the forces resulting from an oblate Earth which act on the satellite produce a change in the orbital parameters.

This causes the satellite to drift as a result of regression of the nodes and the latitude of the point of perigee (point closest to the Earth). This leads to rotation of the line of apsides. As the orbit itself is moving with respect to the Earth, the resultant changes are seen in the values of argument of perigee and right ascension of ascending node.

Due to the non-spherical shape of Earth, one more effect called as the "Satellite Graveyard" is seen. The non-spherical shape leads to the small value of eccentricity (10-5) at the equatorial plane. This causes a gravity gradient on GEO satellite and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

Atmospheric Drag

For Low Earth orbiting satellites, the effect of atmospheric drag is more pronounces. The impact of this drag is maximum at the point of perigee. Drag (pull towards the Earth) has an effect on velocity of Satellite (velocity reduces).

This causes the satellite to not reach the apogee height successive revolutions. This leads to a change in value of semi-major axis and eccentricity. Satellites in service are maneuvered by the earth station back to their original orbital position.

Station Keeping

In addition to having its attitude controlled, it is important that a geo- stationary satellite be kept in its correct orbital slot. The equatorial ellipticity of the earth causes geostationary satel- lites to drift slowly along the orbit, to one of two stable points, at 75°E and 105°W.

To counter this drift, an oppositely directed velocity com-ponent is imparted to the satellite by means of jets, which are pulsed once every 2 or 3 weeks.

These maneuvers are termed east-west station-keeping maneuvers.

Satellites in the 6/4-GHz band must be kept within 0.1° of the desig- nated longitude, and in the 14/12-GHz band, within 0.05°.

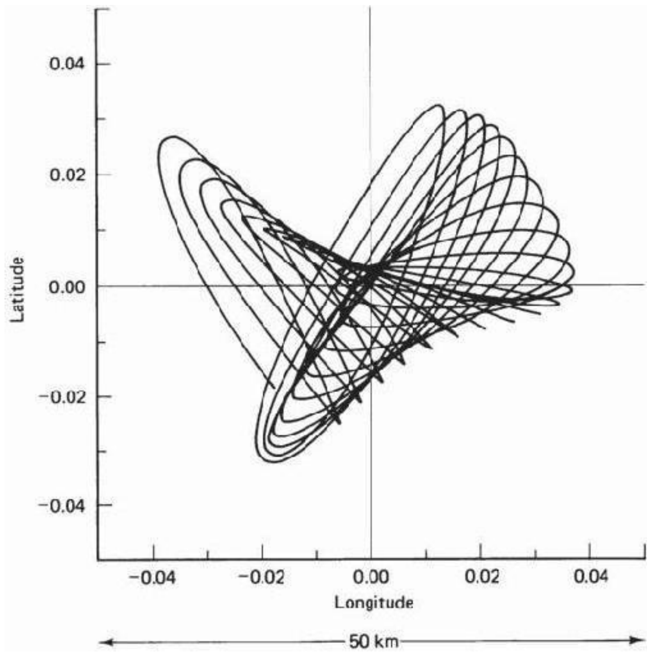


Figure Typical satellite motion.(CourtesyofTelesat,Canada,1983.)

Types of remote sensing platforms

Space-borne Platform

Air-borne Platform

Ground-borne Platform

Remote sensing platforms are broadly classified into three divisions, based on their location. These are mentioned below.

1. Space-borne Platform

Space-borne platforms denote the spacecrafts or satellites or space shuttles, holding the remote sensing sensors. These orbit the Earth at an altitude of about 250 to 36,000 kilometres from the Earth surface.

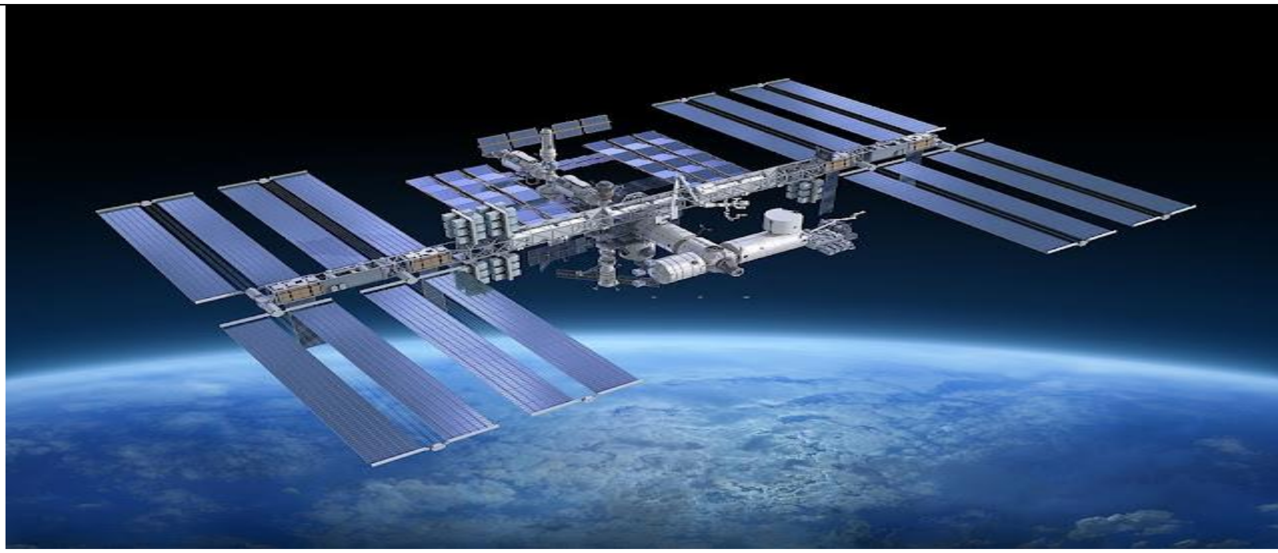


Illustration of International Space Station

The unique advantage of space-borne platforms are, it covers a large area of the earth surface at a time, and literally it allows to photograph the whole Earth surface. Besides this remote sensing cameras in the space-borne platforms can capture the image of the study are repeatedly with a certain time frequency. The mechanism involved in the space-borne platforms are semi-automated type.

The space-borne platforms can be classified into two types, viz.

Unmanned Platform : These are the space-borne platforms in which the sensors of remote sensing are not controlled manually by the astronauts. Rather sensors automatically carry out the remote sensing process. Some instances of such unmanned space-borne platforms include IRS satellites, NavIC Constellation, GPS Constellation, NASA's Landsat series satellites, and many more.

Manned or Crewed Platform : In the manned or crewed space-borne platforms, the remote sensing instruments are operated manually by astronauts. They carry forward various crucial experiments being manually present in the space-borne platforms. A bright example of manned space-borne platform includes the International Space Station.

2. Air-borne Platform

Air-borne platform is the aerial vehicle which carries the remote sensing sensor in it. This platform allows the sensor to capture a larger portion of the Earth surface, and the detailing of the obtained image depends on the resolution of the sensor onboard.

In remote sensing, air-borne platforms are mainly used for aerial photography that allows to study terrain features.

This air-borne platform can be of various types. Such as,

Aircraft : An aircraft is a vehicle that is able to files in the air following the theory of buoyancy. Thenceforth, if an remote sensor is attached with such an aircraft, then it will act as an air-borne remote sensing platform.

Drone : It is also known as Unmanned Aerial Vehicle (UAV). It is a remotely controlled tiny aircraft that can fly or land immediately without any runway. It consists of various sensors to play different roles, and the devices onboard recorded and store all the data obtained. The benefit of using a drone in remote sensing is that, it is comparatively low cost, and its preciseness of locating an area for study, whether during day time or at night.

Balloon : In recent times, balloons are hardly used for remote sensing, mostly because of its instability and uncertainty of its flight way. It floats at an altitude of almost 35 kilometres from mean sea level. Balloons have a durable base for holding the remote sensing instruments, e.g., sensors. Though miniature balloons with some further expandable probes are still applied in recent days for remote sensing, i.e. aerial photography, weather study, nature observation, etc.

Air-borne Platform (Left) and Ground-borne Platform (Right)

3. Ground-borne Platform

In ground-borne platform, the sensor or camera is placed in a ground based vehicle. This allows to study surface topography or other features from ground level. In some cases ground-borne platforms provide detailed observation rather than a higher altitude platform.

Its applications include the observation, detection, characterization, and categorization of surface features of the Earth. Spectroradiometer, portable telescopic mast, etc. are some prominent example of ground-borne platform for remote sensing.

Remote sensing platforms are instruments or vehicles used to acquire information about the Earth's surface or atmosphere from a distance. There are various types of remote sensing platforms, each designed for specific purposes. Here are some common types:

Satellites:

- Orbital Satellites: These are placed in orbit around the Earth and can be either polar or geostationary. They are widely used for a variety of applications, including monitoring weather, land use, and environmental changes.
- Microsatellites and Nanosatellites: Smaller satellites designed for specific tasks, often with lower costs. They may be part of constellations for more frequent coverage.

Aircraft:

- Manned Aircraft: Piloted airplanes equipped with remote sensing instruments for high-resolution and targeted data collection.
- Unmanned Aerial Vehicles (UAVs or Drones): Unmanned aircraft that can carry sensors for various remote sensing applications, including agriculture, environmental monitoring, and disaster assessment.

Balloons:

- Weather Balloons: Equipped with sensors to collect atmospheric data, including temperature, humidity, and pressure.
- Stratospheric Balloons: Used for high-altitude observations and data collection.

Ground-Based Platforms:

- Fixed Ground Stations: Permanent installations on the Earth's surface equipped with sensors for continuous monitoring.
- Mobile Ground Platforms: Vehicles equipped with remote sensing instruments for on-the-go data collection.

Helicopters:

- Helicopter-based Platforms: Helicopters can be equipped with sensors for detailed and flexible data acquisition in areas where fixed-wing aircraft may have limitations.

