(ii) Mie Scattering
Mie scattering is caused by pollen, dust, smoke, water droplets, and other particles in the lower portion of atmosphere. This scattering is most affected in the lower 4.5 km of the atmosphere. Mie scattering (Figure 5.6) occurs when diameter of the particle present in the atmosphere is roughly of the same size as wavelength (λ). This scattering deteriorates the quality of multispectral images under heavy atmospheric haze. The greater the amount of smoke and dust particles in the atmospheric column, the more violet and blue light will be scattered away and only the longer orange and red wavelength light will reach our eyes.

(iii) Non-selective Scattering
Non-selective scattering is produced when the particles in the lower atmosphere are several times bigger than the diameter of the wavelength (λ). It takes places when the lower atmosphere contains suspended aerosols of diameter at least 10 times larger than the wavelengths. It is called as non-selective, as all wavelengths are scattered, not just blue, green, or red, equally, as evident from Figure 5.6. The large particles of smoke, water vapor, water droplets, ice crystals, present in the atmosphere, scatter all wavelengths of visible light almost equally, and due to this, the cloud appears as white. This scattering can severely reduce the information content of remotely sensed data that the imagery loses the contrast.

3. Absorption
It is the process by which incident radiation is taken in by a medium. A portion of the absorbed radiation is converted into internal heat energy, which may be subsequently emitted at longer thermal infrared wavelengths. Absorption of UV in the atmosphere is mainly due to electronic transitions of the atomic and molecular oxygen and nitrogen. The primary gases that are responsible for the atmospheric absorption of energy are; ozone, water vapour and carbon dioxide. Ozone in the stratosphere absorbs about 99% of the harmful solar UV radiation, and eventually protects us from diseases, like skin cancer.

There is a very little absorption of the EMR in the visible part of spectrum. The absorption in the infrared (IR) region is mainly due to water vapour (H_2O) and carbon dioxide (CO_2) molecules. The water and carbon dioxide molecules have absorption bands centred at the wavelengths from near to far infrared (0.7 to 15 µm). In the far infrared region, most of the radiations are absorbed by the atmosphere. In microwave radiation, there is no absorption, and that's why it is able to penetrate through atmosphere. Absorption reduces the solar radiance, and may alter the apparent spectral signature of the target being observed.

4. Transmission
In contrast to the absorption, transmission is the process by which incident radiations pass through the atmosphere and reach the Earth's surface. Visible wavelengths are able to penetrate to the Earth's surface with little atmospheric interaction, as shown in Figure 5.7. Microwaves and Radio waves have little interaction with the atmosphere, and easily penetrate to the surface.

5.8.2 Atmospheric windows
Atmospheric windows are those regions in the atmosphere where transmission of EMR from source to object and back to the sensor is maximum, and other losses are minimum. In optical remote sensing, many wavelengths within the visible and infrared portions of the electromagnetic spectrum (0.40-2.50 µm) have the ability to penetrate the Earth's atmosphere. Such wavelength regions, as shown in Figure 5.7, white regions in the curve, are considered to be very suitable in remote sensing. In these regions, sensors may be designed to capture the reflected radiations, providing images with good contrast. It is therefore important

that a sensor is designed to operate in these regions where the atmospheric losses are minimum. These windows are found in the visible, near-infrared, certain bands in thermal infrared and the microwave regions, as given in Table 5.2.

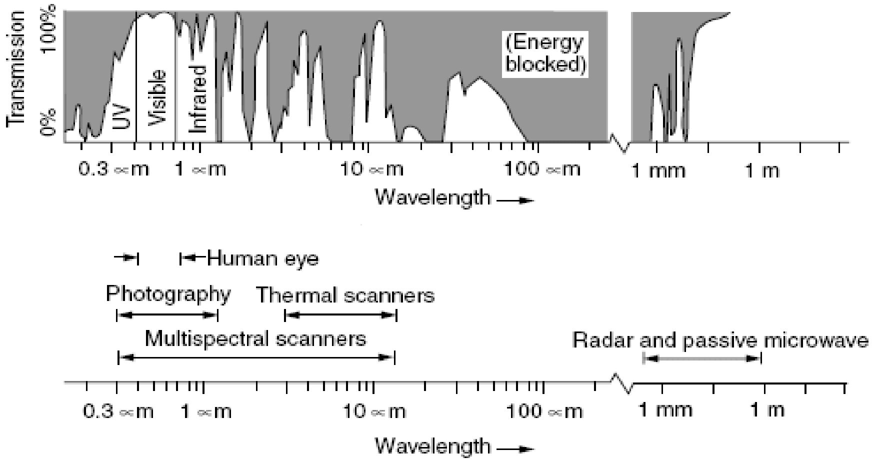

Figure 5.7 Atmospheric transmission process (Colwell, 1983)

Table 5.2 Major atmospheric windows used in remote sensing (Garg, 2019)

Atmospheric window	**Wavelength (μm)**	**Characteristics**
Upper ultraviolet, Visible and photographic	IR 0.3-1.0 approx.	95% transmission
Reflected infrared	1.3, 1.6 and 2.2	Three narrow bands
Thermal infrared	3.0-5.0 and 8.0-14.0	Two broad bands
Microwave	>5000	Atmosphere is mostly transparent

5.9 Spectral Signature of Objects

Spectral signature is the variation of reflectance or emittance of a material with reference to wavelengths (Figure 5.8). For any given material, the amount of solar radiation that is incident on it and then reflected back will vary with the wavelength. Every object due to its own chemical composition and physical properties reflects and emits EMR over a range of wavelengths. This EMR from objects over different wavelengths help in separating them distinctly based on their reflected response for a given wavelength, due to their different spectral signatures.

