Er. PERUMAL MANIMEKALAI COLLEGE OF ENGINEERING

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Koneripalli, HOSUR - 635 117.

COURSE MATERIAL
REMOTE SENSING
UNIT I & II

for

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BY

Dr.V.SENTHILKUMAR
ASSOCIATE PROFESSOR
DEPARTMENT OF ELECTRONICS AND COMMUNICATION

UNIT I REMOTE SENSING

DEFINITION AND PROCESS OF REMOTE SENSING

INTRODUCTION

1) Now-a-days scientists, researchers, students, and even common people are showing great interest for better understanding of our environment. By environment we mean the geographic space of their study area and the events that take place there. In other words, we have come to realize that geographic space along with the data describing it, is part of our everyday world; almost every decision we take is influenced or dictated by some fact of geography.

2) Advancement in sophisticated space technology (which can provide large volume of spatial data), along with declining costs of computer hardware and software (which can handle these data) has made Remote Sensing and G.I.S. affordable to not only complex environmental / spatial situation but also affordable to an increasingly wider audience.

REMOTE SENSING AND ITS COMPONENTS:

Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information." In much of remote sensing, the process involves an interaction beteen incident adiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. However, that remote sense also involves the sensing of emitted energy and the use of non-imaging sensors.

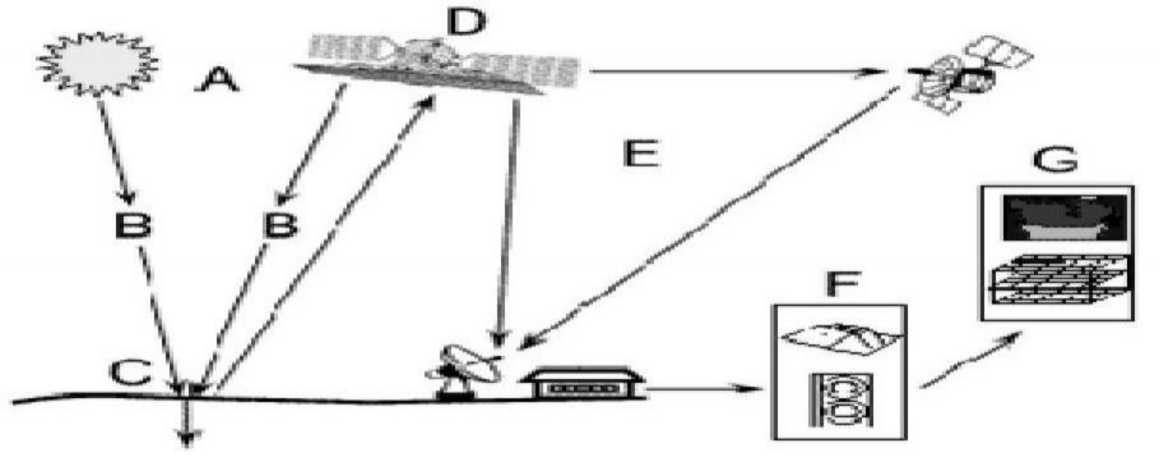


Fig 1.1- Components of Remote Sensing

Energy Source or Illumination (A) – the first requirement for remote sensing is to havean energy source which illuminates or provides electromagnetic energy to the target of interest.

Radiation and the Atmosphre (B) – as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

Interaction with the Target (C) - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.

Recording of Energy by the Sensor (D) - after the energy has been scattered by,or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.

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).

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

Application (G) - the final element of the remote sensing process is achieved whenwe apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

HISTRY OF REMOTE SENSING:

1839 - first photograph

1858 - first photo from a balloon1903 - first plane

1909 first photo from a plane1903-4 -B/W infrared film

WW I and WW II1960 – space

Passive/ Active Remote Sensing

Depending on the source of electromagnetic energy, remote sensing can be classified as passive or active remote sensing.

In the case of passive remote sensing, source of energy is that naturally available such as the Sun. Most of the remote sensing systems work in passive mode using solar energy as the source of EMR. Solar energy reflected by the targets at specific wavelength bands are recorded using sensors on board air-borne or space borne platforms. In order to ensure ample signal strength received at the sensor, wavelength / energy bands capable of traversing through the atmosphere, without significant loss through atmospheric interactions, are generally used in remote sensing Any object which is at a temperature above 0o K (Kelvin) emits some radiation, which is approximately proportional to the fourth power of the temperature of the object. Thus the Earth also emits some radiation since its ambient temperature is about 300o K. Passive sensors can also be used to measure the Earth‘s radiance but they are not very popular as the energy content is very low.

In the case of active remote sensing, energy is generated and sent from the remote sensing platform towards the targets. The energy reflected back from the targets are recorded using sensors on board the remote sensing platform. Most of the microwave remote sensing is done through active remote sensing.

As a simple analogy, passive remote sensing is similar to taking a picture with an ordinary camera whereas active remote sensing is analogous to taking a picture with camera having built-in flash

What is Sensor Platform?

Platform is a stage where sensor or camera is mounted to acquire information about a target under investigation.

According to Lillesand and Kiefer (2000), a platform is a vehicle, from which a sensor can be operated.

For remote sensing applications, sensors should be mounted on suitable stable platforms

As the platform height increases the spatial resolution and observational area increases.

The types or characteristics of platform depend on the type of sensor to be attached and its application.

Type of Platforms:

Platforms can vary from stepladders to satellites.

There are different types of platforms and based on its altitude above earth surface.

Three types of platforms are used to mount the remote sensors

1. Ground based Platform
2. Air - borne Platform, and
3. Space-borne Platform

Ground based Platforms:

- Ground based platforms are used to record detailed information about the objects or features of the earth's surface
- These are developed for the scientific understanding on the signal-object and signal-sensor interactions.
- It includes both the laboratory and field study, used for both in designing sensors and identification and characterization of land features.
- Example: Handheld platform, cherry picker, towers, portable masts and vehicles etc.
- Portable handheld photographic cameras and spectroradiometers are largely used in laboratory and field experiments as a reference data and ground truth verification.
- Crane, Ground based platform (cherry Picker Platform extend up to approx. 15m.)

Air- borne/ based Platforms:

- Airborne platforms were the sole non-ground-based platforms for early remote sensing work.
- Aircraft remote sensing system may also be referred to as sub-orbital or airborne, or aerial remote sensing system
- At present, airplanes are the most common airborne platform.
- observation platforms include balloons, drones (short sky spy) and high altitude sounding rockets. Helicopters are occasionally used.

Balloons:

- Balloons are used for remote sensing observation (aerial photography) and nature conservation studies.
- The first aerial images were acquired with a camera carried aloft by a balloon in 1859.
- Balloon floats at a constant height of about 30 km.

- Balloons as platforms are not very expensive like aircrafts. They have a great variety of shapes, sizes and performance capabilities.
- The balloons have low acceleration, require no power and exhibit low vibrations.
- It consists of a rigid circular base plate for supporting the entire sensor system which is protected by an insulating and shock proof light casing.
- The payload used for Indian balloon experiment of three Hasselblad cameras with different film filter combinations, to provide PAN, infra red black and white and infra red false color images.
- Flight altitude being high compared to normal aircraft height used for aerial survey, balloon imagery gives larger synoptic views.
- The balloon is governed by the wind at the floating altitude
- There are three main types of balloon systems, viz. free balloons, Tethered balloons and Powered Balloons.
- Free balloons can reach almost top of the atmosphere; hence, they can provide a platform at intermediate altitude between those of aircraft and spacecraft (shown in fig.)
- Have altitude range of 22-40 km and can be used to a limited extent as a platform.

Drone:

- Drone is a miniature remotely piloted aircraft.
- It is designed to fulfill requirements for a low cost platform, with long endurance, moderate payload capacity and capability to operate without a runway or small runway.
- Drone includes equipment of photography, infrared detection, radar observation and TV surveillance. It uses satellite communication link.
- An onboard computer controls the payload and stores data from different sensors and instruments.

Aircraft Platform:

- Aircraft are used to collect very detailed images.
- Helicopters can be for pinpoint locations but it vibrates and lacks stability.
- Special aircraft with cameras and sensors on vibration less platforms are traditionally used to acquire aerial photographs and images of land surface features.
- While low altitude aerial photography results in large scale images providing detailed information on the terrain, the high altitude smaller scale images offer advantage to cover a larger study area with low spatial resolution
- Aircraft platforms offer an economical method of remote sensing data collection for

small to large study areas with cameras, electronic imagers, across- track and along-track scanners, and radar and microwave scanners.

- Low Altitude Aircraft: It is most widely used and generally operates below 30,000 ft.
- It is suitable for obtaining image data for small areas having large scale
- High altitude aircraft: It includes jet aircraft with good rate of climb, maximum speed, and high operating ceiling. It acquires imagery for large areas

Rockets as Platforms:

- High altitude sounding rocket platforms are useful in assessing the reliability of the remote sensing techniques as regards their dependence on the distance from the target is concerned.
- Balloons have a maximum altitude of approximately 37 km, while satellites cannot orbit below 120 km. High altitude sounding rockets can be used to a moderate altitude above terrain
- Synoptic imagery can be obtained from rockets for areas of some 500,000 square km.

Space-borne/ based Platforms:

- In space- borne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the earth.

- Space-borne or satellite platform are onetime cost effected but relatively lower cost per unit area of coverage, can acquire imagery of entire earth without taking permission.
- Space-borne imaging ranges from altitude 250 km to 36000 km.
- Space-borne remote sensing provides the following advantages:

Large area coverage;

- Frequent and repetitive coverage of an area of interest;
- Quantitative measurement of ground features using radiometrically calibrated sensors;
- Semi-automated computerised processing and analysis;
- Relatively lower cost per unit area of coverage.

Spacecraft as Platform:

- Remote sensing is also conducted from the space shuttle or artificial satellites. Artificial satellites are manmade objects, which revolve around another object.
- Satellite can cover much more land space than planes and can monitor areas on a regular basis.
- Later on with LANDSAT and SPOT satellites program, space photography received a higher impetus

ELECTROMAGNETIC SPECTRUM

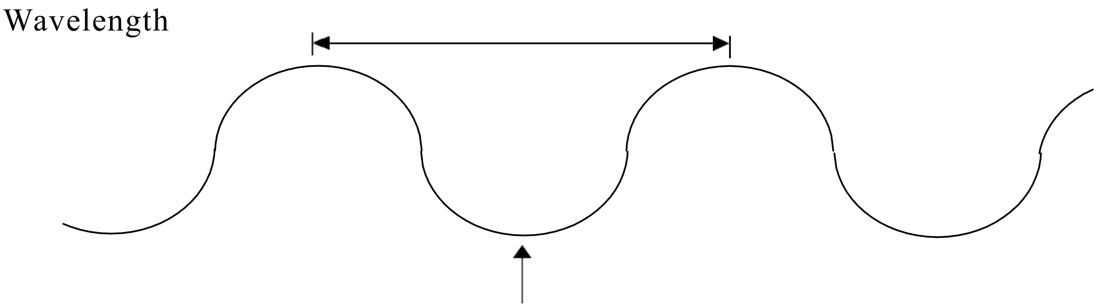
The first requirement for remote sensing is to have an **energy source to illuminate the target** (unless thesensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation. All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basicsof wave theory.

Electromagnetic radiation consists of an electrical field (E) which varies inmagnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field

(M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c). Two characteristics of electromagnetic radiation are particularly important to understand remote sensing. These are the **wavelength and frequency.**

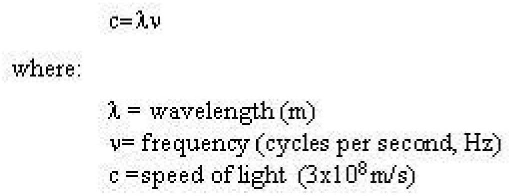
Electromagnetic radiation (EMR) as an electromagnetic wave that travels throughspace at the speed of light C which is $3x10^8$ meters per second.

Theoretical model of random media including the anisotropic effects, random distribution discrete scatters, rough surface effects, have been studied for remote sensing with electromagnetic waves.



The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of metres such as **nanometres** (nm, 10- 9 metres), **micrometres** (μm, 10-6 metres) (μm, 10-6 metres) or centimetres (cm, 10-2 metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in **hertz** (Hz), equivalent to one cycle per second, and various multiples of hertz.

Wavelength and frequency are related by the following formula:



$$c = \lambda \nu$$

where:

λ = wavelength (m)
ν= frequency (cycles per second, Hz)
c =speed of light (3×10^8 m/s)

Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency. Understanding the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data.

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing.

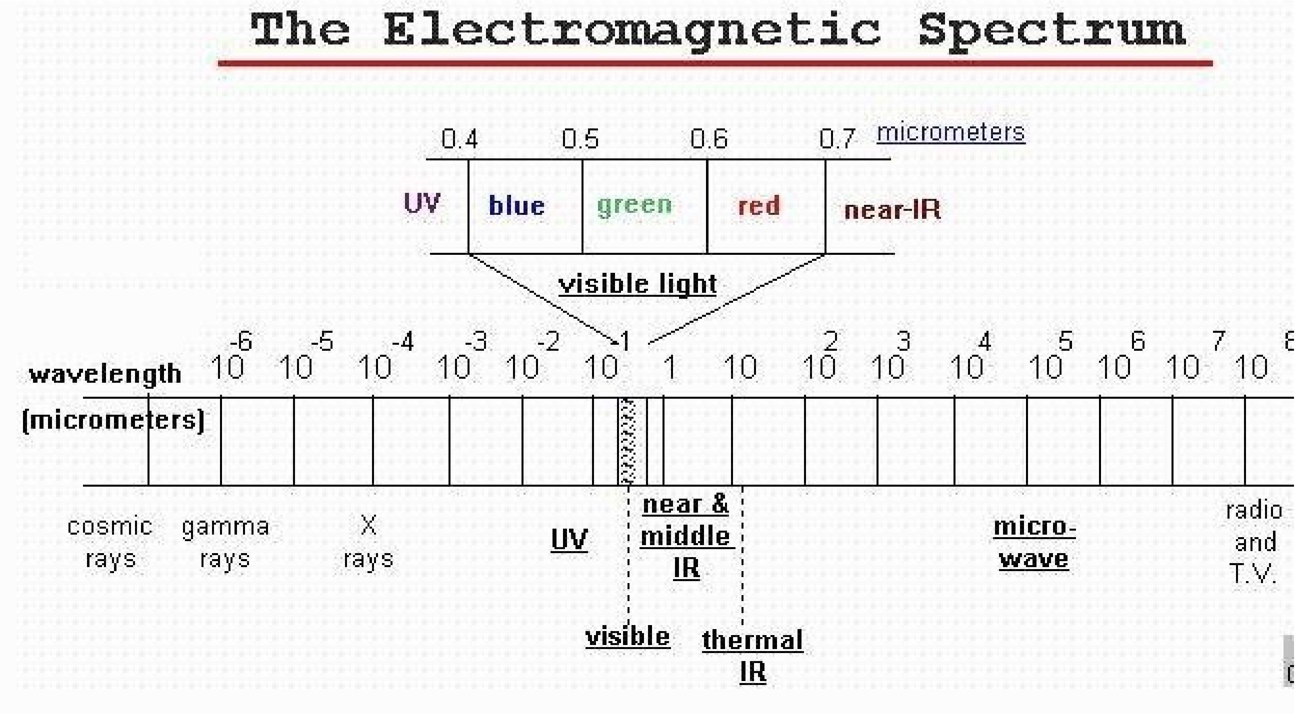


Fig 3 – Electromagnetic Spectrum

WAVELENGTH REGIONS IMPORTANT TO REMOTE SENSING:

Ultraviolet or UV

For the most purposes ultraviolet or UV of the spectrum shortest wavelengths are practical for remote sensing. This wavelength beyond the violet portion of the visible wavelengths hence it name. Some earth surface materials rocks and materials are emit visible radiation when illuminated by UV radiation.

Visible Spectrum

The light which our eyes - our "remote sensors" - can detect is part of the **visible spectrum**. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 0.4 to 0.7 μm. The longest visible wavelength is red and the shortest is violet. Common wavelengths of what we perceive as particular colours from the visible portion of the spectrum are listed below. It is important to note that this is the only portion of the spectrum we can associate with the concept of **colors**.

Violet: 0.4 -0.446 µm

Blue: 0.446 -0.500 µm

Green: 0.500 -0.578 µm

Yellow: 0.578 -0.592 µm

Orange: 0.592 -0.620 µm

Red: 0.620 -0.7 µm

Blue, **green**, and **red** are the **primary colours** or wavelengths of the visible spectrum. They are defined as such because no single primary colour can be created from the other two, but all other colours can be formed by combining blue, green, and red in various proportions. Although we see sunlight as a uniform or homogeneous colour, it is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum. The visible portion of this radiation can be shown in its component colours when sunlight is passed through a **prism**, which bends the light in differing amounts according to wavelength.

Infrared (IR)

The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 µm to 100 µm more than 100 times as wide as the visible portion. The infrared can be divided into 3 categories based on their radiation properties-the reflected near- IR middle IR and thermal IR.

The reflected near IR covers wavelengths from approximately 0.7 µm to 1.3 µm is commonly used to expose black and white and color-infrared sensitive film.

The middle-infrared region includes energy with a wavelength of 1.3 to 3.0 µm.

The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 µm to 100 µm.

Microwave

This wavelength (or frequency) interval in the electromagnetic spectrum is commonly referred to as a band, channel or region.The major subdivision

The portion of the spectrum of more recent interest to remote sensing is the microwave region from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radiobroadcasts.

Region	Wavelength	Remarks
Gamma ray	<0.03 nm	Incoming radiation is completely absorbed by the upper atmosphere and is not available for remote sensing.
X-ray	0.03 to 3.0 nm	Completely absorbed by atmosphere. Not employed in remote sensing.
Ultraviolet	0.3 to 0.4 μm	Incoming wavelengths less than 0.3 μm are completely absorbed by ozone in the upper atmosphere.
Photographic UV band	0.3 to 0.4 μm	Transmitted through atmosphere. Detectable with film and photodetectors, but atmospheric scattering is severe
Visible	0.4 to 0.7 μm	Imaged with film and photodetectors. Includes reflected energy peak of earth at 0.5 μm.
Infrared	0.7 to 1.00 μm	Interaction with matter varies with wave length. Atmospheric transmission windows are separated.
Reflected IR band	0.7 to 3.0 μm	Reflected solar radiation that contains information about thermal properties of materials. The band from 0.7 to 0.9 μm is detectable with film and is called the photographic IR band.
Thermal IR	3 to 5 μm band	Principal atmospheric windows in the 8 to 14 μm thermal region. Images at these wavelengths are acquired by optical mechanical scanners and special vidicon systems but not by film. Microwave 0.1 to 30 cm longer wavelengths can penetrate clouds, fog, and rain. Images may be acquired in the active or passive mode.
Radar	0.1 to 30 cm	Active form of microwave remote sensing. Radar images are acquired at various wavelength bands.
Radio	>30 cm	Longest wave length portion of electromagnetic spectrum. Some classified radars with very long wavelengths operate in this region.

WAVE THEORY AND PARRTICAL THEORY

Light can exhibit both a wave theory, and a particle theory at the same time. Much of the time, light behaves like a wave. Light waves are also called electromagnetic waves because they are made up of both electric (*E*) and magnetic (*H*) fields. Electromagnetic fields oscillate perpendicular to the direction of wave travel, and perpendicular to each other. Light waves are known as transverse waves as they oscillate in the direction traverse to the direction of wave travel.

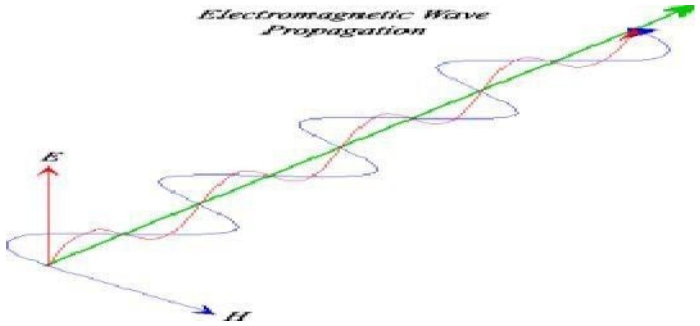


Fig 1.4 – Electromagnetic propagation

Waves have two important characteristics - wavelength and frequency.

The sine wave is the fundamental waveform in nature. When dealing with light waves, we refer to the sine wave. The period (*T*) of the waveform is one full 0 to 360 degree sweep. The relationship of frequency and the period is given by the equation:

$f = 1 / TT = 1 / f$

The waveforms are always in the time domain and go on for infinity.

The speed of a wave can be found by multiplying the two units together. The wave's speed is measured in units of length (distance) per second:

Wavelength x Frequency = Speed

As proposed by Einstein, light is composed of photons, a very small packets of energy. The reason that photons are able to travel at light speeds is due to the fact that they have no mass and therefore, Einstein's infamous equation - $E=MC^2$ cannot be used. Another formula devised by Planck, is used to describe the relation between photon energy and frequency - *Planck's*

Constant (*h*) - 6.63×10^{-34} Joule-Second. $E = hf$(or)$E = hc$
/ɣ

E is the photonic energy in Joules, *h* is Planks constant and *f* is the frequency in Hz.

PARTICAL THEORY

The basic idea of quantum theory is that radiant energy is transmitted in indivisible packets whose energy is given in integral parts, of size hv, where h is Planck's constant = 6.6252 x 10-34 J - s, and v is the frequency of the radiation. These are called quanta or photons.

The dilemma of the simultaneous wave and particle waves of electromagnetic energy may be conceptually resolved by considering that energy is not supplied continuously throughout a wave, but rather that it is carried by photons. The classical wave theory does notgive the intensity of energy at a point in space, but gives the probability of finding a photon atthat point. Thus the classical concept of a wave yields to the idea that a wave simply describes the probability path for the motion of the individual photons.

The particular importance of the quantum approach for remote sensing is thatit provides the concept of discrete energy levels in materials. The values and arrangement of these levels are different for different materials. Information about a given material is thus available in electromagnetic radiation as a consequence of transitions between these energy levels. A transition to a higher energy level is caused by the absorption of energy, or from a higher to a lower energy level is caused by the' emission of energy. The amounts of energy either absorbed or emitted correspond precisely to the energy difference between the two levels involved in the transition. Because the energy levels are different for each material, the amount of energy a particular substance can absorb or emit is different for that material from any other materials. Consequently, the position and intensities of the bands in the spectrum of a given material are characteristic to that material.

STEFAN–BOLTZMANN LAW

Stefan–Boltzmann law, also known as **Stefan's law**, describes the power radiated from a black body in terms of its temperature. Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time (also known as the black-body *radiant exitance* or *emissive power*), $j^{\star}$, is directly proportional to the fourth power of the black body's thermodynamic temperature *T*:

$$j^{\star} = \sigma T^{4}.$$

WIEN'S DISPLACEMENT LAW

Wien's displacement law states that the black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature. The shift of that peak of the Planck radiation law which describes the spectral brightness of black body radiation as a function of wavelength at any given temperature.

However it had been discovered by Wilhelm Wien several years before Max

Planck developed that more general equation, and describes the entire shift of the spectrum of black body radiation toward shorter wavelengths as temperature increases.

Formally, Wien's displacement law states that the spectral radiance of black body radiation per unit wavelength, peaks at the wavelength λ_{max} given by:

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

where T is the absolute temperature in degrees kelvin. b is a constant of proportionality called *Wien's displacement constant*, equal to $2.8977721(26) \times 10^{-3}$ mK.[1], or more conveniently to obtain wavelength in microns, $b \approx 2900$ µm K.

If one is considering the peak of black body emission per unit frequency r per proportional bandwidth, one must use a different proportionality constant. However the form of the law remains the same: the peak wavelength is inversely proportional to temperature (or the peak frequency is directly proportional to temperature).

Wien's displacement law may be referred to as "Wien's law", a term which is also used for the Wien approximation.

Blackbody Radiation

A blackbody is a hypothetical, ideal radiator. It absorbs and reemits the entire energy incident upon it.

Total energy emitted by a black body varies with temperature as given in Eq. 4. The total energy is distributed over different wavelengths, which is called the spectral distribution or spectral curve here. Area under the spectral curve gives the total radiant exitance *M.*

In addition to the total energy, the spectral distribution also varies with the temperature. Fig. 4 shows the spectral distribution of the energy radiated from black bodies at different temperatures. The figure represents the Stefan-Boltzmann's law graphically. As the temperature increases, area under the curve, and hence the total radiant exitance increases.

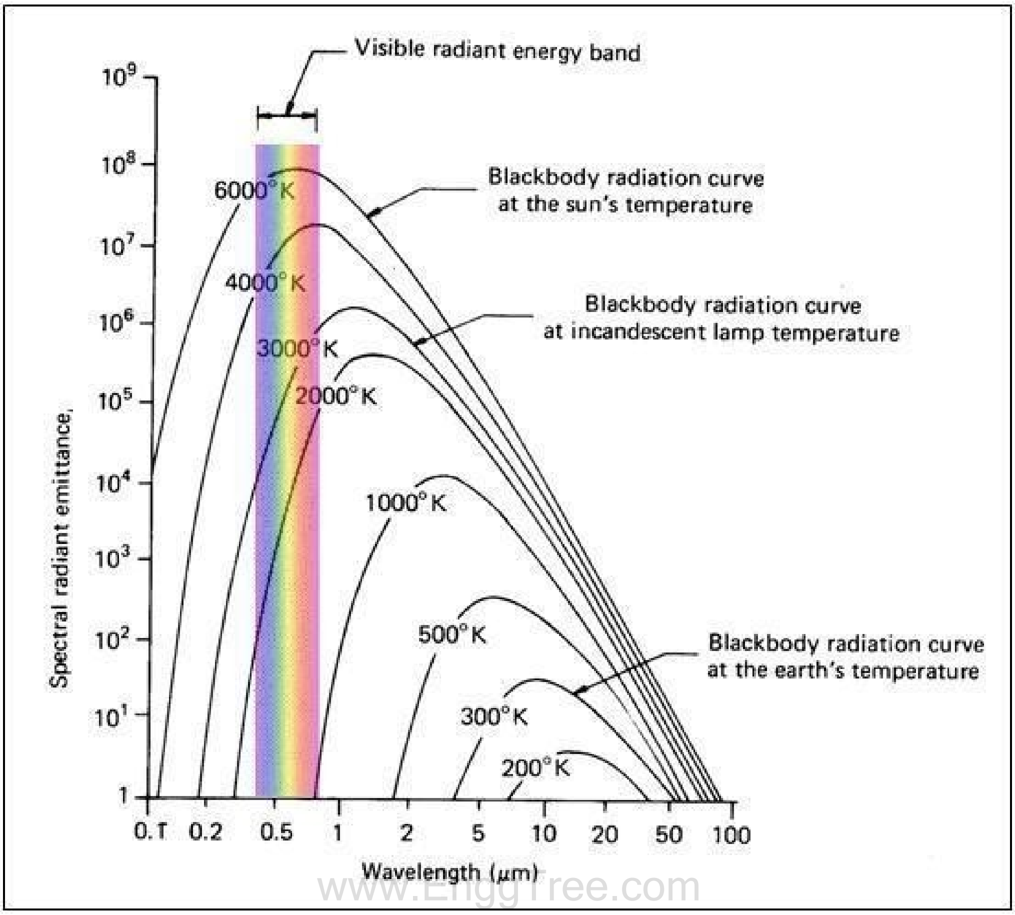


Figure5. Spectral energy distribution of blackbody at various temperatures

From Fig. 4, it can be observed that the peak of the radiant exitance varies with wavelength. As the temperature increases, the peak shifts towards the left. This is explained by the Wien's displacement law. It states that the dominant wavelength at which a black body radiates λ_m is Inversely proportional to the absolute temperature of the black body (in *K*) and is represented as given below.

UNIT II EMR INTERACTION WITH ATMOSPHERE AND EARTH MATERIALS

ENERGY INTERACTIONS WITH THE ATMOSPHERE

Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of scattering and absorption .

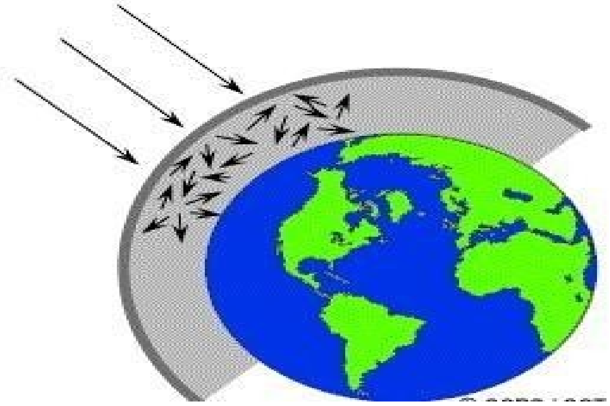


Fig 2.1 Energy Interaction with Atmosphere

SCATTERING

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. How much scattering takes place dependson several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere. Thereare three (3) types of scattering which take place.

RAYLEIGH SCATTERING

Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. These could bearticles such as small specks of dust or nitrogenand oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during theday is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. At **sunrise and sunset** the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.

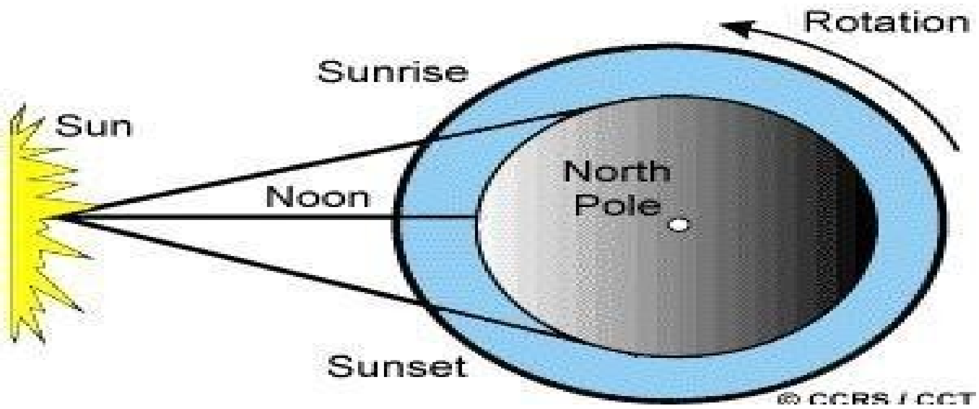


Fig2.2 . Raleigh Scattering

ABORPTION

Absorption is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapor are the three main atmospheric constituents which absorb radiation. **Ozone** serves to absorb the harmful (to most living things) ultraviolet radiation for the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight. **Carbon dioxide** referred to as a greenhouse gas. This is because it tends to absorb radiation strongly in the far infrared portion of the spectrum - that area associated with thermal heating - which serves to trap this heat inside the atmosphere. Water vapour in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation (between 22μm and 1m). The presence of water vapour in the lower atmosphere varies greatly from location to location and at different times of the year. For example, the air mass above a desert would have very little water vapour to absorb energy, while the tropics would have high concentrations of water vapour (i.e. high humidity).

MIE SCATTERING

Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

The final scattering mechanism of importance is called **nonselective scattering**. This occurs when the particles are much larger than the wavelength of the radiation.