Spaceborne Instruments:

- Space Probes: Robotic spacecraft designed to explore other celestial bodies, equipped with various instruments for remote sensing and data collection.

Underwater Vehicles:

- Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs): Used for remote sensing of underwater environments, including oceanography and marine biology.

High-Altitude Platforms:

- Stratospheric Aircraft: Aircraft designed to fly at high altitudes, providing a platform for various remote sensing applications.

The classification of satellites

There are various orbits in which satellites are placed, depending on their intended purpose and mission requirements. Here, we delve into the 5 most common types of orbits for remote sensing satellites:

Low Earth Orbit (LEO) Satellites

LEO satellites are positioned at altitudes between 160 and 2,000 kilometers (99 to 1,243 miles) above Earth. They typically complete an orbit in approximately 90 to 120 minutes, enabling them to provide frequent coverage over a specific area. **Some key features of LEO satellites include:**

High-resolution imagery

Rapid revisit times

Reduced communication latency

Shorter life span due to atmospheric drag
Applications of LEO satellites include weather monitoring, disaster management, and military reconnaissance.

Some examples of LEO satellites used in remote sensing are Landsat, Sentinel, and Aqua.

Medium Earth Orbit (MEO) Satellites

MEO satellites are positioned at altitudes between 2,000 and 35,786 kilometers (1,243 to 22,236 miles) above Earth. These satellites have an orbital period ranging from 2 to 24 hours. Characteristics of MEO satellites include:

Medium-resolution imagery

Larger coverage area compared to LEO satellites

Longer life span than LEO satellites

Moderate communication latency
MEO satellites are primarily used for navigation and communication purposes.

Some examples of MEO satellites used in remote sensing are GPS, GLONASS, and Galileo.

Geostationary Orbit (GEO) Satellites

GEO satellites are positioned at an altitude of approximately 35,786 kilometers (22,236 miles) above Earth. They have an orbital period of 24 hours, which allows them to remain stationary relative to a specific location on Earth's surface. Key features of GEO satellites are:

Continuous coverage over a fixed geographical area

Lower resolution imagery compared to LEO and MEO satellites

High communication latency

Long life span
Some examples of GEO satellites used in communication are Intelsat, SES, and Eutelsat.

Sun-Synchronous Orbit (SSO) Satellites

SSO satellites have a unique orbit, which enables them to pass over the same location on Earth at the same local solar time on each orbit. SSO satellites are typically positioned at altitudes between 600 and 800 kilometers (373 to 497 miles). Features of SSO satellites include:

Consistent illumination conditions for imaging

Frequent revisit times

High-resolution imagery

Ideal for monitoring polar regions
SSO satellites are primarily used for Earth observation, including monitoring land use, vegetation, and ice sheets.

Some examples of SSO satellites used in remote sensing are MODIS, ASTER, and Landsat.

Geostationary Transfer Orbit (GTO) Satellites

GTO is an elliptical orbit used as an intermediate step for satellites transitioning from a low Earth orbit to a geostationary orbit. GTO satellites have the following characteristics:

Highly elliptical orbit with an apogee close to GEO altitude

Short-term use during satellite transition

Primarily used for communication satellites
Some examples of GTO satellites used in communication are the Inmarsat fleet, and the EchoStar fleet.

Types of Satellites In Remote Sensing by Functions

Satellites can also be classified based on their functions. There are four main types of satellites used in remote sensing applications based on their functions, as follows:

Communication Satellites

Communication satellites are designed to transmit and receive signals, such as voice, data, and video, between ground stations and other communication devices.

Communication satellites are commonly used for television broadcasting, internet connectivity, telephone networks, and military communication. In remote sensing, communication satellites are used to transmit data acquired by other types of remote sensing satellites to the ground stations.

Examples of communication satellite systems include the Globalstar, Iridium, and Intelsat networks.

Earth Observation Satellites

Earth observation satellites are designed to acquire data about the earth's surface and atmosphere.

The data acquired by earth observation satellites can be used for various applications, such as land cover mapping, vegetation monitoring, oceanography, disaster management, and weather forecasting. Earth observation satellites use various sensors, such as optical, radar, and thermal sensors, to acquire data.

Examples of Earth observation satellite missions include Landsat, Copernicus Sentinel, and MODIS.

Navigation Satellites

Navigation satellites are designed to provide accurate location information to users on the ground.

Navigation satellites use signals transmitted by the satellites to determine the user's location. Navigation satellites are commonly used in GPS systems, which are used for various applications, such as navigation, surveying, and mapping.

Examples of navigation satellite systems include the Global Positioning System (GPS), GLONASS, and Galileo.

Astronomical Satellites

Astronomical satellites are designed to study objects beyond the earth's atmosphere, such as stars, planets, and galaxies.

Astronomical satellites are equipped with specialized sensors, such as telescopes, to observe and study these objects. Astronomical satellites are used to study various phenomena, such as the formation of galaxies, the evolution of stars, and the search for extraterrestrial life.

Examples of astronomical satellite missions include the Hubble Space Telescope, Chandra X-ray Observatory, and James Webb Space Telescope.

Geostationary Satellites

There are 2 kinds of manmade satellites in the heavens above: One kind of satellite ORBITS the earth once or twice a day, and the other kind is called a communications satellite and it is PARKED in a STATIONARY position 22,300 miles (35,900 km) above the equator of the STATIONARY earth.

A type of the orbiting satellite includes the space shuttle and the international space station which keep a low earth orbit (LEO) to avoid the deadly Van Allen radiation belts.

The most prominent satellites in medium earth orbit (MEO) are the satellites which comprise the GLOBAL POSITIONING SYSTEM or GPS as it is called.

The Global Positioning System

The global positioning system was developed by the U.S. military and then opened to civilian use. It is used today to track planes, ships, trains, cars or literally anything that moves. Anyone can buy a receiver and track their exact location by using a GPS receiver.

These satellites are traveling around the earth at speeds of about 7,000 mph (11,200 kph). GPS satellites are powered by solar energy. They have backup batteries onboard to keep them running in the event of a solar eclipse, when there's no solar power.

Small rocket boosters on each satellite keep them flying in the correct path. The satellites have a lifetime of about 10 years until all their fuel runs out.

At exactly 22,300 miles above the equator, the force of gravity is cancelled by the centrifugal force of the rotating universe. This is the ideal spot to park a stationary satellite.

Legrange Orbit

In celestial mechanics, the Lagrange points (/ləˈɡrɑːndʒ/; also Lagrangian points or libration points) are points of equilibrium for small-mass objects under the gravitational influence of two massive orbiting bodies.

L1 point

The L1 point lies on the line defined between the two large masses M1 and M2. It is the point where the gravitational attraction of M2 and that of M1 combine to produce an equilibrium. An object that orbits the Sun more closely than Earth would typically have a shorter orbital period than Earth, but that ignores the effect of Earth's gravitational pull. If the object is directly between Earth and the Sun, then Earth's gravity counteracts some of the Sun's pull on the object, increasing the object's orbital period. The closer to Earth the object is, the greater this effect is. At the L1 point, the object's orbital period becomes exactly equal to Earth's orbital period. L1 is about 1.5 million kilometers, or 0.01 au, from Earth in the direction of the Sun.

L2 point

The L2 point lies on the line through the two large masses beyond the smaller of the two. Here, the combined gravitational forces of the two large masses balance the centrifugal force on a body at L2. On the opposite side of Earth from the Sun, the orbital period of an object would normally be greater than Earth's. The extra pull of Earth's gravity decreases the object's orbital period, and at the L2 point, that orbital period becomes equal to Earth's. Like L1, L2 is about 1.5 million kilometers or 0.01 au from Earth (away from the sun). An example of a spacecraft at L2 is the James Webb Space Telescope, designed to operate near the Earth–Sun L2.Earlier examples include the Wilkinson Microwave Anisotropy Probe and its successor, Planck.

L3 point

The L3 point lies on the line defined by the two large masses, beyond the larger of the two. Within the Sun–Earth system, the L3 point exists on the opposite side of the Sun, a little outside Earth's orbit and slightly farther from the center of the Sun than Earth is. This placement occurs because the Sun is also affected by Earth's gravity and so orbits around the two bodies' barycenter, which is well inside the body of the Sun. An object at Earth's distance from the Sun would have an orbital period of one year if only the Sun's gravity is considered. But an object on the opposite side of the Sun from Earth and directly in line with both "feels" Earth's gravity adding slightly to the Sun's and therefore must orbit a little farther from the barycenter of Earth and Sun in order to have the same 1-year period. It is at the L3 point that the combined pull of Earth and Sun causes the object to orbit with the same period as Earth, in effect orbiting an Earth+Sun mass with the Earth-Sun barycenter at one focus of its orbit.

The L4 and L5 points lie at the third vertices of the two equilateral triangles in the plane of orbit whose common base is the line between the centers of the two masses, such that the point lies 60° ahead of (L4) or behind (L5) the smaller mass with regard to its orbit around the larger mass.

UNIT IV SENSING TECHNIQUES

Classification of remote sensors – Resolution concept: spatial, spectral, radiometric and temporal resolutions - Scanners - Along and across track scanners – Optical-infrared sensors – Thermal sensors – microwave sensors – Calibration of sensors – High Resolution Sensors - LIDAR, UAV – Orbital and sensor characteristics of live Indian earth observation satellites.