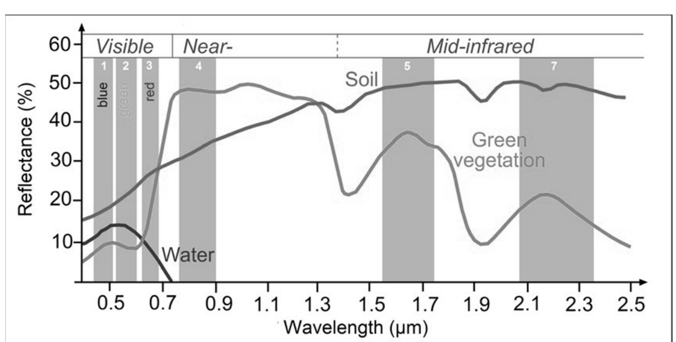

Figure 5.8 Spectral signature curves (Chavez et al., 1994)

Figure 5.8 shows typical spectral signature curves for three features; water, soils and green vegetation, where the wavelength regions are plotted on x-axis and percentage reflectances on y-axis. The percentage reflectance can be measured and computed as-

Reflectance (%) = (Incident energy/reflected energy)*100 (5.8)

By comparing the reflectance response patterns of different objects, several useful information may be derived. For example, water and vegetation may reflect somewhat similarly in the visible wavelengths but are distinctly separable in the infrared region. The underlying principle is that the two objects may exhibit different reflectances in a certain wavelength region, and thus these two objects are easily identifiable from an image. For example, at certain wavelengths, soil reflects more energy than the green vegetation, while at other wavelengths it absorbs more (reflects less) energy. Thus, various kinds of surface materials can be distinguished from each other by their different characteristics of spectral signature. The spectral response can also vary with time and with wavelength, even for the same object. Satellite sensors normally record different reflected energy in the red, green, blue, or infrared bands of the spectrum, called *multispectral images*. The ability of sensors to detect small changes in reflectance pattern provides a basis for analysis of multispectral remote sensing data.

The spectral signature of various objects can be accurately measured in the field using an instrument, known as *Spectro-radiometer* (or *Radiometer* or *Ground Truth Radiometer*). It is a field-based instrument that measures the intensity of radiation reflected from various objects in several wavelengths of EMS (Figure 5.9). It also helps in measuring the differences in the reflectance pattern of various objects (or spectral signatures) as a function of wavelength. The reflected radiation of various objects is measured in the field through spectro-radiometer in different wavelength regions, and these values are plotted on a graph, representing spectral signature of features. The associate software can automatically generate the signatures curves for various objects so that a detailed analysis can be carried out.

Figure 5.9 Field spectro-radiometer (Prolite, 2021)

Other possible applications of spectro-radiometer are:

- Inputs into models for plant growth, estimating crop biomass & crop yield, estimating leaf area index and crop loss due to disease, insect infestation, etc.
- Effects of drought on plant growth and yield
- Soil moisture and fertility studies
- Irrigation scheduling studies
- Water pollution and contaminants
- Land surface reclamation studies
- Mineral mapping
- Ground truth for remote sensing image analysis.

5.10 Types of Orbits

A space-borne remote sensing platform is placed in an orbit in which it moves continuously. From geometrical characteristics point of view, orbits of the space-borne platform can be circular, elliptic, parabolic or hyperbolic. But in practice, elliptical orbits are used. There are various satellite platforms to collect remote sensing data. These satellite move in two major orbits; Geo-synchronous orbits and Sun-synchronous orbits. The satellites moving in these are orbits are called Geo-synchronous satellites and Sun-synchronous satellites, respectively (Figure 5.10).

1. Geo-synchronous Satellites

Geo-synchronous or *Geo-stationary satellite* moves in an orbit so that it covers one revolution in the same time as the Earth to rotate once about its polar axis. The satellites revolve in the same direction as that of the Earth (west to east) at an angular velocity equal to the Earth's rotation rate. In order to achieve this orbital period, geo-synchronous orbits are generally at high altitude of 36,000 km above the equator, making an inclination of 0º from the equatorial plane. Thus from any point on the equator, the satellite moving in such orbit appears to be stationary. The INSAT series of satellites launched by Indian Space Research Organization, Department of Space, Government of India, is an example of these satellites.

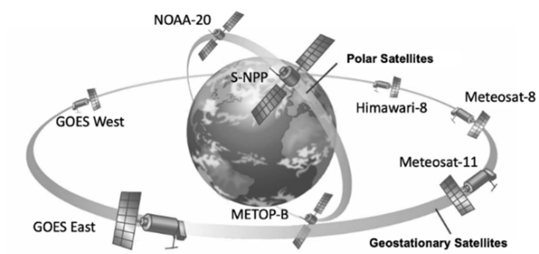

Figure 5.10 Sun-synchronous and Geosynchronous orbits (Jenson, 2007)

The geo-synchronous satellites, like INSAT, MeteoSAT, GOES, GMS etc., are used for communication and meteorological purposes. Satellites in the geo-synchronous orbit are located at any particular longitude to get a continuous view of that particular region, thus providing frequent images of the same area in a day. Such images are very useful in weather forecasting and meteorological studies. The signals from these satellites are used for communication and television broadcast purposes. Since the images from these satellites cover a large area, the spatial resolution of such images is poor, and thus can't be used for detailed natural resource mapping.

2. Sun-synchronous Satellites

Sun-synchronous or *Polar satellites* move in low orbits (approximately 700-900 km) above the equator. The orbital period typically varies from 90-103 minutes, covering several orbits per day. These satellites make more than one revolution around the Earth in a single day. Sun synchronous orbits maintain a constant angle between the aspect of incident sun and viewing by the satellite, so that the sun-lit portion of the Earth is always below the satellite. These orbits maintain nearly 87° inclination from the equatorial plane. These satellites are passing close to poles that's why they are called Polar satellites. The National Oceanic and Atmospheric Administration (NOAA) series of satellites, like NOAA 17, NOAA 18, IRS, LANDSAT, SPOT. all are examples of polar orbiting satellites.

