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6. Types of Remote Sensing and Sensor Characteristics

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Abstract:

Remote sensing is a pivotal technology revolutionizing data acquisition for various applications. Optical sensors, capturing electromagnetic radiation in the visible and infrared spectrum, enable detailed visual analysis and vegetation monitoring. Microwave sensors, with their penetrating capability, offer insights into subsurface features and are crucial for soil and moisture assessment. Thermal infrared sensors detect emitted heat, aiding in temperature mapping and industrial monitoring. Furthermore, hyperspectral sensors capture a multitude of narrow spectral bands, facilitating detailed material identification. LiDAR (Light Detection and Ranging) sensors use laser pulses to measure distances, generating precise 3D models for applications in topography and forestry. Each sensor type possesses unique characteristics influencing data resolution, accuracy, and application suitability. Sensor characteristics include spatial resolution, defining the smallest discernible features; spectral resolution, determining the number and width of spectral bands; radiometric resolution, quantifying the sensor's ability to distinguish variations in brightness; and temporal resolution, specifying revisit frequency. Balancing these characteristics is crucial for optimizing data acquisition based on specific project requirements.

Keywords:

Remote Sensing, Thermal infrared, Electromagnetic radiation, Sensors.

6.1 Introduction:

In the 1950s, Ms. Evelyn Pruitt of the U.S. Office of Naval Research coined the term "remote sensing," which has since been widely utilized to refer to the science and art of recognizing, observing, and measuring an object without coming into physical contact with it. So, by definition remote sensing is “The science (and to some extent, the art) of learning about the surface of the Earth without actually touching it”. This is accomplished by detecting and capturing energy that is reflected or emitted, as well as by processing, analyzing, and using that data. A significant portion of remote sensing involves interacting between the targets of interest and incident radiation.

The National Remote Sensing Agency of India states that remote sensing is a technique for learning about objects on the surface of the planet without actually touching them.

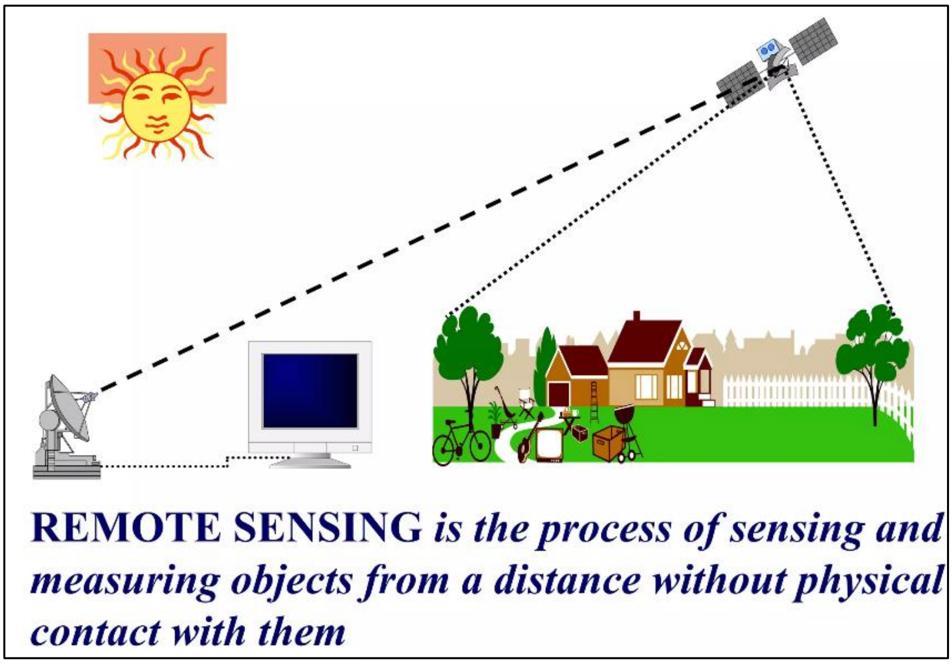

Figure 6.1: Remote Sensing

6.2 Principle of Remote Sensing (RS):

Electromagnetic radiation is the term given to the energy the Earth receives from the sun. Radiation is reflected, absorbed, and emitted by the Earth's atmosphere or surface. With calibrated instruments, scientists can measure the height, temperature, moisture content (and more) for nearly every feature of the Earth's atmosphere, hydrosphere, lithosphere, and biosphere. Satellites carry instruments or sensors that measure electromagnetic radiation reflected or emitted from both terrestrial and atmospheric sources (Figure-6.1)

Only the part of the Electromagnetic (EM) scale in the band length range of 0.4 - 0.7 m is detectable by the human eye, i.e., the reflected sun radiation that people actually see. However, remote sensing technology enables the detection of other reflecting and radiating (for example, thermal) energy band-length ranges that reach or are emitted by the Earth's surface, and even some of the atmosphere of the planet reflects, for example, the EM reflective properties of clouds.