Classification of remote sensors

Remote sensors are devices that gather information about an object or phenomenon without direct contact with it. They are commonly used in various fields such as environmental monitoring, agriculture, meteorology, and remote sensing. Remote sensors can be classified based on several criteria, including the type of energy they detect, the platform they are mounted on, and their application. Here is a classification based on these criteria:

1. **Based on Energy Detection:**
    - **Electromagnetic Sensors:** These sensors detect electromagnetic radiation, including visible light, infrared, microwave, and radio waves. Examples include cameras, thermal infrared sensors, and radar.
    - **Acoustic Sensors:** These sensors detect sound waves and are used in applications such as underwater monitoring.
2. **Based on the Platform:**
    - **Satellite Sensors:** Sensors mounted on satellites orbiting the Earth, providing a global perspective. Examples include optical sensors on Earth observation satellites.
    - **Aerial Sensors:** Sensors mounted on aircraft, such as airplanes or drones, offering a more localized and higher-resolution view compared to satellites.
    - **Ground-based Sensors:** Sensors positioned on the Earth's surface, including fixed stations and mobile units.
3. **Based on Application:**
    - **Environmental Sensors:** Used for monitoring and studying environmental parameters such as temperature, humidity, air quality, and vegetation health.
    - **Weather Sensors:** Specialized sensors for monitoring atmospheric conditions, including temperature, pressure, humidity, and wind speed.
    - **Geological Sensors:** Used for geological studies, including seismic activity and landform changes.
    - **Agricultural Sensors:** Employed for monitoring crop health, soil moisture, and other factors related to agriculture.
    - **Military Sensors:** Designed for defense applications, including surveillance, reconnaissance, and threat detection.
4. **Based on Sensing Modality:**
    - **Passive Sensors:** Detect natural radiation emitted or reflected by the object or scene under observation. Examples include optical cameras and thermal infrared sensors.
    - **Active Sensors:** Emit energy and measure the return signal. Examples include radar and lidar (Light Detection and Ranging).
5. **Based on the Spectrum of Detection:**
    - **Visible and Near-Infrared Sensors:** Capture information in the visible and near-infrared spectrum, commonly used for optical imaging.

- **Infrared Sensors:** Detect thermal radiation and are used for applications such as temperature sensing and night vision.
- **Microwave and Radio Sensors:** Utilize longer wavelengths for applications like radar.

Understanding these classifications helps in choosing the right remote sensing technology for specific applications and objectives. Different sensors excel in different environments and conditions, providing valuable data for a wide range of purposes.

On the basis of the sources of electromagnetic energy, the remote sensing can be classified as passive and active remote sensing. In a simple way, we can understand that the passive remote sensing is similar to taking a picture with an ordinary camera where as active remote sensing is analogous to taking picture with camera having built-in flash.

On the basis of the energy source, the active remote sensing generates and uses its own energy to illuminate the target and records the reflected energy whereas the passive remote sensing depend on solar radiation to illuminate the target. On the basis of region of spectrum in which they operate, the active remote sensing operate in the microwave region of the electromagnetic spectrum whereas the passive remote sensing operate in the visible and infrared region of the electromagnetic spectrum. The wave lengths of the active remote sensing are longer than 1 whereas the passive remote sensing, the wave length range from 0.4 to 1.0 mm.

Some examples of active sensors are Fluorosensor and Synthetic Aperture Radar (SAR). Passive sensors record radiation reflected from the earth's surface. The source of this radiation must come from outside the sensor; in most cases, this is solar energy. Because of this energy requirement, passive solar sensors can only capture data during daylight hours. **Active sensors** are different from passive sensors. Unlike passive sensors, active sensors require the energy source to come from within the sensor. A laser-beam remote sensing system is an active sensor that sends out a beam of light with a known wavelength and frequency. This beam of light hits the earth and is reflected back to the sensor, which records the time it took for the beam of light to return.

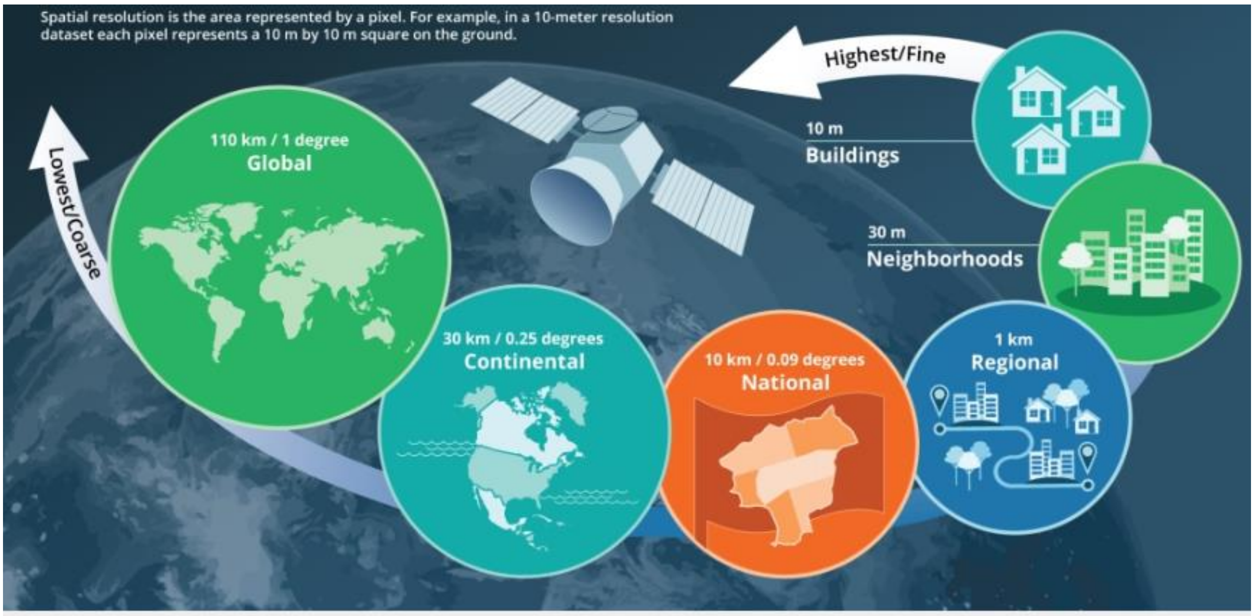
Resolution concept: spatial, spectral, radiometric and temporal resolutions

Resolution

Resolution plays a role in how data from a sensor can be used. Resolution can vary depending on the satellite’s orbit and sensor design. There are four types of resolution to consider for any dataset—radiometric, spatial, spectral, and temporal.

Radiometric resolution is the amount of information in each pixel, that is, the number of bits representing the energy recorded. Each bit records an exponent of power 2. For example, an 8 bit resolution is 2^8, which indicates that the sensor has 256 potential digital values (0-255) to store information. Thus, the higher the radiometric resolution, the more values are available to store information, providing better discrimination between even the slightest differences in energy. For example, when assessing water quality, radiometric resolution is necessary to distinguish between subtle differences in ocean color.

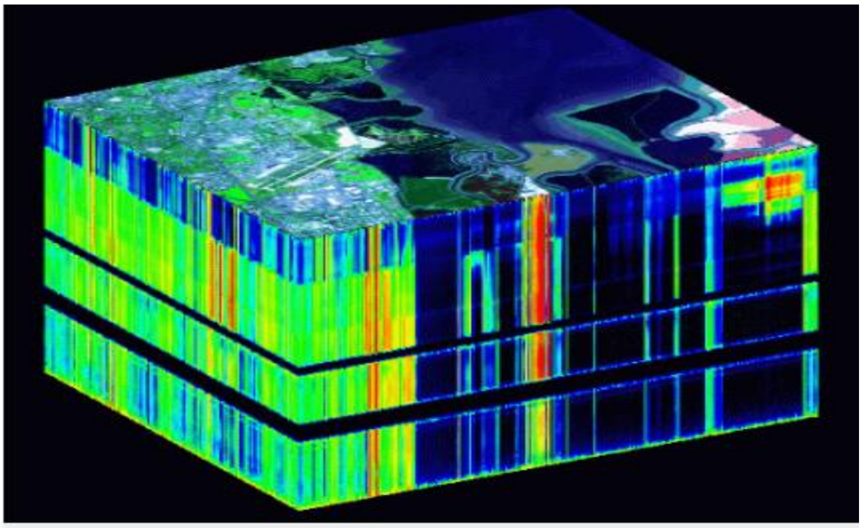
Spatial resolution is defined by the size of each pixel within a digital image and the area on Earth's surface represented by that pixel.



Different spatial resolutions can be used for specific observational or research needs. This image shows spatial resolution examples for common NASA sensor products and a research scale for which they are suited (regional, national, continental, etc.). Credit: NASA Earthdata

For example, the majority of the bands observed by the Moderate Resolution Imaging Spectroradiometer have a spatial resolution of 1km; each pixel represents a 1 km x 1km area on the ground. MODIS also includes bands with a spatial resolution of 250 m or 500 m. The finer the resolution (the lower the number), the more detail you can see. In the image below, you can see the difference in pixelation between a 30 m/pixel image (left image), a 100 m/pixel image (center image), and a 300 m/pixel image (right image).

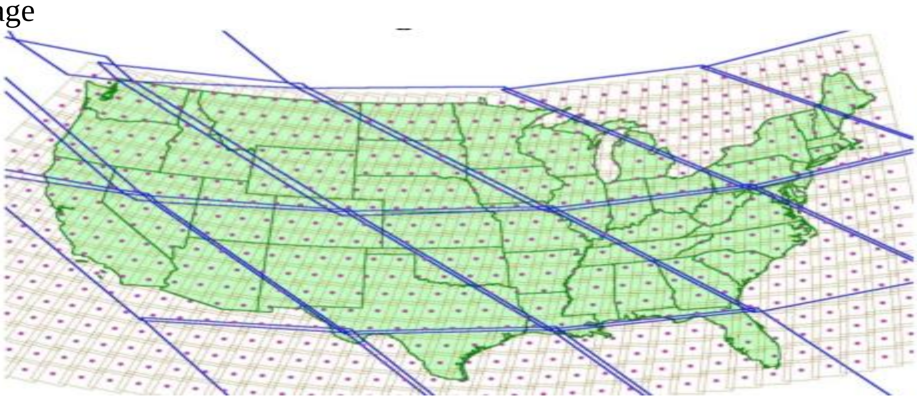
Spectral resolution is the ability of a sensor to discern finer wavelengths, that is, having more and narrower bands. Many sensors are considered to be multispectral, meaning they have 3-10 bands. Some sensors have hundreds to even thousands of bands and are considered to be *hyperspectral*. The narrower the range of wavelengths for a given band, the finer the spectral resolution. For example, the Airborne Visible/Infrared Imaging Spectrometer captures information in 224 spectral channels. The cube on the right represents the detail within the data. At this level of detail, distinctions can be made between rock and mineral types, vegetation types, and other features. In the cube, the small region of high response in the right corner of the image is in the red portion of the visible spectrum (about 700 nanometers), and is due to the presence of 1-centimeter-long (half-inch) red brine shrimp in the evaporation pond.