Due to the rotation of the Earth on its own axis, each time the satellite moves in the orbit, it observes a new area below it. The satellite's orbit period and the rotation of the Earth together are synchronized to allow complete the coverage of the Earth's surface, after a few days. It is generally between 14-22 days, and is known as *revisit period* or *repeat period* of the satellite.

Revisit period is the time elapsed between two successive views of the same area by the same satellite. Images from sun-synchronous satellites have good spatial resolution, thus very useful for resource surveys and thematic mapping.

These are many polar satellites with steerable sensors, which can view off-nadir areas before and after the satellite passes over a ground in an orbit. With the off-nadir viewing capability of the satellites, revisit time can be reduced considerably than its repeat period. The revisit time is important, especially when frequent images of an area are required to be analysed for change detection, such as floods, earthquake, forest fire, etc. These satellites will cover areas at high latitudes more frequently than the equatorial zone due to the increasing overlap in adjacent orbit paths.

5.11 Types of Remote Sensing Platforms

Essentially, there are three different types of platforms (Figure 5.11) that are used to collect information on Earth's surface features, used to carry out analysis and interpretation. These platforms are:

1. Ground based platforms: Such platforms are operational from or near the ground kept near the object under investigation. The studies from the data collected by ground-based platforms are carried out extensively, both at laboratory and in the field. The results greatly help in the development of reflectance pattern and design of sensors for the characterization of Earth surface features, as well as detailed mapping of minute changes, such as cracks, deformations. Terrestrial cameras, handheld cameras, spectro-radiometers, laser based equipment, and GPS are the examples used for laboratory and field experiments to collect information about the Earth features.

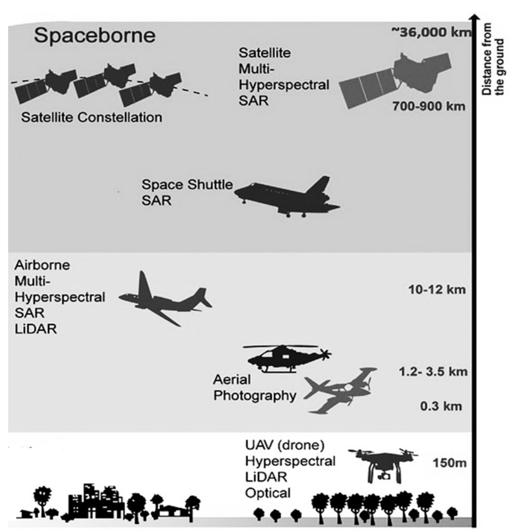

Figure 5.11 Various platforms used in remote sensing (Lechner et al., 2020)

2. Air-borne platforms: These platforms are used to collect the data from a low height above the ground or to test the performance of the sensors before they are actually mounted in the space-borne platforms. These systems cover a larger area than the ground-based methods, and offer speed in data collection. Important airborne platforms include; balloons, aircrafts, drones/Unmanned Aerial Vehicles (UAVs), and laser scanners. Aircrafts and drone offer an economical method of collecting the high resolution ground data. Laser based equipment are also being mounted on aerial platforms to collect the data. The drones (UAVs) are also gaining popularity to collect large scale data about the land surface.

3. Space-borne platforms: These platforms operate at much greater heights, such as Landsat, SPOT and IRS remote sensing satellites, the NOAA series of meteorological satellites, the GOES and INSAT series of geostationary satellites. They carry the sensors which have been tested earlier on previous platforms, and collect the data for a large area in a short time.

5.12 Different Types of Resolutions

A satellite image can be best described in terms of its resolution. In remote sensing, the term resolution is used as the capability to identify the presence of two or more objects. Objects closer than the spatial resolution appear as a single object in the image. An image showing finer details is said to have higher resolution as compared to the image that shows coarser details. In remote sensing, four different types of information are needed, such as spatial information, spectral information, temporal information, and radiometric (intensity) information. This information from an object is gathered by using the multispectral sensors/scanners onboard various satellite platforms.

Four important types of resolutions used in remote sensing work are: spatial resolution, spectral resolution, radiometric resolution and temporal resolution, and are described below.

1. Spatial Resolution

A digital image consists of an array of pixels in rows and columns, and each pixel contains information about a small area on the land surface. Spatial resolution is the size of the smallest dimension on the Earth's surface over which an independent measurement can be made by the sensor. It is the minimum separation between the two objects that a sensor is able to record distinctly. It is usually described by the instantaneous field of view (IFOV) of the sensor. The IFOV of the ground seen from the detector of a sensor is also called a *pixel* (Figure 5.12). The IFOV is dependent on the altitude of the satellite; higher the altitude, larger is the IFOV. The spatial resolution describes the size of a pixel of a satellite image covering the Earth surface (Figure 5.12). High spatial resolution images have < 5 m, while low spatial resolution images are > 500 m pixel size. An object of smaller dimension than a pixel but with good contrast with respect to its background can also be detected. Due to this reason, several features, such as roads, canals, railway lines and drainages are detectable on satellite images.

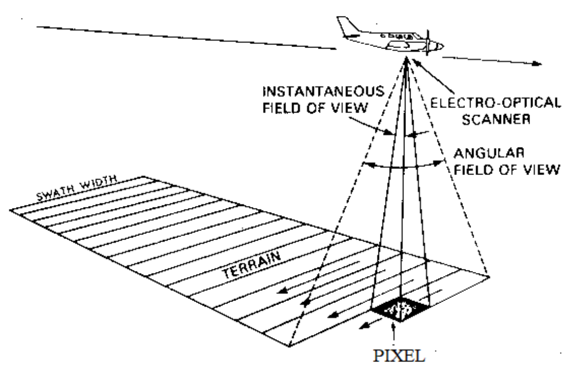

Figure 5.12 Concept of IFOV and pixel (Garg, 2019)