In order to express the reflective qualities of objects in these EM band-length groups for viewing purposes, red, green, and blue (RGB) false color assignments are used. Combining and mixing these false color assignments expresses the real physical reflective qualities of all objects present in an image.

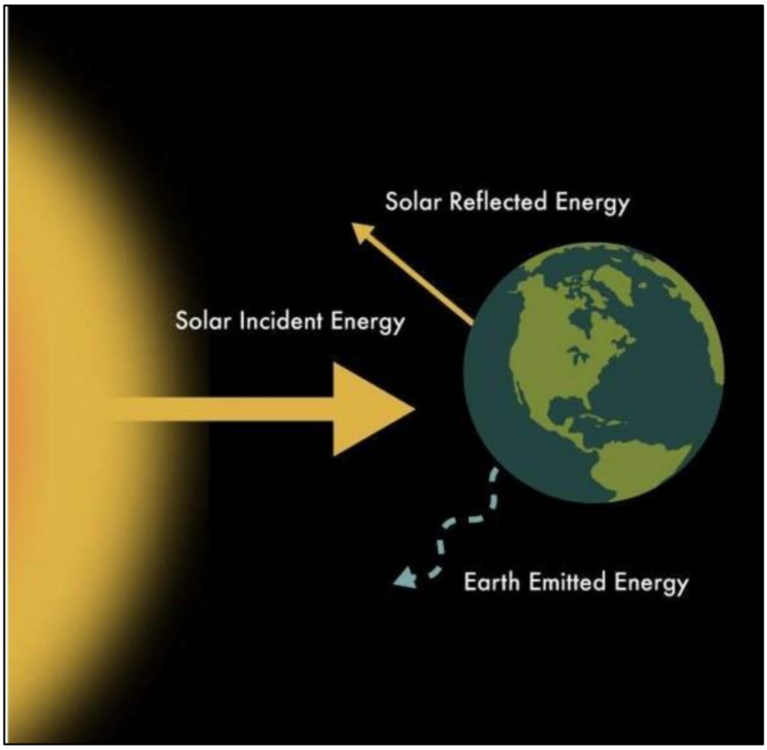

Figure 6.2: NASA Applied Remote Sensing Program

So basically, RS principles involves-

- Detection and recording of the radiant radiation that is reflected or emitted by objects or surfaces in order to distinguish between different objects or surface features.
- It depends on the material's properties (physical, structural, and chemical), the roughness of its surface, the angle at which it is incident, the intensity of its radiant energy, and the wavelength of its radiation that it emits.
  Different things reflect different amounts of energy in different bands of the electromagnetic spectrum.

6.3 Processes Involved in Remote Sensing:

6.3.1 Data Acquisition:

A. Energy source: An energy source that illuminates or provides electromagnetic energy to the target of interest is the first prerequisite for remote sensing. The energy used to illuminate the target comes from electromagnetic radiation.

An electrical field (E) and a magnetic field (M) are the two fluctuating fields that make up an electromagnetic wave. Both of these oscillate at a right angle to one another and parallel to the path of transmission.

B. **Radiation and the Atmosphere:** The energy will interact and encounter the atmosphere it passes through as it moves from its source to the target. As the energy moves from the target to the sensor, this interaction might happen again.

The scattering and absorption mechanisms are responsible for these effects. Electromagnetic radiation gets diverted from its original direction by interaction with atmospheric particles or big gas molecules, which is known as scattering. Several variables, including as the wavelength of the radiation, the prevalence of particles or gases, and the length of the radiation's passage through the atmosphere, affect how much scattering occurs.

There are three types of scattering that takes place.

a. Rayleigh scattering- occurs when particles are very small compared to the wavelength of the radiation.
b. Mie scattering - occurs when the particles are just about the same size as the wavelength of the radiation.
c. Non- Selective scattering- occurs when the particles are much larger than the wavelength of the radiation.

Absorption - As a result of this phenomena, atmospheric molecules absorb energy at different wavelengths. The three main atmospheric components that absorb radiation are ozone, carbon dioxide, and water vapor.