The top of the cube is a false-color image made to accentuate the structure in the water and evaporation ponds on the right. The sides of the cube are slices showing the edges of the top in all 224 of the AVIRIS spectral channels. The tops of the sides are in the visible part of the spectrum (wavelength of 400 nanometers), and the bottoms are in the infrared (2,500 nanometers). Credit: NASA JPL.

Temporal resolution is the time it takes for a satellite to complete an orbit and revisit the same observation area. This resolution depends on the orbit, the sensor's characteristics, and the swath width. Because geostationary satellites match the rate at which Earth is rotating, the temporal resolution is much finer. Polar orbiting satellites have a temporal resolution that can vary from 1 day to 16 days. For example, the MODIS sensor aboard NASA's Terra and Aqua satellites has a temporal resolution of 1-2 days, allowing the sensor to visualize Earth as it changes day by day. The Operational Land Imager (OLI) aboard the joint NASA/USGS Landsat 8 satellite, on the other hand, has a narrower swath width and a temporal resolution of 16 days; showing not daily changes but bi-monthly changes.

Image



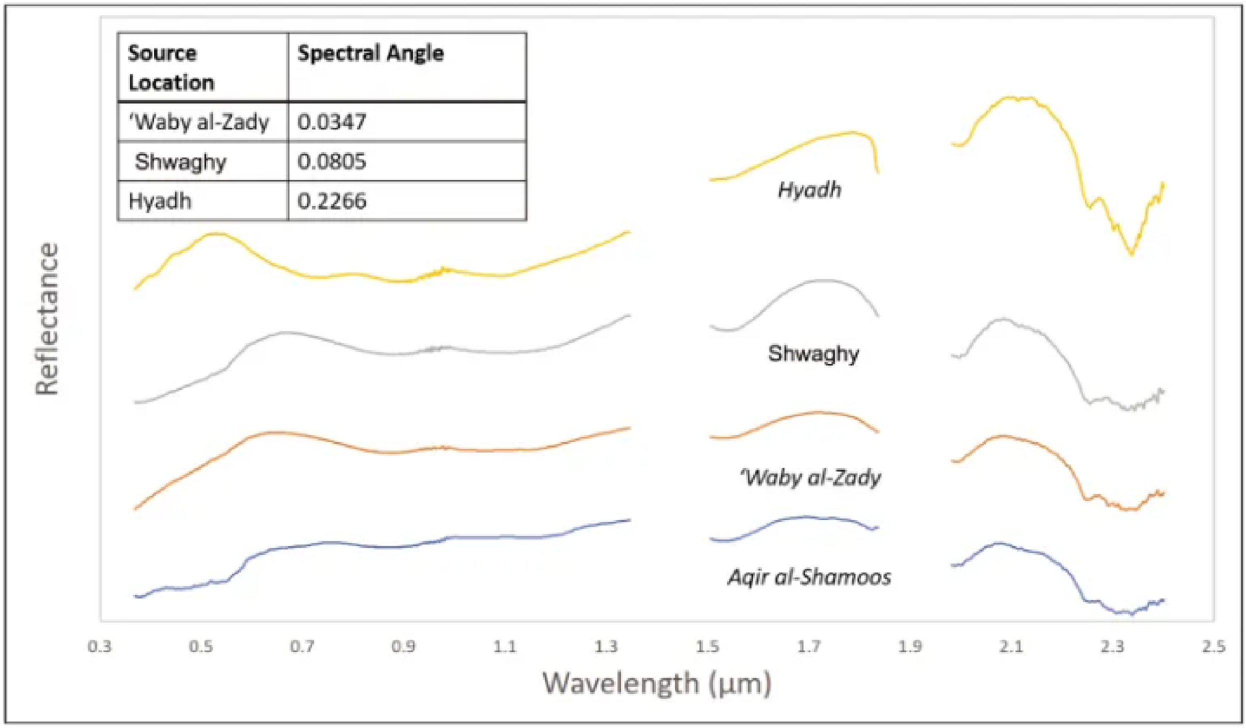
Orbital swath of MODIS (blue boxes) versus the orbital swath of the OLI aboard Landsat 8 (boxes with red dots). Due to its much wider imaging swath, MODIS provides global coverage every 1-2 days versus 16 days for the OLI. Red dots indicate the center point of each Landsat tile. Credit: NASA Applied Remote Sensing Training (ARSET).

Why not build a sensor combining high spatial, spectral, and temporal resolution? It is difficult to combine all of the desirable features into one remote sensor. For example, to acquire observations with high spatial resolution (like OLI, aboard Landsat 8) a narrower swath is required, which requires more time between observations of a given area resulting in a lower temporal resolution. Researchers have to make trade-offs. This is why it is very important to understand the type of data needed for a given area of study. When researching weather, which is dynamic over time, a high temporal resolution is critical. When researching seasonal vegetation changes, on the other hand, a high temporal resolution may be sacrificed for a higher spectral or spatial resolution.

Spectral Resolution

Spectral resolution is the number and size of bands in the electromagnetic spectrum that a remote sensing platform can capture. For example, the first two Landsat satellites use a multi-spectral scanner (MSS) and captured images using four spectral bands (green, red, and two near-infrared bands). On the other hand, hyperspectral platforms (e.g., Hyperion) can capture hundreds of bands on the electromagnetic spectrum.

In order to obtain a detailed spectral signature and detect chloritite, a high spectral resolution was crucial.

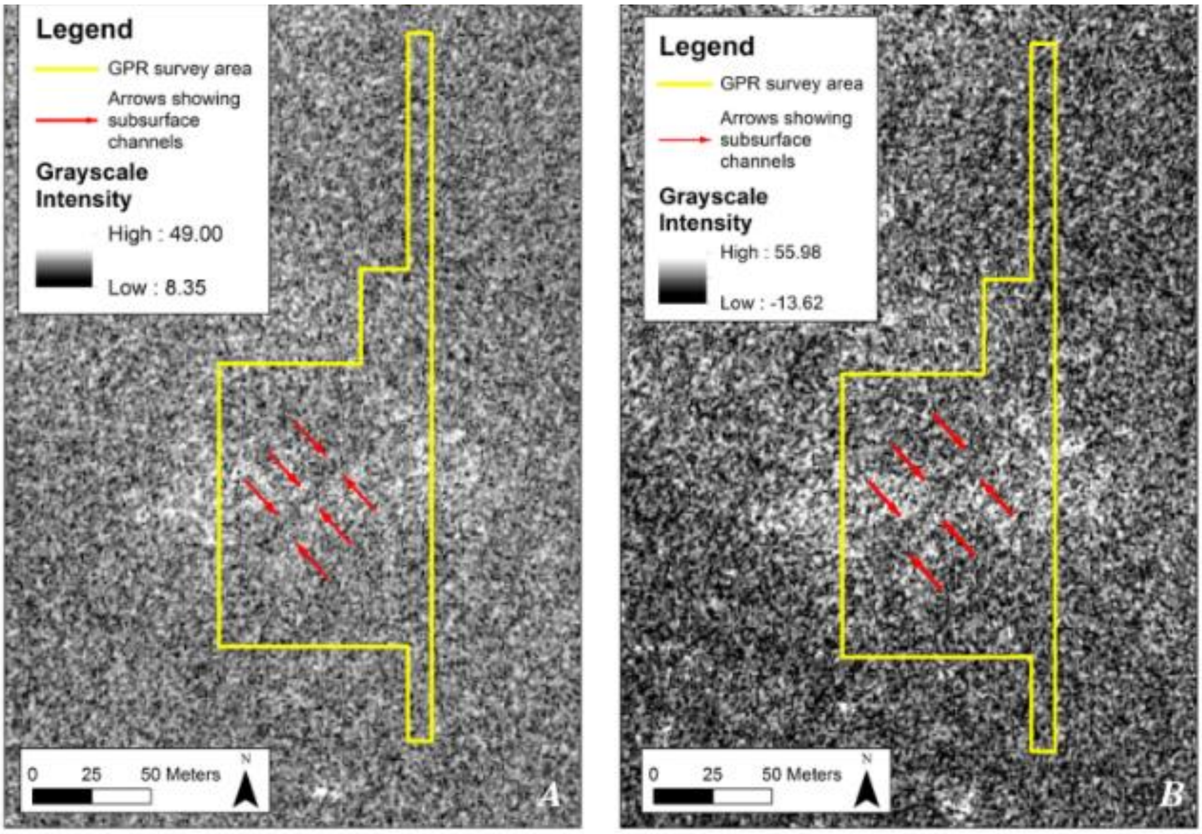


This image was taken from Sivitskis et al. 2018 and compares spectral signatures and measured spectral angles for Aqir al-Shamoos chloritite against chloritite from the sites of 'Waby al-Zady, Shwaghy, and Hyadh.

Spatial Resolution

Spatial resolution measures the smallest angular separation between two objects. For satellite images, this is represented in pixels and the spatial resolution for a given image is noted as how many meters that pixel represents. For example, the satellite SPOT 4's multispectral scanner has a spatial resolution of 20m. This means that each individual, square pixel represents a spatial area of 400 square meters. There are instances in which pixel size and resolution are not the same, especially when multiple images are combined and the pixel sizes are averaged to represent a larger area..