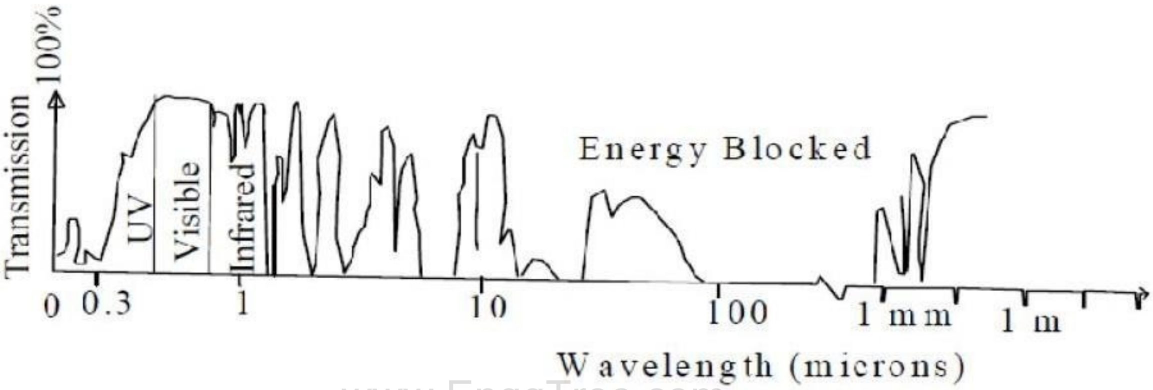
Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue+green+red light = white light).

ATMOSPHERIC WINDOWS

While EMR is transmitted from the sun to the surface of the earth, it passes through the atmosphere. Here, electromagnetic radiation is scattered and absorbed by gases and dust particles. Besides the major atmospheric gaseous components like molecular nitrogen and oxygen, other constituents like water vapour, methane, hydrogen, helium and nitrogen compounds play important role in modifying electro magnetic radiation. This affects image quality. Regions of the electromagnetic spectrum in which the atmosphere is transparent are called atmospheric windows. In other words, certain spectral regions of the electromagnetic radiation pass through the atmosphere without much attenuation are called atmospheric windows. The atmosphere is practically transparent in the visible region of the electromagnetic spectrum and therefore, many of the satellite based remote sensing sensors are designed to collect data in this region. Some of the commonly used atmospheric windows are shown in the figure.

Figure . They are: 0.38-0.72 microns (visible), 0.72-3.00 microns (near infra-red and middle infra-red), and 8.00-14.00 microns (thermal infra-red).

Transmission100%UVVisibleInfraredEnergy Blocked0.3 Wavelength (microns)1101001 mm



SPECTRAL SIGNATURE CONCEPTS-TYPICAL SPECTRAL REFLECTANCE **CHARACTRISTICS OF WATER, VEGETATION AND SOIL:**

A basic assumption made in remote sensing is that a specific target has an individual and characteristic manner of interacting with incident radiation. The manner of interaction is described by the spectral response of the target. The spectral reflectance curves describe the spectral response of a target in a particular wavelength region of electromagnetic spectrum, which, in turn depends upon certain factors, namely, orientation of the sun (solar azimuth), the height of the Sun in the sky (solar elevation angle), the direction in which the sensor is pointing relative to nadir (the look angle) and nature of the target, that is, state of health of vegetation.

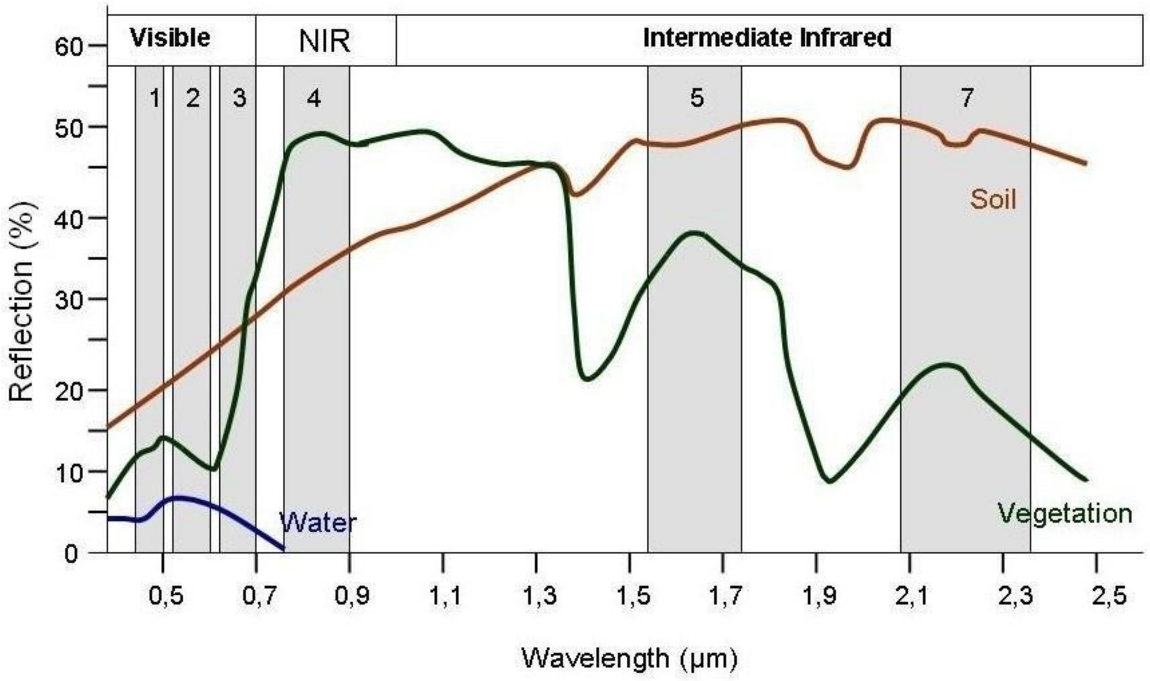


Fig 2.3 Spectral reflectance Curve

Every object on the surface of the earth has its unique spectral reflectance. Fig. 2.3 shows the average spectral reflectance curves for three typical earth's features: vegetation, soil and water. The spectral reflectance curves for vigorous vegetation manifests the "Peak- and-valley" configuration. The valleys in the visible portion of the spectrum are indicative of pigments in plant leaves. Dips in reflectance (Fig. 2.3) that can be seen at wavelengths of

0.65 .µm, 1.4 µm and 1.9 µm are attributable to absorption of water by leaves. The soil curve shows a more regular variation of reflectance. Factors that evidently affect soil reflectance are moisture content, soil texture, surface roughness, and presence of organic matter. The term spectral signature can also be used for spectral reflectance curves. Spectral signature is a set of characteristics by which a material or an object may be identified on any satellite image or photograph within the given range of wavelengths. Some time &, spectral signatures are used to denote the spectral response of a target.

The characteristic spectral reflectance curve Fig2.3 for water shows that from about 0.5µm, a reduction in reflectance with increasing wavelength, so that in the near infrared range, the reflectance of deep, clear water is virtually a zero (Mather, 1987). However, the spectral reflectance of water is significantly affected by the presence of dissolved and suspended organic and inorganic material and by the depth of the water body. Fig. 1.8 shows the spectral reflectance curves for visible and near-infrared wavelengths at the surface and at 20 m depth.

Suspended solids

in water scatter the down welling radiation, the degree of scatter being proportional to the concentration and the color of the sediment. Experimental studies in the field and in the laboratory as well as experience with multispectral remote sensing have shown that the specific targets are characterized by an individual spectral response. Indeed, the successful development of remote sensing of environment over the past decade bears witness to its validity. In the remaining part of this section, typical and representative spectral reflectance curves for characteristic types of the surface materials are considered. Imagine a beach on a beautiful tropical island. of electromagnetic radiation with the top layer of sand grains on the beach. When an incident ray of electromagnetic radiation strikes an air/grain interface, part of the ray is reflected and part of it is transmitted into the sand grain. The solid lines in the figure represent the incident rays, and dashed lines 1, 2, and 3 represent rays reflected from the surface but have never penetrated a sand grain. The latter are called specular rays by Vincent and Hunt (1968), and surface-scattered rays by Salisbury and Wald

(1992); these rays result from first-surface reflection from all grains encountered. For a given reflecting surface, all specular rays reflected in the same direction, such that the angle of reflection (the angle between the reflected rays and the normal, or perpendicular to the reflecting surface) equals the angle of incidence (the angle between the incident rays and the surface normal). The measure of how much electromagnetic radiation is reflected off a surface is called its reflectance, which is a number between 0 and 1.0. A measure of 1.0 means the 100% of the incident radiation is reflected off the surface, and a measure of 0 means that 0% is reflected.

ENERGY INTERACTIONS WITH EARTH SURFACE FEATURES

Energy incident on the Earth‘s surface is absorbed, transmitted or reflected depending on the wavelength and characteristics of the surface features (such as barren soil, vegetation, water body). Interaction of the electromagnetic radiation with the surface features is dependent on the characteristics of the incident radiation and the feature characteristics. After interaction with the surface features, energy that is reflected or re-emitted from the features is recorded at the sensors and are analysed to identify the target features, interpret the distance of the object, and /or its characteristics.

This lecture explains the interaction of the electromagnetic energy with the Earth‘s surface features.

Energy Interactions

The incident electromagnetic energy may interact with the earth surface features in three possible ways: Reflection, Absorption and Transmission. These three interactions are

Reflection Absorption Earth Transmission

Incident radiation

Reflection occurs when radiation is redirected after hitting the target. According to the law of reflection, the angle of incidence is equal to the angle of reflection the EM energy which is absorbed by the Earth‘s surface is available for emission and as thermal radiation at longer wavelengths.

Transmission occurs when radiation is allowed to pass through the target. Depending upon the characteristics of the medium, during the transmission velocity and wavelength of the radiation changes, whereas the frequency remains same. The transmitted energy may further get scattered and / or absorbed in the medium.

These three processes are not mutually exclusive. Energy incident on a surface may be partially reflected, absorbed or transmitted. Which process takes place on a surface depends on the following factors:

- Wavelength of the radiation
- Angle at which the radiation intersects the surface
- Composition and physical properties of the surface

The relationship between reflection, absorption and transmission can be expressed through the principle of conservation of energy. Let E_I denotes the incident energy, E_R denotes the reflected energy, E_A denotes the absorbed energy and E_T denotes the transmitted energy. Then the principle of conservation of energy (as a function of wavelength λ) can be expressed as

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda) \quad (1)$$

Since most remote sensing systems use reflected energy, the energy balance relationship can be better expressed in the form

$$E_R(\lambda) = E_I(\lambda) - E_A(\lambda) - E_T(\lambda) \quad (2)$$

The reflected energy is equal to the total energy incident on any given feature reduced by the energy absorbed or transmitted by that feature.

Reflection

Reflection is the process in which the incident energy is redirected in such a way that the angle of incidence is equal to the angle of reflection. The reflected radiation leaves the surface at the same angle as it approached.

Scattering is a special type of reflection wherein the incident energy is diffused in many directions and is sometimes called diffuse reflection.

When electromagnetic energy is incident on the surface, it may get reflected or scattered depending upon the roughness of the surface relative to the wavelength of the incident energy. If the roughness of the surface is less than the wavelength of the radiation or the ratio of roughness to wavelength is less than 1, the radiation is reflected. When the ratio is more than 1 or if the roughness is more than the wavelength, the radiation is scattered.

Fraction of energy that is reflected / scattered is unique for each material. This will aid in distinguishing different features on an image

A feature class denotes distinguishing primitive characteristic or attribute of an image that have been classified to represent a particular land cover type/spectral signature. Within one feature class, the proportion of energy reflected, emitted or absorbed depends on the wavelength. Hence, in spectral range two features may be indistinguishable; but their reflectance properties may be different in another spectral band. In multi-spectral remote sensing, multiple sensors are used to record the reflectance from the surface features at different wavelength bands and hence to differentiate the target features.

Variations in the spectral reflectance within the visible spectrum give the colour effect to the features.

For example, blue colour is the result of more reflection of blue light. An object appears as ―green‖ when it reflects highly in the green portion of the visible spectrum. Leaves appear green since its chlorophyll pigment absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Similarly, water looks blue-green or blue or green if viewed through visible band because it reflects the shorter wavelengths and absorbs the longer wavelengths in the visible band. Water also absorbs the near infrared wavelengths and hence appears darker when viewed through red or near infrared wavelengths. Human eye uses reflected energy variations in the visible spectrum to discriminate between various features.

For example, shows a part of the Krishna River Basin as seen in different bands of the Landsat ETM+ imagery. As the concepts of false colour composite (FCC) have been covered in module 4, readers are advised to refer to the material in module 4 for better understanding of the colour composite imageries as shown in Fig. 5. Reflectance of surface features such as water, vegetation and fallow lands are

different in different wavelength bands. A combination of more than one spectral band helps to attain better differentiation of these features.

Diffuse and Specular Reflection

Energy reflection from a surface depends on the wavelength of the radiation, angle of incidence and the composition and physical properties of the surface.

Roughness of the target surface controls how the energy is reflected by the surface. Based on the roughness of the surface, reflection occurs in mainly two ways.

Specular reflection: It occurs when the surface is smooth and flat. A mirror-like or smooth reflection is obtained where complete or nearly complete incident energy is reflected in one direction. The angle of reflection is equal to the angle of incidence. Reflection from the surface is the maximum along the angle of reflection, whereas in any other direction it is negligible.

Diffuse (Lambertian) reflection: It occurs when the surface is rough. The energy is reflected uniformly in all directions. Since all the wavelengths are reflected uniformly in all directions, diffuse reflection contains spectral information on the "color" of the reflecting surface. Hence, in remote sensing diffuse reflectance properties of terrain features are measured. Since the reflection is uniform in all direction, sensors located at any direction record the same reflectance and hence it is easy to differentiate the features.

Based on the nature of reflection, surface features can be classified as specular reflectors, Lambertian reflectors. An ideal specular reflector completely reflects the incident energy with angle of reflection equal to the angle incidence. An ideal Lambertian or diffuse reflector scatters all the incident energy equally in all the directions.

The specular or diffusive characteristic of any surface is determined by the roughness of the surface in comparison to the wavelength of the incoming radiation. If the wavelengths of the incident energy are much smaller than the surface variations or the particle sizes, diffuse reflection will dominate. For example, in the relatively long wavelength radio range, rocky terrain may appear smooth to incident energy. In the visible portion of the spectrum, even a material such as fine sand appears rough while it appears fairly smooth to long wavelength microwaves.

Most surface features of the earth are neither perfectly specular nor perfectly diffuse reflectors. In near specular reflection, though the reflection is the maximum along the angle of reflection, a fraction of the energy also gets reflected in some other angles as well. In near Lambertian reflector, the reflection is not perfectly uniform in all the directions. The characteristics of different types of reflectors are

Near diffusive Near specular Ideal diffusive Ideal specular Angle of reflection Angle of incidence

Lambertian reflectors are considered ideal for remote sensing. The reflection from an ideal Lambertian surface will be the same irrespective of the location of the sensor. On the other hand, in case of an ideal specular reflector, maximum brightness will be obtained only at one location and for the other locations dark tones will be obtained from the same target. This variation in the spectral signature for the same feature affects the interpretation of the remote sensing data.

Most natural surfaces observed using remote sensing are approximately Lambertian at visible and IR wavelengths. However, water provides specular reflection. Water generally gives a dark tone in the image. However due to the specular reflection, it gives a pale tone when the sensor is located in the direction of the reflected energy.

Spectral Reflectance of Earth Surface

Vegetation

In general, healthy vegetation is a very good absorber of electromagnetic energy in the visible region. Chlorophyll strongly absorbs light at wavelengths around 0.45 (blue) and 0.67 µm (red) and reflects strongly in green light, therefore our eyes perceive healthy vegetation as green. Healthy plants have a high reflectance in the near-infrared between 0.7 and 1.3 µm. This is primarily due to healthy internal structure of plant leaves. As this internal structure varies amongst different plant species, the near infrared wavelengths can be used to discriminate between different plant species.

Water

In its liquid state, water has relatively low reflectance, with clear water having the greatest reflectance in the blue portion of the visible part of the spectrum. Water has high absorption and virtually no reflectance in near infrared wavelengths range and beyond. Turbid water has a higher reflectance in the visible region than clear water. This is also true for waters containing high chlorophyll concentrations.

Ice and Snow

Ice and snow generally have high reflectance across all visible wavelengths, hence their bright white appearance. Reflectance decreases in the near infrared portion and there is very low reflectance in the SWIR (shortwave infrared). The low reflection of ice and snow in the SWIR is related to their microscopic liquid water content. Reflectance differs for snow and ice depending on the actual composition of the material including impurities and grain size.

Soil

Bare soil generally has an increasing reflectance, with greater reflectance in near-infrared and shortwave infrared. Some of the factors affecting soil reflectance are:

- Moisture content
- Soil texture (proportion of sand, silt, and clay)
- Surface roughness
- Presence of iron oxide
- Organic matter content

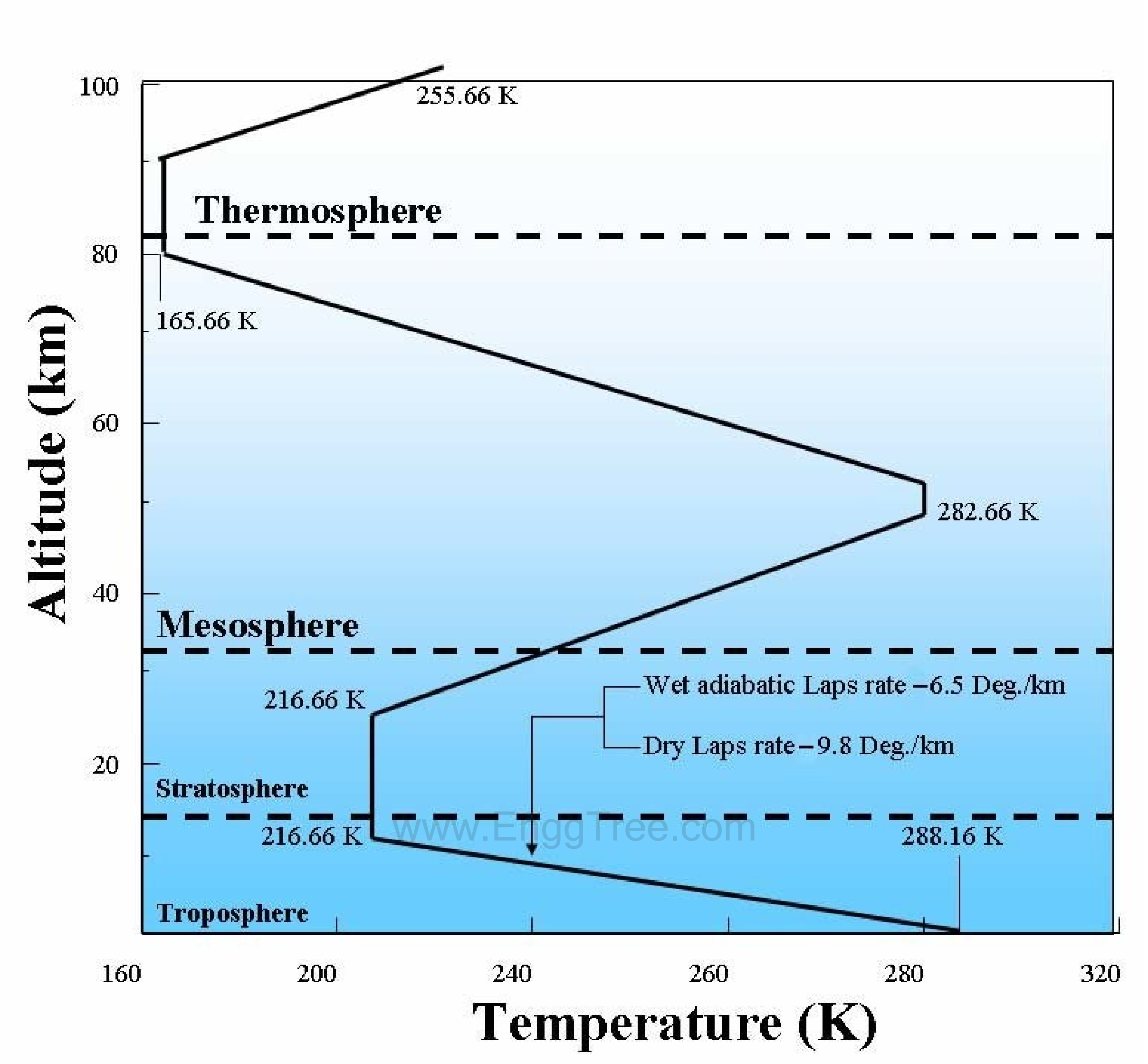
UNIT -II EMR INTERACTION WITH ATMOSPHERE AND EARTH MATERIAL

Standard atmospheric profile:

The standard atmospheric profile is a representation of the vertical distribution of key atmospheric parameters under standard atmospheric conditions. These conditions are typically used as a reference for various scientific and engineering purposes. The standard atmospheric profile provides information on temperature, pressure, density, and other atmospheric properties at different altitudes.

Here is a brief overview of the standard atmospheric profile according to this model:

1. Troposphere (0 to 11 kilometres or 0 to 36,090 feet):
    - Temperature: Generally decreases with altitude.
    - Pressure: Decreases exponentially with altitude.
    - Density: Decreases with altitude.
    - Contains about 75-80% of the total atmospheric mass.
    - Most weather events occur in this layer.
2. Stratosphere (11 to 50 kilometres or 36,090 to 164,042 feet):
    - Temperature: Initially remains constant, then increases with altitude due to the presence of the ozone layer.
    - Pressure: Decreases with altitude.
    - Density: Decreases with altitude.
    - Contains the ozone layer, which absorbs and scatters ultraviolet (UV) solar radiation.
3. Mesosphere (50 to 85 kilometres or 164,042 to 278,871 feet):
    - Temperature: Decreases with altitude.
    - Pressure: Decreases with altitude.
    - Density: Decreases with altitude.
    - Where most meteorites burn up upon entering the Earth's atmosphere.
4. Thermosphere (85 to 600 kilometres or 278,871 to 1,968,504 feet):
    - Temperature: Increases significantly with altitude due to the absorption of high-energy solar radiation.
    - Pressure: Extremely low, almost a vacuum.
    - Density: Extremely low, with individual molecules widely spaced.
    - The region where the International Space Station (ISS) orbits.



Main Atmospheric Regions and its Characteristics:

The Earth's atmosphere is divided into several main regions, each with distinct characteristics in terms of temperature, pressure, composition, and other properties.

1. **Troposphere:**
    - **Altitude:** 0 to approximately 8-15 kilometers (0 to 5-9 miles).
    - **Characteristics:**
        - Decreasing temperature with altitude.
        - Where weather events, including clouds and precipitation, occur.
        - Contains the majority of the Earth's atmospheric mass.

2. **Stratosphere:**
    - **Altitude:** Approximately 15 to 50 kilometers (9 to 31 miles).
    - **Characteristics:**
        - Temperature generally increases with altitude due to the presence of the ozone layer.
        - Contains the ozone layer, which absorbs and scatters ultraviolet (UV) solar radiation.
        - Jet streams are found in the upper part of this layer.
3. **Mesosphere:**
    - **Altitude:** Approximately 50 to 85 kilometers (31 to 53 miles).
    - **Characteristics:**
        - Decreasing temperature with altitude.
        - The region where meteorites burn up upon entering the Earth's atmosphere.
        - Thermospheric temperatures decrease with altitude.
4. **Thermosphere:**
    - **Altitude:** Approximately 85 kilometers and extends upward to about 600 kilometers (53 miles to about 373 miles).
    - **Characteristics:**
        - Temperature increases significantly with altitude due to the absorption of high-energy solar radiation.
        - Extremely low pressure and density.
        - The region where auroras occur.
5. **Exosphere:**
    - **Altitude:** Beyond 600 kilometers (373 miles) and extends into space.
    - **Characteristics:**
        - Gradual transition to the vacuum of space.
        - Very low density of gas particles.
        - Satellites orbit in this region.

Interaction of radiation with atmosphere – Scattering, absorption and refraction

EMR interactions with the Earth's atmosphere and surface

After electromagnetic radiation has been created by the Sun, the part of it that has found its way through the vacuum of space to the top of the Earth's atmosphere must pass through the atmosphere, be reflected by the Earth's surface, pass through the atmosphere again on its way back to space, and then arrive at the sensor in order to be recorded. While nothing happens to the radiation field as it passes through empty space, several things happen as it interacts with the Earth's atmosphere and surface. It is due to these interactions that the measured radiation ends up containing information about the Earth environment, so it is important to take a closer look at exactly what happens in these interactions, and how it affects the radiation field.

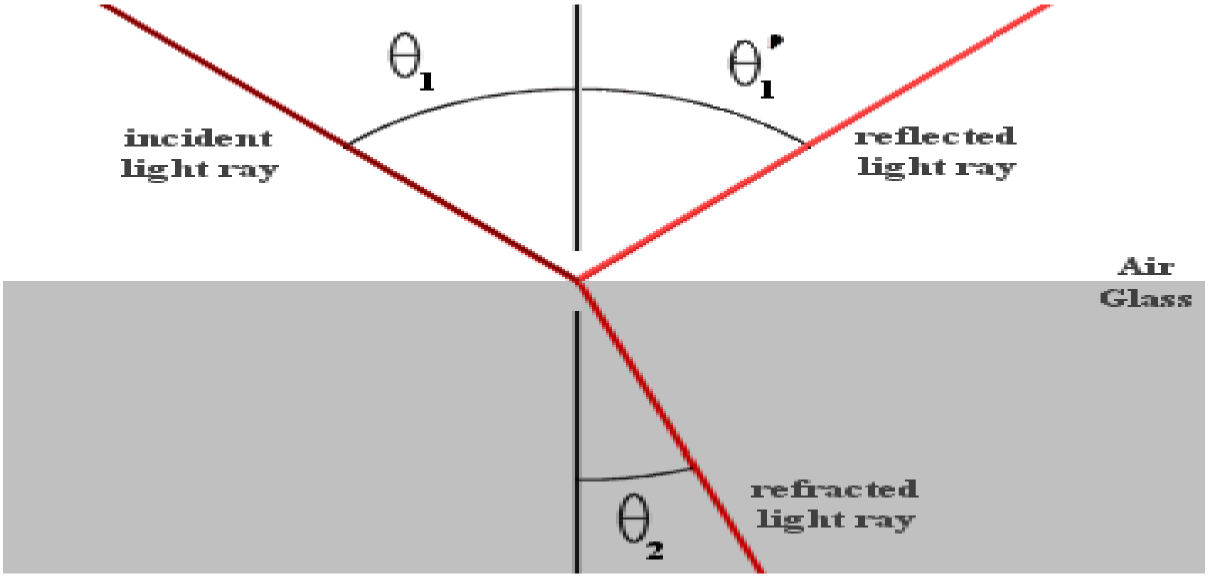
Interactions with the atmosphere

The interaction between electromagnetic radiation and the Earth's atmosphere can be considered to have three components: *refraction* that changes the direction of propagation of the radiation field due to density differences between outer space and the atmosphere, *scattering* that changes the direction of propagation of individual photons as they are absorbed and re-emitted by gasses or aerosols or other atmospheric constituents without changing wavelength, and *absorption* that convert photons into vibrations in a molecule, energy which is (later) re-emitted as one or more photons with longer wavelength(s). Each will be considered in more detail below.

Refraction

Refraction is the bending (and slowing down) of the direction of propagation of electromagnetic radiation as it moves between two media with different densities. This happens as radiation arrives from outer space (density ≈0) and enters the atmosphere (density >0). The angle at which the direction of propagation changes is determined by the refractive indices of the two media. The refractive index of a medium (n) is determined as the ratio of the speed of electromagnetic radiation in a vacuum (c) to the similar speed in the medium (c_n): $n=c/c_n$. The refractive index of a standard atmosphere is 1.0003, while the refractive index of water is 1.33. Using the refractive indices of the two media, the amount of refraction can be determined with Snell's Law: $n_1 * \sin\Theta_1 = n_2 * \sin\Theta_2$.

where n are the refractive indices of the two media and Θ are the angles at which the direction of propagation intersects the normal of the surface separating the two media (Figure 22). Refraction is rarely a relevant factor in the practical use of remote sensing data. Its only important influence concerns the georeferencing of imagery collected when the Sun is close to the horizon, and this is a problem that is nearly always dealt with by the image provider. One important situation in which refraction is important and must be considered is when an image analyst needs to precisely geolocate underwater objects (such as features on the seafloor in coastal areas).



One of the two remaining processes that influence electromagnetic radiation as it passes through the atmosphere is scattering. Scattering happens when a photon interacts with something in the atmosphere that causes it to change direction. Depending on the size of the object that the photon interacts with, two distinct types of scattering are recognized. *Rayleigh* scattering happens when the object is much smaller than the wavelength of the radiation. In the case of sunlight and the Earth's atmosphere this means that Rayleigh scattering is cause by atmospheric gasses like N_2, O_2, CO_2 etc. *Mie* scattering happens when the object is similar in size to the wavelength of the radiation, which means that it is caused by aerosols like smoke and dust particles. Additional scattering can happen if radiation interacts with particles larger in size than its wavelength, like water droplets or sand particles.

While refraction is predictable and can be determined by Snell's Law, scattering is an inherently stochastic process: what happens to an individual photon as it passes through the atmosphere is entirely unpredictable, including whether or not it experiences any scattering, and if so which direction it is reemitted in. However, the magnitude and direction of scattering that happens on average to the many photons in a radiation field is predictable.

Rayleigh scattering

A fact that has great importance for remote sensing of the Earth is that the magnitude of Rayleigh scattering is inversely related to the 4th power of the wavelength of the radiation. In other words, radiation with shorter wavelengths is scattered much more by Rayleigh scattering than radiation at longer wavelengths. In the visible wavelengths, this means that blue light is scattered more than green light, which in turn is scattered more than red light. This is the process that makes the Earth's oceans look blue when viewed from space. What happens is that over very dark Earth surfaces, such as the oceans, the majority of radiation reaching the Earth surface is absorbed rather than reflected by it. What is visible from space is thus not radiation reflected by the surface, but rather radiation scattering from within the atmosphere. Because blue wavelengths are those most strongly scattered through Rayleigh scattering, this scattered radiation as a whole looks blue (Figure 23). Another effect of Rayleigh scattering is that regardless of what is on the Earth's surface, a space-based sensor will detect a substantial amount of blue light coming from the Earth-Atmosphere system. This can be a problem because the 'blue signal' form the atmosphere overwhelms variations in 'blue reflectance' on the surface. But it can also be an advantage, because measurements in the blue wavelengths can help assess the strength of Rayleigh scattering across the visible and infrared spectrum, which can in turn be corrected for. This is the basis for the ‘aerosol’ band that was included on Landsat 8 OLI (but was not found on its predecessor instruments), on Sentinel-2, and on the WorldView-2 and -3 sensors.

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While any scattering in the atmosphere is a source of noise (for those interested in using satellite imagery to characterize the Earth’s surface), Rayleigh scattering is a relatively benign source of noise because its wavelength dependence makes it largely predictable, and because the gasses responsible for it tend to have stable concentrations across space and time. Rayleigh scattering is therefore not a source of great uncertainty for most remote sensing applications.