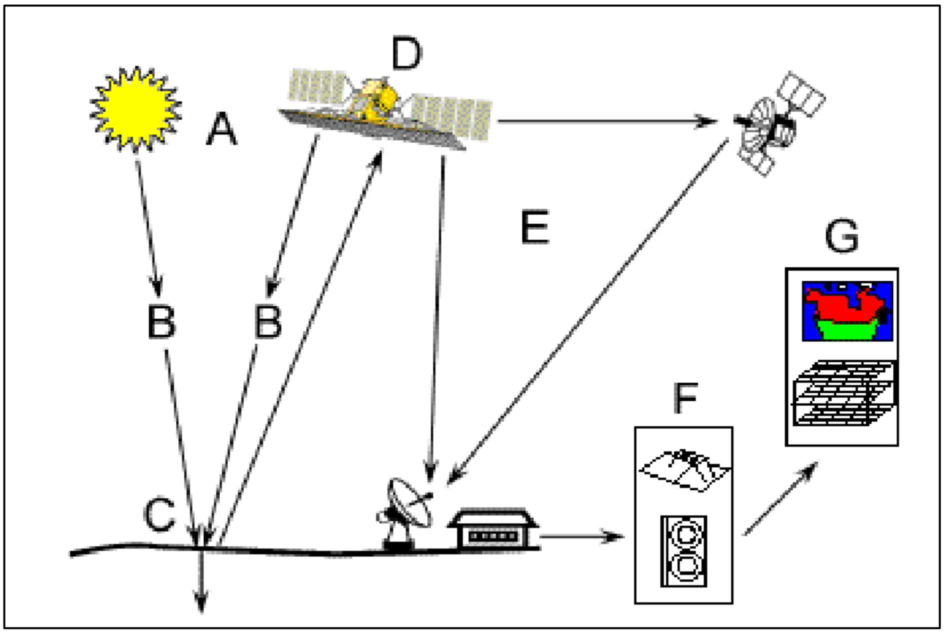

Figure 6.3: Elements of RS

C. Interaction with the Target: After travelling through the atmosphere to the target, the energy interacts with the target based on the characteristics of both the radiation and the target.

Based on incident light, three types of interaction may take place

a. When radiation (energy) is absorbed by the target, this is known as Absorption (A).
b. Radiation strikes a target and transmits (T) through it is Transmission.
c. When radiation "bounces" off the target and is redirected, reflection (R) takes place.

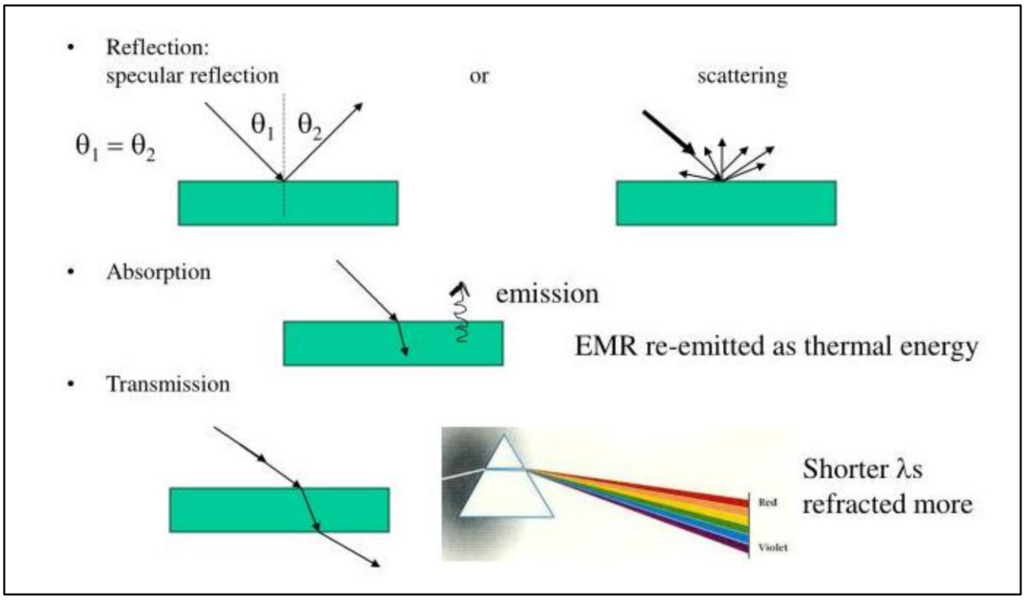

Figure 6.4: Basic Interactions Between EMR and the Earth Surface

D. Recording of Energy by the Sensor: We need a remote sensor (one that is not in direct touch with the target) to gather and record electromagnetic radiation after it has been scattered by or emitted by the target.