This study focuses on the methodology used to detect and map the channel-like feature our team discovered at ‘Uqdat al-Bakrah. The C- and X-bands have a shorter-wavelength than the commonly used L-band, BUT they have a higher spatial resolution. L-bands have the ability to penetrate more deeply into soils, but at shallow sandy sites like ‘Uqdat al-Bakrah the increased spatial resolution of C- and X-band data can help researchers to better see features.



These images are taken from Wiig et al. 2018 and use DLR's TanDEM-X satellite (A: Summed stack of 10 VV images and B: Summed stack of HH images) with greyscale intensity to display the channel-like feature. Check out the paper to see other images and analyses that map the feature.

Temporal Resolution

Temporal resolution refers to the frequency at which imagery is recorded for a particular area. For example, the MODIS satellite captures the same area every one to two days, while most Landsat satellites take images of the same area every 16 days.

Depending on the question or phenomenon being observed, temporal resolution could play an important role in imagery selection. A recent paper by Emily Hammer and colleagues harnesses both high spatial resolution and high temporal resolution to examine patterns of destruction from looting, agricultural activity, military occupation, urban growth, mining, and other types of development at 1000 archaeological sites across Afghanistan from 2001-2017. They used various types of satellite imagery including DigitalGlobe and CORONA and discerned interesting trends. For more information, check out their paper, ‘Remote sensing assessments of the archaeological heritage situation in Afghanistan‘.

Radiometric Resolution

Radiometric resolution is the sensitivity of a remote sensing platform to detect slight differences in energy, specifically, radiant flux (radiant energy emitted per unit time).

Remote sensing platforms typically use either a passive or active sensor. **Passive sensors** record electromagnetic radiation, which is reflected from the earth's surface. **Active sensors** coat the earth's surface in machine-made electromagnetic energy and record the quantity of radiant flux that is emitted back to the sensor.

Resolution in remote sensing refers to the level of detail or clarity in the information captured by a sensor. There are four main types of resolutions in remote sensing: spatial, spectral, radiometric, and temporal resolutions.

1. **Spatial Resolution:**
    - **Definition:** Spatial resolution refers to the size of the smallest discernible objects in an image.
    - **Example:** A high spatial resolution image can distinguish small objects or features on the Earth's surface, such as individual buildings or trees, while a low spatial resolution image might only show larger features like cities or forests.
    - **Units:** Usually measured in meters per pixel or centimeters per pixel.
2. **Spectral Resolution:**
    - **Definition:** Spectral resolution refers to the ability of a sensor to distinguish between different wavelengths or bands in the electromagnetic spectrum.
    - **Example:** A sensor with high spectral resolution can capture a wide range of wavelengths, enabling the discrimination of different features based on their spectral characteristics (e.g., vegetation, water, or soil).
    - **Units:** Measured in terms of the number and width of spectral bands.
3. **Radiometric Resolution:**
    - **Definition:** Radiometric resolution refers to the sensitivity of a sensor to differences in the intensity of reflected or emitted radiation.
    - **Example:** A high radiometric resolution allows the sensor to detect subtle differences in brightness levels, which can be important for distinguishing between similar materials or features.
    - **Units:** Expressed in bits, with higher bit depth indicating higher radiometric resolution.
4. **Temporal Resolution:**
    - **Definition:** Temporal resolution refers to the frequency at which a sensor revisits or captures data for a specific location on the Earth's surface.
    - **Example:** A satellite with high temporal resolution might capture images of the same area every day, while a sensor with lower temporal resolution might revisit the area less frequently.
    - **Units:** Measured in time units (e.g., hours, days, or years) and indicates the frequency of data acquisition.

In summary, these four resolutions collectively impact the quality and utility of remote sensing data. Balancing these resolutions depends on the specific goals of a remote sensing application. For example, monitoring dynamic processes may require high temporal resolution, while detailed land cover analysis might benefit from high spatial and spectral resolutions.

SCANNERS

In the context of remote sensing, scanners refer to instruments or devices that capture data from the Earth's surface, atmosphere, or other celestial bodies. Remote sensing scanners are crucial for acquiring information about the environment without direct physical contact. Here are a few types of scanners used in remote sensing:

1. **Optical Scanners:** These scanners capture data in the visible, infrared, and ultraviolet portions of the electromagnetic spectrum. They are commonly used for tasks such as vegetation monitoring, land cover classification, and satellite imagery.
2. **Thermal Infrared Scanners:** Designed to capture data in the thermal infrared portion of the spectrum, these scanners are valuable for applications like monitoring temperature variations on the Earth's surface, identifying heat anomalies, and assessing vegetation health.
3. **Lidar (Light Detection and Ranging) Scanners:** Lidar scanners use laser light to measure distances and create detailed three-dimensional representations of the Earth's surface. Lidar is often employed in terrain mapping, forestry, and urban planning.
4. **Radar (Radio Detection and Ranging) Scanners:** Radar scanners use radio waves to capture information about the Earth's surface. They are particularly useful in areas with persistent cloud cover or during nighttime. Radar can be employed for applications such as terrain mapping, agriculture, and monitoring changes in land surfaces.
5. **Hyperspectral Scanners:** These scanners capture data in numerous narrow and contiguous bands across the electromagnetic spectrum. Hyperspectral imagery is valuable for detailed spectral analysis, allowing for more precise identification of materials and land cover.

The data collected by these scanners is crucial for various applications, including environmental monitoring, agriculture, disaster response, and urban planning in the field of remote sensing. Different scanners are chosen based on the specific requirements of the remote sensing mission and the characteristics of the information needed.
In sensing techniques, scanners play a crucial role in capturing data from the environment for analysis and interpretation. The type of scanner used depends on the sensing technique and the specific requirements of the application. Here are some sensing techniques where scanners are commonly employed:

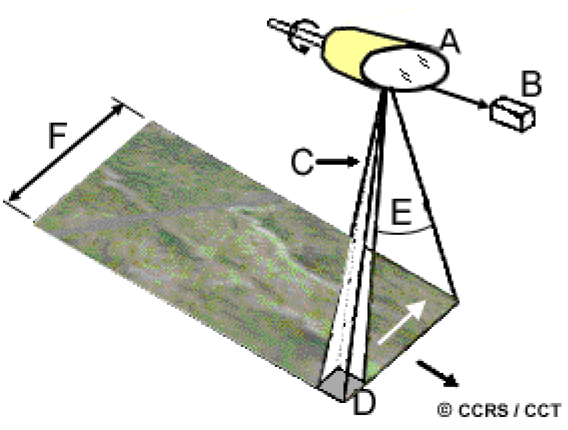
1. **LiDAR (Light Detection and Ranging):** LiDAR scanners use laser beams to measure distances and create detailed three-dimensional maps of the terrain. LiDAR is widely used in applications such as topographic mapping, forestry, urban planning, and autonomous vehicle navigation.
2. **Radar (Radio Detection and Ranging):** Radar scanners utilize radio waves to detect and locate objects. They are commonly used in applications such as weather monitoring, air traffic control, and military surveillance.
3. **Sonar (Sound Navigation and Ranging):** Sonar scanners use sound waves to detect objects underwater. They are employed in marine applications for tasks such as depth measurement, underwater mapping, and fish detection.
4. **Barcode Scanners:** In various industries, barcode scanners are used to capture information from barcodes for inventory management, retail transactions, and logistics.

5. **Infrared Scanners:** Infrared scanners capture data in the infrared spectrum and are used in applications such as thermography for detecting temperature variations in objects, night vision, and industrial process monitoring.
6. **Optical Scanners:** Optical scanners capture visible light and are used in applications such as document scanning, image processing, and optical character recognition (OCR).
7. **CT Scanners (Computed Tomography):** In medical imaging, CT scanners use X-rays to create detailed cross-sectional images of the body. They are essential for diagnostic purposes.
8. **MRI Scanners (Magnetic Resonance Imaging):** MRI scanners use strong magnetic fields and radio waves to generate detailed images of internal body structures. They are commonly used in medical diagnostics.

These are just a few examples, and the choice of scanner depends on the specific sensing technique and the characteristics of the target environment or object. Scanners enable the collection of data in various forms, facilitating the analysis and interpretation of information for scientific, industrial, and medical purposes.

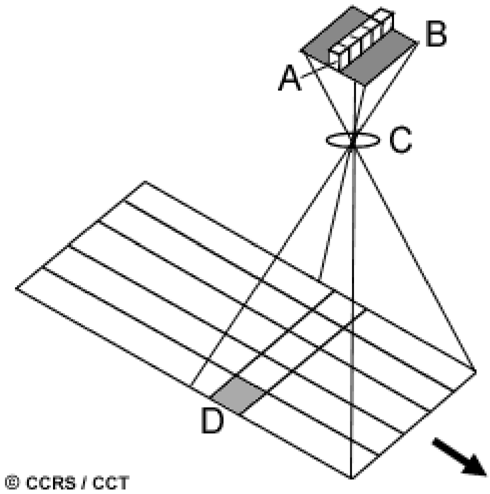
MULTISPECTRAL SCANNER

Many electronic (as opposed to photographic) remote sensors acquire data using **scanning systems**, which employ a sensor with a narrow field of view (i.e. IFOV) that sweeps over the terrain to build up and produce a two-dimensional image of the surface. Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. A scanning system used to collect data over a variety of different wavelength ranges is called a **multispectral scanner (MSS)**, and is the most commonly used scanning system. There are two main modes or methods of scanning employed to acquire multispectral image data - **across-track scanning**, and **along-track scanning**.