Remote sensing systems with spatial resolution more than 500 m are generally considered as low resolution systems, e.g., MODIS and AVHRR sensors. The moderate resolution systems have the spatial resolution between 100–500 m, for example, IRS WiFS (188m), band 6, i.e., thermal infrared band of the Landsat TM (120m), and bands 1-7 of MODIS having resolution

250-500 m. High resolution systems have spatial resolution approximately 5-100 m, such as Landsat ETM+ (30 m), IRS LISS-III (23 m MSS and 6 m Panchromatic) and AWiFS (56-70 m), SPOT-5 (2.5-5 m Panchromatic). Very high resolution systems provide less than 5 m spatial resolution, such as GeoEye (0.45 m for Panchromatic and 1.65 m for MSS), IKONOS (0.8-1 m Panchromatic), and QuickBird (2.4-2.8 m). Figure 5.13 shows a comparison of four images taken at different spatial resolutions. Image (A) at 1 m spatial resolution is the best for identification of features, while the image (D) is the worst as at 250 m spatial resolution, one can only see the pixels with grey shades but without any information contents.

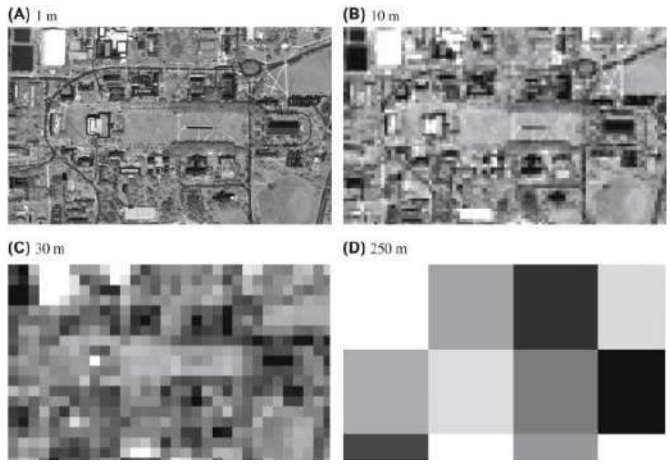

Figure 5.13 (Leslie, 2020)

2. Spectral Resolution

The spectral resolution is the ability of a sensor to define the fine wavelength intervals in order to characterize different features of the Earth surface. The finer the spectral resolution, the narrower the wavelength range for a particular band. A satellite sensor, depending on the type, can capture the data in various spectral wavelength regions. In remote sensing, high spectral resolution is achieved by narrow the bandwidths which are collectively likely to provide more accurate spectral signatures of objects than the broad bandwidths, for example, hyperspectral sensors. Many remote sensing systems provide between three and eight bands data, called *multispectral images*, for example Landsat, SPOT and IRS. The number of bands and wavelength of bands, both are important while defining the spectral resolution.

Various sensors provide images at high spectral resolution (>100 bands), medium spectral resolution (3-15 bands), and low spectral resolution (3 bands). For example, IRS LISS-III provides 4 band images, and hyper-spectral sensors provide more than hundreds of very narrow spectral band images. With a higher spectral resolution, single objects can be identified and spectrally distinguished. But when several features/objects are to be identified such as vegetation type, built-up, water, rock classification, crop types, etc., multiple narrow band images are helpful than a single wide band. Figure 5.14 presents Landsat ETM images taken in 8 spectral regions. It is observed that some objects are easily identifiable in one spectral band, while other features are easily distinguishable on another spectral band. The three band images may also be used to create a colour composite.

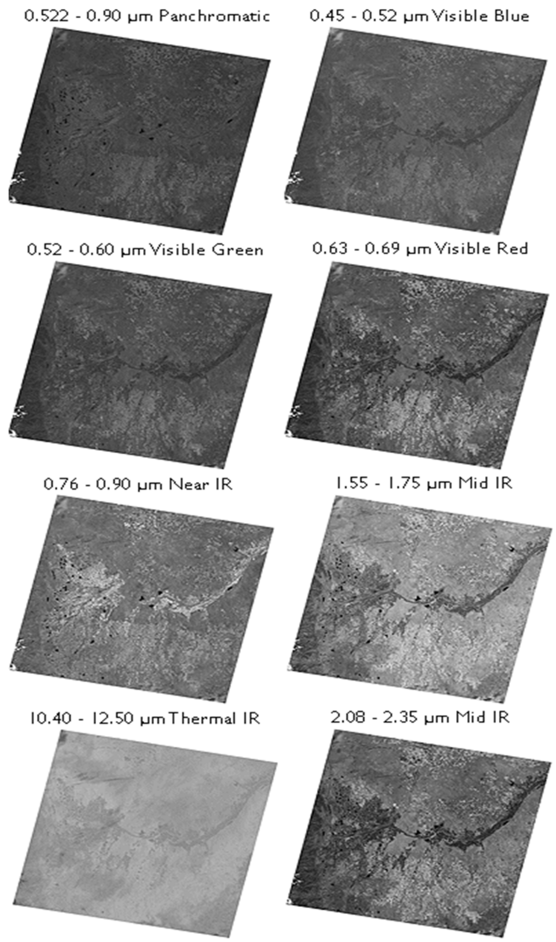

Figure 5.14 Landsat ETM images at different spectral bands (Stevens et al., 2012)

3. Radiometric Resolution

Radiometric resolution is determined by the number of discrete levels into which reflected radiations may be divided (quantization) by a sensor. With a given spectral resolution, increasing the number of quantizing levels (radiometric resolution) will improve the clarity/identification of the objects. Radiometric resolution depends on the wavelengths and the type of the sensor used. If the radiometric resolution is higher, the small differences in reflected or emitted radiations can be measured accurately, but the volume of data storage will be larger. Most images used in remote sensing are 8 bit (i.e., 2^8= 256), so in many examples in remote sensing literature are related to 8 bit images. Generally, higher the bits, better is the image quality for interpretation. Example of various images at different bits include, Landsat-MSS [Landsat 1-3 provided 6 bits (64 grey values)], IRS-LISS I-III: 7 bits (128 grey values), Landsat-TM (from Landsat 4-5), SPOT-HRV: 8 bits (256 grey values), Landsat-ETM & ETM+ (from Landsat 6-7): 9 bits (only 8 bits are transmitted), IRS-LISS IV: 10 bits (only 7 bits are transmitted), and IKONOS and QuickBird: 11 bits images. Figure 5.15 shows four images of the same area taken by the sensor in 8 bit (256 levels), 4 bit (16 levels), 2 bit (4 levels) and 1 bit (2 levels).