Mie scattering

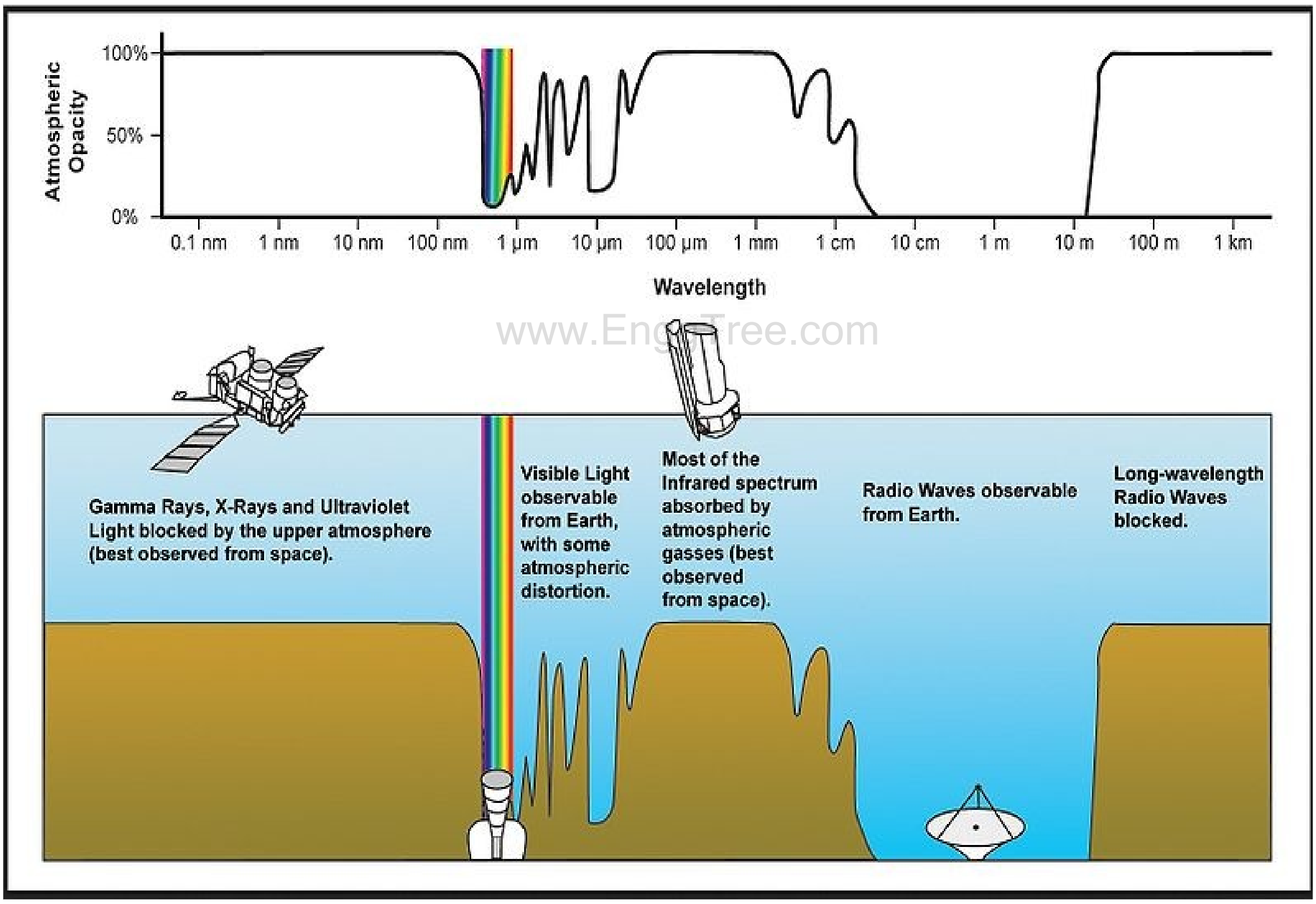
Mie scattering, because its strength and wavelength dependence depends on the type and density of the particulates that cause it to happen, varies substantially through time and space. As a result it is one of the most important causes of uncertainty in remote sensing, especially when using satellite data to study dark parts of the Earth’s surface from which the amount of reflected radiation is small relative to the total signal from atmospheric scattering. For the same reason it is hard to generalize its importance, but broadly speaking the strength of Mie scattering exceeds that of Rayleigh scattering, and while it still diminishes with increasing wavelength its influence extends further into the infrared spectrum. Because Mie scattering is caused by atmospheric particulates, it is often dramatically increased during dust storms, forest fires, or other events that caused the atmospheric aerosol load to increase. One such example is seen in Figure 24.

Absorption

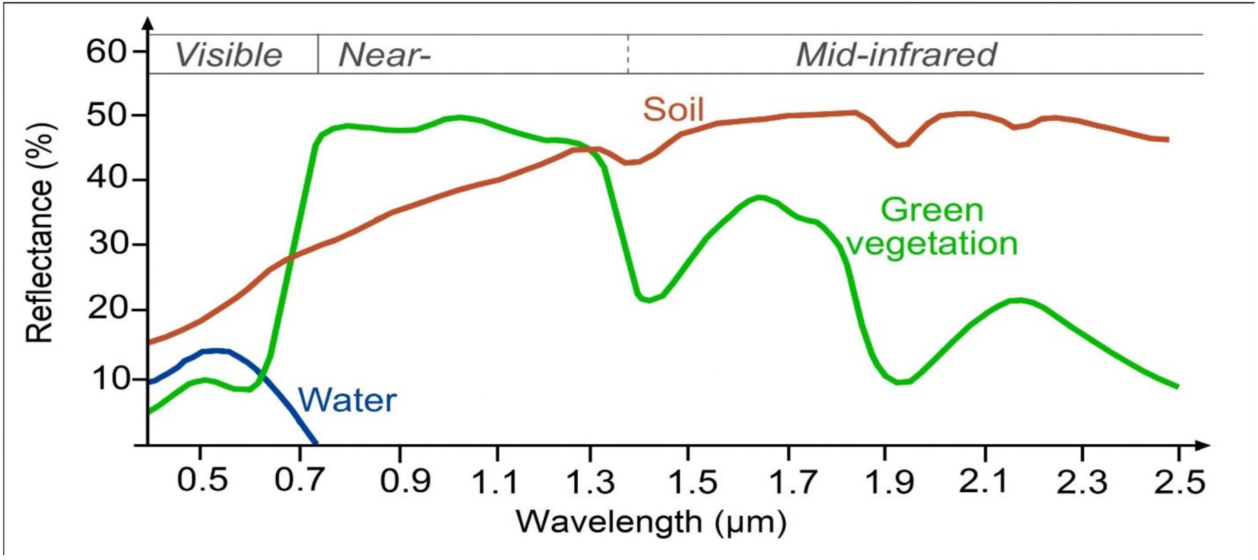
The last important thing that happens to electromagnetic radiation as it passes through the atmosphere is that it is partially absorbed by atmospheric gasses (mostly H_2O, CO_2 and O_3). While the energy absorbed is ultimately re-emitted by these gas molecules, the re-emission happens at wavelengths typically outside the spectrum considered in optical remote sensing (but which may be important for thermal remote sensing), so for practical purposes the absorbed photons can be considered gone when absorbed. The strength of absorption is highly dependent on wavelength because it happens most easily when the radiation has a wavelength (frequency) that is similar to a resonant frequency of the gas doing the absorption, which in turn depends on its atomic or molecular structure. For example, due to its molecular structure, O_2 is particularly good at absorbing electromagnetic radiation with wavelengths right around 760 nm, but not at 750 or 770 nm. Similar wavelengths exist at which other gasses are effective or not at absorbing EMR, and in combination the atmospheric gasses let some wavelengths pass through the atmosphere with almost no absorption, while other wavelengths are almost entirely absorbed before they reach the surface of the Earth (Figure 25 and Figure 26). As is especially clear in Figure 26, water vapour is responsible for much of the total gaseous absorption of EMR in the atmosphere, including in the visible spectrum (not clearly shown on that figure). This is an important challenge for remote sensing because while the concentrations of the other gasses are relatively stable through time and space, water vapour concentrations vary greatly through time (humid vs. dry days) and through space (dry arctic vs. humid tropical

Interactions with the surface

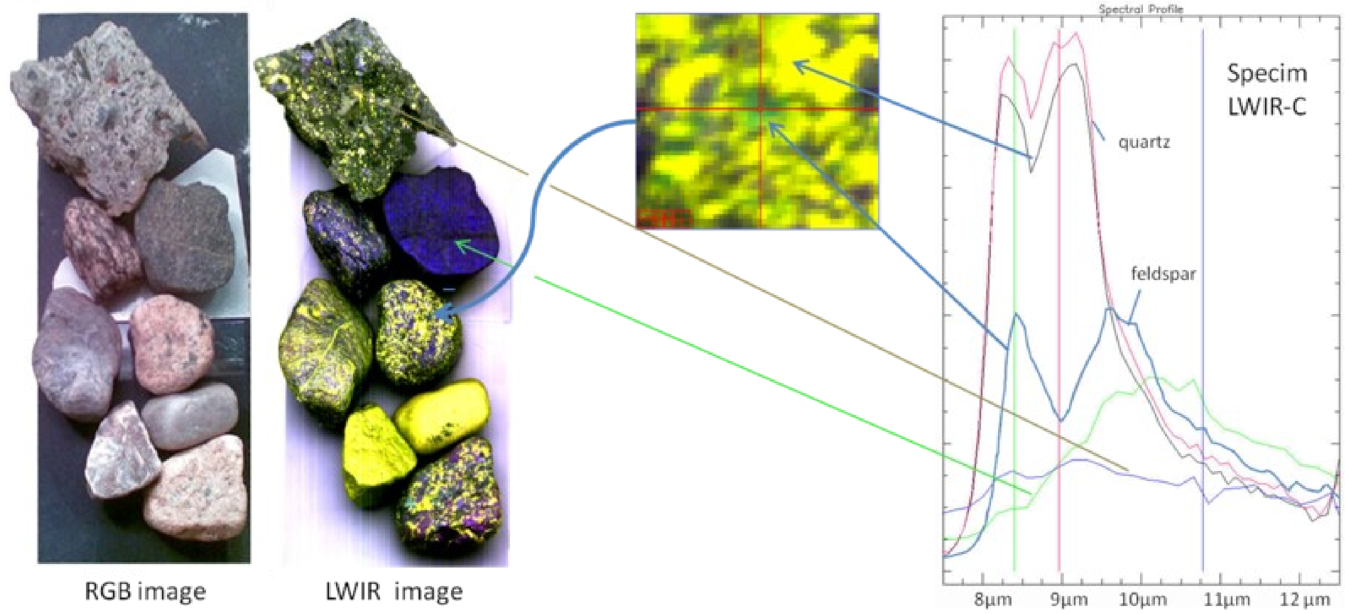
The part of the radiation field that has made it through the atmosphere without being absorbed or scattered back toward space now reaches the Earth's surface. For any wavelength that is of relevance to remote sensing, only one of two things can now happen to each individual photon – it can be absorbed by the Earth's surface, or it can be reflected back toward space. The probability of reflection rather than absorption happening is termed the reflectance of the surface, and it depends on the material on the surface as well as the wavelength of the incoming radiation. Each surface material has a unique 'signature' that defines what proportion of radiation is reflected for each wavelength. For example, water reflects a small amount of blue and green wavelengths (typically around 5% – 10% depending on turbidity), less of the red wavelengths, and almost nothing in the infrared wavelengths. Vegetation, on the other hand, reflected around half of all incoming infrared radiation, except for specific wavelengths that are effectively absorbed by liquid water in the leaves. These spectral signatures are commonly portrayed as graphs, with wavelengths along the x-axis and reflectance along the y-axis (as in Figure 27).



Spectral signatures are what enables us to differentiate between different materials on the Earth’s surface when we look at a satellite image. As shown in Figure 27, water has near-zero reflectance at wavelengths longer than 0.7 µm (700 nm), while both soil and green vegetation has reflectances around 40% at 1.3 µm. Measuring the amount of radiation reflected off the Earth-Atmosphere system at 1.3 µm will thus be particularly helpful at differentiating water from the two terrestrial surface types. Similarly, measurements at wavelengths around 1.4 µm (where liquid water in vegetation is a strong absorber) or 1.9 µm (same) can be effective to differentiate between soil and green vegetation.



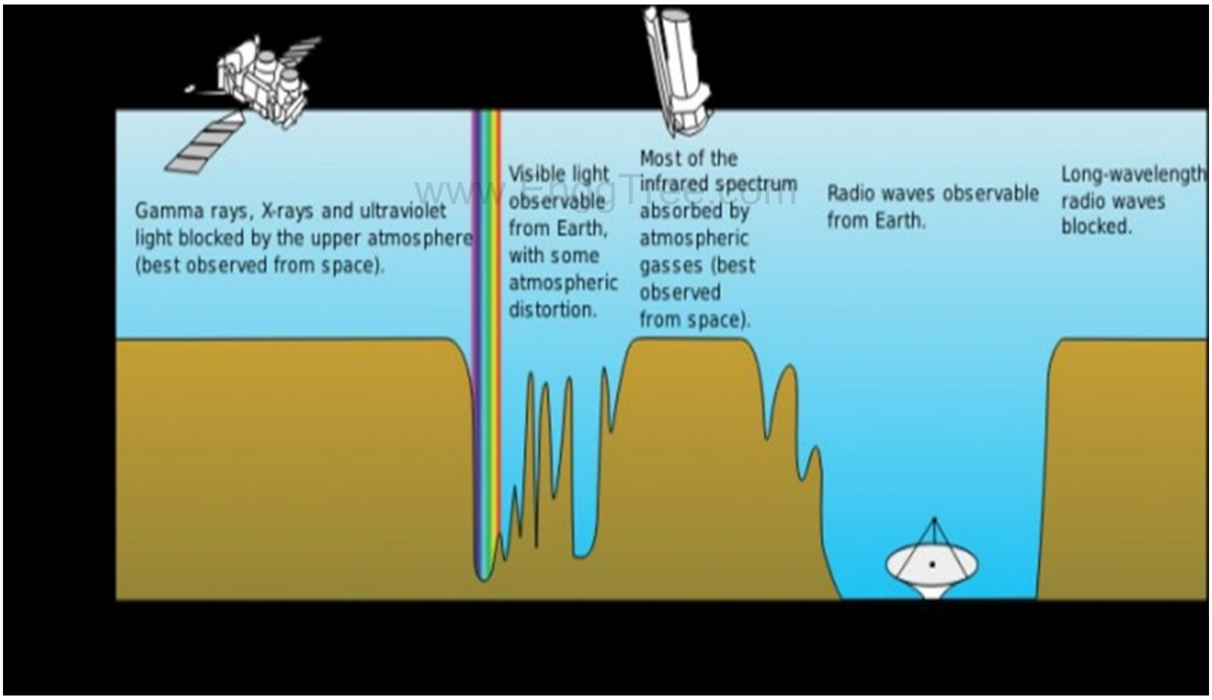
As a more detailed example, spectral signatures have been effective for large-scale geological surveying/prospecting because different minerals (that may be characteristic of different sub-surface conditions) can be identified through their unique spectral signatures (Figure 28).



The part of the radiation field that is reflected by the Earth’s surface must naturally make its way back up through the atmosphere, with the attendant refraction, scattering and absorption, before it can be measured by any space-based sensor. While there are many relative advantages and disadvantages to air-borne vs. space-borne sensors, the ability of air-borne sensors to measure the reflected EMR field before it has had to pass through the atmosphere a second time is one distinct advantage.

Atmospheric Windows:

"atmospheric windows" refer to specific wavelength ranges in the electromagnetic spectrum where the Earth's atmosphere is relatively transparent, allowing certain types of electromagnetic radiation to pass through with minimal absorption or interference. These windows are crucial for observations and measurements from ground-based or space-based instruments, as they enable the study of celestial objects, weather patterns, and various Earth processes. Different atmospheric windows exist for different regions of the electromagnetic spectrum. Some key atmospheric windows include:



1. **Visible Light:**
    - The atmosphere is highly transparent to visible light, allowing sunlight to reach the Earth's surface. This transparency is essential for human vision and for various optical observations.
2. **Near-Infrared (NIR):**

- Certain wavelengths in the near-infrared region are relatively transparent in the Earth's atmosphere. This transparency is exploited in remote sensing applications, such as satellite imagery, where NIR observations provide valuable information about vegetation health, cloud cover, and surface characteristics.

3. **Shortwave Infrared (SWIR):**

    - Similar to NIR, the shortwave infrared region also has atmospheric windows that allow certain wavelengths to pass through. This is useful for various remote sensing applications, including geological studies and moisture content measurements.

4. **Radio Waves:**

    - In the radio frequency range, there are specific atmospheric windows that allow radio waves to propagate efficiently. This is important for radio astronomy and communication purposes.

5. **Microwaves:**

    - Microwaves have specific atmospheric windows that are exploited in applications such as weather radar, microwave ovens, and satellite communication.

6. **Millimeter and Submillimeter Waves:**

    - Certain atmospheric windows exist for observing millimeter and submillimeter waves. These windows are crucial for studying molecular transitions in the Earth's atmosphere and for astronomical observations.

astronomers choose specific wavelengths that are transparent to the Earth's atmosphere for ground-based and space-based observations to minimize distortion and absorption. Remote sensing applications, including satellite observations and weather monitoring, also benefit from knowledge about atmospheric windows to capture accurate and meaningful data.

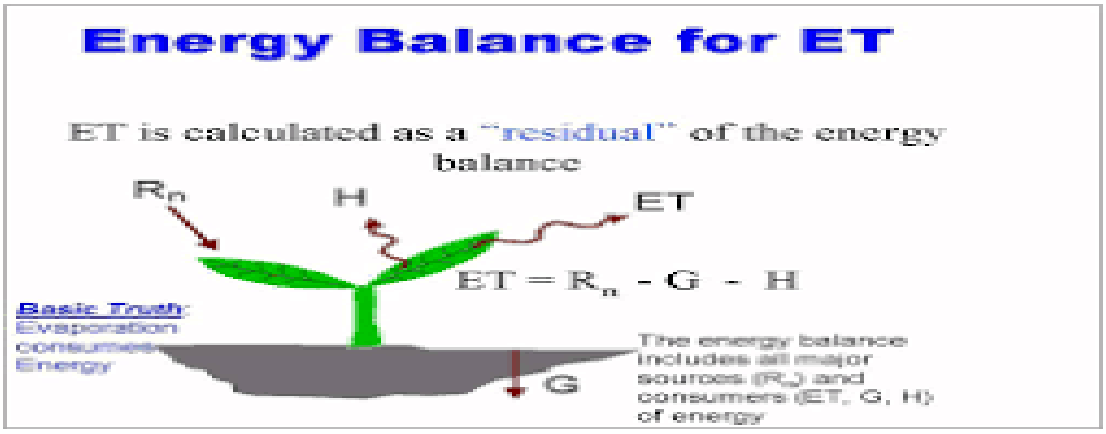
Energy Balance Equation:

energy balance equation is a fundamental principle in thermodynamics and physics, expressing the conservation of energy within a system. It is commonly used in various fields, including physics, engineering, and environmental science. The general form of the energy balance equation can be stated as:

Energy In−Energy Out=Energy Stored Energy Lost

In more specific terms, considering a closed system, the equation can be written as:

Σin−Σout=Δsystem



Energy Balance for ET

ET is calculated as a "residual" of the energy balance

$ET = R_n - G - H$

Basic Truth: Evaporation consumes Energy

The energy balance includes all major sources (R_n) and consumers (ET, G, H) of energy

Where:

- Σin represents the sum of all forms of energy entering the system.
- Σout represents the sum of all forms of energy leaving the system.
- Δsystem represents the change in internal energy of the system.

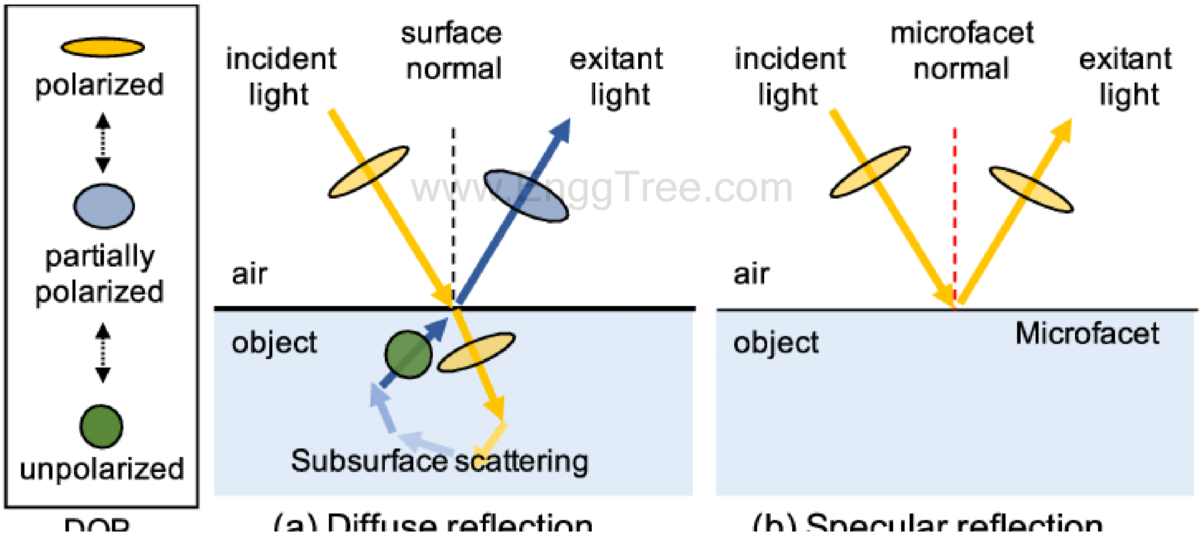
This equation is based on the first law of thermodynamics, which states that energy cannot be created or destroyed; it can only change forms. The energy balance equation helps analyze and quantify the flow of energy in a given system, whether it's a physical process, a chemical reaction, or an environmental system.

Specular and diffuse reflectors:

1. Specular Reflectance in Remote Sensing:
    - Characteristics:
        - Specular reflection is associated with smooth and reflective surfaces.
        - Light reflects off such surfaces in a specific direction, following the law of reflection.
    - Applications:
        - Specular reflection is significant in the study of water bodies. For instance, the sun's reflection on a calm water surface can create specular highlights.
        - It is relevant for monitoring highly reflective surfaces such as glass, metal, or other smooth materials.
2. Diffuse Reflectance in Remote Sensing:
    - Characteristics:
        - Diffuse reflection involves the scattering of light in various directions, typical of rough or non-reflective surfaces.

    - Light interacts with the surface irregularities, scattering in multiple directions.
- Applications:
    - Most natural surfaces, such as vegetation, soil, and rocky terrain, exhibit diffuse reflectance.
    - Diffuse reflection is crucial for assessing land cover types, as different materials have distinct diffuse reflectance signatures.
    - It is used in the analysis of urban areas where building materials and land cover can vary widely.

Remote sensing instruments, such as satellites or airborne sensors, capture the reflected energy from surfaces. Spectral signatures derived from these reflections help identify and classify different materials on the Earth's surface. Analyzing the variations in reflectance properties allows remote sensing scientists to interpret land cover, identify changes, and monitor environmental conditions.



Spectral reflectance & emittance– Spectroradiometer:

Spectral Reflectance in Remote Sensing:

- Definition: Spectral reflectance refers to the ratio of the reflected light intensity from a surface at a particular wavelength to the incident light intensity at the same wavelength.
- Importance: Different materials have unique spectral reflectance signatures, and these signatures are exploited in remote sensing to identify and classify land cover types.

- Measurement: Spectral reflectance is often measured across various wavelengths, forming a spectral reflectance curve or spectrum for a particular material. These curves help create spectral libraries for different surfaces.

Spectral Emittance in Remote Sensing:

- Definition: Spectral emittance is the ratio of the radiant exitance of a surface (emitted radiation) at a particular wavelength to the radiant exitance of a perfect blackbody at the same temperature.

- Importance: Spectral emittance is crucial for studying the thermal properties of surfaces. Different materials emit thermal radiation in distinct ways, and this information is valuable for applications such as land surface temperature estimation.

- Measurement: Similar to spectral reflectance, spectral emittance is measured across different wavelengths, forming an emittance spectrum. This spectrum helps understand how much thermal radiation is emitted by a surface at different wavelengths.

Spectroradiometer in Remote Sensing:

- Definition: A spectroradiometer is an instrument used to measure the intensity of radiation as a function of wavelength. It measures both the spectral reflectance and emittance of surfaces.

- Components: A spectroradiometer typically includes a spectrometer, which disperses light into its different wavelengths, and a radiometer, which measures the intensity of light at those wavelengths.

- Applications: Spectroradiometers are employed in various remote sensing applications, including satellite and airborne sensors. They help collect detailed information about the spectral characteristics of the Earth's surface, aiding in the identification of materials and the assessment of environmental conditions.

In summary, spectral reflectance and emittance, measured by spectroradiometers, are crucial components of remote sensing. They provide valuable information about the interaction of electromagnetic radiation with the Earth's surface, enabling scientists to characterize and analyse different land cover types and understand thermal properties.

Spectral Signature concepts:

Spectral signature is a fundamental concept in remote sensing, describing the unique pattern of energy reflected, emitted, or transmitted by an object or surface across different wavelengths. Each material has a distinct spectral signature, and these signatures are used to identify and classify land cover types, monitor changes, and extract valuable information in remote sensing applications. Here are key concepts related to spectral signatures in remote sensing:

1. **Spectral Bands:**
    - Remote sensing instruments, such as satellites or airborne sensors, are equipped with sensors that capture electromagnetic radiation in specific bands or ranges of the electromagnetic spectrum.
    - Each spectral band corresponds to a particular range of wavelengths, and the combination of bands forms the spectral signature of a surface.
    -
2. **Reflectance and Absorption:**
    - Materials interact with incoming radiation in different ways. Some materials absorb certain wavelengths, while others reflect or transmit them.
    - The reflectance and absorption characteristics of materials contribute to the shape of their spectral signature.

3. **Spectral Reflectance Curves:**
    - The spectral signature is often represented by a spectral reflectance curve, which shows the reflectance values of a material across different wavelengths.
    - Peaks and valleys in the curve correspond to specific features or absorption bands associated with certain materials.
    -
4. **Feature Identification:**
    - Spectral signatures are used to identify and discriminate between different land cover features. For example, vegetation, water bodies, soil, and urban areas have distinct spectral signatures.
    - Comparing the spectral signature of an unknown area to spectral libraries helps in feature identification.

-

5. **Temporal Variability:**
    - Spectral signatures can vary over time due to seasonal changes, growth cycles, or other environmental factors.
    - Monitoring temporal changes in spectral signatures is valuable for tracking land cover dynamics and assessing environmental conditions.
    -
6. **Supervised and Unsupervised Classification:**
    - In image classification, spectral signatures play a crucial role. Supervised classification involves training a classifier using known spectral signatures, while unsupervised classification identifies clusters of similar spectral signatures without predefined classes.
7. **Multispectral and Hyperspectral Imaging:**
    - Multispectral sensors capture data in a few distinct bands, while hyperspectral sensors capture data in numerous narrow bands, providing more detailed spectral information.
    - Hyperspectral imaging allows for finer discrimination between materials with similar spectral signatures.

analysing spectral signatures are essential for extracting meaningful information from remote sensing data, enabling applications such as land cover mapping, environmental monitoring, and resource management.

Typical spectral reflectance curves for vegetation, soil and water:

Spectral reflectance curves for vegetation, soil, and water exhibit distinct patterns across different wavelengths of the electromagnetic spectrum. These characteristic curves help in the identification and classification of land cover types in remote sensing. Here are typical spectral reflectance curves for vegetation, soil, and water:

1. **Vegetation:**
    - **Characteristics:**
        - Vegetation strongly absorbs radiation in the red and blue parts of the spectrum due to the presence of chlorophyll.
        - It reflects strongly in the near-infrared (NIR) region, resulting in a peak in reflectance.
        - The red-edge region (around 700-750 nm) is often characterized by a distinctive change in reflectance due to chlorophyll absorption.

- **Typical Spectral Reflectance Curve for Vegetation:**

2. **Soil:**
   - **Characteristics:**
     - Soil typically has lower reflectance in the visible and higher reflectance in the NIR.
     - Absorption features in the shortwave infrared (SWIR) can be associated with minerals present in the soil.
   - **Typical Spectral Reflectance Curve for Soil:**
3. **Water:**
   - **Characteristics:**
     - Water absorbs radiation in the visible spectrum, particularly in the blue and red wavelengths.
     - Near-infrared is generally reflected, but absorption occurs in the SWIR.
     - Clear water can show high reflectance in the NIR, but this varies with water quality and constituents.
   - **Typical Spectral Reflectance Curve for Water:**

These curves illustrate the distinctive patterns associated with each land cover type, allowing remote sensing scientists to use spectral signatures for classification and mapping. It's important to note that variations in these spectral signatures can occur due to factors such as vegetation health, soil moisture content, and water quality, influencing the overall reflectance characteristics observed in remote sensing data.

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 when it is predominantly composed of solid materials, such as soil, rock, or man-made structures. Microwave remote sensing, particularly in the microwave region of the electromagnetic spectrum, has applications in fields like radar imaging, soil moisture estimation, and geological studies. Here are some key points related to solid surface scattering in the microwave region:

1. **Surface Roughness:**
    - The interaction between microwaves and a solid surface is influenced by the roughness of the surface.
    - In the microwave region, rough surfaces can cause scattering of the incident radiation in various directions.
2. **Frequency Dependence:**
    - The behavior of solid surface scattering depends on the frequency of the microwaves.
    - Higher frequency microwaves tend to interact more with the surface roughness, leading to increased scattering effects.
3. **Radar Cross Section (RCS):**
    - The Radar Cross Section is a measure of how well a target reflects radar signals.
    - Solid surfaces with irregularities or roughness can have a significant impact on the RCS, influencing the detectability of objects.
4. **Vegetation and Dielectric Properties:**
    - In areas with vegetation cover, the interaction of microwaves with leaves and branches can also contribute to scattering.
    - The dielectric properties of the solid materials play a role in determining how microwaves penetrate or interact with the surface.
5. **Soil Moisture Sensing:**
    - Microwave remote sensing is often used to estimate soil moisture content, as the interaction between microwaves and the soil surface is influenced by its moisture content.
    - Moisture affects the dielectric properties of soil, impacting the scattering and absorption of microwaves.
6. **Geological Applications:**
    - In geological studies, microwave remote sensing can be used to analyze the composition and structure of solid surfaces.
    - Differences in the microwave response can help identify geological features and material types.
7. **Synthetic Aperture Radar (SAR):**
    - Synthetic Aperture Radar is a type of radar used in microwave remote sensing.

- SAR systems utilize microwave signals to create high-resolution images of the Earth's surface, and solid surface scattering is a critical factor in SAR signal interactions.

Solid surface scattering in the microwave region is essential for interpreting microwave remote sensing data and extracting meaningful information about the Earth's surface, especially in applications related to agriculture, hydrology, geology, and environmental monitoring.

UNIT 3

ORBITS AND PLATFORMS

INTRODUCTION

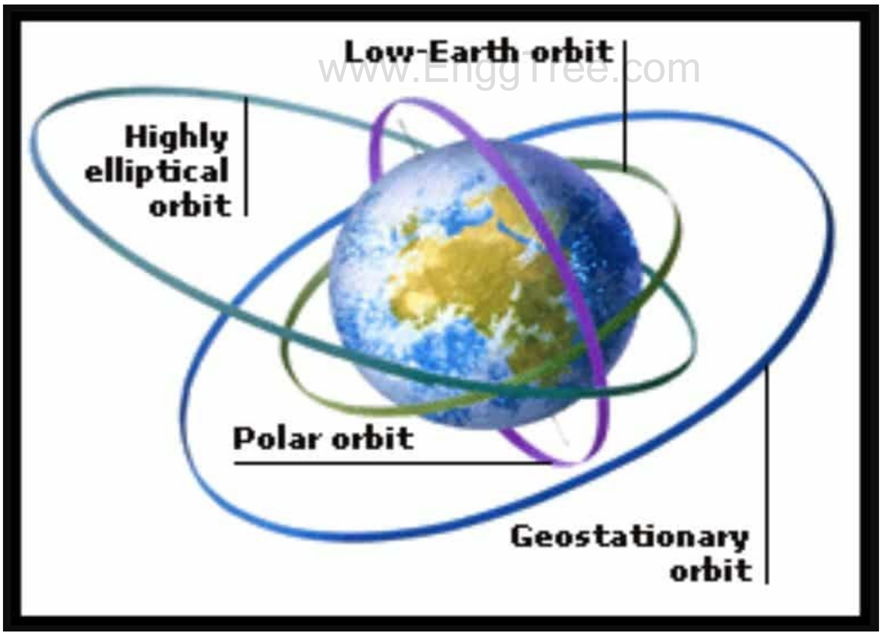
Remote sensing has revolutionized our ability to observe and understand the Earth's surface and atmosphere from afar. By utilizing various platforms and orbits, remote sensing technologies enable us to gather valuable data for a wide range of applications, including environmental monitoring, disaster management, urban planning, agriculture, and climate studies. In this introduction, we will explore the fundamentals of orbits and platforms used in remote sensing and their significance in acquiring high-quality data.