Across-track scanners scan the Earth in a series of lines. The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath). Each line is scanned from one side of the sensor to the other, using a **rotating mirror (A)**. As the platform moves forward over the Earth, successive scans build up a two-dimensional image of the Earth´s surface. The incoming reflected or emitted radiation is separated into several spectral components that are detected independently. The UV, visible, near-infrared, and thermal radiation are dispersed into their constituent wavelengths. A bank of internal **detectors (B)**, each sensitive to a specific range of wavelengths, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing.

The **IFOV (C)** of the sensor and the altitude of the platform determine the **ground resolution cell viewed (D)**, and thus the spatial resolution. The **angular field of view (E)** is the sweep of the mirror, measured in degrees, used to record a scan line, and determines the width of the imaged **swath (F)**. Airborne scanners typically sweep large angles (between 90º and 120º), while satellites, because of their higher altitude need only to sweep fairly small angles (10-20º) to cover a broad region. Because the distance from the sensor to the target increases towards the edges of the swath, the ground resolution cells also become larger and introduce geometric distortions to the images. Also, the length of time the IFOV "sees" a ground resolution cell as the rotating mirror scans (called the **dwell time**), is generally quite short and influences the design of the spatial, spectral, and radiometric resolution of the sensor.



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, 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 (i.e. along track). These systems are also referred to as **pushbroom scanners**, as the motion of the detector array is analogous to the bristles of a broom being pushed along a floor. 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. A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded.

Along-track scanners with linear arrays have several advantages over across-track mirror scanners. The array of detectors combined with the pushbroom motion allows each detector to "see" and measure the energy from each ground resolution cell for a longer period of time (dwell time). This allows more energy to be detected and improves the radiometric resolution. The increased dwell time also facilitates smaller IFOVs and narrower bandwidths for each detector. Thus, finer spatial and spectral resolution can be achieved without impacting radiometric resolution. Because detectors are usually solid-state microelectronic devices, they are generally smaller, lighter, require less power, and are more reliable and last longer because they have no moving parts. On the other hand, cross-calibrating thousands of detectors to achieve uniform sensitivity across the array is necessary and complicated.

Regardless of whether the scanning system used is either of these two types, it has several advantages over photographic systems. The spectral range of photographic systems is restricted to the visible and near-infrared regions while MSS systems can extend this range into the thermal infrared. They are also capable of much higher spectral resolution than photographic systems. Multi-band or multispectral photographic systems use separate lens systems to acquire each spectral band. This may cause problems in ensuring that the different bands are comparable both spatially and radiometrically and with registration of the multiple images. MSS systems acquire all spectral bands simultaneously through the same optical system to alleviate these problems. Photographic systems record the energy detected by means of a photochemical process which is difficult to measure and to make consistent. Because MSS data are recorded electronically, it is easier to determine the specific amount of energy measured, and they can record over a greater range of values in a digital format. Photographic systems require a continuous supply of film and processing on the ground after the photos have been taken. The digital recording in MSS systems facilitates transmission of data to receiving stations on the ground and immediate processing of data in a computer environment.

Multispectral scanning principle Cameras and their use for aerial photography are the simplest and oldest of sensors used for remote sensing of the Earth's surface. Cameras are framing systems (Figure), which acquire a near-instantaneous "snapshot" of an area of the Earth's surface. Camera systems are passive optical sensors that use a lens (or system of lenses collectively referred to as the optics) to form an image at the focal plane, the "aerial image plane" at which an image is sharply defined. Many electronic (as opposed to photographic) remote sensors acquire data using scanning systems, which employ a sensor with a narrow field of view that sweeps over the terrain to build up and produce a two-dimensional image of the surface. Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. A scanning system used to collect data over a variety of different wavelength ranges is called a multispectral scanner (MSS), and is the most commonly used scanning system. There are two main modes or methods of scanning employed to acquire multispectral image data - acrosstrack scanning, and along-track scanning. Across-track scanners scan the Earth in a series of lines (Figure). The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath). Each line is scanned from one side of the sensor to the other, using a rotating mirror. As the platform moves forward over the Earth, successive scans build up a two-dimensional image of the Earth's surface. So, the Earth is scanned point by point and line after line. These systems are referred to as whiskbroom scanners. The incoming reflected or emitted radiation is separated into several spectral components that are detected independently. A bank of internal detectors, each sensitive to a specific range of wavelengths, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing.

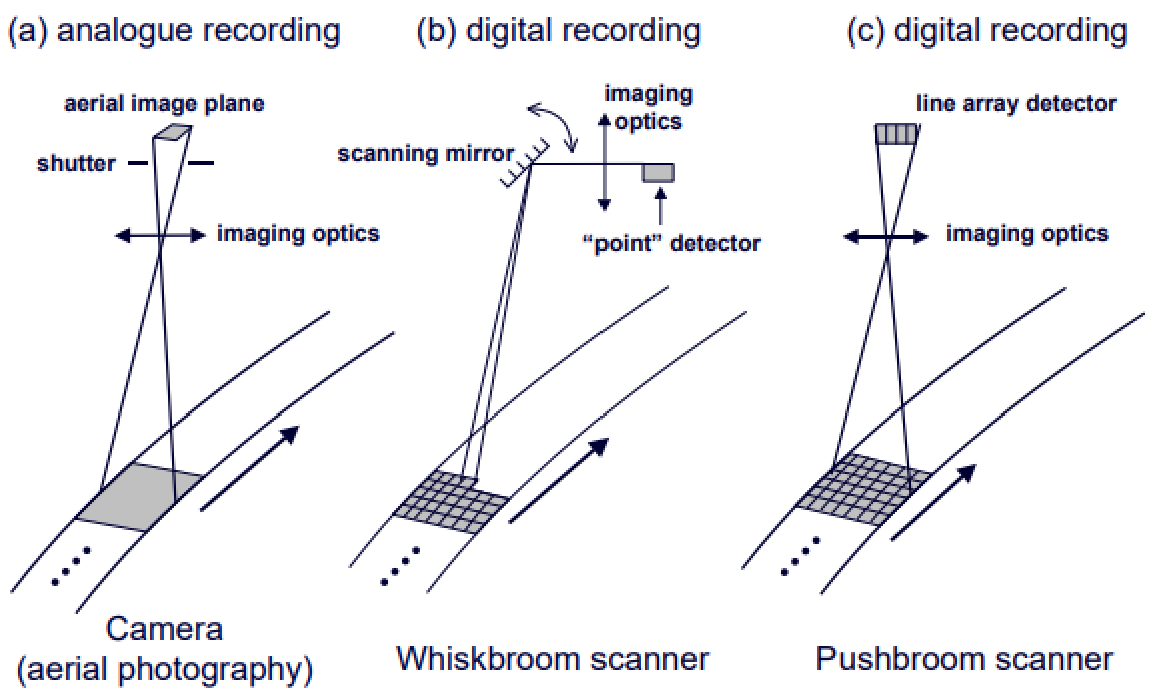


Figure 3.1: Principle of imaging sensor systems; (a) framing system, (b) whiskbroom scanner, (c) pushbroom scanner.

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 (Figure 3.1c). However, instead of a scanning mirror, they use a linear array of detectors (so-called charge-coupled devices, CCDs) located at the focal plane of the image formed by lens systems, which are "pushed" along in the flight track direction (i.e. along track). These systems are also referred to as pushbroom scanners, as the motion of the detector array is analogous to a broom being pushed along a floor. A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded. Regardless of whether the scanning system used is either of these two types, it has several advantages over photographic systems. The spectral range of photographic systems is restricted to the visible and near-infrared regions while MSS systems can extend this range into the thermal infrared. They are also capable of a much higher spectral resolution than photographic systems. Multi-band or multispectral photographic systems use separate lens systems to acquire each spectral band. This may cause problems in ensuring that the different bands are comparable both spatially and radiometrically and with registration of the multiple images. MSS systems acquire all spectral bands simultaneously through the same optical system to alleviate these problems. Photographic systems record the energy detected by means of a photochemical process which is difficult to measure and to make consistent. Because MSS data are recorded electronically, it is easier to determine the specific amount of energy measured, and they can record over a greater range of values in a digital format. Photographic systems require a continuous supply of film and processing on the ground after the photos have been taken. The digital recording in MSS systems facilitates transmission of data to receiving stations on the ground and immediate processing of data in a computer environment.

Thermal imaging Many multispectral (MSS) systems sense radiation in the thermal infrared as well as the visible and reflected infrared portions of the spectrum. However, remote sensing of energy m) is different from theμm to 15 μemitted from the Earth's surface in the thermal infrared (3 sensing of reflected energy. Thermal sensors use photon detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation. The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions. Thermal sensors essentially measure the surface temperature and thermal properties of targets. Thermal imagers are typically across-track scanners (like those described in the previous section) that detect emitted radiation in only the thermal portion of the spectrum. Thermal sensors employ one or more internal temperature references for comparison with the detected radiation, so they can be related to absolute radiant temperature. The temperature resolution of current sensors can reach 0.1 °C. For analysis, an image of relative radiant temperatures is depicted in grey levels, with warmer temperatures shown in light tones, and cooler temperatures in dark tones. Imagery, which portrays relative temperature differences in their relative spatial locations, is sufficient for most applications. Absolute temperature measurements may be calculated but require accurate calibration and measurement of the temperature references and detailed knowledge of the thermal properties of the target, geometric distortions, and radiometric effects.

Optical-infrared sensors

The IR region of the electromagnetic spectrum is the wavelength region longer than the visible but shorter than radiowaves. The IR region is typically subdivided into near-infrared (~ 0.75 – 1.4 µm), the short-, mid-, and long-wavelength regions, and the far infrared (~ 15 – 1000µm). These sub-classifications are useful as different optical technologies are required within the different wavelength ranges.

One of the most useful elements in IR sensing is that any object with a finite temperature will emit IR radiation. Whereas with visible light, the detection of an object with a camera requires sufficient illumination and direct line of light, IR images can be used to 'see through' certain objects as well as recover temperature information on the object.