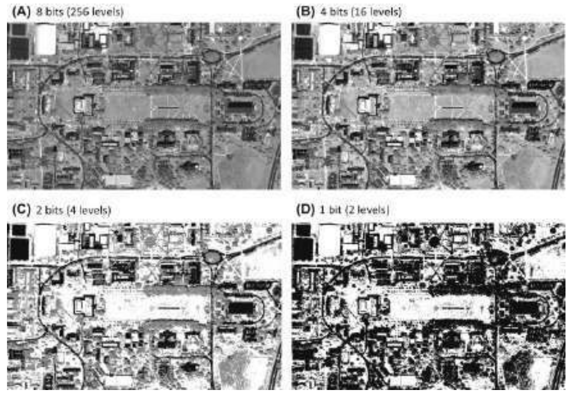

Figure 5.15 Same image at different radiometric resolutions (Leslie, 2020)

4. Temporal Resolution

Temporal resolution is related to the repeat period between two successive visits of a satellite to a particular area. Smaller the revisit time, better is the temporal resolution of the sensor system. High temporal resolution may be <24 hours-3 days, medium temporal resolution between 4-16 days, and low temporal resolution >16 days. For example, the temporal resolution of IKONOS is 14 days, Landsat 7: 16 days, and SPOT: 26 days, while Meteorological satellites, such as METEOSAT 7 every half an hour and METEOSAT 8 with 15 min have extremely shorter repeat period. Temporal images are suitable for monitoring the dynamic surface features or processes, like the seasonal change of vegetation, growth and development of agricultural crops, floods, expansion of cities, deforestation, etc. Figure 5.16 present two image of urban area taken after a time interval of 4 years to study the changes in the urban area. It is evident that year 2008 image exhibits new buildings and infrastructure that have come up in last 4 years.

For monitoring the changes, temporal resolution is important when determining the resolution characteristics of a sensor system. Many times, images may have cloud cover present on the day of pass, in such cases, next clear image of the area/activity may be available after certain days. In order to reduce the temporal resolution to monitor such area/activity, temporal images of that area/activity can be acquired from various satellites or the off-nadir capabilities of the same satellite are used.

Figure 5.16 Temporal images to study the changes (A) QuickBird (May 2004), and (B) WorldView-2 (June 2008) (Veettil and Zanardi, 2012)

Table 5.3 gives the spatial and temporal resolutions of some popular satellites.

Table 5.3 Spatial and temporal resolutions of some popular satellites (Garg, 2022)

Satellite	Sensors	Resolution		
		Spectral Bands (µm)	**Spatial (m)**	**Temporal (days)**
LANDSAT-1, 2 and 3*	RBV MSS	Blue-green (0.475-0.575) Orange-red (0.580-0.68) Red to Near-Infrared (0.69-83) Green (0.5 to 0.6) Red (0.6 to 0.7) NIR (0.7 to 0.8) NIR (0.8 to 1.1) TIR (10.4 to 12.6)*	80 40* 80	18
LANDSAT-4, and 5	MSS TM	Same as LANDSAT -1 and 2 Blue (0.45-0.52) Green (0.52-0.60) Red (0.63-0.69) NIR (0.76-0.90) NIR (1.55-1.75) Thermal (10.40-12.50) Mid-IR (2.08-2.35)	80 30 120	16
LANDSAT 7	ETM+	Blue (0.45-0.52) Green (0.52-0.60) Red (0.63-0.69) NIR (0.77-0.90) NIR (1.55 - 1.75) Thermal (10.40-12.50) Mid-IR (2.08-2.35) PAN (0.52-0.90)	30 60 15	16
LANDSAT 8	Operational Land Imager (OLI) Thermal Infrared Sensor (TIRS)	(0.43 - 0.45) Blue (0.450 - 0.51) Green (0.53 - 0.59) Red (0.64 - 0.67) NIR (0.85 - 0.88) SWIR 1(1.57 - 1.65) SWIR 2 (2.11 - 2.29) PAN (0.50 - 0.68) Cirrus (1.36 - 1.38) TIRS 1 (10.6 - 11.19) TIRS 2 (11.5 - 12.51)	30 15 100 100	16
SPOT-1, 2 and 3	HRV PAN	Green (0.50 – 0.59) Red (0.61 – 0.68) NIR (0.78 – 0.89) (0.50 – 0.73)	20 10	26 4-5 days by using steering capabilities
SPOT-4	HR-VIR	In addition to HRV and PAN MIR (1.58-1.75)	20	26 4-5 days by using steering capabilities
SPOT-5	2 HRG sensors	Green (0.50 – 0.59) Red (0.61 – 0.68) NIR (0.78 – 0.89) SWIR (1.58 – 1.75) Pan (0.51 – 0.73)	10 10 10 10 5	26 4-5 days by using steering capabilities
SPOT-6 and 7		Pan (0.45–0.75) Blue (0.45–0.53) Green (0.53–0.59) Red (0.62–0.69)	1.5 8.0	26 4-5 days by using steering capabilities