E. Transmission, Reception and Processing: The energy captured by the sensor must be sent, frequently in electronic form, to a receiving and processing unit where the data are converted into a picture (hardcopy or digital).

6.3.2 Data Analysis:

A. Interpretation and analysis: The processed image is digitally or visually interpretated to extract information about the target.

B. Application: The remote sensing process's final step, application, is when we use the knowledge, we were able to gather from the target's imagery to either deepen our understanding of it, reveal new information, or help us solve a specific problem.

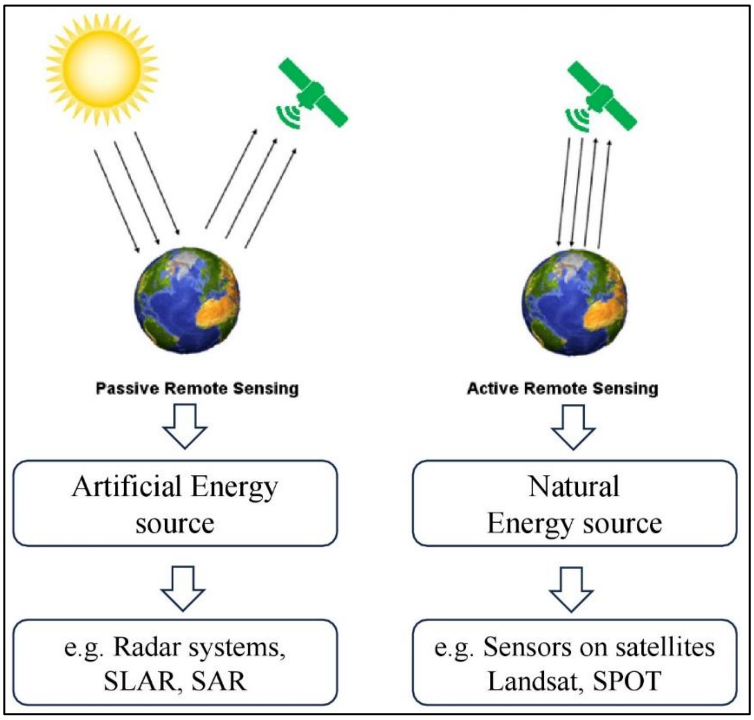

Figure 6.5: Type of remote sensing

6.4 Components of Remote Sensing:

These include Platform and sensor. The sensor is in charge of recognizing and capturing the energy that the target has either emitted or reflected. The sensor needs to be located on Platforms, which are stable surfaces, in order to capture the energy.

Platforms- different types of platforms in remote sensing, including ground-based, aerial, and satellite platforms.

- Airborne platform- Remote sensing aircraft that fly through the atmosphere of the planet are called airborne platforms. These include drones and aircraft. High-resolution photos and data may be easily collected over small areas using airborne platforms. They are frequently employed in mapping, surveying, and aerial photography.
- Ground based platforms- These are remote sensing vehicles that move over the surface of the Earth. These consist of transporting objects like trucks, boats etc. In order to collect data from a close range to the Earth's surface, ground platforms are used. They are frequently used to keep an eye on vegetation growth, ocean currents, and soil moisture.
- Space borne platforms- These are space-based remote sensing vehicles. Among these are satellites, the most popular space vehicles for remote sensing. Global data collection through the use of satellites enables us to track changes in the Earth's atmosphere, oceans, and land. They are also employed in national security and catastrophe management.