A completely passive IR sensor will consist only of an IR-sensitive detector. Excitation of the sample of interest with a radiation source is not required due to the object's thermal emission of IR light. Typical sensor types include pyroelectric sensors, but some progress is being made on the development of IR-sensitive phosphor-based sources.2 The sensor type will need to correspond to the particular wavelength region in which the device will be operating.

Often a series of optical filters will be used in an IR sensor. This includes longpass, shortpass, bandpass, and interference filters. Filters are used for a number of purposes in IR sensing devices. Often, this ensures transmission of only the spectral region of interest so the device does not become saturated by any unwanted wavelengths. Filters can also be used for the attenuation of strong signals or to improve signal-to-noise ratios and signal contrast.

Midinfrared filters are commonly used in astronomical and remote sensing equipment. A series of filter types may be integrated into telecommunications devices to avoid cross-talk between communications on different frequency ranges.

Longpass filters: Longpass filters are normally defined by their cut-on edge, which is the wavelength below which all other wavelengths of light will be blocked.

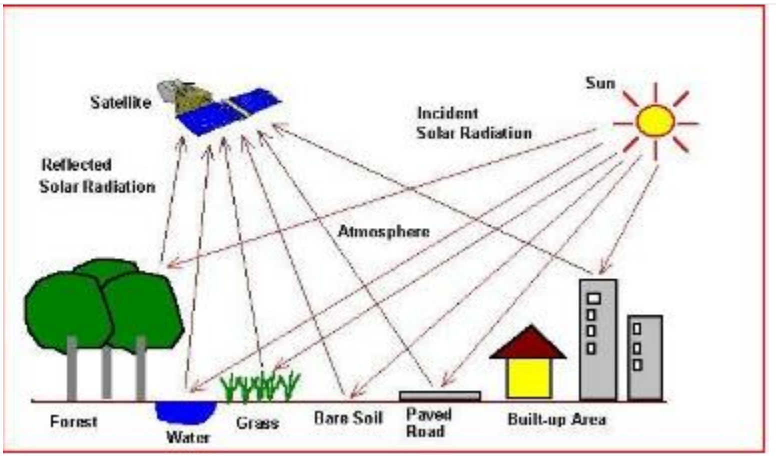
Shortpass filters: Shortpass filters are the inverse of longpass filters and are a type of edge filter that allows shorter wavelengths to be transmitted while all longer wavelengths are blocked.
Bandpass filters: Bandpass filters are defined by their central wavelength, which determines which region of the spectrum they allow to pass through. Bandpass filters have a full-width half maximum which determines how broad the transmitted spectral region is.
Interference filters: Interference filters are sometimes called dichroic filters, and they allow for the reflection of one or more spectral bands and the transmission of all other wavelength regions. Unlike most filters that absorb all wavelengths that are not transmitted, interference filters instead separate spectral mixtures through reflection and transmission. An interference filter may also have longpass, shortpass, or bandpass characteristics.
Some important properties of filters are the wavelengths of the cut-on and cut-off points, the contrast between the transmitted and blocked regions, and the steepness of the blocked region.
In conclusion, when designing IR sensing, it is essential to consider the properties of the optical components, particularly if the sensitivity to weak signals is important, so any unwanted spectral contributions must be filtered out. High-quality filter design can improve device performance and allow IR imaging to be performed over selected wavelength regions.

Optical-infrared sensors are devices designed to detect and measure electromagnetic radiation in both the optical (visible) and infrared (IR) spectrums. These sensors are used in various applications across industries, including aerospace, defense, automotive, environmental monitoring, medical imaging, and consumer electronics.

Some key points about optical-infrared sensors:

1. **Detection Range**: Optical-infrared sensors can detect electromagnetic radiation in the range of wavelengths that encompass both the visible spectrum (approximately 400 to 700 nanometers) and the infrared spectrum (wavelengths longer than visible light, up to several micrometers).
2. **Types of Sensors**:
   - **Photodetectors**: These sensors convert light into electrical signals. Examples include photodiodes, phototransistors, and photomultiplier tubes.
   - **Thermal Infrared Sensors**: These sensors detect the heat emitted by objects in the infrared spectrum. Examples include bolometers and thermopiles.
   - **Image Sensors**: Used in cameras and imaging devices to capture visual information across the optical and infrared spectra.
3. **Applications**:
   - **Surveillance and Security**: Optical-infrared sensors are used in surveillance cameras, night vision systems, and motion detectors for security applications.
   - **Remote Sensing**: They are employed in satellites and unmanned aerial vehicles (UAVs) for environmental monitoring, agriculture, and resource exploration.
   - **Automotive**: Used in advanced driver-assistance systems (ADAS), such as lane departure warning systems and adaptive headlights.
   - **Medical Imaging**: Infrared sensors are used in devices like pulse oximeters and thermal imaging cameras for medical diagnostics.
   - **Consumer Electronics**: Optical sensors are found in smartphones, digital cameras, and optical mice.

4. **Technology Advancements**: Recent advancements in optical-infrared sensor technology include improvements in sensitivity, resolution, and miniaturization. Additionally, developments in materials science have led to the production of more efficient and cost-effective sensors.
5. **Challenges**: Challenges in optical-infrared sensor technology include mitigating noise, enhancing sensitivity, and extending the detection range. In some applications, such as long-range surveillance or deep-space observation, achieving high sensitivity and signal-to-noise ratio is critical.
6. **Multispectral and Hyperspectral Imaging**: Advanced optical-infrared sensors can capture information across multiple wavelengths, enabling multispectral and hyperspectral imaging. These techniques provide detailed spectral information about the observed scene, facilitating tasks like material identification and environmental monitoring.



The OIR sensors can be divided into 2 main categories : ⁄ Photographic ⁄ Electro-optical sensors

♦ Photographic system : The images are transformed directly on a film.

♦ Electro-optical sensors : The optical image is first converted into an electrical signal and further processed to record or transmit the data

♦ The basic elements of an imaging system in the OIR region can be broadly classified as :

Collecting optics

imaging system

Detectors

Scanners

Inflight calibration system

Associated electronics

Importance of Infrared Sensors in Remote Sensing:

1. **Detecting Thermal Radiation**: Infrared sensors are capable of detecting and measuring the thermal radiation emitted by objects. This allows remote sensing systems to capture temperature variations across landscapes, bodies of water, and urban areas.
2. **Vegetation Analysis**: Infrared sensors can discern subtle differences in the reflectance of infrared light by vegetation. This information aids in assessing vegetation health, identifying species, monitoring crop growth, and detecting changes in land cover.

3. **Weather Monitoring**: Infrared sensors are employed in weather satellites to observe cloud patterns, measure surface temperatures, and identify atmospheric features. They are crucial for monitoring weather phenomena such as storms, fog, and wildfires.
4. **Urban Heat Island Monitoring**: Infrared sensors help detect and analyze urban heat islands—areas of elevated temperatures within cities compared to surrounding rural areas. This information is valuable for urban planning, climate adaptation, and mitigating heat-related risks.
5. **Oceanography**: Infrared sensors on satellites monitor sea surface temperatures, aiding in the study of ocean circulation patterns, climate change impacts on marine ecosystems, and forecasting weather events like hurricanes.

Functionality of Infrared Sensors:

1. **Passive vs. Active Sensors**: Infrared sensors can be passive or active. Passive sensors detect natural infrared radiation emitted or reflected by objects, while active sensors emit their own infrared radiation and measure the response. Both types have specific applications in remote sensing.
2. **Spectral Bands**: Infrared sensors often operate in specific spectral bands, such as near-infrared (NIR), short-wave infrared (SWIR), mid-wave infrared (MWIR), and long-wave infrared (LWIR). Different bands provide unique information about the characteristics of the observed targets.
3. **Resolution and Sensitivity**: The resolution and sensitivity of infrared sensors determine their ability to detect small temperature variations and spatial features on the Earth's surface. High-resolution sensors can capture fine details, whereas sensors with greater sensitivity can detect subtle temperature differences.
4. **Calibration and Correction**: To ensure the accuracy of remote sensing data, infrared sensors undergo calibration and correction procedures. These processes account for sensor drift, atmospheric effects, and other factors that may influence the observed measurements.
5. **Data Processing**: Infrared data collected by remote sensing systems undergo extensive processing to extract meaningful information. This involves techniques such as image enhancement, spectral analysis, and data fusion to derive actionable insights for various applications.

Microwave sensors

Microwave sensors are remote sensing instruments that operate in the microwave portion of the electromagnetic spectrum. They utilize microwave radiation to gather information about the Earth's surface and atmosphere. Microwave sensors come in various types, each with its own characteristics and applications. Some of the different types of microwave sensors include:

1. **Radar (Radio Detection and Ranging) Sensors**: Radar sensors emit microwave pulses towards the Earth's surface and measure the time it takes for the pulses to return after being reflected by objects or surfaces. Radar sensors can measure distance, direction, speed, and size of objects, making them versatile tools for a wide range of applications. Types of radar sensors include:
    - **Synthetic Aperture Radar (SAR):** SAR sensors capture high-resolution radar images by combining multiple radar pulses collected along the sensor's flight path.

SAR is widely used for applications such as land cover mapping, agriculture, forestry, and disaster monitoring.

- **Interferometric SAR (InSAR):** InSAR sensors use pairs of radar images to detect ground deformation and topographic changes with high precision. InSAR is used for applications such as monitoring land subsidence, volcanic activity, and earthquake deformation.
- **Polarimetric SAR (PolSAR):** PolSAR sensors transmit and receive microwave radiation in multiple polarizations, allowing for the measurement of the polarization properties of surface materials. PolSAR is used for applications such as terrain classification, forest structure analysis, and soil moisture estimation.
- **Weather Radar**: Weather radar sensors measure the intensity and movement of precipitation and atmospheric phenomena, providing information for weather forecasting, storm tracking, and rainfall estimation.