Orbits

Orbits play a critical role in remote sensing missions as they determine the trajectory and coverage of the satellite or sensor system.

TYPES

1. Low Earth Orbit (LEO)
2. Geostationary Orbit (GEO)
3. Polar Orbit
4. Sun-Synchronous Orbit (SSO)



Low Earth Orbit (LEO): Satellites in LEO typically orbit at altitudes ranging from 160 to 2,000 kilometers above the Earth's surface. These orbits provide high spatial resolution imagery and frequent revisits to specific locations due to their relatively short orbital periods.

Geostationary Orbit (GEO): Satellites in GEO orbit at an altitude of approximately 35,786 kilometers above the equator. They maintain a fixed position relative to the Earth's surface, making them ideal for continuous monitoring of specific regions, such as weather patterns and environmental changes.

Polar Orbit: Polar orbiting satellites pass over the Earth's poles, providing global coverage with each orbit. These orbits are commonly used for environmental monitoring, as they allow for comprehensive observations of land, oceans, and atmosphere over time.

Sun-Synchronous Orbit (SSO): Satellites in SSO maintain a constant angle relative to the Sun as they orbit the Earth, ensuring consistent lighting conditions during each pass over the same area. This orbit is particularly useful for monitoring changes in vegetation, land use, and other surface features.

Platforms:

Remote sensing platforms encompass a variety of vehicles or devices used to carry sensors into the Earth's atmosphere or space. Some common platforms include:

Satellites: Satellites are spacecraft placed into orbit around the Earth or other celestial bodies. They house remote sensing instruments that capture data across different wavelengths of the electromagnetic spectrum.

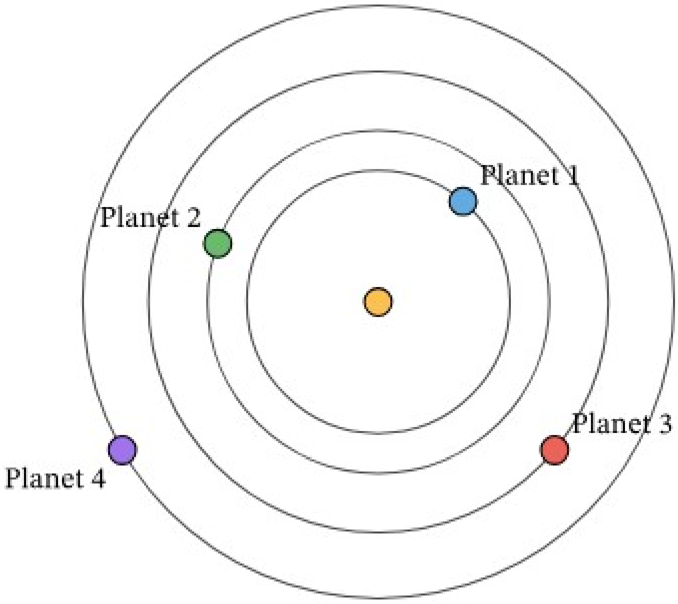
Unmanned Aerial Vehicles (UAVs): UAVs, or drones, are aircraft operated without a human pilot onboard. They are equipped with sensors capable of capturing high-resolution imagery and collecting data over targeted areas with flexibility and cost-effectiveness.

Aircraft: Manned aircraft equipped with remote sensing instruments are used for airborne data collection at various altitudes. These platforms offer higher spatial resolution compared to satellite-based sensors and can be deployed for specialized missions or rapid response tasks.

Ground-Based Platforms: Ground-based sensors and observatories are stationed on the Earth's surface or mounted on fixed structures. They provide continuous monitoring of specific locations and contribute to validating data collected from airborne or satellite platforms.

MOTIONS OF PLANETS AND SATELLITIES

The motions of planets and satellites play a crucial role in remote sensing applications, influencing the positioning, coverage, and data acquisition capabilities of remote sensing instruments. Understanding these motions is essential for optimizing the design and operation of remote sensing missions.



Rotational Motion of Planets:

Planets rotate on their axes, causing day-night cycles and altering the illumination conditions for remote sensing observations.

Remote sensing instruments need to account for this rotation to ensure consistent lighting conditions and accurate data collection.

For example, satellites in sun-synchronous orbits are synchronized with the Earth's rotation, ensuring consistent solar illumination during each orbit pass.

Orbital Motion of Planets:

Planets orbit around the Sun in elliptical paths according to Kepler's laws of planetary motion.

The orbit of a planet affects the positioning and geometry of remote sensing platforms, such as satellites orbiting Earth.

Remote sensing missions need to consider the orbital parameters of planets to optimize coverage, revisit times, and data acquisition strategies.

Satellite Motion:

Satellites used for remote sensing orbit around planets like Earth, Mars, or other celestial bodies.

Different types of orbits, including polar, geostationary, and sun-synchronous, influence satellite motion and coverage patterns.

Satellites may also exhibit additional motions such as precession, nutation, and orbital drift, which must be accounted for in mission planning and data processing.

Relative Motion Between satellite and planets:

It affects the viewing geometry and spatial resolution of remote sensing observations.

Satellites may pass over different latitudes and longitudes on the planet's surface during each orbit, influencing the spatial coverage and distribution of acquired data.

Motion Correction techniques:

To mitigate the effects of planetary and satellite motions on remote sensing data, various correction techniques are employed.

These techniques include georeferencing, orthorectification, and image registration algorithms, which compensate for geometric distortions caused by motion and terrain variations.

Motion correction ensures accurate alignment of remote sensing images with geographic coordinates, facilitating quantitative analysis and integration with other spatial datasets.

NEWTONS LAW OF GRAVITATION

Newton's law of gravitation states that every particle in the universe attracts 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 between their centers. Mathematically, it can be expressed as:

F=Gxm1xm2/r2

Where,

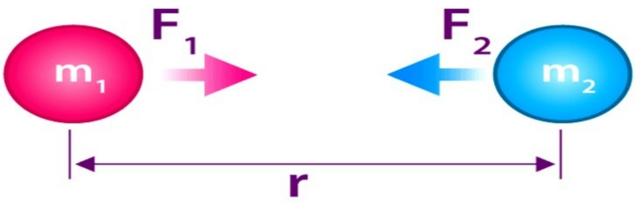
F is the gravitational force between two objects,

G is the gravitational constant

(approximately 6.674×10−11 m3 kg−1 s−2),

m1 and m2 are the masses of the two objects, and

r is the distance between the centers of the two objects.



Satellite Orbits:

Newton's law of gravitation governs the motion of satellites in orbit around celestial bodies, such as the Earth. The gravitational force between the satellite and the Earth determines the shape, size, and stability of the satellite's orbit. Remote sensing satellites rely on specific orbits, such as polar orbits or geostationary orbits, to achieve desired coverage and revisit times.

Trajectory Planning:

Understanding the gravitational interactions between the satellite and other celestial bodies (e.g., the Moon, the Sun) is crucial for trajectory planning in remote sensing missions. By accounting for gravitational forces, mission planners can optimize satellite paths, minimize fuel consumption, and ensure accurate positioning for data acquisition.

Orbital Dynamics:

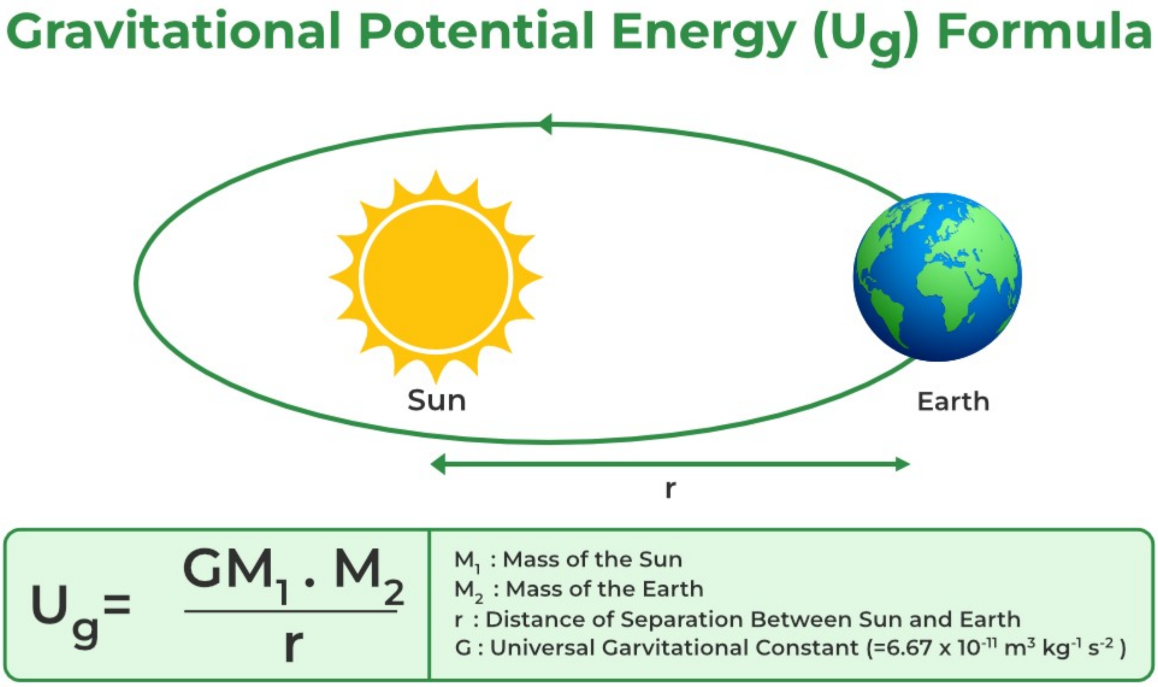
Newton's law of gravitation influences various orbital parameters, including eccentricity, inclination, and periapsis. These parameters dictate the orbital characteristics of remote sensing satellites, such as their altitude, orbital period, and ground track. Precise control of these parameters is essential for achieving desired observational objectives and optimizing data collection strategies.

Gravitational Perturbations:

Gravitational perturbations from other celestial bodies can affect satellite orbits over time. These perturbations may cause orbital precession, nodal regression, or secular drift, which can impact the long-term stability and operational lifespan of remote sensing missions. Understanding and mitigating these effects are vital for maintaining satellite performance and data continuity.

GRAVITATIONAL FIELD AND POTENTIAL

The gravitational field and potential are fundamental aspects of Earth's geophysical environment that influence remote sensing measurements and data interpretation. This concepts is crucial for accurately analyzing remote sensing data and extracting meaningful information about the Earth's surface and subsurface features.



Influence on Satellite Orbits:

The gravitational field of the Earth affects the orbits of satellites used in remote sensing missions. Satellites orbiting the Earth experience gravitational forces that determine their trajectory, altitude, and velocity.

Variations in the Earth's gravitational field due to uneven mass distribution (e.g., mountains, oceans, and variations in the density of underlying geological structures) can perturb satellite orbits, affecting their stability and accuracy in acquiring remote sensing data.

Geoid Modeling:

The geoid represents the equipotential surface of Earth's gravity field that best fits global mean sea level. It serves as a reference surface for measuring elevations and understanding the Earth's shape and gravity field.

Remote sensing techniques, such as satellite gravimetry and altimetry, are employed to precisely measure variations in the geoid. These measurements contribute to refining geoid models, which are essential for geodetic applications, including mapping, navigation, and geophysical studies.

Gravity Anomalies:

Gravity anomalies are deviations from the average gravitational field of the Earth and are indicative of subsurface geologic structures, such as sedimentary basins, volcanic features, and mineral deposits.

Remote sensing technologies, such as satellite gravimetry and airborne gravity surveys, are used to map gravity anomalies with high spatial resolution. These data aid in geological mapping, mineral exploration, and understanding tectonic processes.

Subsurface Characterization:

Gravitational data, when integrated with other remote sensing datasets (e.g., multispectral imagery, radar data), can provide valuable insights into subsurface characteristics, such as lithology, density variations, and groundwater resources.

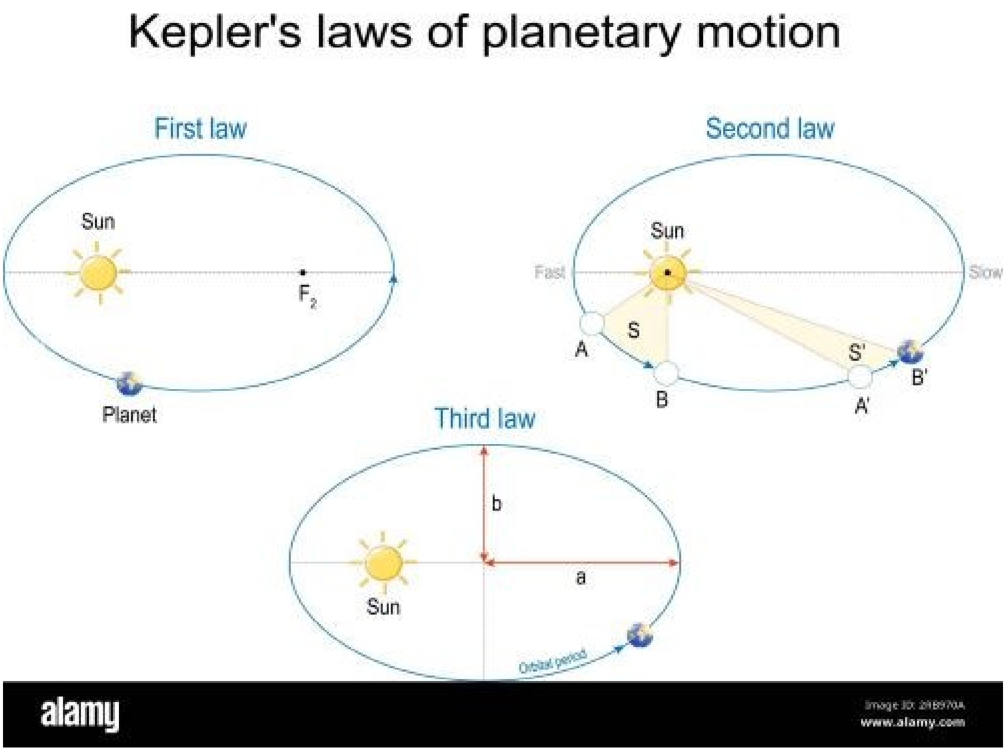
Gravity surveys, combined with geophysical inversion techniques, enable the estimation of subsurface properties and the delineation of geological structures, facilitating resource exploration and environmental assessment.

ESCAPE VELOCITY

Escape velocity is a concept in physics referring to the minimum velocity an object needs to escape the gravitational pull of a massive body, such as a planet or a moon, without being propelled further by additional force. In the context of remote sensing, escape velocity is not directly relevant because remote sensing typically involves objects, such as satellites or drones, that are intentionally placed into orbit around the Earth rather than being launched into space or escaping Earth's gravitational field entirely.

KEPLER'S LAW OF PLANETARY MOTION

Kepler's laws of planetary motion are a set of three fundamental principles describing the motion of planets and other celestial bodies around the Sun. While these laws are primarily concerned with the dynamics of celestial bodies in the solar system, they have implications for remote sensing, particularly in the context of satellite orbits and orbital dynamics.



Kepler's First Law (Law of Ellipses):

Kepler's First Law states that the orbit of a planet around the Sun is an ellipse with the Sun at one of the two foci.

In the context of remote sensing, satellites can be placed into various types of orbits around the Earth, including elliptical orbits. While circular orbits are often preferred for their simplicity and stability, certain missions may benefit from elliptical orbits, such as those designed for polar observation or high-resolution imaging over specific regions.

Kepler's Second Law (Law of Equal Areas):

Kepler's Second Law states that a line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.

This law implies that planets move faster when they are closer to the Sun (at perihelion) and slower when they are farther away (at aphelion). Similarly, satellites in elliptical orbits around the Earth experience variations in orbital velocity as they move closer to or farther away from the planet.

Remote sensing satellites in elliptical orbits may encounter changes in orbital velocity and ground speed, which can affect the timing and coverage of data acquisition over different regions of the Earth's surface.

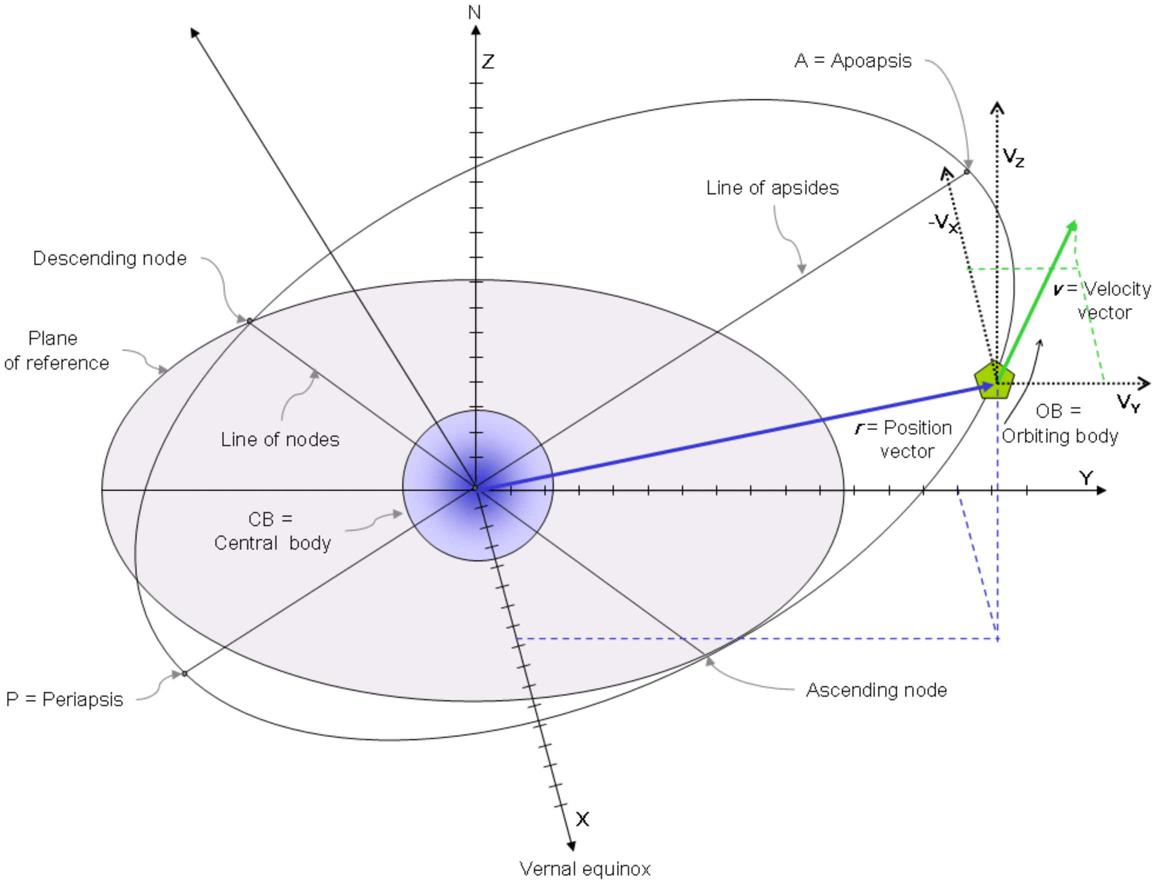
Kepler's Third Law (Law of Harmonies):

Kepler's Third Law relates the orbital period of a planet (or satellite) to its average distance from the Sun (or central body). Specifically, the square of the orbital period is proportional to the cube of the semi-major axis of the orbit.

In remote sensing, Kepler's Third Law influences the design and planning of satellite missions. For example, satellites in higher orbits have longer orbital periods, resulting in fewer revisits to specific locations on Earth but providing broader coverage. Conversely, satellites in lower orbits have shorter orbital periods, leading to more frequent revisits but narrower coverage swaths.

ORBIT ELEMNTS AND TYPES

Orbital elements and types play a crucial role in remote sensing missions, determining the trajectory, coverage, and observational characteristics of satellites or sensors. Understanding these elements and types is essential for designing, planning, and operating remote sensing missions effectively.



ELEMENTS

Semi-Major Axis (a):

The semi-major axis is half of the major axis of an ellipse representing the orbit. It defines the average distance between the satellite and the center of the Earth.

Eccentricity (e):

Eccentricity measures the deviation of an orbit from a perfect circle. It ranges from 0 (circular orbit) to 1 (highly elliptical orbit), determining the shape of the orbit.

Inclination (i):

Inclination is the angle between the orbital plane and the equatorial plane of the Earth. It defines the orientation of the orbit relative to the Earth's rotation axis.

Right Ascension of the Ascending Node (RAAN):

RAAN is the angle measured from a reference direction (typically the vernal equinox) to the point where the orbit crosses the equatorial plane from south to north.

Argument of Perigee (ω):

The argument of perigee is the angle measured from the ascending node to the point of closest approach (perigee) to the Earth's surface.

True Anomaly (ν):

True anomaly is the angle measured from the perigee to the current position of the satellite, defining its position along the orbit.

TYPES

1. Low Earth Orbit (LEO)
2. Geostationary Orbit (GEO)
3. Polar Orbit
4. Sun-Synchronous Orbit (SSO)
5. Molniya Orbit
6. Highly Elliptical Orbit (HEO)

Low Earth Orbit (LEO):

Satellites in LEO typically orbit at altitudes ranging from 160 to 2,000 kilometers above the Earth's surface. LEOs offer high spatial resolution imagery and frequent revisits to specific locations due to their short orbital periods.

Geostationary Orbit (GEO):

Satellites in GEO orbit at an altitude of approximately 35,786 kilometers above the equator. They remain stationary relative to the Earth's surface, providing continuous monitoring of specific regions, such as weather patterns.

Polar Orbit:

Polar orbiting satellites pass over the Earth's poles, providing global coverage with each orbit. They are commonly used for environmental monitoring and scientific research due to their comprehensive observational capabilities.

Sun-Synchronous Orbit (SSO):

Satellites in SSO maintain a constant angle relative to the Sun as they orbit the Earth, ensuring consistent lighting conditions during each pass over the same area. SSOs are suitable for monitoring changes in vegetation, land use, and climate.

Molniya Orbit:

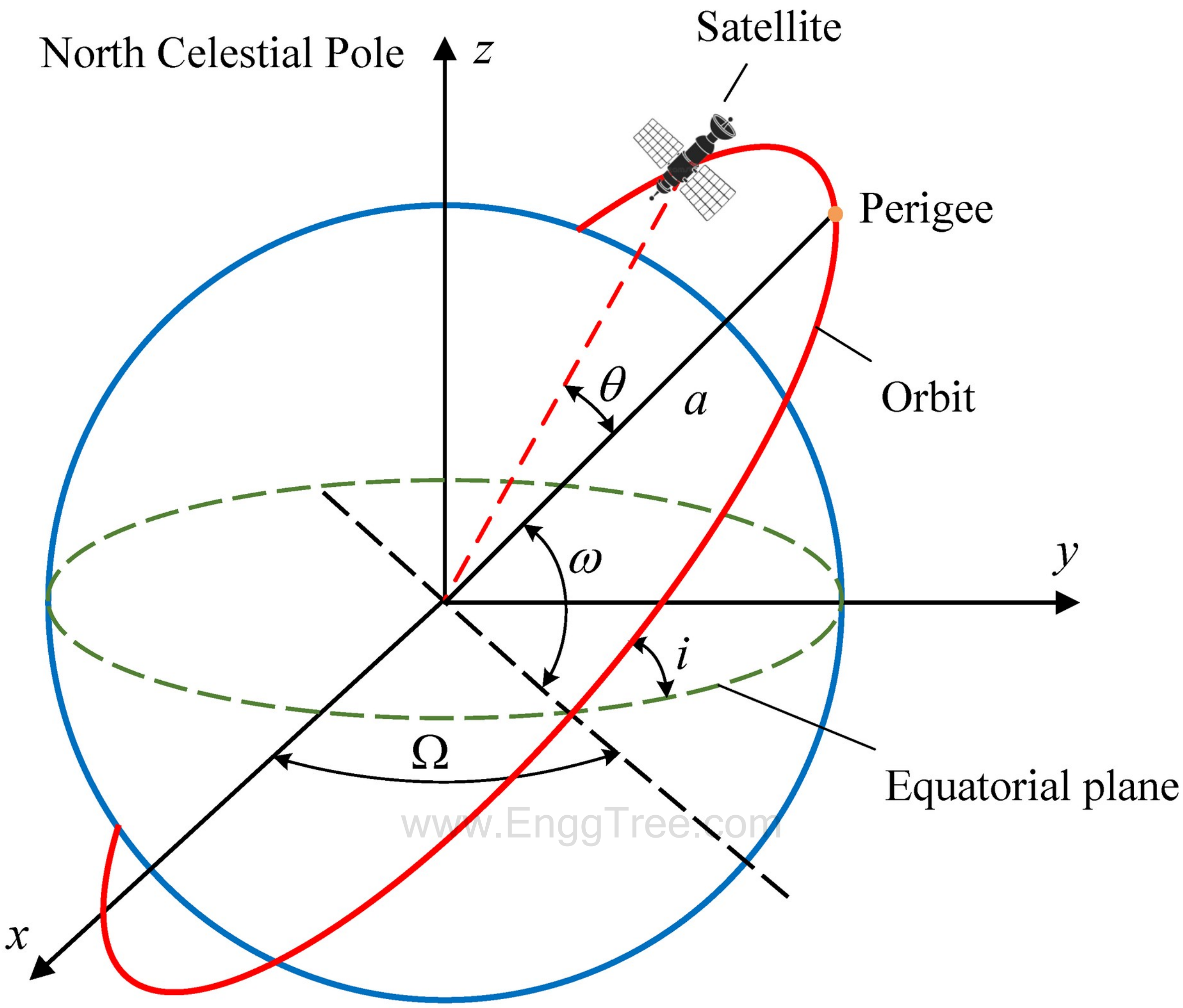
Molniya orbits are highly elliptical orbits with high inclinations, optimized for providing extended coverage of high-latitude regions. They are commonly used in communication and remote sensing satellites for observing polar regions.

Highly Elliptical Orbit (HEO):

HEOs have highly elliptical shapes with apogees far from the Earth and perigees relatively close to the planet. They are utilized for specialized missions requiring long dwell times over specific areas, such as communication or Earth observation.

ORBITAL PERTURBATIONS AND MANEUVERS

Orbital perturbations and maneuvers are essential considerations in remote sensing missions to ensure the stability, accuracy, and efficiency of satellite orbits for data acquisition. Perturbations are deviations from the ideal orbital path caused by gravitational, atmospheric, and other factors. Maneuvers involve intentional adjustments to the satellite's orbit to compensate for perturbations or achieve specific mission objectives.



Orbital Perturbations:

Gravitational Perturbations:

Gravitational forces from the Earth, Moon, and other celestial bodies cause variations in the satellite's orbit, leading to perturbations. These perturbations can include changes in orbital eccentricity, inclination, and nodal regression over time.

Atmospheric Drag:

Satellites in low Earth orbit (LEO) experience atmospheric drag, causing their orbits to decay gradually. This drag results from interactions with the Earth's atmosphere, particularly at lower altitudes, and requires periodic maneuvers to maintain the satellite's altitude and orbital parameters.

Solar Radiation Pressure:

Solar radiation exerts pressure on the satellite's surface, causing small accelerations that affect its orbit. Solar radiation pressure perturbations can cause deviations in the satellite's position, leading to drift over time and requiring periodic corrections.

Geopotential Variations:

Variations in the Earth's gravitational field due to uneven mass distribution (e.g., mountains, oceans, and density variations in the Earth's interior) induce perturbations in satellite orbits. These variations can affect orbital elements such as inclination, eccentricity, and orbital precession.

Orbital Maneuvers:

Orbit Raising or Lowering:

Satellites in LEO may perform orbit-raising maneuvers to counteract atmospheric drag and maintain their altitude. Conversely, orbit-lowering maneuvers can be conducted to deorbit the satellite at the end of its operational life or to transition to a lower orbit for mission requirements.

Plane Change Maneuvers:

Plane change maneuvers involve adjusting the satellite's inclination to align its orbital plane with a desired ground track or to synchronize with other satellites in a constellation. These maneuvers are useful for optimizing coverage and revisits over specific regions of interest.

Station-Keeping Maneuvers:

Station-keeping maneuvers are performed to maintain a satellite's position relative to a specific location on the Earth's surface or to other satellites in a constellation. These maneuvers ensure consistent coverage and facilitate continuous monitoring of target areas.

Collision Avoidance Maneuvers:

Satellites may perform collision avoidance maneuvers to mitigate the risk of collisions with other space objects, such as debris or operational satellites. These maneuvers involve adjusting the satellite's orbit to avoid potential collisions and ensure mission safety.

Orbital Resonance Adjustment:

Satellites in certain orbits, such as those in resonance with the Earth's rotation or other celestial bodies, may require periodic adjustments to maintain resonance conditions or prevent destabilizing effects.

TYPES OF REMOTE SENSING PLATFORMS

Remote sensing platforms encompass a variety of vehicles or devices used to carry sensors into the Earth's atmosphere or space to collect data about the Earth's surface and atmosphere. The three main types of remote sensing platforms are

1. Ground-based
2. Airborne
3. Spaceborne platforms.

Ground-Based Platforms:

Ground-based remote sensing platforms are stationary or mobile platforms located on the Earth's surface. They include:

Fixed Observatories: These are permanent installations equipped with various sensors and instruments for continuous monitoring of specific locations. Examples include weather stations, flux towers, and seismic stations.

Mobile Platforms: Mobile platforms such as vehicles, boats, or drones are equipped with remote sensing instruments and can traverse different terrains to collect data over specific areas of interest. Mobile platforms offer flexibility and versatility in data collection.

Terrestrial LiDAR: Terrestrial LiDAR systems are ground-based laser scanning devices used to capture high-resolution 3D data of terrain, vegetation, buildings, and infrastructure. They are often used for mapping, urban planning, and infrastructure management.

Ground-based platforms are advantageous for their relatively low cost, ease of deployment, and ability to collect data at high spatial resolutions. However, their coverage is limited compared to airborne and spaceborne platforms.

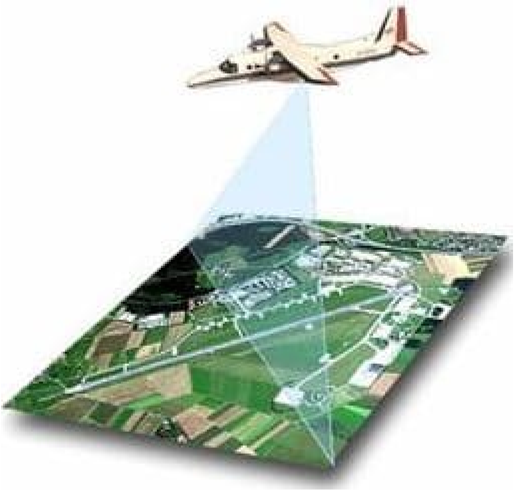
Airborne Platforms:

Airborne remote sensing platforms operate from aircraft, helicopters, or unmanned aerial vehicles (UAVs) and provide an intermediate level of altitude between ground-based and spaceborne platforms. They include:

Manned Aircraft: Manned aircraft equipped with remote sensing instruments fly at various altitudes to capture data over large areas. They are used for aerial photography, multispectral imaging, and LiDAR mapping.