		NIR (0.76–0.89)		
IRS-1A	LISS-I, and LISS-II A/B (3 sensors)	Blue (0.45-0.52) Green (0.52-0.59) Red (0.62-0.68) NIR (0.77-0.86)	72.5 m LISS-I 36 m LISS-II	22
IRS-1B	LISS-I and LISS-II	same as for IRS-1A		22
IRS-1C & 1D	LISS-III	Green (0.52-0.59) Red (0.62-0.68) NIR (0.77-0.86) NIR (1.55-1.70)	23.5 23.5 23.5 70	24
	PAN	(0.50-0.75)	5.8	24 (5)
	WiFS	Red (0.62-0.68) NIR (0.77-0.86)	188	5
IRS-P3	WiFS	Red (0.62-0.68) NIR (0.77-0.86) NIR (1.55-1.70)	188	5
	MOS-A MOS-B MOS-C	(0.75-0.77) (0.41-1.01) (1.595-1.605)	1500 520 550	Ocean surface
IRS-P4 (OceanSat-1)	OCM MSMR	(0.40-0.90) 6.6, 10.65, 18, 21 GHz (frequencies)	360 x 236 105x68, 66x43, 40x26, 34x22 (km for frequency sequence)	2 2
IRS-P6 ResourceSat-1	LISS-IV	Green (0.52-0.59 Red (0.62-0.68 NIR (0.77-0.86	5.8 5.8 5.8	24 (5)
	LISS-III	Green (0.52-0.59) Red (0.62-0.68) NIR (0.77-0.86) NIR (1.55-1.70)	23.5 23.5 23.5 23.5	24
	AWiFS	Red (0.62-0.68) NIR (0.77-0.86) NIR (1.55-1.70)	70 70 70	5
IRS-P5 CartoSat-1	PAN-F PAN-A	(0.50-0.75) (0.50-0.75)	2.5 2.5	2-line stereo camera
CartoSat-2	PAN camera	(0.50-0.85)	< 1	
OceanSat-2	OCM SCAT ROSA	(0.40-0.90) 8 bands 13.515 GHz GPS occultation	360 x 236 25 km x 25 km	2

Table 5.4 presents the requirements of spatial and temporal resolutions for various applications (Briottet et.al., 2016), ranging from high to low. This table can guide in properly selecting the spatial and temporal resolution for a particular application.

Table 5.4 Requirements of spatial and temporal resolutions for various applications (Briottet et.al., 2016)

Broad application	**Applications**	**Spatial resolution**	**Temporal resolution**
Vegetation and Agriculture	Monitoring/status	High	High
	Monitoring/disease	High	High
	Classification	Medium/High	High
Geology and Soils	Mapping properties	Medium/High	Low
	Exploration	High	Low
Land use	Classification/change	Medium	Low
Urban	Classification/change	High	Low

Water Resources	Quality assessment	Low	Low
	Bathymetry	Low	Low
	Classification of coastal ecosystems	Low	Low
	Component bloom	Medium	High
Disasters	Prevention	Medium	Low/High
	Monitoring	Medium/High	
	Post-crisis	Medium	Low/Medium

5.13 Different Types of Sensors

Sensor is a device that captures the reflected/emitted radiations from the objects, and coverts these radiations (analog signals) into digital signals. Satellite sensors record the reflected and emitted radiations not only the visible spectrum, but also infrared, near infrared, and thermal infrared bands, and microwave bands. So, normally more than one sensor is deployed in a satellite. Figure 5.17 summarizes the types of sensors being used in remote sensing. There are two broad categories of sensors; Passive sensors and Active sensors, which are further sub-classified.

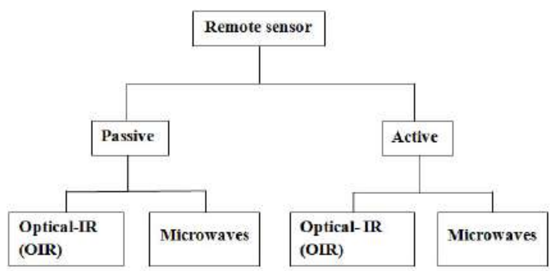

Figure 5.17 Types of sensors

5.13.1 Based on the source of illumination

1. Passive Sensors

The Sun provides a useful and important source of natural energy for remote sensing applications. The sensors record the reflected Sun energy from the objects. A sensor that depends on an external (natural) source to illuminate the target to be sensed is called a *passive sensor*. In visible light, the Sun illuminates the target/object, and the reflected light from the target is detected by the sensor (Figure 5.18). Most sun-synchronous (Polar) satellites employ passive sensors with them. Landsat MSS is an example of passive sensor. Passive remote sensing images have been used frequently for natural resource mapping and monitoring.

2 Active Sensors

The Sun's energy is available only in the sunlit portion of Earth and not in the other half dark portion of Earth surface, at any given time. So, when taking images in dark or poor weather conditions, sensors carry their own source of energy to illuminate the objects and record reflected and emitted energy from these objects. A sensor that consists of both the source to illuminate the targets and sensor to record the reflected and emitted energy from the objects/targets is called *active sensor* (Figure 5.18). The majority of active sensors operate in microwave portion of the EMS, and are able to penetrate the atmosphere all the time under any conditions. These sensors have the advantage of obtaining data any time of day or season. The Synthetic Aperture Radar (SAR) is a good example of active sensor which transmits microwave pulses from its transmitter antenna to illuminate the target and receives the return signals by its receiver antenna. Active remote sensing images can be used for a variety of applications, such as soil moisture, agriculture, geology, vegetation, including marine, and search and rescue missions.

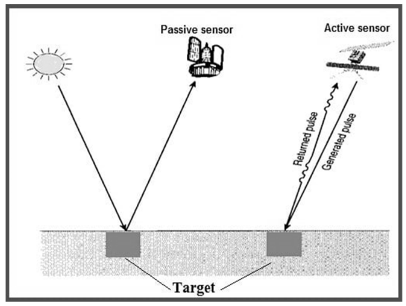

Figure 5.18 Passive and active remote sensing sensors (Castleman, 1996)

Passive and active sensors both are further divided into *scanning* and *non-scanning systems*. A sensor classified as a combination of passive, non-scanning and non-imaging method is a type of profile recorder, for example a microwave radiometer. A sensor classified as passive, non-scanning and imaging method, is a camera, such as an aerial survey camera or a space camera. Sensors classified as a combination of passive, scanning and imaging are classified further into *image plane scanning sensors*, such as TV cameras and solid state scanners, and object plane scanning sensors, such as multispectral scanners (optical-mechanical scanner) and scanning microwave radiometers.