2. **Radiometers:** Microwave radiometers measure the natural emission of microwave radiation from the Earth's surface and atmosphere. They detect thermal radiation emitted by objects and surfaces, allowing for the estimation of surface temperature, soil moisture, and atmospheric humidity. Microwave radiometers are used in applications such as weather forecasting, climate monitoring, and soil moisture mapping.

3. **Scatterometers**: Scatterometers measure the backscattered microwave radiation from the Earth's surface, providing information about surface roughness, wind speed, and direction. They are used for ocean surface wind measurements, sea ice monitoring, and weather forecasting. Scatterometers are particularly valuable for studying ocean dynamics and climate phenomena such as El Niño and La Niña.

4. **Radiometers**: Microwave radiometers measure the natural emission of microwave radiation from the Earth's surface and atmosphere. They detect thermal radiation emitted by objects and surfaces, allowing for the estimation of surface temperature, soil moisture, and atmospheric humidity. Microwave radiometers are used in applications such as weather forecasting, climate monitoring, and soil moisture mapping.

These are just a few examples of microwave sensors used in remote sensing. Microwave remote sensing plays a critical role in various fields, including meteorology, hydrology, agriculture, oceanography, and environmental monitoring, providing valuable information for scientific research, weather forecasting, and resource management.

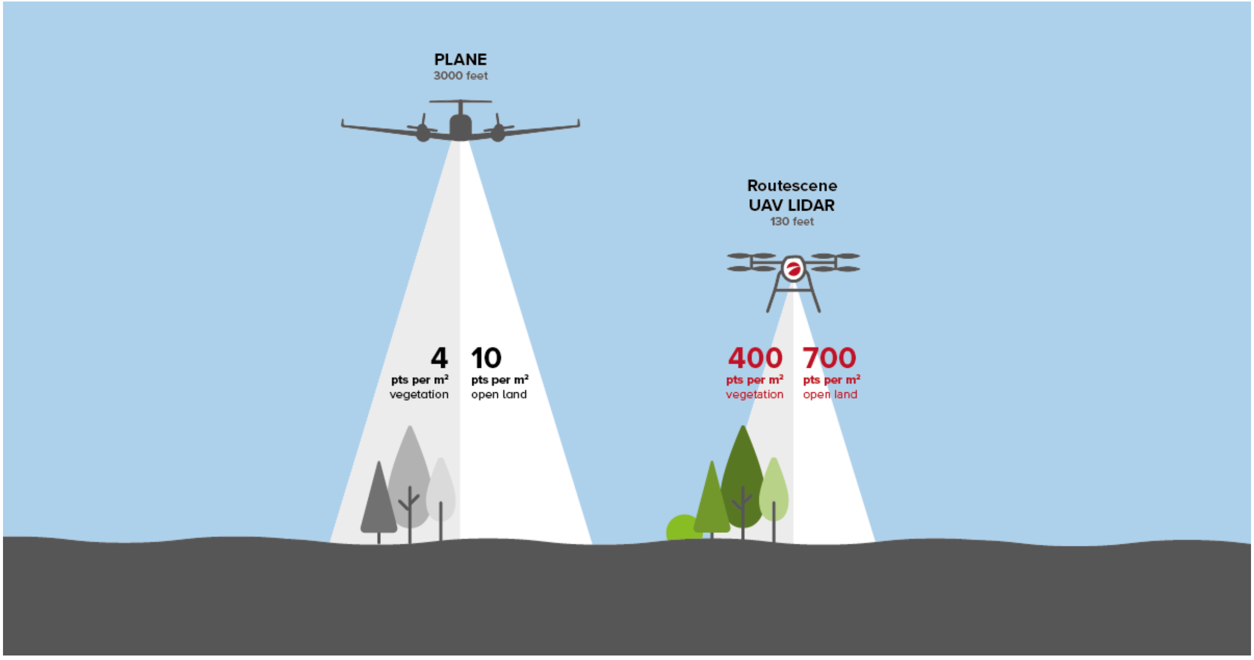
LIDAR and UAV

LIDAR is an active remote sensing system that uses laser light to measure the distance of the sensor from objects in a scene. A lidar sensor emits laser pulses that reflect off of surrounding objects.

LIDAR (Light Detection and Ranging) is a remote sensing technology that measures distances by illuminating a target with laser light and analyzing the reflected light. The system calculates distances by measuring the time it takes for the laser pulse to travel to the target and back. LIDAR can generate highly accurate three-dimensional maps of the Earth's surface, capturing details such as terrain elevation, vegetation structure, and the shape of buildings and infrastructure. It's widely used in applications such as cartography, urban planning, forestry management, and archaeology.

Lidar — Light Detection and Ranging — is a remote sensing method used to examine the surface of the Earth. Lidar data collected using NOAA survey aircraft reveals a top-down and side view of Loggerhead Key Lighthouse, Dry Tortugas, Florida.

A LiDAR drone uses a laser-based imaging system to capture data while a photogrammetry drone uses cameras to capture images. Both technologies are capable of producing excellent aerial mapping results; however, they differ in their price, accuracy, and applications.
LiDAR is an active remote sensing system. An active system means that the system itself generates energy - in this case, light - to measure things on the ground. In a LiDAR system, light is emitted from a rapidly firing laser. You can imagine light quickly strobing (or pulsing) from a laser light source.
LIDAR is an active remote sensing technology where the time for a laser pulse to return to a detector along with highly accurate position and attitude data are used to provide information on the elevation of various surfaces.



UAV (Unmanned Aerial Vehicle), commonly known as a drone, is an aircraft that operates without a human pilot onboard. UAVs can be remotely controlled by a human operator or autonomously controlled by onboard computers. These vehicles come in various sizes and configurations, from small quadcopters to large fixed-wing aircraft. UAVs are equipped with cameras, sensors, and other payloads to perform a wide range of tasks, including aerial photography, surveillance, crop monitoring, search and rescue operations, infrastructure inspection, and package delivery. UAVs offer flexibility, cost-effectiveness, and the ability to access remote or hazardous areas that may be difficult or dangerous for manned aircraft or ground-based surveys. When equipped with LIDAR sensors, UAVs can collect high-resolution 3D data for mapping and surveying purposes with improved efficiency and accuracy.

These include aerial photography, area coverage, precision agriculture, forest fire monitoring, river monitoring, environmental monitoring, policing and surveillance, infrastructure inspections, smuggling, product deliveries, entertainment, and drone racing.

Netra. The Netra UAV, compact and portable, serves the Indian Army in surveillance and reconnaissance missions. Covering a range of 2 km and operating at an altitude of 200 meters, it is equipped with a day/night camera for real-time video and imagery transmission.

There were two meanings for drone then: a "male bee," or a "monotonous, sustained sound." Which was the inspiration for applying the term? The aircraft's function can clue you in: it's an extension of the "bee" meaning. Drones are bigger and heavier than worker bees, and they leave the hive and swarm in the fall.

In the late 1970s and 80s, Israel developed the Scout and the Pioneer, which represented a shift toward the lighter, glider-type model of UAV in use today. Israel pioneered the use of unmanned aerial vehicles (UAVs) for real-time surveillance, electronic warfare, and decoys.

Abraham Karem (born 1937) is a designer of fixed and rotary-wing unmanned aircraft. He is regarded as the founding father of UAV (drone) technology.

Orbital and sensor characteristics of live Indian earth observation satellites:

India operates a series of Earth observation satellites with various orbital and sensor characteristics. Here's an overview:

Orbital Characteristics:

1. **Low Earth Orbit (LEO)**: Many of India's Earth observation satellites are placed in Low Earth Orbit, typically at altitudes ranging from a few hundred to a few thousand kilometers above the Earth's surface. These orbits provide high-resolution imaging capabilities and revisit times suited for various applications.
2. **Sun-Synchronous Orbit (SSO)**: Several Indian Earth observation satellites are placed in Sun-Synchronous Orbits. These orbits are synchronized with the sun's position, resulting in consistent lighting conditions during imaging passes. It enables consistent illumination for monitoring changes on the Earth's surface over time.
3. **Geostationary Orbit (GEO)**: India also operates satellites in Geostationary Orbit, which orbit at an altitude of approximately 36,000 kilometers above the Earth's equator. Satellites in GEO remain stationary relative to a fixed point on the Earth's surface, making them suitable for applications such as meteorology and communication.

Sensor Characteristics:

1. **Optical Sensors**: Indian Earth observation satellites are equipped with optical sensors capable of capturing images in various spectral bands, including visible, near-infrared, and sometimes thermal infrared. These sensors provide high-resolution imagery for applications such as land cover mapping, agriculture monitoring, urban planning, and disaster management.
2. **Synthetic Aperture Radar (SAR):** Some Indian satellites carry Synthetic Aperture Radar (SAR) sensors. SAR sensors can acquire images regardless of weather conditions or daylight,

making them valuable for applications such as terrain mapping, forest monitoring, disaster response, and maritime surveillance.

3. **Multispectral and Hyperspectral Sensors**: Indian satellites may carry multispectral and hyperspectral sensors capable of capturing imagery in multiple spectral bands. These sensors enable detailed analysis of vegetation health, soil composition, water quality, and other environmental parameters.
4. **Radiometers:** Some Indian satellites are equipped with radiometers to measure various parameters such as sea surface temperature, land surface temperature, and atmospheric temperature. These measurements contribute to climate research, weather forecasting, and oceanography.
5. **Atmospheric Sensors**: Certain satellites may carry atmospheric sensors to monitor parameters such as aerosol concentration, greenhouse gases, and atmospheric composition. These sensors aid in climate monitoring, air quality assessment, and environmental research.

Overall, Indian Earth observation satellites are equipped with a diverse range of sensors and deployed in various orbital configurations to address a wide range of applications for environmental monitoring, disaster management, natural resource management, and scientific research.