Unmanned Aerial Vehicles (UAVs): UAVs, or drones, are increasingly utilized for remote sensing applications due to their ability to collect high-resolution data at low altitudes with flexibility and cost-effectiveness. UAVs are used in agriculture, environmental monitoring, disaster assessment, and infrastructure inspection.

Airborne platforms offer advantages such as rapid deployment, high spatial resolution, and the ability to access remote or hazardous areas. However, they are limited by their endurance and operational altitude compared to spaceborne platforms.



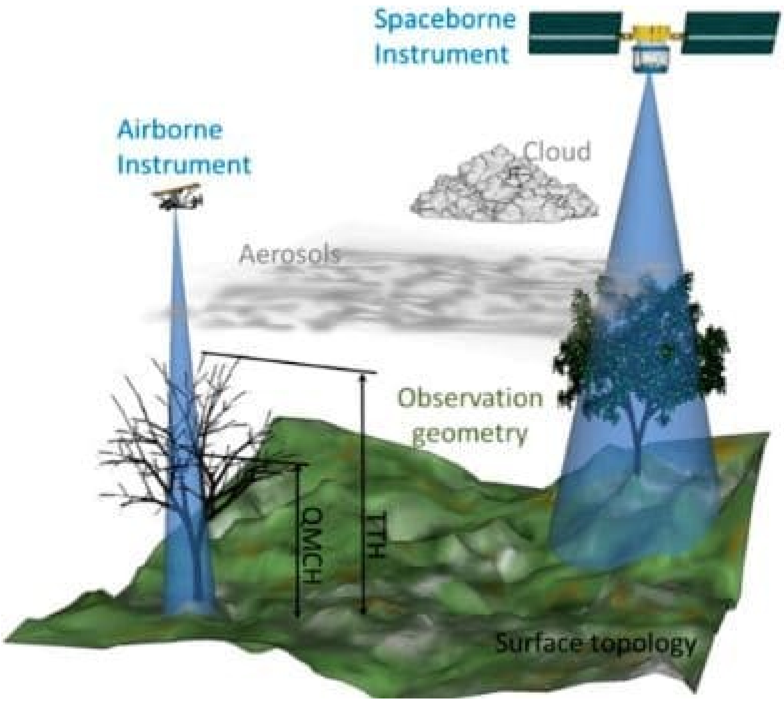
Spaceborne Platforms:

Spaceborne remote sensing platforms operate from satellites orbiting the Earth and provide a global perspective of the planet's surface and atmosphere. They include:

Earth Observation Satellites: Earth observation satellites are equipped with a variety of sensors, including optical, thermal, radar, and multispectral instruments. They orbit the Earth at different altitudes and inclinations to capture data for various applications, including environmental monitoring, weather forecasting, land use mapping, and disaster management.

Spaceborne LiDAR: Spaceborne LiDAR systems mounted on satellites are used to measure the elevation of the Earth's surface with high precision. They provide valuable data for mapping terrain, monitoring glaciers, forests, and urban areas, and assessing topographic changes.

Spaceborne platforms offer global coverage, long-term monitoring capabilities, and access to remote or inaccessible regions. However, they require significant investment in launch and satellite development and have limitations in spatial resolution compared to airborne platforms.



CLASSIFICATION OF SATELLITES

Satellites can be classified based on various criteria, including their orbits, missions, and applications. There are two types,

1. Sun-synchronous satellites
2. Geostationary satellites.

Sun-Synchronous Satellites:

It is also known as polar orbiting satellites, orbit the Earth in a near-polar orbit while maintaining a consistent angle relative to the Sun. This characteristic ensures that the satellite passes over any given point on the Earth's surface at roughly the same local solar time during each orbit. Sun-synchronous satellites typically have the following characteristics:

Orbit: Sun-synchronous satellites typically orbit the Earth in a near-polar, low Earth orbit (LEO) at altitudes ranging from a few hundred to a few thousand kilometers. These orbits are inclined at an angle relative to the equator, allowing the satellite to cover different latitudes with each orbit while maintaining a consistent solar angle.

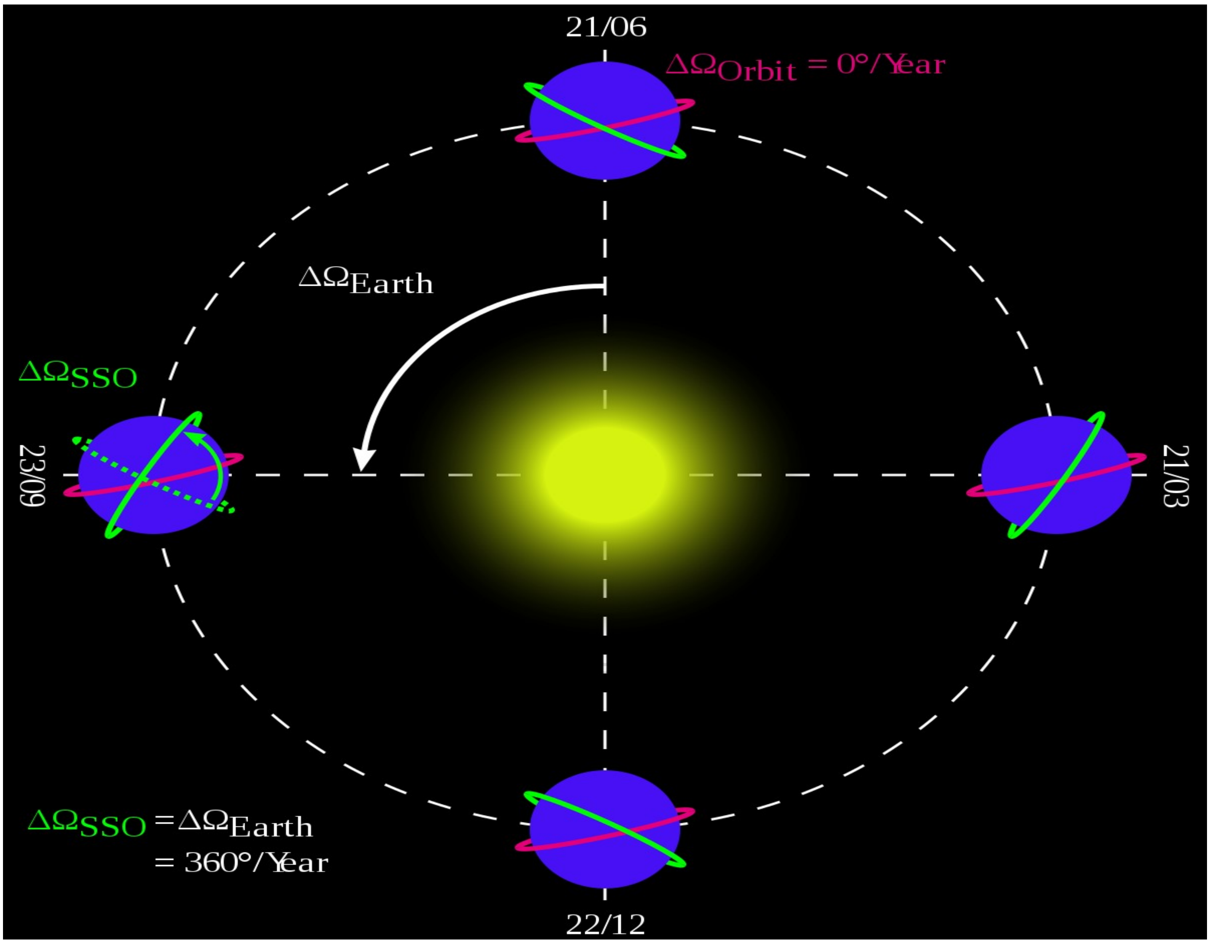
Advantages: Sun-synchronous satellites offer several advantages for remote sensing and Earth observation missions:

Consistent Lighting Conditions: By maintaining a consistent angle relative to the Sun, Sun-synchronous satellites ensure uniform lighting conditions during each pass over the Earth's surface. This consistency is critical for applications such as vegetation monitoring, land cover mapping, and change detection.

Seasonal Coverage: Sun-synchronous orbits allow satellites to cover the entire globe over the course of several days or weeks, providing comprehensive seasonal coverage of the Earth's surface.

Repeat Pass Capability: Sun-synchronous satellites have a repeatable ground track, enabling them to revisit the same locations on the Earth's surface at regular intervals. This capability is valuable for monitoring changes over time and detecting trends in environmental phenomena.

Applications: Sun-synchronous satellites are used for a wide range of applications, including environmental monitoring, climate studies, land use mapping, agriculture, forestry, disaster management, and scientific research.



Geostationary Satellites:

Geostationary satellites, also known as geosynchronous equatorial orbit (GEO) satellites, orbit the Earth directly above the equator at a fixed position relative to the Earth's surface. These satellites orbit the Earth at the same rate as the Earth's rotation, resulting in a stationary position relative to a specific point on the Earth's surface. Geostationary satellites typically have the following characteristics:

Orbit: Geostationary satellites orbit the Earth at an altitude of approximately 35,786 kilometers above the equator. They orbit the Earth in the same direction and at the same rate as the Earth's rotation, completing one orbit approximately every 24 hours.

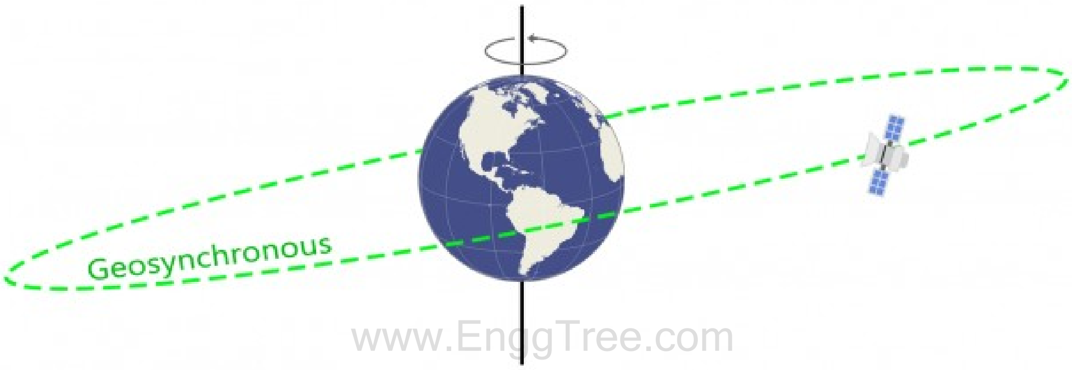
Advantages: Geostationary satellites offer several advantages for communications, weather monitoring, and other applications:

Continuous Coverage: Geostationary satellites provide continuous coverage of a fixed area on the Earth's surface, making them ideal for applications that require real-time monitoring, such as weather forecasting, telecommunications, and disaster management.

High-Elevation Angles: Geostationary satellites provide high-elevation angles, allowing them to capture wide-area images of the Earth's surface with minimal distortion.

Long-Term Monitoring: Geostationary satellites can monitor changes in weather patterns, cloud cover, and environmental conditions over extended periods, facilitating long-term climate studies and trend analysis.

Applications: Geostationary satellites are primarily used for weather monitoring, telecommunications, broadcast television, navigation, and environmental monitoring.



LEGRANGE ORBIT

The Lagrange points, also known as libration points or Lagrangian points, are positions in space where the gravitational forces of two large bodies, such as the Earth and the Moon or the Earth and the Sun, balance the centripetal force felt by a smaller object. There are five Lagrange points labeled L1 through L5. While Lagrange points are not typically used for remote sensing satellites, they can be advantageous for certain specialized missions due to their unique orbital characteristics. Let's explore how Lagrange points could potentially be utilized for remote sensing:

Lagrange Point 1 (L1):

L1 is located between the Earth and the Sun, directly along the line connecting their centers. At this point, the gravitational forces of the Earth and the Sun balance out, allowing a satellite to maintain a relatively stable position with respect to both bodies.

Advantages for Remote Sensing: A satellite positioned at L1 could provide continuous solar observation, monitoring space weather phenomena, and providing early warning of solar storms, which can impact satellite communications and power grids on Earth.

Lagrange Point 2 (L2):

L2 is located on the opposite side of the Earth from the Sun, approximately 1.5 million kilometers away from Earth. Like L1, the gravitational forces of the Earth and the Sun balance out at this point, providing a stable orbit for satellites.

Advantages for Remote Sensing: Satellites positioned at L2 could offer uninterrupted views of the dark side of the Moon and provide valuable data for lunar exploration missions. Additionally, L2 could serve as a platform for space-based observatories, offering a vantage point for astronomical observations away from the interference of Earth's atmosphere.

Lagrange Point 5 (L5):

L5 is located approximately 60 degrees ahead of or behind the Earth in its orbit around the Sun, forming an equilateral triangle with the Earth and the Sun. At this point, the gravitational forces of the Earth and the Sun, along with the centrifugal force of their combined motion, provide a stable location for satellites.

Advantages for Remote Sensing: Satellites positioned at L5 could offer a unique perspective for Earth observation, potentially providing continuous monitoring of specific regions or phenomena, such as weather patterns, climate change, or environmental phenomena.

UNIT IV- SENSING TECHNIQUES

CLASSIFICATION OF REMOTE SENSORS

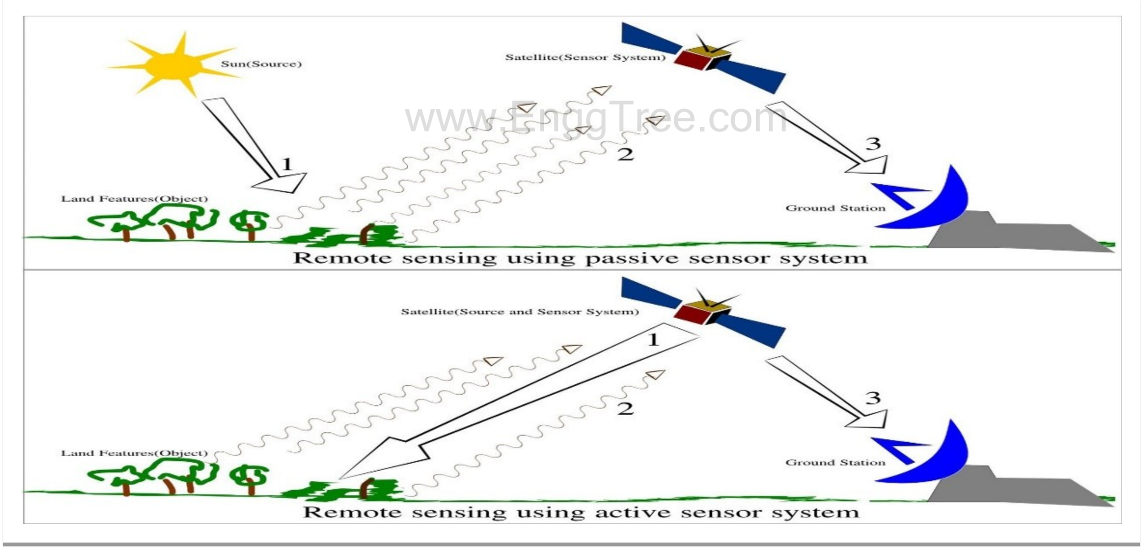
Remote sensors can be classified in various ways based on their characteristics, operating principles, and applications.

1. Based on Energy Source
2. Based on the Spectrum of Measurement
3. Based on Platform
4. Based on Spatial Resolution
5. Based on Application

Based on Energy Source:

Passive Sensors: These sensors measure natural energy (e.g., sunlight) reflected or emitted by objects in the Earth's surface or atmosphere. Examples include optical sensors (visible, infrared) and thermal sensors.

Active Sensors: These sensors emit energy (e.g., microwaves, lasers) and measure the energy reflected or backscattered by objects. Examples include RADAR (Radio Detection and Ranging) and LIDAR (Light Detection and Ranging) sensors.

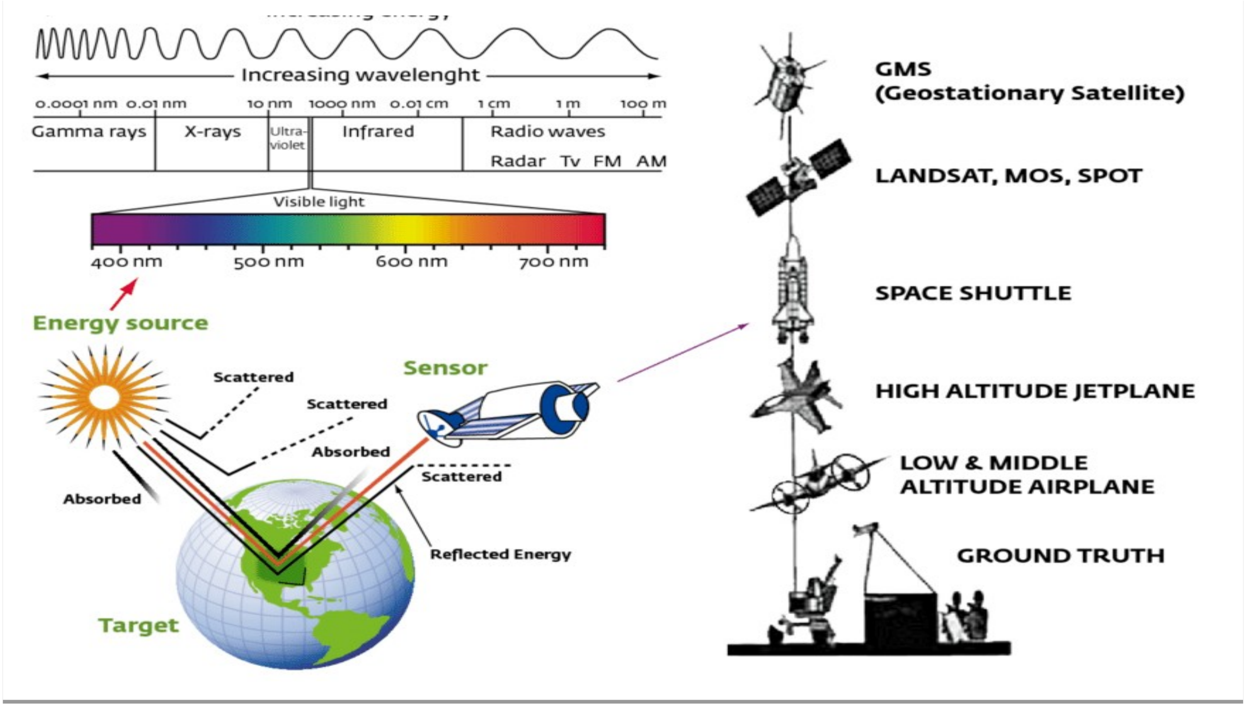


Based on the Spectrum of Measurement:

Visible Spectrum Sensors: Capture electromagnetic radiation within the visible range (approximately 400 to 700 nanometers) and are commonly used for color imaging.

Infrared Sensors: Capture electromagnetic radiation beyond the visible spectrum, including near-infrared (NIR), short-wave infrared (SWIR), mid-wave infrared (MWIR), and thermal infrared (TIR). These sensors are useful for applications such as vegetation analysis, soil moisture assessment, and thermal mapping.

Microwave Sensors: Operate in the microwave portion of the electromagnetic spectrum and are particularly suitable for applications requiring penetration through clouds, vegetation, and soil. They are commonly used for radar imaging and sensing.

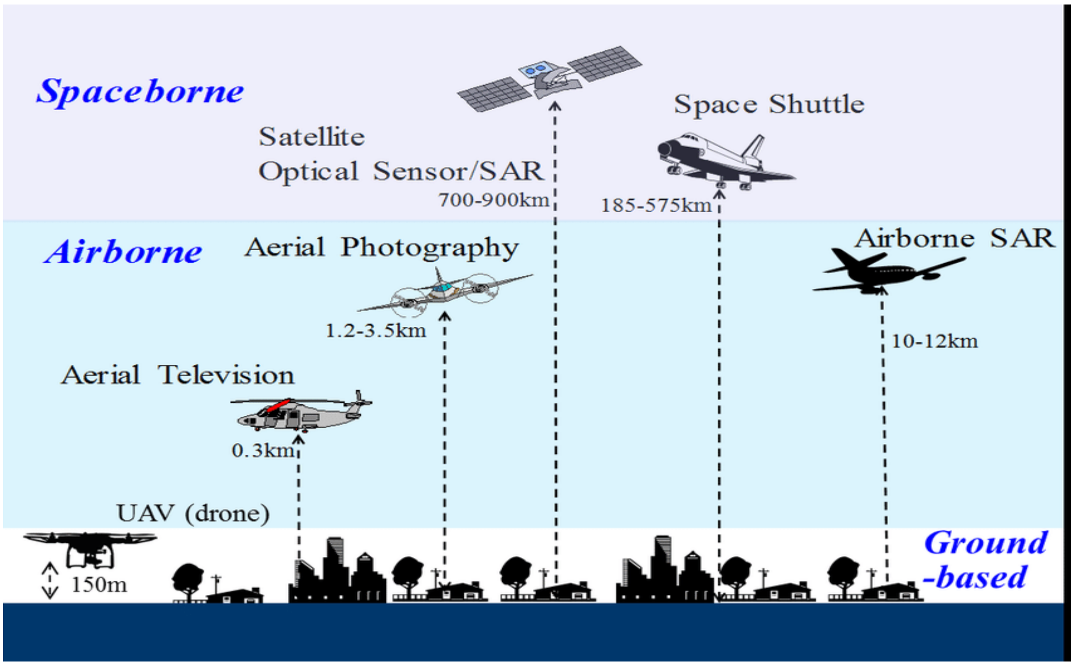


Based on Platform:

Satellite Sensors: Mounted on satellites orbiting the Earth, these sensors provide global coverage and are used for various applications such as environmental monitoring, weather forecasting, and disaster management.

Aerial Sensors: Mounted on aircraft or drones, these sensors provide high-resolution imagery and are suitable for localized and rapid data collection over specific areas.

Ground-Based Sensors: Fixed or mobile sensors deployed on the ground, which are used for specific applications such as weather monitoring, traffic monitoring, and environmental research.



Based on Spatial Resolution:

High-Resolution Sensors: Provide detailed imagery with fine spatial resolution, suitable for applications requiring detailed mapping and analysis.

Medium-Resolution Sensors: Offer moderate levels of detail, suitable for regional mapping and land cover classification.

Low-Resolution Sensors: Provide broader coverage with lower detail, suitable for global-scale studies and monitoring.

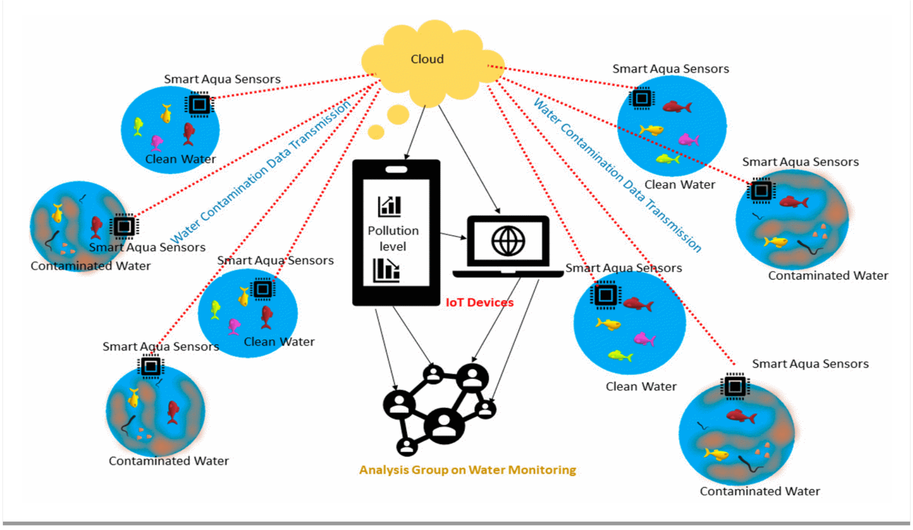
Based on Application:

Environmental Monitoring: Sensors used for assessing and monitoring environmental parameters such as land cover, vegetation health, water quality, and air pollution.

Weather and Climate Monitoring: Sensors used for measuring meteorological parameters such as temperature, humidity, precipitation, and atmospheric composition.

Defense and Security: Sensors used for surveillance, reconnaissance, and intelligence gathering in defense and security applications.

Agriculture and Forestry: Sensors used for monitoring crop health, estimating yields, assessing forest resources, and detecting forest fires.



RESOLUTION CONCEPT

The concept of resolution in remote sensing refers to the ability of a sensor to distinguish between objects or features in the Earth's surface or atmosphere. It is a critical aspect that determines the level of detail present in the imagery or data collected by the sensor. Resolution can be classified into several types

1. Spatial Resolution
2. Spectral Resolution
3. Temporal Resolution
4. Radiometric Resolution

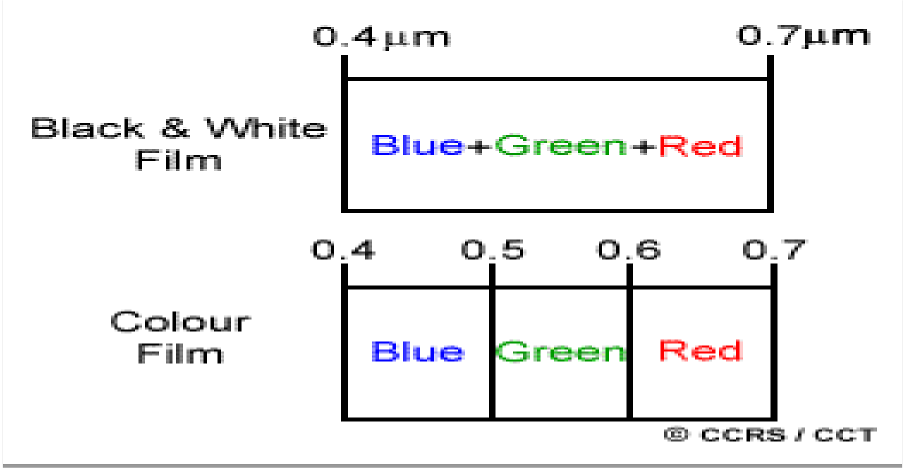
Spatial Resolution:

- Spatial resolution refers to the size of the smallest discernible or resolvable feature in the imagery. For optical sensors, it is typically measured in terms of meters per pixel or centimeters per pixel on the ground.
- Higher spatial resolution means smaller pixel sizes and greater detail in the imagery, allowing for the identification of smaller objects or features.

Spatial resolution is influenced by factors such as the sensor's spatial sampling capabilities, altitude, and optics.

Spectral Resolution:

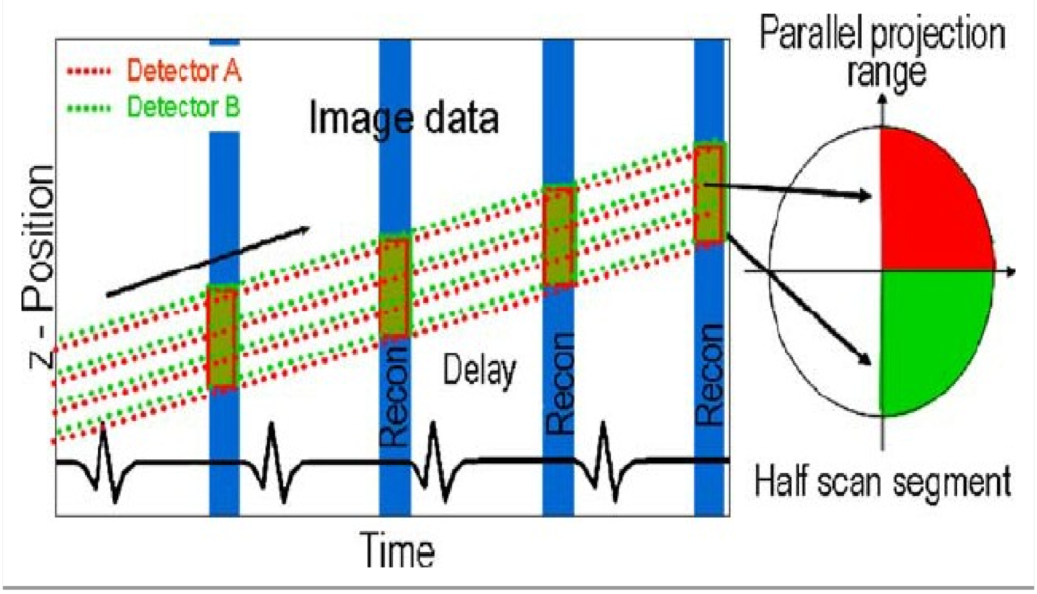
- Spectral resolution refers to the ability of a sensor to distinguish between different wavelengths or bands of electromagnetic radiation.
- It is determined by the number and width of the spectral bands captured by the sensor.
- Sensors with higher spectral resolution can discriminate between a greater number of spectral features, enabling more detailed analysis of surface properties such as vegetation health, mineral composition, and land cover types.



Temporal Resolution:

- Temporal resolution refers to the frequency at which a sensor revisits or acquires data over a particular area.
- It is measured in terms of the time interval between successive observations.

- Sensors with higher temporal resolution provide more frequent updates of the Earth's surface, allowing for monitoring of dynamic processes such as land cover changes, crop growth cycles, and natural disasters.



Radiometric Resolution:

- Radiometric resolution refers to the sensor's ability to detect and record variations in the intensity or brightness of electromagnetic radiation.
- It is determined by the number of bits used to represent the digital values of the recorded data.
- Higher radiometric resolution enables the sensor to capture subtle differences in reflectance or emission, leading to greater sensitivity and accuracy in quantitative analysis.