5.13.2 Based on internal geometry

The internal geometry of design of a space-borne multispectral sensor is quite different from an aerial camera. Figure 5.19 shows six types of remote sensing sensor systems; digital frame area array, scanning mirrors, linear pushbroom arrays, linear whiskbroom areas, and frame area arrays. A linear array, or pushbroom scanner is used in many space-borne platforms, such as SPOT, IRS, QuickBird, OrbView, and IKONOS. The geometric distortions in the images, such as skew caused by the rotation of the Earth, are required to be corrected before analysing the imagery. Several air-borne systems, like Leica ADS-40, ITRES CASI, SASI, and TABI also employ pushbroom technology where each line of imagery is captured at a time, corresponding to an instantaneous position and attitude of the aircraft.

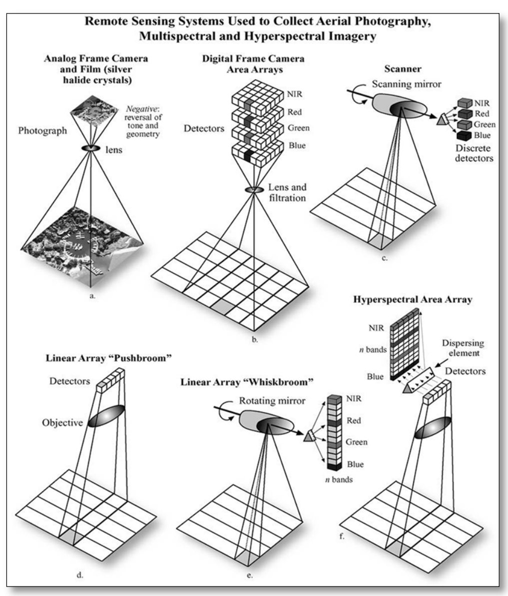

Figure 5.19 Remote sensing sensor systems (Jensen, 2007)

The internal geometry of images captured by space-borne scanning systems is much more complex. Across-track scanning and whiskbroom systems are more similar to a LiDAR scanner than to a digital array sensor. Each pixel is captured at a unique time, and there is a stack of recording pixels, one for each spectral band, which are required to be precisely co-registered pixel-by-pixel to create an accurate multispectral image.

5.13.3 Based on the wavelength

1. Optical Sensors

The optical remote sensing devices operate in the visible, near infrared, middle infrared and short wave infrared portions of the EMS within a range 0.30 µm to 3.0 µm, e.g., bands of IRS P6 LISS IV sensor work in optical range of EMS.

2. Thermal Sensors

Thermal infrared energy is emitted as heat by all the objects, both natural and manmade, that have a temperature greater than absolute zero. Even in complete darkness and poor weather conditions, thermal imaging is able to detect small temperature differences. For example, water, rocks, soil, vegetation, and the atmosphere, all have the ability to conduct heat directly through them (thermal conductivity) onto another surface and to store heat (thermal capacity). Some materials respond to changes in temperature more rapidly or slowly than the others (thermal inertia).

Human eyes can't detect the thermal infrared energy as they are not sensitive to the infrared (0.7-3.0 µm) or thermal infrared (3-14 µm) regions. The 3 to 5 µm range is related to high temperature phenomenon, like forest fire, while 8 to 14 µm range is related with the general Earth features having lower temperatures. Thermal remote sensing is very useful to measure the surface temperature and thermal properties of targets, for example, fire detection and thermal pollution studies. For example, the last five bands of ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and band 6 of Landsat ETM+ are thermal. The ASTER data are used to create detailed maps of surface temperature of land, emissivity, reflectance, geology and elevation. Useful reviews on thermal remote sensing are given by Kahle (1980), Sabins (1996) and Gupta (1991).

Thermal infrared sensor data may be collected by (i) across-track thermal scanners, and (ii) push-broom linear and area array charge-coupled device (CCD) detectors. The Daedalus DS-1260, DS-1268, and Airborne Multispectral Scanner (AMS) provide useful high spatial and spectral resolution thermal infrared data for monitoring the environment. Landsat TM 4 and 5 sensors collected 120 x 120 m thermal infrared data (10.4-12.5 µm) along with two bands of middle infrared data. The NOAA (National Oceanic and Atmospheric Administration) Geostationary Operational Environmental Satellite (GOES) collected thermal infrared data at a spatial resolution of 8 km x 8 km which could be used for weather prediction. Entire Earth is imaged every 30 minutes both day and night by the thermal infrared sensors. The NOAA Advanced Very High Resolution Radiometer (AVHRR) collected thermal infrared local area coverage (LAC) data at 1.1 x 1.1 km and global area coverage (GAC) at 4 x 4 km. Sensors, such as NOAA-AVHRR, ERS-ATSR and TERRA-MODIS can provide images at 3.8 µm wavelength that can be used for the detection of fire and hot spots. Figure 5.20 shows various sensors operating in thermal regions.