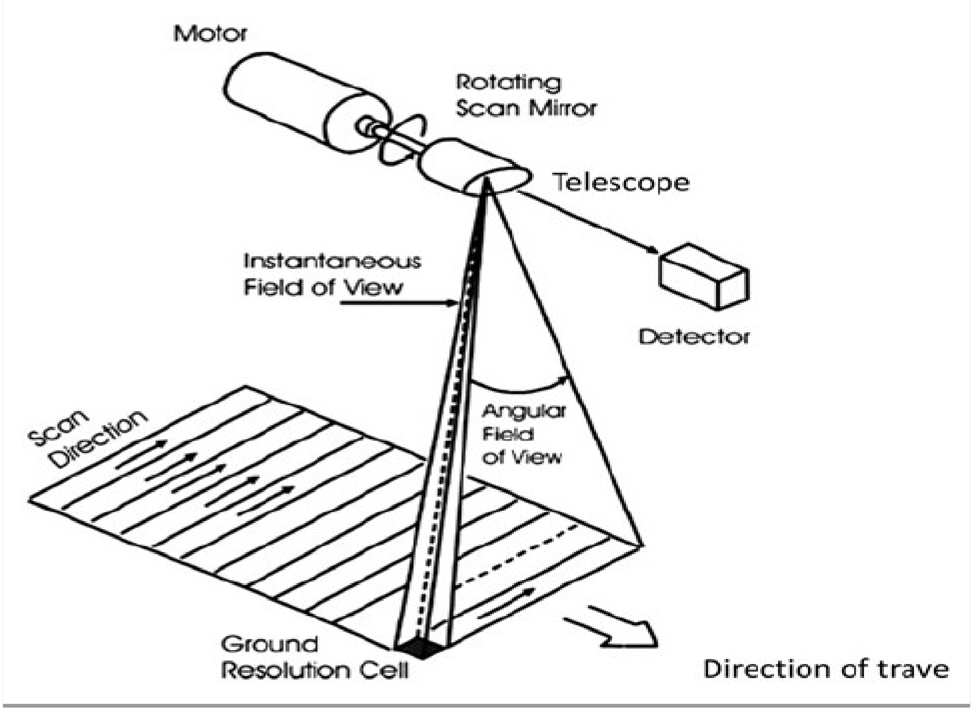
SCANNERS

In remote sensing, scanners can be classified based on the direction in which they acquire image data relative to the platform's movement. Two common types of scanners are

1. Along-track scanners
2. Across-track scanners

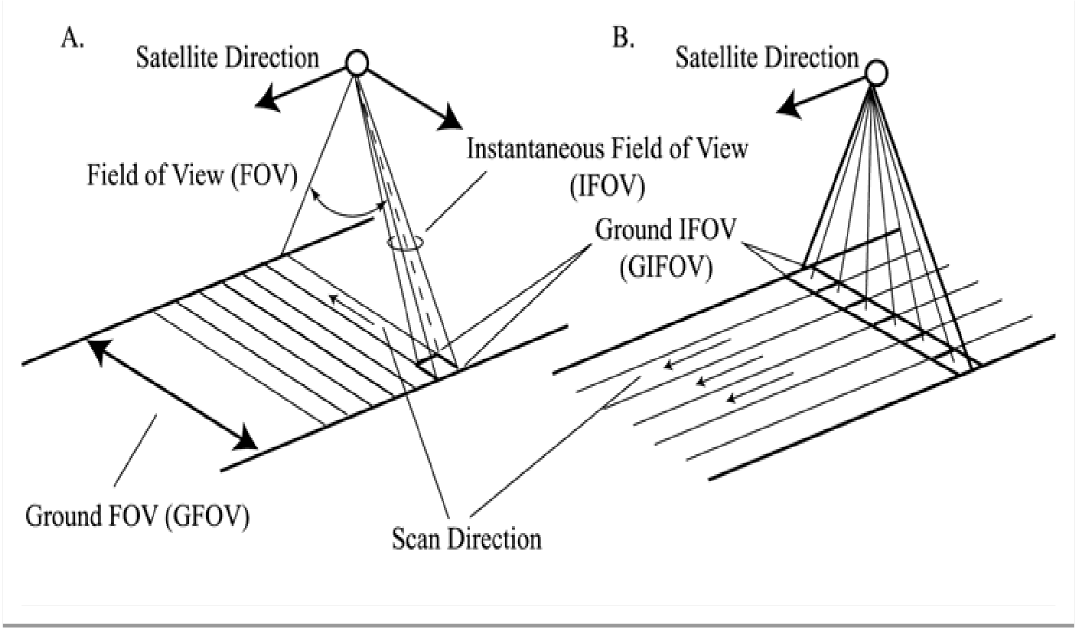
Along-Track Scanners:

- Along-track scanners, also known as "pushbroom" scanners, acquire image data in the direction of the platform's movement.
- These scanners use linear or two-dimensional arrays of detectors to capture a continuous swath of data perpendicular to the platform's flight path.
- As the platform moves forward, the detectors collect data continuously along the track, producing an image composed of adjacent scan lines.
- Examples of platforms equipped with along-track scanners include most satellite sensors, where the satellite moves along its orbital path while scanning the Earth's surface below.



Across-Track Scanners:

- Across-track scanners, also known as "whiskbroom" scanners, acquire image data across the platform's track, perpendicular to the direction of movement.
- These scanners typically use a single or multiple detectors that scan across the swath of interest as the platform moves forward.
- The detectors collect data along individual scan lines across the swath, and the platform may need to make multiple passes to cover the entire area of interest.
- Examples of platforms equipped with across-track scanners include some airborne sensors and ground-based systems.



Key Differences:

Spatial Coverage:

- Along-track scanners cover a continuous swath perpendicular to the platform's path, providing a wider spatial coverage in a single pass.
- Across-track scanners cover a swath across the platform's path, requiring multiple passes or scans to achieve the same spatial coverage as along-track scanners.

Image Formation:

- Along-track scanners produce images composed of adjacent scan lines collected continuously along the platform's track.
- Across-track scanners produce images composed of scan lines collected across the swath width, typically with gaps between adjacent lines that may need to be stitched together.

Applications:

- Along-track scanners are well-suited for satellite-based remote sensing applications, where wide-area coverage is essential.
- Across-track scanners are commonly used in airborne remote sensing applications, where high spatial resolution and detailed imaging of smaller areas are required.

OPTICAL SENSORS

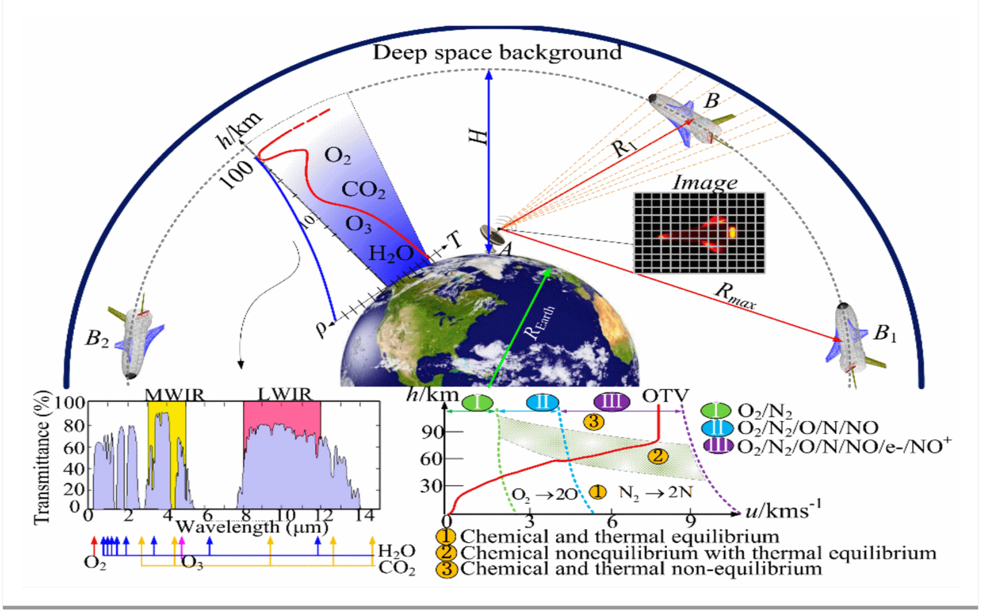
Principle: Optical sensors operate in the visible, near-infrared (NIR), and short-wave infrared (SWIR) regions of the electromagnetic spectrum. They detect the reflected sunlight from the Earth's surface. Different materials reflect and absorb light differently, allowing optical sensors to discern various features on the ground.

Applications: Optical sensors are widely used in land cover classification, vegetation monitoring, urban planning, agriculture, and environmental studies.

Calibration: Calibration of optical sensors involves correcting for radiometric and geometric distortions in the imagery. Radiometric calibration ensures that pixel values represent accurate reflectance values. Geometric calibration corrects for distortions such as terrain relief, sensor tilt, and Earth curvature.

INFRARED SENSORS

Principle: Infrared sensors operate in the infrared portion of the electromagnetic spectrum, beyond the visible range. They detect thermal radiation emitted by objects. Infrared sensors can be further divided into near-infrared (NIR), short-wave infrared (SWIR), mid-wave infrared (MWIR), and thermal infrared (TIR) sensors, each sensitive to different wavelengths.

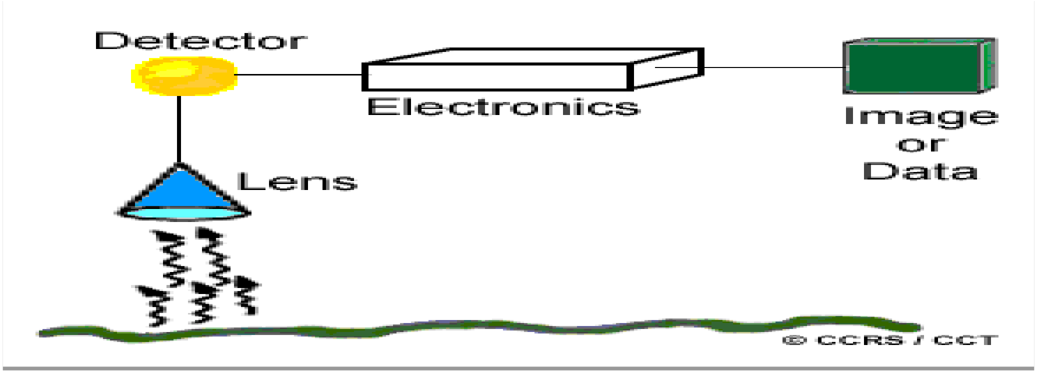


Applications: Infrared sensors are used for applications such as vegetation health assessment, soil moisture estimation, mineral identification, and heat mapping.

Calibration: Calibration of infrared sensors involves correcting for sensor noise, atmospheric effects, and temperature variations. Radiometric calibration ensures that pixel values accurately represent thermal radiance or temperature values.

THERMAL SENSORS

Principle: Thermal sensors operate specifically in the thermal infrared (TIR) region of the electromagnetic spectrum, detecting the thermal radiation emitted by objects. They measure the temperature of objects or surfaces based on their thermal emissions.

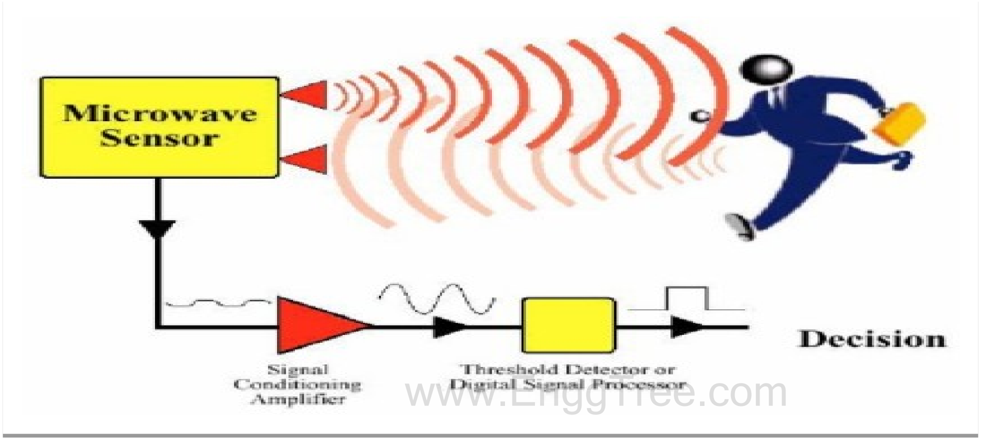


Applications: Thermal sensors are used for applications such as monitoring land surface temperature, detecting heat anomalies, assessing thermal properties of buildings, and identifying thermal signatures of vegetation stress or fires.

Calibration: Calibration of thermal sensors involves ensuring accurate temperature measurements by calibrating the sensor's response to known temperature references. Corrections are made for sensor drift, non-uniformity, and atmospheric effects.

MICROWAVE SENSORS

Principle: Microwave sensors operate in the microwave portion of the electromagnetic spectrum. They emit microwave pulses and measure the backscattered radiation reflected from the Earth's surface. Microwave sensors can penetrate clouds, vegetation, and soil, making them useful for all-weather and day-night imaging.



Applications: Microwave sensors are used for applications such as terrain mapping, soil moisture estimation, sea surface monitoring, ice detection, and agricultural monitoring.

Calibration: Calibration of microwave sensors involves correcting for system noise, antenna patterns, and atmospheric effects. Radiometric calibration ensures accurate measurements of backscattered microwave signals.

CALIBRATION OF SENSORS

Calibration of sensors in remote sensing is a critical process to ensure that the data collected by the sensors are accurate, reliable, and consistent. Calibration involves a series of steps to correct for various sources of error and uncertainty in the sensor measurements.

1. Radiometric Calibration
2. Geometric Calibration
3. Temporal Calibration
4. Cross-Track Calibration
5. In-Flight Calibration

Radiometric Calibration:

Purpose: Radiometric calibration ensures that the digital numbers (DN) or sensor readings recorded by the sensor accurately represent the radiance or reflectance of the objects being observed.

Steps:

- Response Calibration: The sensor's response to known radiance or reflectance standards is measured and used to establish a calibration curve relating sensor readings to physical units (e.g., watts per square meter per steradian).
- Correction for Systematic Errors: Corrections are applied to compensate for sensor-specific errors such as dark current, sensor gain variations, non-linearity, and stray light.
- Atmospheric Correction: Corrections are made to account for atmospheric effects such as scattering, absorption, and path radiance, which can affect the observed radiance values.

Geometric Calibration:

Purpose: Geometric calibration ensures that the spatial relationships between objects in the imagery are accurately represented, correcting for distortions introduced by the sensor and platform.

Steps:

- Sensor Model Calibration: Mathematical models are used to characterize the sensor's geometric properties, including its focal length, lens distortion, and sensor orientation.
- Ground Control Points (GCPs): GCPs with known coordinates on the Earth's surface are identified in the imagery and used to estimate and correct geometric distortions such as scale, rotation, and translation.
- Orthorectification: Orthorectification is performed to project the image pixels onto a map coordinate system, correcting for terrain relief and platform tilt effects.

Temporal Calibration:

Purpose: Temporal calibration ensures temporal consistency and continuity in the sensor data over time, allowing for meaningful comparisons and analysis of multi-temporal datasets.

Steps:

- Inter-Sensor Calibration: If data are collected from multiple sensors or platforms, calibration procedures are performed to ensure consistency and compatibility between datasets.
- Radiometric Normalization: Datasets acquired at different times may exhibit variations in radiometric properties due to changes in atmospheric conditions, solar angle, and sensor characteristics. Radiometric normalization techniques are applied to standardize the data to a common radiometric scale.

Cross-Track Calibration:

Purpose: Cross-track calibration ensures uniformity and consistency in image quality across the entire swath width of the sensor.

Steps:

- Detector Response Calibration: Detector response variations across the sensor's field of view are measured and corrected to ensure uniform sensitivity and accuracy.

- Stray Light Correction: Stray light from adjacent pixels or off-nadir angles can contaminate the signal, leading to inaccuracies in the image. Corrections are applied to minimize stray light effects.

In-Flight Calibration:

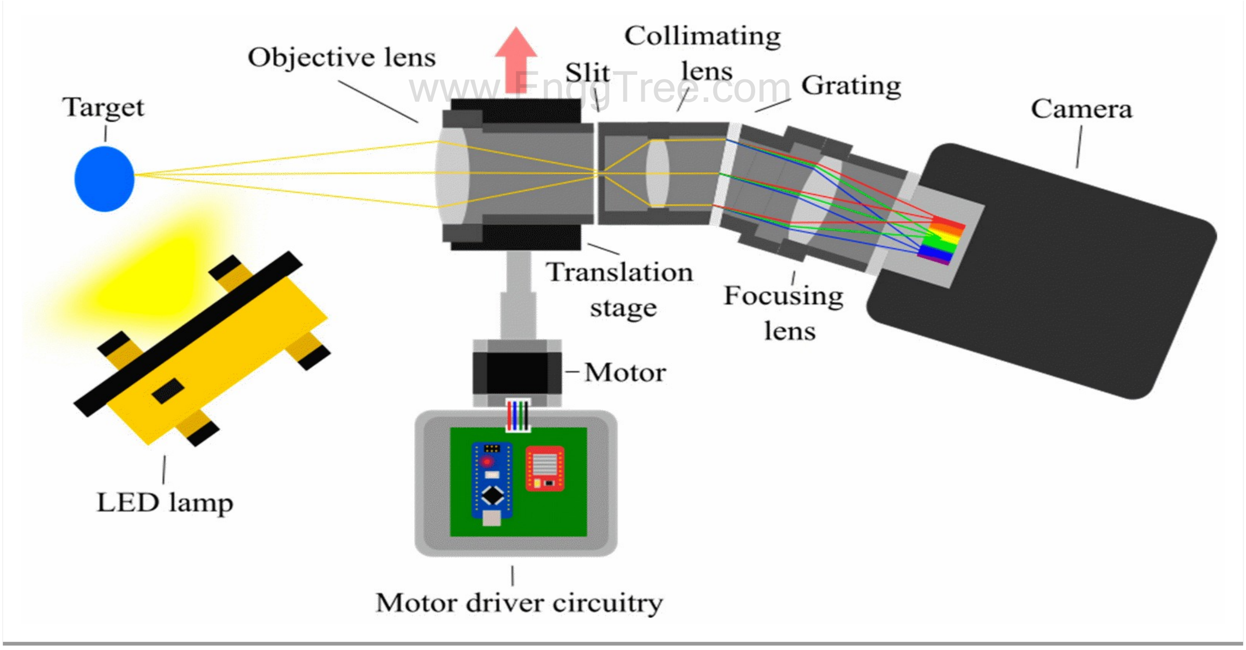
Purpose: In-flight calibration involves periodic measurements and adjustments made during sensor operation to monitor and maintain sensor performance over time.

Steps:

- Onboard Calibration Targets: Some sensors are equipped with onboard calibration targets or instruments to monitor sensor stability and performance.
- Regular Monitoring: Sensor parameters such as signal-to-noise ratio, dynamic range, and stability are monitored and recorded during routine operations. Adjustments and recalibrations are made as needed to ensure data quality.

HIGH RESOLUTION SENSORS

Principle: High-resolution sensors capture imagery with finer spatial detail compared to standard-resolution sensors. They may utilize various technologies such as along-track or across-track scanning, multiple spectral bands, and advanced optics to achieve high spatial resolution.

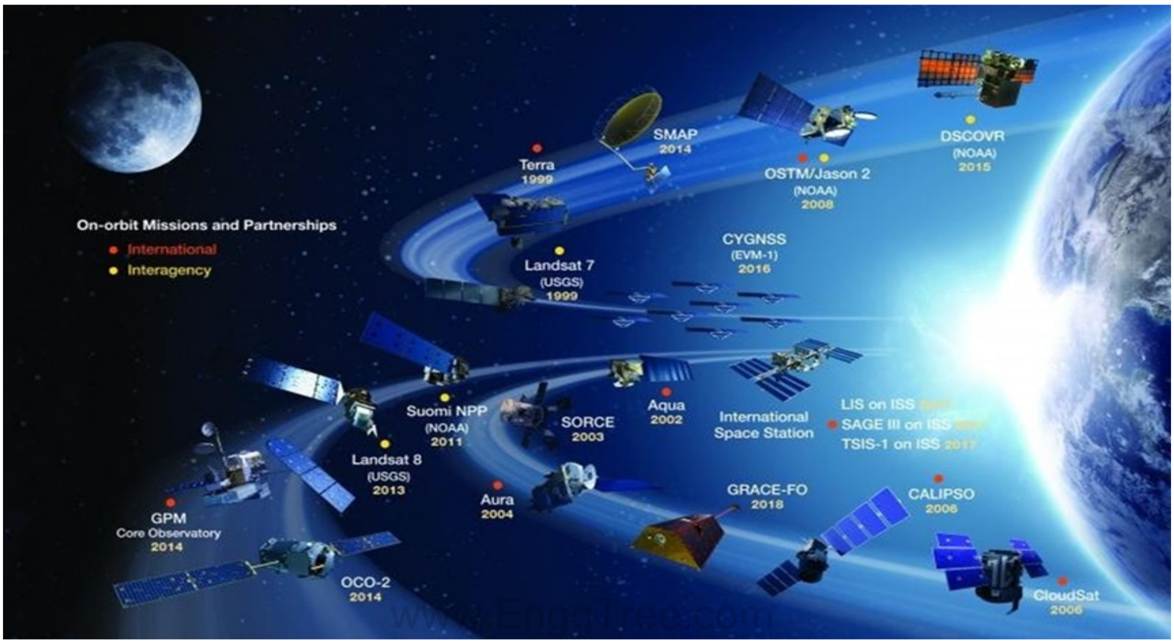


Applications: High-resolution sensors are used for detailed mapping, urban planning, infrastructure monitoring, disaster assessment, and other applications requiring fine spatial detail.

Calibration: Calibration of high-resolution sensors involves ensuring accuracy in spatial and radiometric measurements. Geometric calibration corrects for distortions in the imagery, while radiometric calibration ensures accurate representation of pixel values.

LIDAR, UAV ORBITAL AND SENSOR CHARACTERISTICS OF LIVE INDIAN EARTH OBSERVATION SATELLITES

India has several operational Earth observation satellites that provide data for various applications, including agriculture, forestry, disaster management, urban planning, and environmental monitoring. Here are some characteristics of a few prominent Indian Earth observation satellites along with information on LIDAR and UAV platforms



LIDAR:

- India has utilized LIDAR technology for various applications, including topographic mapping, forest canopy analysis, urban planning, and infrastructure monitoring.
- The Indian Space Research Organisation (ISRO) has developed LIDAR payloads for some of its satellites, such as the Terrain Mapping Camera (TMC) onboard the Chandrayaan-1 lunar mission and the Chandrayaan-2 mission, which included the Terrain Mapping Camera-2 (TMC-2) for lunar surface topography mapping.

UAV (Unmanned Aerial Vehicle):

- UAVs are increasingly being used for remote sensing applications in India, particularly for high-resolution imaging, agricultural monitoring, disaster assessment, and infrastructure inspection.
- Indian institutions and organizations, including ISRO, the Indian Institute of Remote Sensing (IIRS), and various research institutes and universities, have been involved in the development and deployment of UAVs for remote sensing purposes.
- UAV platforms equipped with multispectral or hyperspectral sensors are utilized for crop monitoring, land cover mapping, forest health assessment, and environmental monitoring.

Orbital Earth Observation Satellites:

- ResourceSat series: The ResourceSat series comprises multispectral Earth observation satellites developed by ISRO. These satellites carry payloads such as the Linear Imaging Self-Scanning Sensor (LISS) and Advanced Wide Field Sensor (AWiFS) for medium-resolution imaging.
- Cartosat series: The Cartosat series includes high-resolution Earth observation satellites designed for cartographic applications, urban planning, and infrastructure development. These satellites carry panchromatic and multispectral cameras capable of capturing imagery with sub-meter to sub-half-meter resolution.
- RISAT series: The Radar Imaging Satellite (RISAT) series consists of synthetic aperture radar (SAR) satellites for all-weather, day-and-night imaging. These satellites provide high-resolution radar imagery for applications such as agriculture, forestry, soil moisture estimation, and disaster management.
- EOS series: The EOS (Earth Observation Satellite) series includes satellites equipped with optical and microwave sensors for various remote sensing applications. These satellites carry payloads such as optical cameras, hyperspectral sensors, and microwave radiometers for imaging and data collection.

Sensor Characteristics:

- Indian Earth observation satellites are equipped with a range of sensors, including optical imagers, SAR instruments, and specialized payloads for specific applications.
- Optical sensors typically capture imagery in the visible, near-infrared, and short-wave infrared spectral bands, enabling the detection and characterization of surface features such as vegetation, water bodies, and urban areas.
- SAR sensors operate in the microwave portion of the electromagnetic spectrum and provide all-weather, day-and-night imaging capabilities with high spatial resolution. SAR imagery is particularly useful for applications requiring penetration through clouds and vegetation cover, such as flood monitoring, crop mapping, and forest inventory.

UNIT V-DATA PRODUCTS AND INTERPRETATION

PHOTOGRAPHIC AND DIGITAL PRODUCTS

Introduction

- Remote sensing involves the collection and interpretation of data about the Earth's surface without direct contact.
- Both photographic and digital technologies play vital roles in capturing and analyzing remote sensing data.
- Traditional methods relied on photographic film, while modern approaches use digital sensors. The remote sensing data products are available to the users in the form of

1. photographic products such as paper prints, film negatives, dispositive of black and white,and false colour composite (FCC) on a variety of scales
2. digital form as computer compatible tape (CCTs) after necessary corrections.

- Broadly, satellite data products can be classified into different types based on satellite and sensor, level of preprocessing and the media.
- Data products acquired for the specific period can be generated if the data pertaining to the period of interest is available in archives.
- Depending upon the corrections applied and on the level of processing, data products can be classified as :raw data, partially corrected products, standard products, geocoded products, and precision products.
- The raw data is radiometrically and geometrically uncorrected data with ancillary information (stereo products for photogrammetric studies). Standard products are radiometrically and geometrically corrected for systematic errors. Geocoded products are systematically and geometrically corrected products. The systematic corrections are based on the standard

survey of India toposheet and rotation of pixels to align to true north and resampled to standard square pixel.

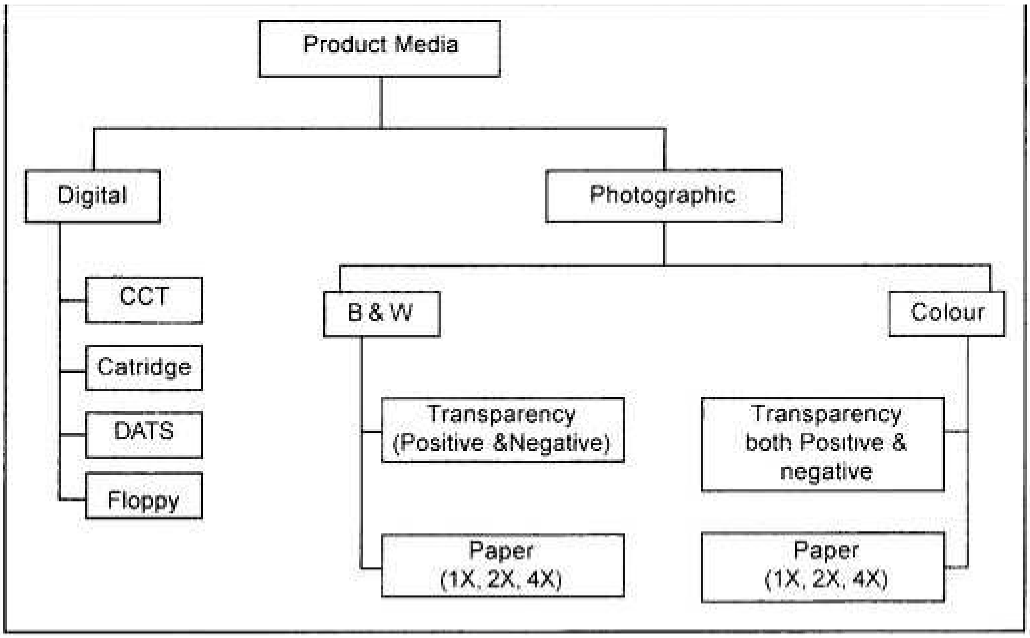
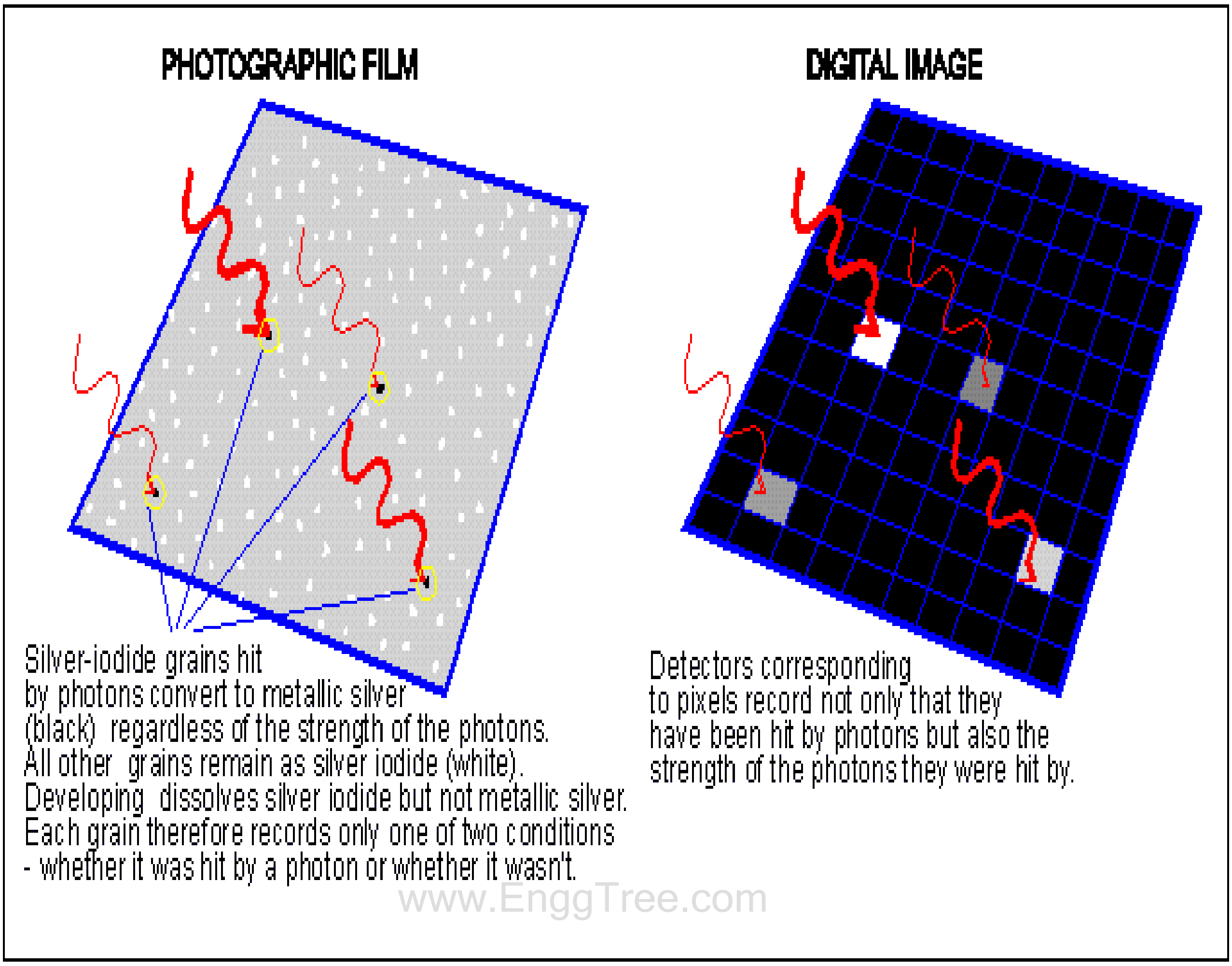


Figure Types of product media (NRSA, 1999)

- Precision products are radiometric and geometric corrections refined with the use of ground control points to achieve greater locational accuracy.
- Data products can be broadly classified into two types depending upon the output media, as photographic and digital.
- The Figure shows the types of products based on media. Photographic products can either be in black and white, or colour. Further they could be either film or paper products, and in films it is possible to have either positive film or negative film.
- The sizes of photographic products can vary depending on the enlargement needed, and this is specified as 1X, 2X, 4X and so on. The size of film recorders is generally 240 mm and this is the basic master output from which further products are generated. When we say colour photographic products, it generally means false colour composites (plate3).

- FCCs are generated by combining the data contained in 3 different spectral bands into one image by assigning blue, green and red colours to the data in three spectral bands respectively during the exposure of a colour negative.
- The choice of band combinations can be determined depending upon the application on hand.
- Different types of photographic products supplied by National Remote Sensing Agency (NRSA) data centre, Govt., of India (NDC) are: Standard B/W and FCC, films. Standard products are available in colour, and black and white in the form of 240 mm films, either as negatives or positives. Figure shows the various photographic products of different sizes and different media of printing. Paper prints both Band Wand FCC are supplied in various scales.
- They are 1 X (contact prints) , 2X (two times enlarged) and 4X (four times enlarged) and 5X (5 times enlarged). Depending upon the enlargement the scale of the product varies (IRS handbook, 1998).
- The photographic products contain certain details annotated on the margins. These are useful for identifying the scene, sensor, date of pass, processing level, band combination, and so on .
- Basically, the visual interpretation of the remote sensing data is based on the False Colour Composites (FCCs). Even after the digital techniques, the results are visually interpreted.
- Scientists, analysts and other users may interpret the same scene for different purposes. In fact it is one of the rare sources of information which can generate multiple themes, such as , water resources, soil, land use, and urban sprawl.

Figure Photographic and digital



TYPES, LEVELS AND OPEN SOURCE SATELLITE DATA PRODUCTS

Types of Satellite Data:

1. Optical Imagery
2. Radar Imagery
3. Hyperspectral Imagery
4. LiDAR Data
5. Thermal Imagery

Optical Imagery:

Captured by satellites equipped with optical sensors, these images are similar to what the human eye perceives. They provide information in various spectral bands, including visible, near-infrared, and thermal infrared, allowing for the analysis of land cover, vegetation health, urban development, and more.

Figure optical imagery

Radar Imagery:

Synthetic Aperture Radar (SAR) satellites emit microwave signals and measure the return signal to create images. SAR data is useful for all-weather and day-night imaging, terrain mapping, monitoring changes in Earth's surface, and detecting objects such as ships and oil spills.

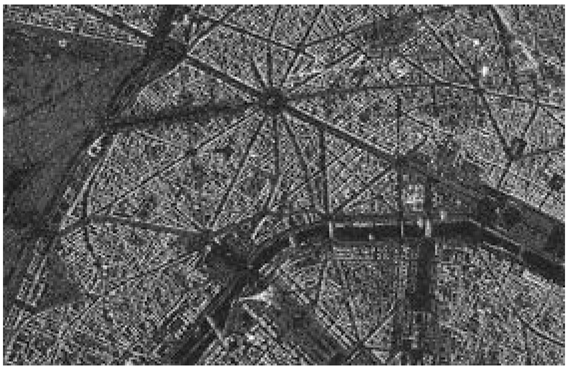


Figure radar image

Hyperspectral Imagery:

These images capture information in hundreds of narrow spectral bands, providing detailed spectral signatures for materials on the Earth's surface. Hyperspectral data is valuable for tasks like mineral identification, environmental monitoring, and precision agriculture.

Figure hyperspectral imagery

Thermal Imagery:

Sensors aboard satellites measure thermal infrared radiation emitted by the Earth's surface. Thermal imagery is used for detecting heat anomalies, monitoring volcanic activity, assessing urban heat islands, and studying climate change impacts.

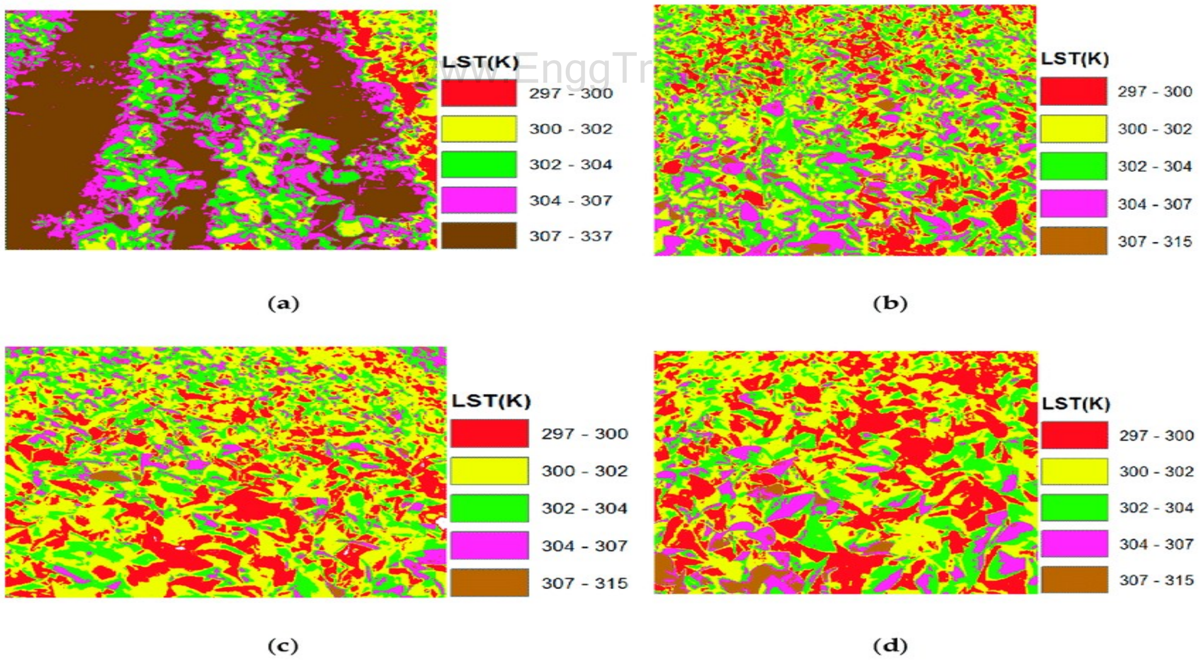


Figure thermal imagery

LiDAR Data:

LiDAR sensors emit laser pulses and measure the time it takes for the pulses to return, providing highly accurate elevation data. LiDAR is essential for creating Digital Elevation Models (DEMs), assessing terrain characteristics, and mapping landforms and vegetation structure.

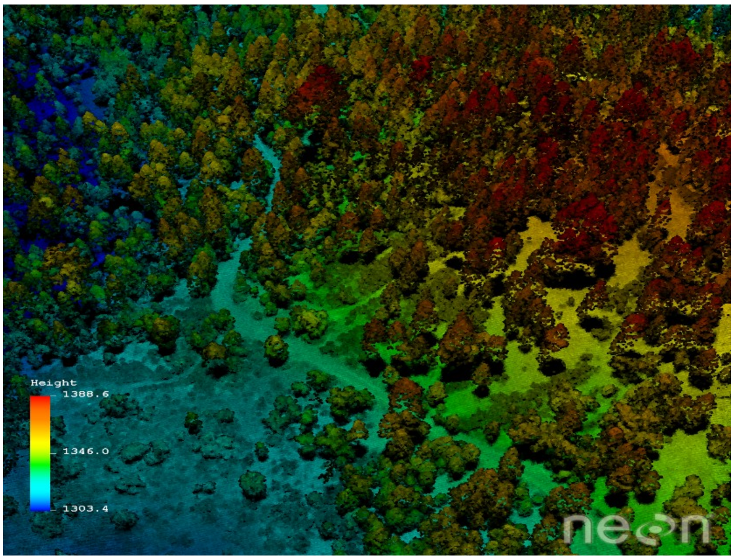


Figure lidar imagery

Levels of Satellite Data:

1. Level-0
2. Level-1
3. Level-2
4. Level-3
5. Level-4

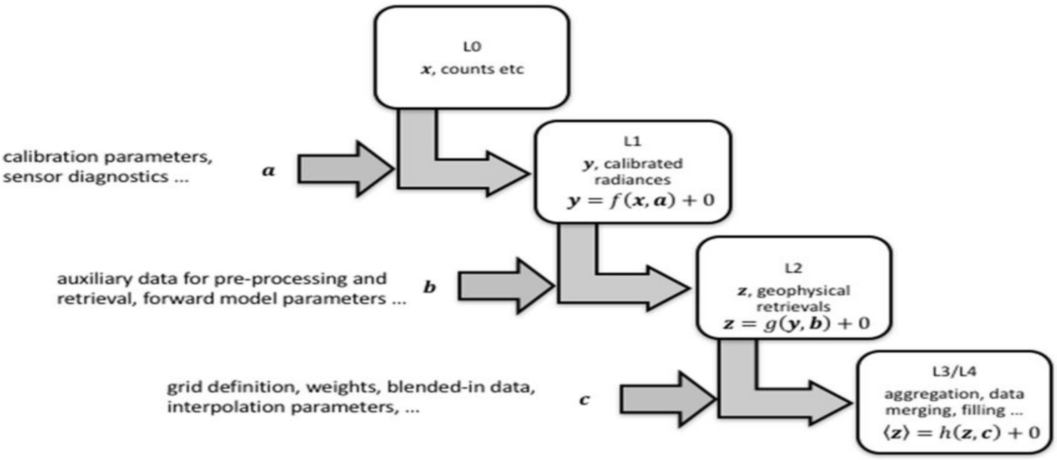


Figure levels of satellite data

Level-0:

Raw data as received from the satellite without any processing.

Level-1:

Data processed to correct for sensor artifacts, geometric distortions, and radiometric calibrations, making it usable for further analysis.

Level-2:

Further processed data with atmospheric correction applied to remove atmospheric effects, enhancing the accuracy of quantitative analysis.

Level-3:

Data that is georeferenced and often aggregated over time or space to create global or regional datasets suitable for thematic mapping and trend analysis.

Level-4:

Derived products generated by combining satellite data with other datasets or models to produce value-added products such as vegetation indices, land cover maps, and climate variables.

Open Source Satellite Data Products:

1. Sentinel Data
2. Landsat Data
3. MODIS Data
4. ESA Earth Observation Data
5. NASA Earth Observing System Data

Sentinel Data:

The European Space Agency's Sentinel satellites offer free and open access to a wealth of optical, radar, and thermal data through the Copernicus Open Access Hub. Sentinel data is widely used for environmental monitoring, disaster management, and scientific research.

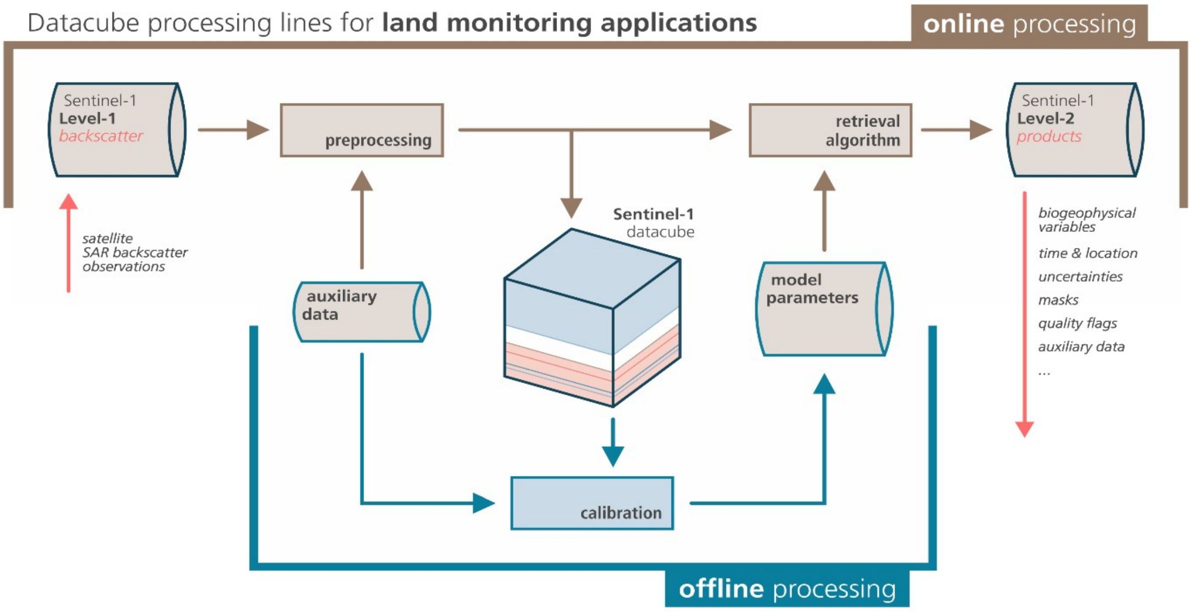


Figure Sentinel Data

Landsat Data:

The Landsat program, jointly managed by NASA and the USGS, provides the longest continuous record of Earth observations from space. Landsat data, including Landsat 8 and Landsat 9, is freely available and widely used for monitoring land cover change, assessing ecosystem health, and managing natural resources.

Figure Landsat Data

MODIS Data:

The Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra and Aqua satellites provides global coverage with moderate spatial resolution and daily revisits. MODIS data is used for monitoring vegetation dynamics, fire activity, sea surface temperature, and atmospheric conditions.

Figure MODIS Data

ESA Earth Observation Data:

In addition to Sentinel data, the European Space Agency (ESA) offers access to other Earth observation missions such as the Envisat, ERS, and CryoSat satellites, providing a diverse range of data products for scientific and operational applications.

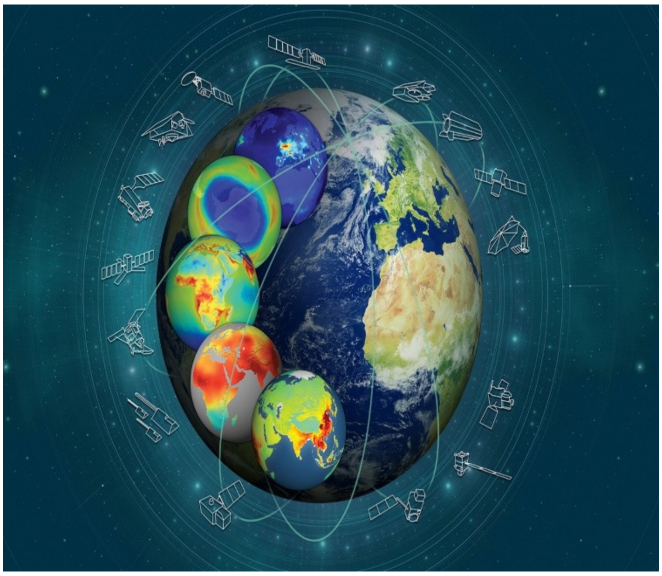


Figure ESA Earth Observation Data

NASA Earth Observing System Data:

NASA's Earth Observing System (EOS) satellites, including Terra, Aqua, and Aura, provide a wealth of data on Earth's atmosphere, oceans, land surfaces, and biosphere. These data are freely available through NASA's Earthdata Search and Distributed Active Archive Centers (DAACs).

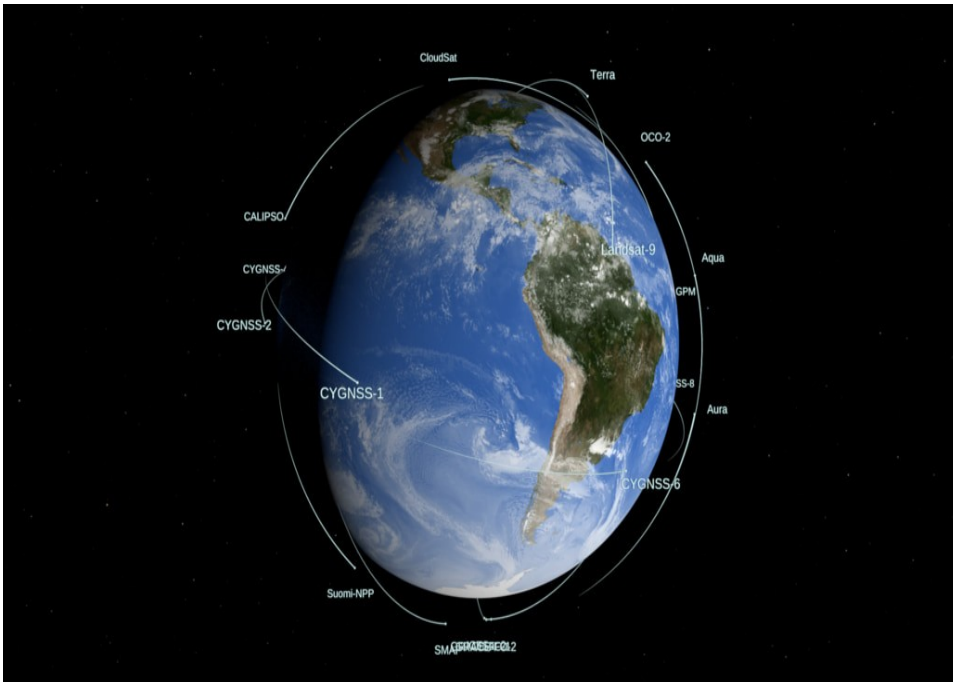


Figure NASA Earth Observing System Data

SELECTION AND PROCUREMENT OF DATA

1. Define Objectives and Requirements
2. Research Available Data Sources
3. Assess Data Quality and Suitability
4. Select Appropriate Data Products
5. Acquire Data
6. Ensure Data Compatibility and Preprocessing
7. Document and Validate Data

Define Objectives and Requirements:

- Clearly define the objectives of your remote sensing project or analysis. Determine what information you need to achieve your goals.
- Identify the spatial and temporal resolutions required for your study area and time frame.
- Consider the spectral bands or data types necessary to address your research questions or applications.

Research Available Data Sources:

- Explore the various sources of remote sensing data, including satellite missions, aerial surveys, government agencies, research institutions, and commercial providers.
- Familiarize yourself with the characteristics, capabilities, and limitations of different sensors and platforms.
- Investigate open-source data repositories and archives that offer free or low-cost access to satellite imagery and other remote sensing datasets.

Assess Data Quality and Suitability:

- Evaluate the quality, accuracy, and reliability of available datasets. Consider factors such as radiometric and geometric calibration, sensor resolution, and spectral characteristics.
- Assess whether the spatial, spectral, and temporal resolutions meet your requirements for the intended application.
- Verify the data's currency and relevance to your study area and research objectives.

Select Appropriate Data Products:

- Choose the remote sensing data products that best match your project's needs and specifications.
- Select datasets that provide the required spatial coverage, spectral information, and temporal frequency for your analysis.
- Consider complementary datasets or multi-sensor/multi-temporal approaches to enhance the robustness and accuracy of your results.

Acquire Data:

- Once you've identified the desired datasets, proceed to acquire the data through appropriate channels.
- Utilize online portals, data archives, and distribution platforms provided by satellite agencies, government organizations, and data providers.
- Depending on the availability and licensing terms, download or request access to the required datasets.

Ensure Data Compatibility and Preprocessing:

- Verify that the acquired data are compatible with your analysis software and workflow.
- Perform necessary preprocessing steps, such as geometric correction, radiometric calibration, and atmospheric correction, to enhance the usability and accuracy of the data.
- Address any potential issues or artifacts that may affect the interpretation or analysis of the remote sensing data.

Document and Validate Data:

- Document the metadata and provenance of the acquired datasets, including sensor specifications, acquisition parameters, and processing history.
- Validate the accuracy and reliability of the data through ground truth measurements, validation studies, or comparison with reference datasets.
- Document any uncertainties or limitations associated with the remote sensing data to ensure transparency and rigor in your analysis.

VISUAL INTERPRETATION- BASIC ELEMENTS AND INTERPRETATION KEYS

Basic elements of image interpretation

A systematic study .of aerial photographs and satellite imageries usually involves several characteristics of features shown on an image. The following characteristics (elements) are called fundamental picture elements. These elements aid visual interpretation process of aerial photos and/or satellite imagery.

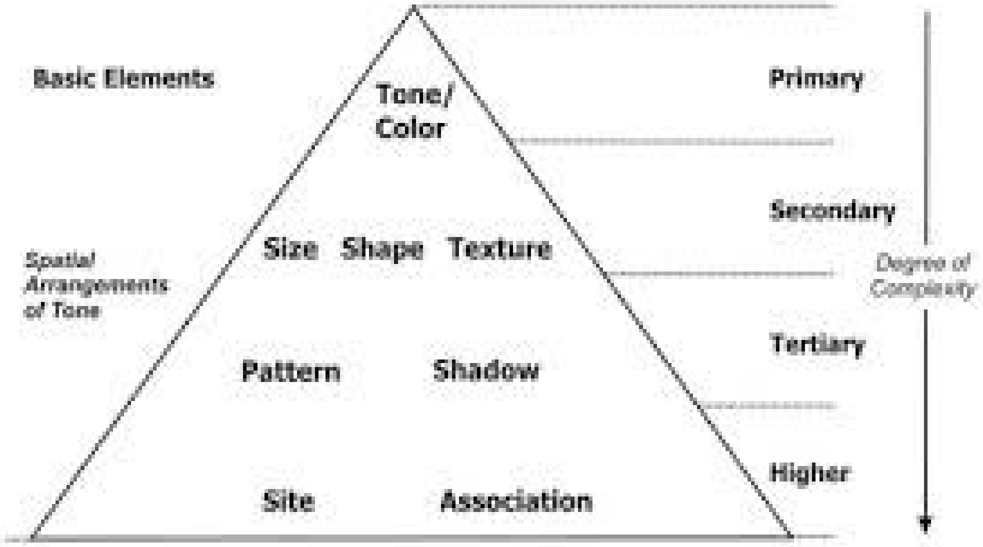


Figure elements of image interpretation

(i) Tone

- Ground objects of different colour reflect the incident radiation differently depending upon the incident wave length, physical and chemical constituents of the objects.
- The imagery as recorded in remote sensing is in different shades or tones. For example, ploughed and cultivated lands record differently from fallow fields. Tone is expressed qualitatively as light, medium and dark.
- In SLAR imagery, for example, the shadows cast by non-return of the microwaves appear darker than those parts where greater reflection takes place. These parts appear of lighter tone.
- Similarly in thermal imagery objects at higher temperature are recorded of lighter tone compared to objects at lower temperature, which appear of medium to darker tone. Similarly top soil appears as of dark tone compared to soil containing quartz sand.
- The coniferous trees appear in lighter tone compared to broad leave tree clumps.
- Tone, therefore, refers to the colour or reflective brightness. Tone along with texture and shadow (as described below) help in Interpretation and hence is a very important key.

- Differences in moisture content of the soil or rock result in differences in tone. In a black and white photograph dark tone indicates dark bodies, namely, greater moisture contents and grey or white tone reflect the dry soil.
- The aerial photos with good contrast bring out tonal differences and hence help in better interpretation. Tonal contrast can be enhanced by use of high contrast film, high contrast paper or by specialized image processing techniques such as 'Dodging' or 'Digital Enhancement'.
- Sometimes Infrared film can give better contrast but it can also reduce resolution and loss of detail in shadows.

(ii) Texture

- Texture is an expression of roughness or smoothness as exhibited by the imagery. It is the rate of change of tonal values.
- Mathematically it is given as dD/dx where D is the Density and 'x' the distance measured from one arbitrary starting point, and can be measured numerically by the use of microdensitometer.
- Changes of density 'D' from point 'A' of the imagery to point 'B' as measured by the micro-densitometer divided by the distance gives the texture values numerically. Texture is dependent upon.

(a) photographic tone
(b) shape,
(c) size,
(d) pattern and scale of the imagery.

- Any slight variation of these can change the texture. Texture can qualitatively be expressed as course, medium and fine. The texture is a combination of several image characteristics such as tone, shadow, size, shape and pattern etc., and is produced by a mixture of features too small to be seen individually because the texture by definition is the frequency of tonal changes.
- As an example, leaves of a tree are too small to be seen on an aerial photo collectively along with shadow they give what is called texture, which in turn helps to differentiate between shrubs and trees. Texture sometimes can be very important factor in determining the slope stability.
- In the case of a humid ground, the blockage of water or bad drainage a characteristic texture results.

- Even spring and seepage of water from the base of clay give a kind of 'turbulant' texture.

(iii) Association

- The relation of a particular feature to its surroundings is an important key to interpretation.
- Sometimes a single feature by itself may not be distinctive enough to permit its identification.
- For example, Sink holes appears as dark spots on an imagery where the surface or immediate subsurface soil consists of lime stones, Thus the appearance of sink holes is always associated with surface lime stone formation.
- An example is that of kettle holes which appear as depressions on photos due to terminal moraine and glacial terrain.
- An another example is that of dark-toned features associated with a flood plain of a river, which can be interpreted as infilled oxbow lakes.

(iv) Shape

Some ground features have typical shapes due to the structure or topography. For example air fields and football stadium easily can be interpreted because of their finite ground shapes and geometry whereas volcanic covers, sand, river terraces, cliffs, gullies can be identified because of their characteristics shape controlled by geology and topography.

(v) Size

- The size of an image also helps for its identification whether it is relative or absolute.
- Sometimes the measurements of height (as by using parallax bar) also gives clues to the nature of the object.
- For example, measurement of height of different clumps of trees gives an idea of the different species, similarly the measurement of dip and strike of rock formation help in identifying sedimentary formation.
- Similarly the measurements of width of roads help in discriminating roads of different categories i.e,national, state, local etc. Size of course, is dependent upon the scale of imagery.

(vi) Shadows

- Shadows cast by objects are sometimes important clues to their identification and
- Interpretation.
- For example, shadow of a suspension bridge can easily be discriminated from that of cantilever bridge.
- Similarly circular shadows are indicative of coniferous trees. Tall buildings and chimneys, and towers etc., can easily be identified for their characteristic shadows. Shadows on the other hand can sometimes render interpretation difficult i.e. dark slope shadows covering important detail.

(vii) Site factor or Topographic Location

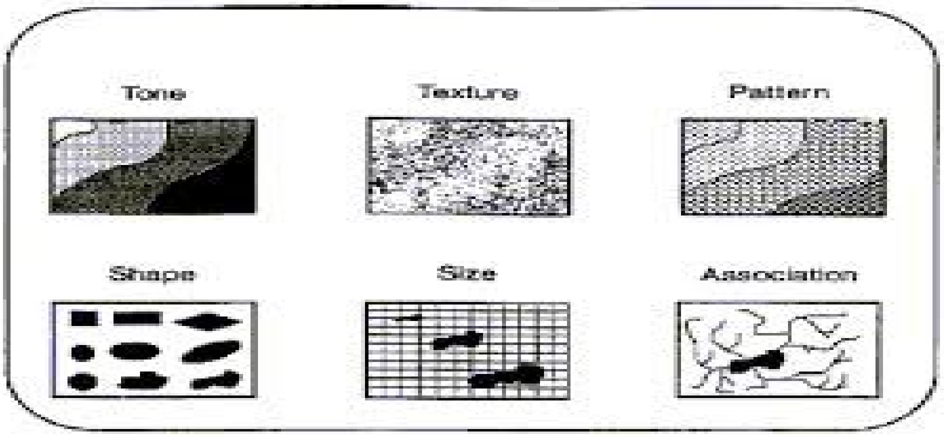
- Relative elevation or specific location of objects can be helpful to identify certain features.
- For example, sudden appearance or disappearance of vegetation is a good clue to the underlying soil type.

(viii) Pattern

- Pattern is the orderly spatial arrangement of geological topographic or vegetation features. This spatial arrangement may be two-dimensional (plan view) or 3-dimensional (space).

- Geological pattern may be linear or curved. Linear pattern are formed of a very large number of continuous or discontinuous short ticks which when viewed by eye appear to be continuous lines.
- Examples of linear geological pattern are faults, fractures, joints, dykes, bedding planes, anticlines etc.,
- Examples of curved features are plunging anticlines and folds. Lineaments or lineations may be short, medium or long running for several hundred kilometers. These are very important expressions of the lithologic characters of the underlying rocks and the attitude of the rock
- bodies, spacing of planes of bedding and other structural weaknesses and the control extendedby them over the surface features. Vegetation pattern may be of the 'Block' type or 'Alignment' type.
- The 'Alignment' type may be further subdivided into the Linear, Parallel and curved type.

- Alignments are due to narrow rockbands or faults. Since faults retain moisture, vegetation is aligned along the fault lines. Example of topographic pattern is the typical drainage patterns(controlled and uncontrolled type). The uncontrolled types are those, which are purely governed by topography, i.e., the slops whereas the controlled type are those, which are governed by the underlying geological formations.



Key Elements of Visual Image Interpretation

- Keys that provide useful reference of refresher materials and valuable trainingaids for novice interpreters are called image interpretation keys.
- These image interpretation keys are very much useful for the interpretation of complex imageries or photographs.
- These keys provide a method of organising the information in a consistent manner and provide guidance about the correct identification of features or conditions on the images.
- Ideally, it consists of two basic parts'

(i) a collection of annotated or captioned images (stereopalrs) illustrative of the features or conditions to be identified, and

(ii) a graphic or word description that sets forth in some systematic fashion the image recognition characteristics of those features or conditions. There are two types of keys: selective key and elimination key.

Selective Key

- Selective key is also called reference key which contains numerous examples images with supporting text.

- The interpreter select one example image that most nearly resembles the fracture or condition found on the image under study.

Elimination Key

- An elimination key is arranged so that interpretation process step by step from general to specific, and leads to the elimination of all features of conditions except the one being identified**.**
- Elimination keys are also called dichotomous keys where the interpreter makes a series of choices between two alternatives and progressively eliminates all but one possible answer.

DIGITAL INTERPRETATION

Digital interpretation in remote sensing refers to the process of analyzing and extracting meaningful information from digital imagery acquired by satellite, aerial, or other remote sensing platforms. Unlike traditional visual interpretation, which relies on human analysts to interpret features in photographs or maps, digital interpretation involves the use of computer-based techniques to automate or assist in the analysis of remote sensing data.The steps carried out are

1. Image Processing
2. Feature Extraction
3. Change Detection
4. Quantitative Analysis
5. Integration with GIS and Modeling
6. Validation and Accuracy Assessment

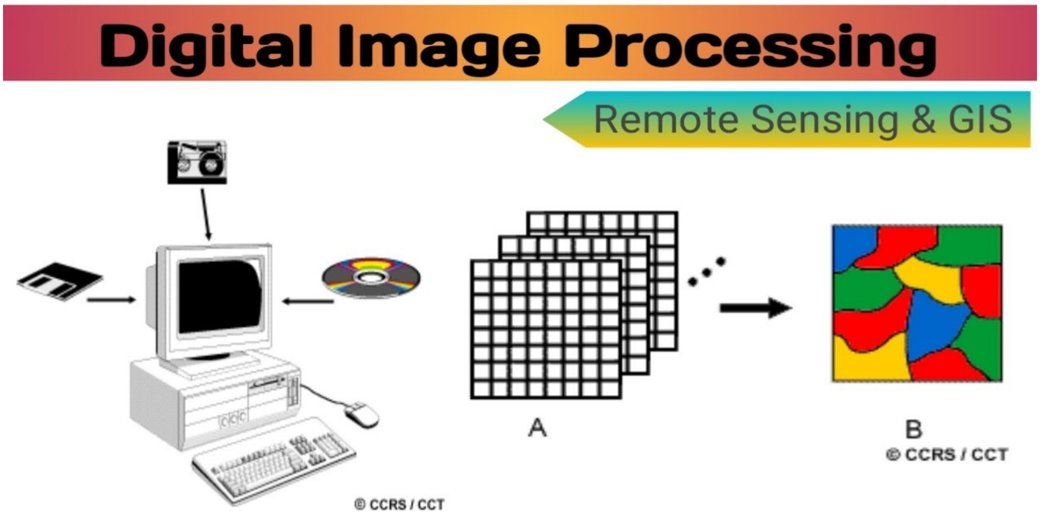


Figure data interpretation

Image Processing:

- Digital interpretation begins with image processing, which involves a series of computational techniques to enhance, correct, and manipulate remote sensing imagery.
- Preprocessing steps may include radiometric and geometric correction, atmospheric correction, noise reduction, and image fusion to improve the quality and usability of the data.

Feature Extraction:

- Digital interpretation techniques are used to automatically or semi-automatically extract features of interest from remote sensing imagery.
- Feature extraction algorithms identify and delineate objects or land cover classes based on their spectral, spatial, and textural characteristics.
- Common feature extraction methods include classification, segmentation, object-based image analysis (OBIA), and machine learning algorithms such as supervised and unsupervised classification.

Change Detection:

- Digital interpretation facilitates the detection and analysis of temporal changes in remote sensing data.

- Change detection algorithms compare multiple images acquired at different times to identify areas of change, such as urban expansion, deforestation, land cover conversion, or natural disasters.
- Techniques such as image differencing, image rationing, and time-series analysis are used to quantify and characterize the magnitude and extent of changes over time.

Quantitative Analysis:

- Digital interpretation enables quantitative analysis of remote sensing data, allowing for the measurement and extraction of numerical information from imagery.
- Quantitative analysis may include calculating vegetation indices, estimating land surface temperature, determining object heights or volumes, and deriving biophysical parameters such as biomass or soil moisture.
- These quantitative measurements provide valuable insights into environmental processes, ecosystem dynamics, and land surface characteristics.