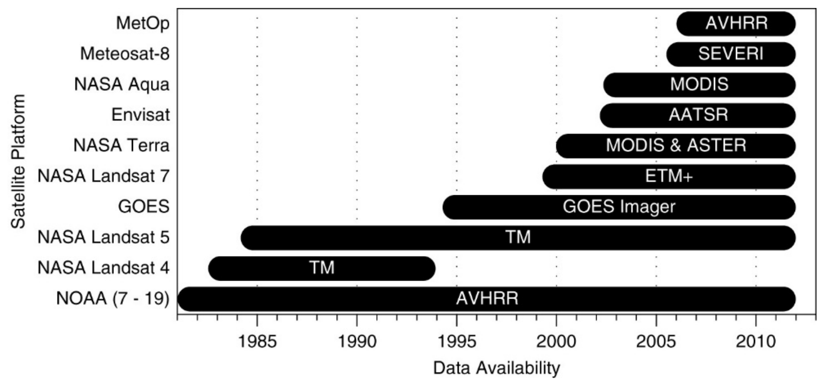

Figure 5.20 Some thermal sensors (Kahle, 1998)

Thermal images have also been adopted by fire and rescue teams, security professionals, maintenance operations, coal fire team, etc. These sensors have been used for sea surface temperature measurement, detection of forest fires or other warm/hot objects, or monitoring volcanic activities, hydrology, coastal zones, seismology, environmental modelling, meteorology, medical sciences, intelligence/military applications, and heat loss from buildings.

3. Microwave Sensors

The microwave region falls between the IR and radio wavelengths, and has a long range extending from approximately 0.1 cm to 1 m. The microwave sensors, e.g., RADARSAT, having their own sources of energy, record the backscattered microwaves and operate independent of weather and solar energy. Microwave energy can pass through clouds, tree canopies, haze, dust and the rainfall, as these are not affected by atmospheric scattering. These sensors therefore have the capability to collect imagery day and night, under all weather conditions.

The microwave sensors could be passive or active type. The *passive microwave sensors* detect the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties of the emitting object or surface. Passive microwave sensors are typically spectro-radiometers or scanners, and they operate in the same manner as other radiometers/scanners, except that an antenna is used to detect and record the microwave energy. Since the field of view is large to detect reflected energy, most passive microwave sensors provide low spatial resolution data. The passive microwave sensors can be used to measure atmospheric profiles, determine water and ozone contents in the atmosphere, and measure soil moisture. Oceanographic applications of such sensors include mapping sea ice, currents, and surface winds as well as detection of pollutants, such as oil slicks.

The active microwave sensors have their own source of microwave radiations to illuminate the targets/objects. These sensors can be divided in to two distinct categories: imaging and non-imaging. An active, scanning and imaging sensor is RADAR **(**RAdio Detection And Ranging), for example SAR which can provide high resolution, imagery, day or night, even under the cloud cover. The working of a RADAR is shown in Figure 5.21. The SAR, whether used airborne or space-borne, emits microwave radiation in a series of pulses from the antenna. This backscattered microwave radiation is detected, and the time required for the energy to travel to the target and return back to the sensor determines the distance or range to the target. By recording the range and magnitude of the energy reflected from all the targets, a two-dimensional image of the surface can be produced.

The intensity in a SAR image would depend on the amount of microwave backscattered by the target and received by the SAR antenna. Since the physical mechanism responsible for this backscatter is different for microwave, the interpretation of SAR images requires the knowledge of how microwaves interact with the targets. Because of these differences, radar and optical data can be complementary to each other as they offer different information content. Other examples of active microwave sensors include ERS-1 launched in 1991, J-ERS satellite launched in 1992, ERS-2 in 1995, and Canada's advanced satellite Radarsat-1 launched in 1995 and Radarsat-2 launched in 2007, IRS-P4 (Oceansat-1), Oceansat-2, RISAT-1, RISAT-2, TerraSAR-X Radar satellite launched in 2007. The Shuttle Radar Topography Mission (SRTM) launched in 2000 uses InSAR which measures Earth's elevation with two antennas to create digital elevation models of Earth.

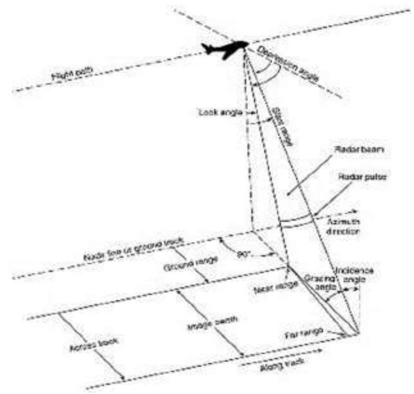

Figure 5.21 Working principle of a RADAR (Gupta, 1991)

Non-imaging microwave sensors include altimeters, LiDAR and scatterometers**.** In most cases, these are profiling devices which take measurements in one linear dimension, as opposed to the two-dimensional representation of imaging sensors. Radar altimeters transmit short microwave pulses and measure the round trip time delay to targets to determine their distance (range) from the sensor. Radar altimetry is used on aircraft for altitude determination and on aircraft & satellites for topographic mapping and sea surface height estimation. The LiDAR is an active microwave sensor that measures ground height, as well as provides coordinates of the points. It consists of a sensor that uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse, and a receiver with detectors to measure the backscattered or reflected light (Figure 5.22). The distance to the object is determined by multiplying time of travel with the speed of light. Scatterometer is a high-frequency microwave radar designed specifically to measure the backscattered radiations. Measurements of backscattered radiations in the microwave spectral region can be used to derive maps of surface wind speed and direction over the ocean surfaces.

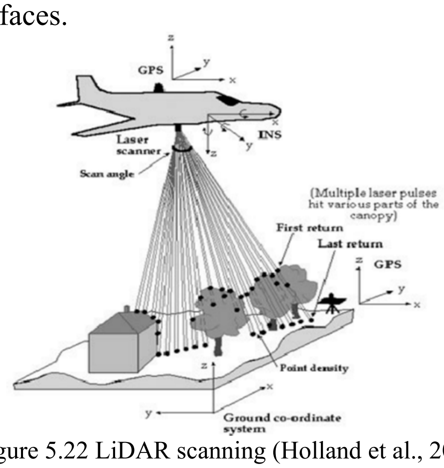

Figure 5.22 LiDAR scanning (Holland et al., 2003)