Integration with GIS and Modeling:

- Digital interpretation outputs are often integrated with geographic information systems (GIS) and spatial analysis tools to perform further analysis, visualization, and modeling.
- GIS allows for the spatial representation, manipulation, and overlay of remote sensing data with other geospatial datasets, enabling comprehensive spatial analysis and decision-making.
- Digital interpretation results can be used as input for environmental modeling, land use planning, resource management, and disaster risk assessment.

Validation and Accuracy Assessment:

- Digital interpretation results are validated and assessed for accuracy through ground truth measurements, reference data, or validation studies.
- Accuracy assessment techniques compare digital interpretation outputs with independently collected data to evaluate the reliability and precision of the analysis.
- Validation ensures the quality and credibility of the digital interpretation results for informed decision-making and scientific research.

CONCEPTS OF IMAGE RECTIFICATION

Introduction

- As seen in the earlier chapters, remote sensing data can be analysed using visual image interpretation techniques if the data are in the hardcopy or pictorial form. It is used extensively to locate specific features and conditions, which are then geocoded for inclusion in GIS.
- Visual image interpretation techniques have certain disadvantages and may require extensive training and are labour intensive. In this technique, the spectral characteristics are not always fully evaluated because of the limited ability of the eye to discern tonal values and analyse the spectral changes.
- If the data are in digital mode, the remote sensing data can be analysed using digital image processing techniques and such a database can be used in raster GIS. In applications where spectral patterns are more informative, it is preferable to analyse digital data rather than pictorial data.
- In today's world of advanced technology where most remote sensing data are recorded in digital format, virtually all image interpretation and analysis involves some element of digital processing.
- Digital image processing may involve numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer.

- In order to process remote sensing imagery digitally, the data must be recorded and available in a digital form suitable for storage on a computer tape or disk. Obviously, the other requirement for digital image processing is a computer system, sometimes referred to as an image analysis system, with the appropriate hardware and software to process the data.
- Several commercially available software systems have been developed specifically for remote sensing image processing and analysis.
- For discussion purposes, most of the common image processing functions available in image analysis systems can be categorized into the following four categories:

1. Preprocessing Image Enhancement
2. Image Transformation
3. Image Classification and Analysis

PREPROCESSING

- Preprocessing functions involve those operations that are normally required prior to the maindata analysis and extraction of information, and are generally grouped as radiometric or geometric corrections.
- Radiometric corrections include correcting the data for sensor irregularities and unwanted sensor or atmospheric noise, and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor.
- Geometric corrections include correcting for geometric distortions due to sensor-Earth geometry variations, and conversion of the data to real world coordinates (e.g. latitude and longitude) on the Earth's surface.
- The objective of the second group of image processing functions grouped under the term of image enhancement, is solely to improve the appearance of the imagery to assist in visual interpretation and analysis.
- Examples of enhancement functionsinclude contrast stretching to increase the tonal distinction between various features in a

scene, and spatial filtering to enhance (or suppress) specific spatial patterns in an image.

- Image transformations are operations similar in concept to those for image enhancement. However, unlike image enhancement operations which are normally applied only to a single channel of data at a time, image transformations usually involve combined processing of data from multiple spectral bands. Arithmetic operations (i.e. subtraction, addition, multiplication, division) are performed to combine and transform the original bands into "new" images which better display or highlight certain features in the scene.
- We will look at some of these operations including various methods of spectral or band ratioing, and a procedure called principal components analysis which is used to more efficiently represent the information

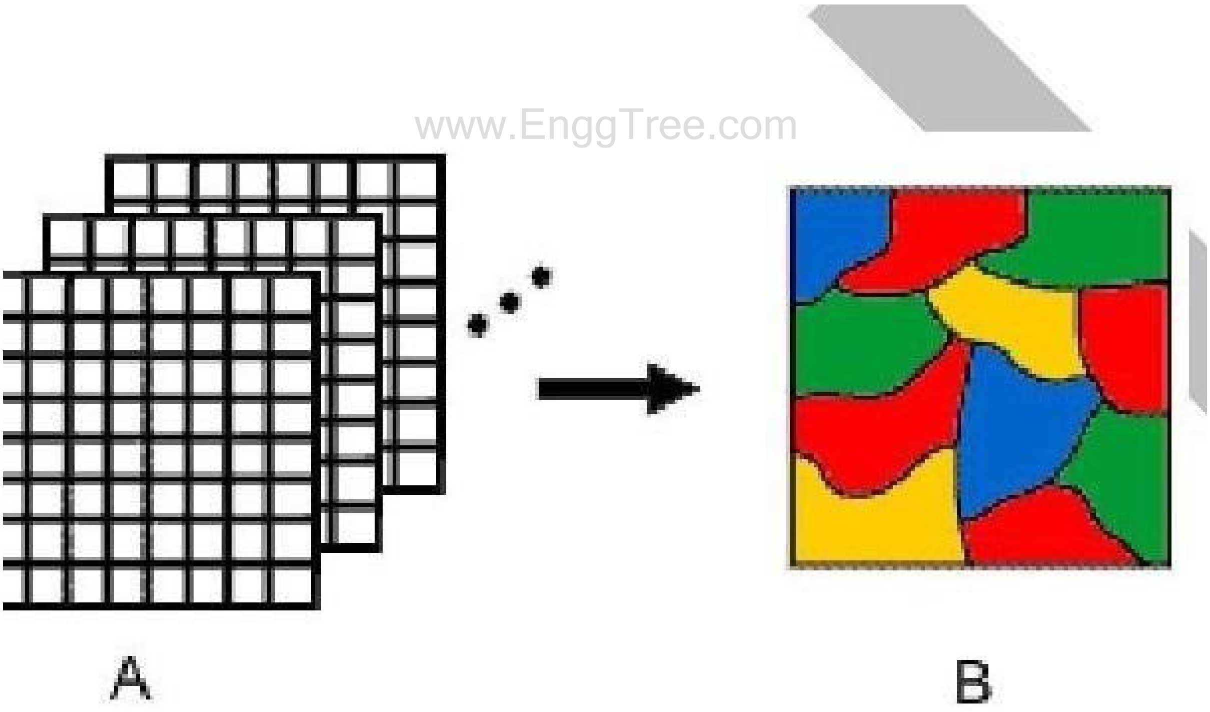


Figure image classification

Image classification

- Image classification is a procedure to automatically categorize all pixels in an image of a terrain into land cover classes.
- Normally, multispectral data are used to perform the classification of the spectral pattern present within the data for each pixel is used as the numerical basis for categorization.
- This concept is dealt under the broad subject, namely, Pattern Recognition.
- Spectral pattern recognition refers to the family of classification procedures that utilises this pixel-by-pixel spectral information as the basis for automated land cover classification.
- Spatial pattern recognition involves the categorization of image pixels on the basis of the spatial relationship with pixels surrounding them. Image classification techniques are grouped into two types, namely
    1. Supervised
    2. Unsupervised
- The classification process may also include features, such as, land surface elevation and the soil type that are not derived from the image.
- A pattern is thus a set of measurements on the chosen features for the individual to be classified. The classification process may therefore be considered a form of pattern recognition, that is, the identification of the pattern associated with each pixel position in an image in terms of the characteristics of the objects or on the earth's surface.

Supervised Classification

- A supervised classification algorithm requires a training sample for each class, that is, a collection of data points known to have come from the class of interest. The classification is thus based on how "close" a point to be classified is to each training sample.
- We shall not attempt to define the word "close" other than to say that both geometric and statistical distance measures are used in practical pattern recognition algorithms.

- The training samples are representative of the known classes of interest to the analyst.
- Classification methods that relay on use of training patterns are called supervised classification methods.
- The three basic steps involved in a typical supervised classification procedure are as follows :

(i) Training stage:

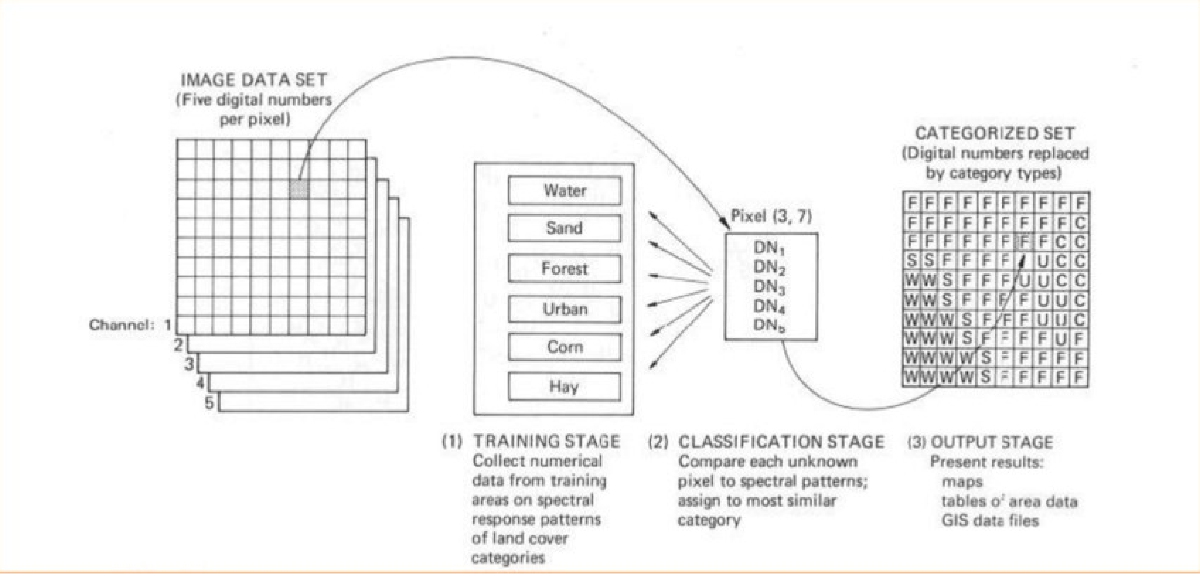
- The analyst identifies representative training areas and develops numerical descriptions of the spectral signatures of each land cover type of interest in the scene.

(ii) The classification stage:

- Each pixel in the image data set IS categorized into the land cover class it most closely resembles. If the pixel is insufficiently similar to any training data set it is usually labeled 'Unknown'.

(iii) The output stage:

- The results may be used in a number of different ways. Three typical
  forms of output products are thematic maps, tables and digital data files which become input data for GIS.
- The output of image classification becomes input for GIS for spatial analysis of the terrain. Figure depicts the flow of operations to be performed during image classification of remotely sensed data of an area which ultimately leads to create database as an input for GIS.



F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	C
F	F	F	F	F	F	F	F	C	C
S	S	F	F	F	F	[illegible]	U	C	C
W	W	S	F	F	F	U	U	C	C
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W	W	W	S	F	F	F	U	U	C
W	W	W	S	F	F	F	F	U	F
W	W	W	W	S	F	F	F	F	F
W	W	W	W	S	F	F	F	F	F

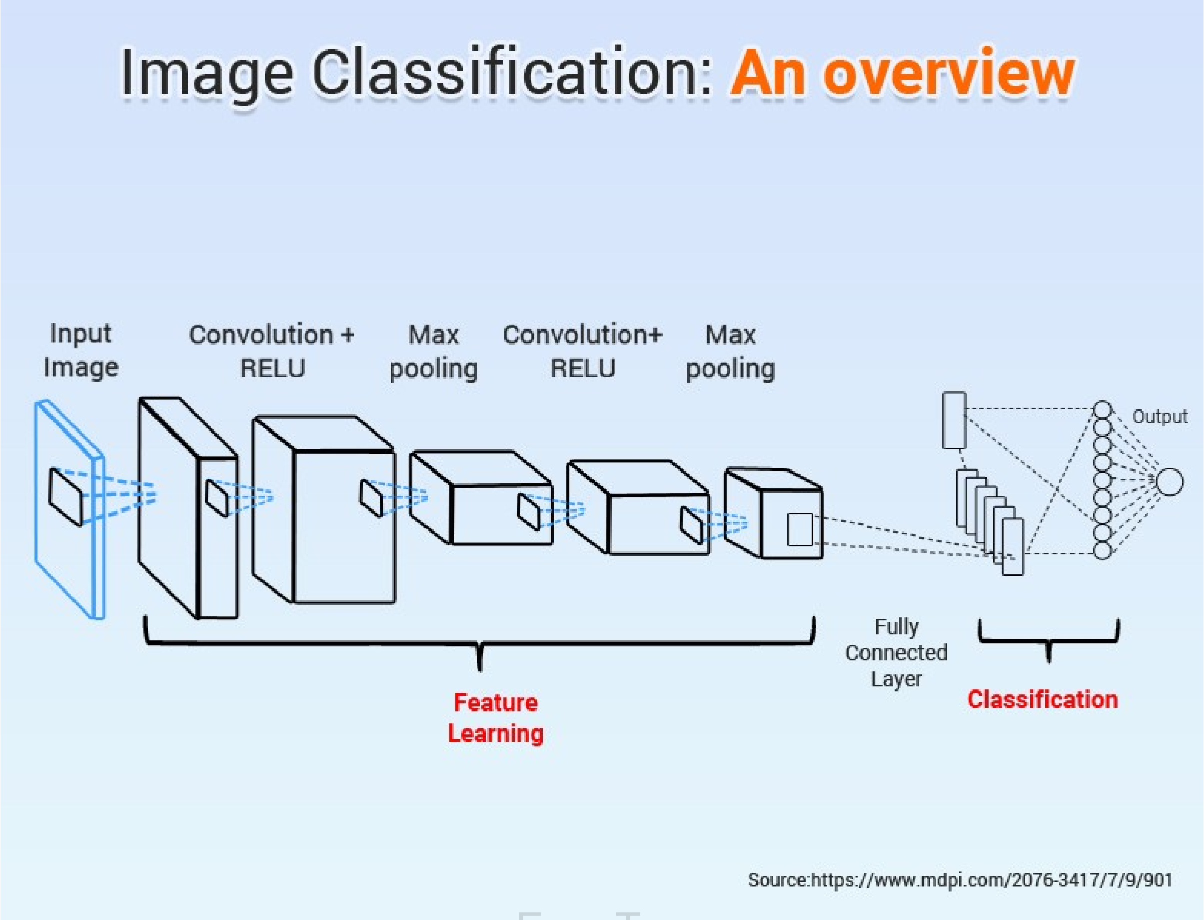
Figure Basic steps supervised classification

- There are a number of powerful supervised classifiers based on the statistics, which are commonly, used for various applications.
- A few of them are a minimum distance to means method, average distance method, parallelepiped method, maximum likelihood method, modified maximum likelihood method, baysian's method, decision tree classification, and discriminant functions.
- The principles and working algorithms of all these supervised classifiers are available in almost all standard books on remote sensing and so details are not provided here.
- Since all the supervised classification methods use training data samples, it is more appropriate to consider some of the fundamental characteristics of training data.

Training Dataset

- A training dataset is a set of measurements (points from an image) whose category membership is known by the analyst.
- This set must be selected based on additional information derived from maps, field surveys, aerial photographs, and analyst's knowledge of usual spectral signatures of different cover classes.
- Selecting a good set of training points is one of the most critical aspects of the classification procedure.
- These guidelines are as following:

(i)Select sufficient number of points for each class. If each measurement vector has N features, then select N+1 points per class and the practical minimum is 10*N per class. If the class shows a lot of variability (the scatter plot showing considerable spreading or scatter among training points), select a larger number of points, subject to practical limits of time, effort and expense. The more the training points, the better the "extra points" to evaluate the accuracy of the classifier.



Source:https://www.mdpi.com/2076-3417/7/9/901

Figure Image Classification

The more the points, the more accurate the classification will be.

(ii)Select training data sets which are representative of the classes of interest that show both typical average feature values and a typical degree of variability. For each class, select several training areas on the image, instead of just one. Each training area should contain a moderately large number of pixels. Pick training areas from seemingly heterogeneous or appearing regions. Pick training areas that are widely and spatially dispersed, across the full image. For each class, select the training areas which are uniformly distributed across the image and with high density.

(iii)Check that selected areas have unimodel distributions (histograms). A bimodal histogram suggests that pixels from two different classes may be included in the training sample.

(iv)Select training sets (physically) using a computer-based classification system:

Poorest method: Using coordinates of training points or training regions directly.

Better method: using joystick, trackball, light pen, directly on the image.
For example. EASI/PACE : The program should show the histograms, mean and standard deviations for each region selected, and for each class in total.
The Program should allow to iterate; do classification using one set of training points, then come back and modify training sets and class definitions without starting all over again. There should be options to combine classes from previous classification.
(v) The program should allow one to designate half of the points as training points, and the other half to test the accuracy of the trained classifier. Before it is used, the training set should be evaluated by examining scatterplots and/or histograms for each class. It should show unimodel distributions, hopefully approximating normal distributions. If not unimodel, one may want to select new training sets. After the discriminant functions and the classification rule is derived, accuracy must be tested.

- Two acceptable techniques which are commonly used are:

(a) Designate a randomly selected half of the training points as test points, before developing classifier. Use the other half for training. Then classify the half of the data not used for training.
Develop contingency table (confusion matrix) to indicate probability of error in each class. This procedure is actually a measure of the consistency of the classifier.
(b) Randomly select a set of pixel regions from the image of an unknown class. Classify them using the discriminant function and rules developed from the training set. Then verify the correctness of the classification (again with a confusion matrix) by checking the identity of these regions using external information sources like maps and aerial photos.
(vi)Separability of classes: So far, we have looked at an ideal situation where there is no overlap between different classes. In reality the classes are likely to overlap. It can be seen that the less the overlap between classes the lower the chance of misclassifying a given pixel. Classes that have little overlap is said to be highly separable.

Unsupervised Classification

- Unsupervised classification algorithms do not compare .points to be classified with training data.
- Rather, unsupervised algorithms examine a large number of unknown data vectors and divide them into classes based on properties inherent to the data themselves.
- The classes that result stem from differences observed in the data. In particular, use is made of the notion that data vectors within a class should be in some sense mutually close together in the measurement space, whereas data vectors in different classes should be comparatively well separated.
- If the components of the data vectors represent the responses in different spectral bands, the resulting classes might be referred to as spectral classes, as opposed to information classes, which represent the ground cover types of interest to the analyst.
- The two types of classes described above, information classes and spectral classes, may not exactly correspond to each other. For instance, two information classes, corn and soya beans, may look alike spectrally. We would say that the two classes are not separable spectrally.

- At certain times of the growing season corn and soya beans are not spectrally distinct while at other times they are. On the other hand a single information class may be composed of two spectral classes.
- Differences in planting dates or seed variety might result in the information
- class" corn" being reflectance differences of tasseled and untasseled corn.

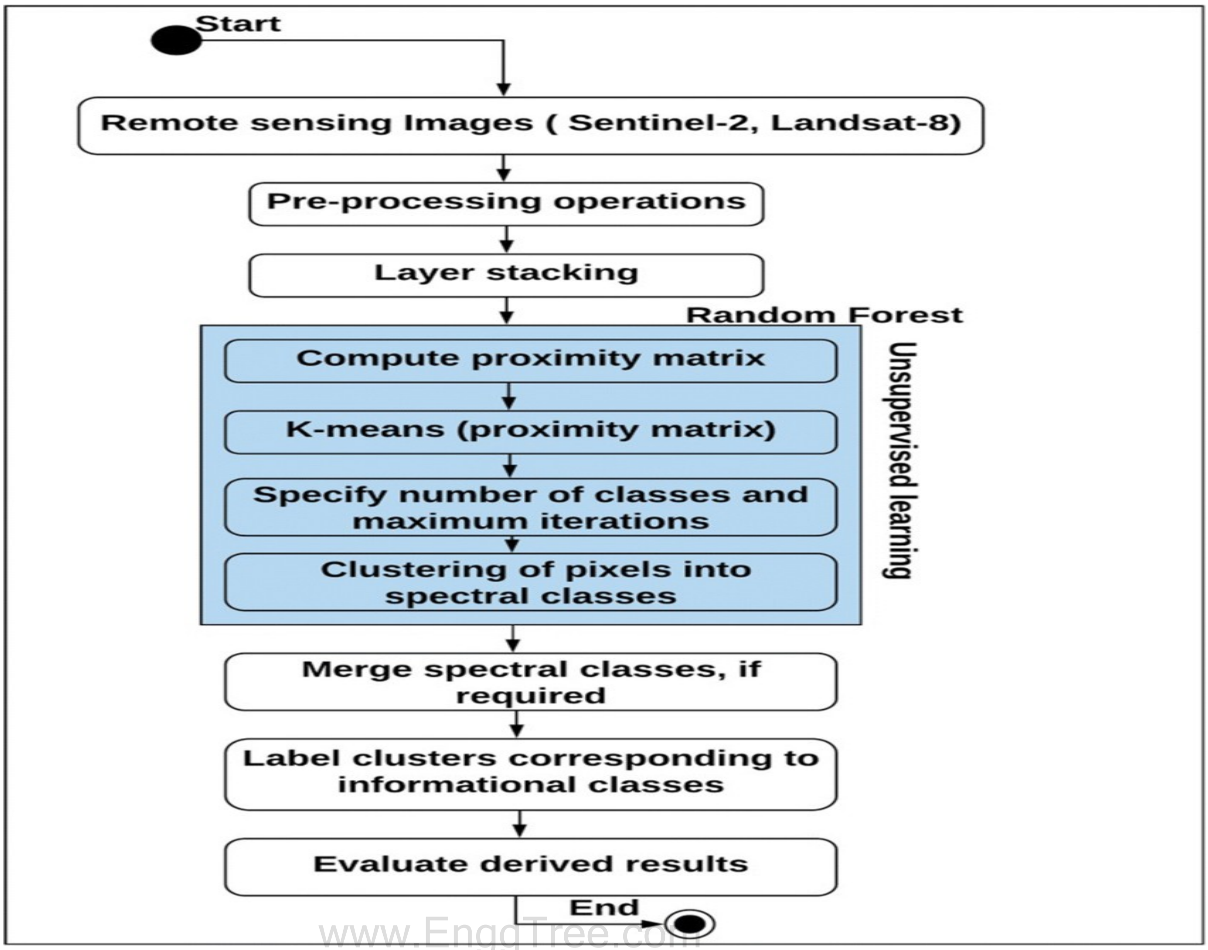


Image enhancement

- Low sensitivity of the detectors, weak signal of the objects present on the earth surface, similar reflectance of different objects and environmental conditions at the time of recording are the major causes of low contrast of the image.
- Another problem that complicates photographic display of digital image is that the human eye is poor at discriminating the slight radiometric or spectral differences that may characterize the features. The main aim of digital enhancement is to amplify these slight differences for better clarity of the image scene.
- This means digital enhancement increases the separability (contrast) between the interested classes or features.
- The digital image enhancement may be defined as some mathematical operations that are to be applied to digital remote sensing input data to improve the visual appearance of an image for better interpretability or subsequent digital analysis. Since the image quality is a subjective measure varying from person to

person , there is no simple rule which may produce a single best result.

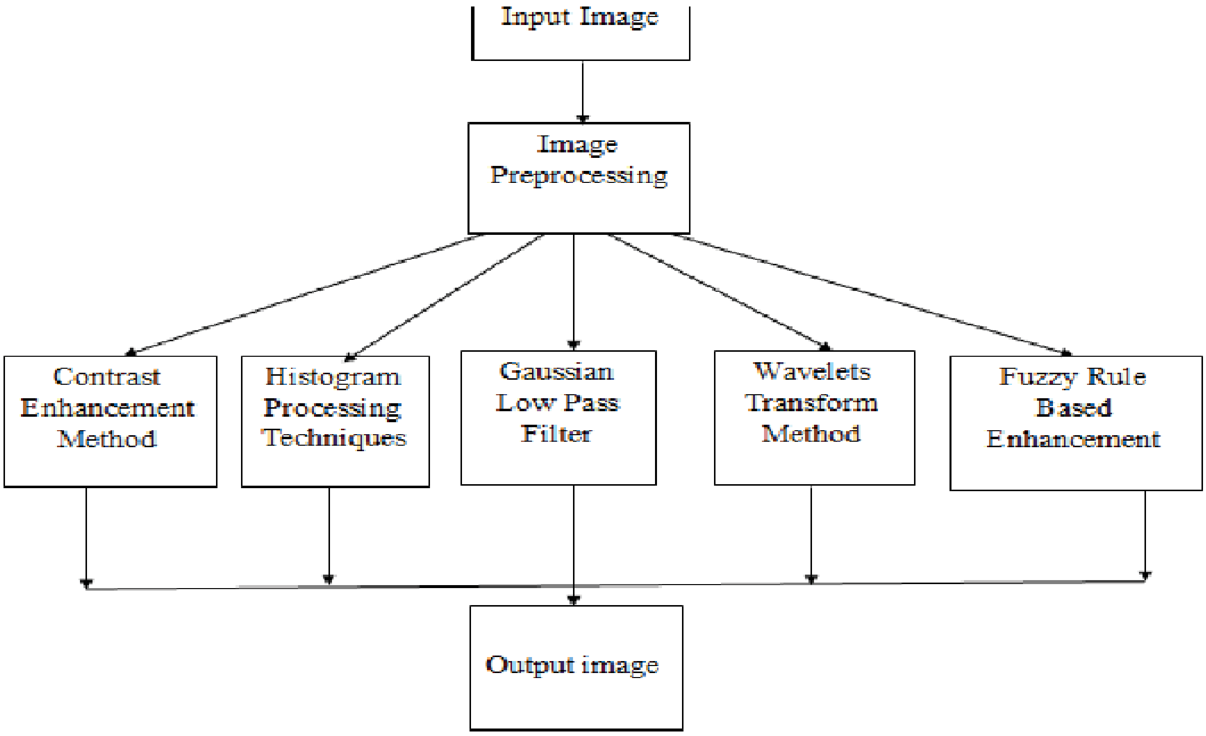


Figure image enhancement

- Normally, two or more operations on the input image may suffice to fulfill the
- desire of the analyst, although the enhanced product may have a fraction of the total information stored in the original image.
- As in many outer areas of knowledge, the distinction between one type of analysis and another is a matter of personal taste and need of the interpreter. In remote sensing literature, many digital enhancement algorithms are available. They are contrast stretching enhancement, rationing, linear combinations, principal component analysis, and spatial filtering.
- Broadly, the enhancement techniques are categorized as point operations and local operations.
- Point operations modify the values of each pixel in an image data set independently, whereas local operations modify the values of each pixel in the context of the pixel values surrounding it.
- Point operations include contrast enhancement and band combinations, but spatial filtering is an example of local operations. In this section, contrast enhancement, linear contrast

stretch ,histogram equalization, logarithmic contrast enhancement, and exponential contrast enhancement are considered.

Contrast Enhancement

- The sensors mounted on board the aircraft and satellites have to be capable of detecting upwelling radiance levels ranging from low (oceans) or ice).

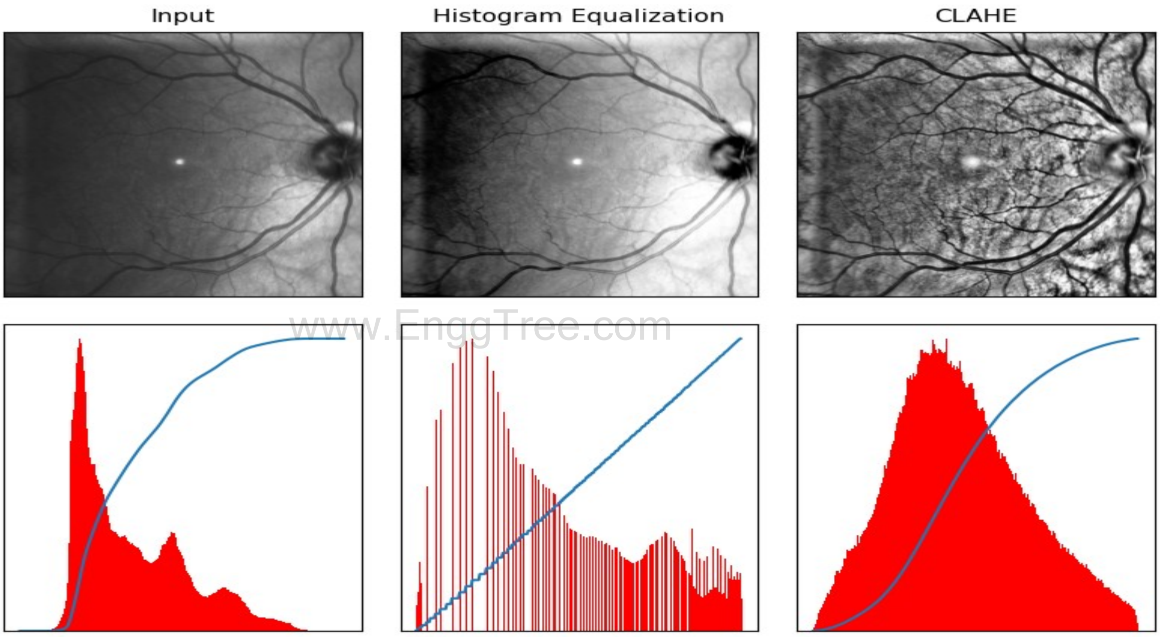


Figure Contrast Enhancement

- For any particular area that is being imaged it is unlikely that the full dynamic range of the sensor will be used and the corresponding image is dull and lacking in contrast or over bright. In terms of the RGB model, the pixel values are clustered in a narrow range of grey levels.
- If this narrow range of gray levels could be altered so as to fit the full range of grey levels, then the contrast between the dark and light areas of the image would be improved while maintaining the relative distribution of the gray levels. It is indeed the manipulation of look-up table values.

- The enhancement operations are normally applied to image data after the appropriate restoration procedures have been performed. The most commonly applied digital enhancement techniques will be considered now.
- The sensitivity of remote sensing detectors was designed to record a wide range of terrain brightness from black asphalt and basaltic rocks to White Sea ice under a wide range of lighting conditions. In general, few of the scenes have the full brightness range to produce an image with optimum contrast ratio it is inevitable to utilize the entire dynamic range. Digital contrast enhancement is thus of prime importance.
- The objective of contrast stretching is to expand the narrow dynamic range of gray values (digital numbers) typically present in an input image.
- A variety of contrast stretching algorithms is available and is broadly categorized as linear contrast stretching and non-linear contrast stretching.

Spatial Filtering Techniques

- Some of the most commonly used filtering techniques are given below.

a. Low Pass Filters
b. Median Filter
c. High Pass Filters
d. Filtering for Edge Enhancement

- A characteristic of remotely sensed images is a parameter called spatial frequency, defined as the number of changes in brightness values per unit distance for any particular part of an image.
- If there are few changes in brightness value over a given area it is termed as a low frequency area. If the brightness values changes dramatically over very short distances, this is called high frequency area.
- Algorithms which perform image enhancement are called filters because they suppress certain frequencies and pass (emphasise) others. Filters that pass high frequencies while emphasizing fine

detail and edges called high frequency filters, and filters that pass low frequencies called low frequency filters.

- Filtering is performed by using convolution windows. These windows are called mask, template filter or kernel. In the process of filtering, the window is moved over the input image from extreme top left hand corner of the scene.
- The discrete mathematical function transforming the original input image digital number to a new digital value.
- First it will move along the line. As soon as the line is complete, it will restart
- for the next line for covering the entire image.
- The mask window may be rectangular (1 x 3, or 1 x 5 pixels) size or square (3 x 3, 5 x 5 or 7 x 7 pixels size). Each pixel of the window is given a weightage. For low pass filters all thenweights in the window will be positive and for high pass filter all the values may be negative or zero, but the central pixel will be positive with higher weightage value.
- In the case of high pass filter the algebraic sum of all the weights in the window will be a zero.
- Many types of mask windows of different sizes can be designed by changing the size and varying weightage within the window.
- The simplest form of mathematical function performed in filtering operation is
- neighbourhood averaging.
- Another commonly used discrete function is to calculate the sum
- of the products given by the elements of the mask and the input image pixel digital numbers of the central pixel digital number in the moving window.