6.5 Sensors:

Sensors are classified as Optical sensor and Microwave sensor

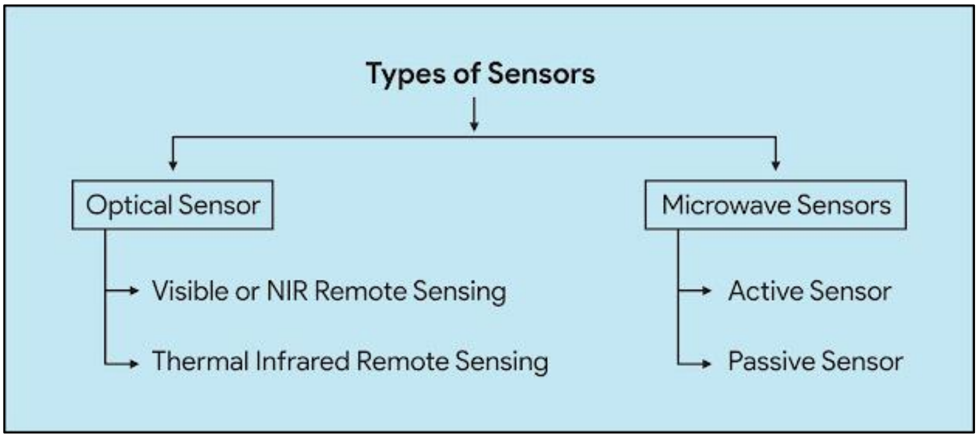

Figure 6.6: Types of Sensors

6.5.1 Optical Sensor:

The term "optical sensor" refers to a sensor that can distinguish between three different forms of infrared radiation, including near infrared, intermediate infrared, and hot infrared. Consequently, an optical sensor performs two types of remote sensing, namely:

A. Visible radiation or Infrared remote sensing- Remote sensing using visible or near infrared radiation occurs when an optical sensor picks up sunlight's backscattered visible and near infrared (NIR) radiation. Analyzing the surface characteristics of the object of interest is made easier by the reflection's strength. However, this sensing technique has several limitations, such as interruptions during periods of heavy cloud cover or nighttime.

B. Thermal Infrared remote sensing- Thermal infrared remote sensing occurs when an optical sensor picks up heat-emitting thermal infrared radiation from an object's surface. This sensing technique aids in the investigation of any occurrence involving the emission of heat, such as wildfires, volcanic eruptions, surface temperatures of various objects, etc.

Even at night, optical sensors can detect heat radiation, although cloud cover also impairs this technique of observation.

6.5.2 Microwave Sensor:

The microwave sensor is the sensor that can track and record microwaves. Since microwave radiation has a longer wavelength than visible light or heat infrared radiation, it can be detected regardless of the presence of clouds, the time of day, or other environmental factors. Two types of sensors perform the role to detect and record microwave radiations, viz. Active sensors and Passive sensors.

There are two types of Remote sensing based on source of energy used *i.e.*, Active remote sensing and Passive remote sensing. Remote sensing systems usually involve both active and passive sensors. Active sensors emit their own signals that are measured after they are reflected off of the Earth's surface.

A. Passive Remote Sensing Sensor:

A passive sensor picks up solar radiation that is reflected or given off by anything on Earth's surface.

As passive sensors rely on the Sun's light to illuminate their target and do not need their own energy source, they are often smaller pieces of equipment. While certain passive optical sensors may record nocturnal lights, clouds, as well as energy discharged from the Earth's surface, most passive optical sensors are constrained by the fact that they need daylight to function. Since these sensors work in the visible and infrared spectrum, the weather and cloud cover have a negative effect on their performance. Finally, it is challenging to assess plant structure beneath a canopy since sunlight is often reflected from a feature's top, such a forest. In such cases active sensors are used to acquire this kind of data. The passive remote sensors include Accelerometer, Hyperspectral radiometer, Spectrometer, Imaging radiometer, Sounder, Spectroradiometer, Radiometer, etc.

B. Active Remote Sensing Sensor:

Active sensors supply their own electromagnetic radiation source to illuminate the target item. The sensor itself emits radiation in the direction of the phenomena or object, and when that radiation is reflected or backscattered from the target, it is once more detected and recorded. Active remote sensors include LIDAR (Light Detection and Ranging), Radar, Sounder, Scatter meter, Laser altimeter, and others.

6.6 Sensor Parameters:

Various earth surface objects are intended to be identified and mapped using the data gathered by the remote sensors. As a result, we can state that the classification and mapping accuracy requirements are used to evaluate the sensor's performance. It is reasonable to anticipate that this will depend on the instrument's capacity to identify minute variations in the earth's surface's emittance and reflectance throughout a range of spectral bands for as few and as frequent objects as feasible. Resolution describes the numerous parameters that define these various types of sensor systems. The spatial, spectral, radiometric, and temporal resolution of the data from remote sensing determines its quality.

6.6.1 Spatial Resolution:

The size of the ground area that a sensor "sees" at any given moment, or more precisely, each time a signal is collected. It is the smallest separation between two objects that a sensor can clearly register ability to recognize nearby little objects in a picture. Higher the spatial resolution, the smaller the ground resolution cell – the higher the resolving power of the system.

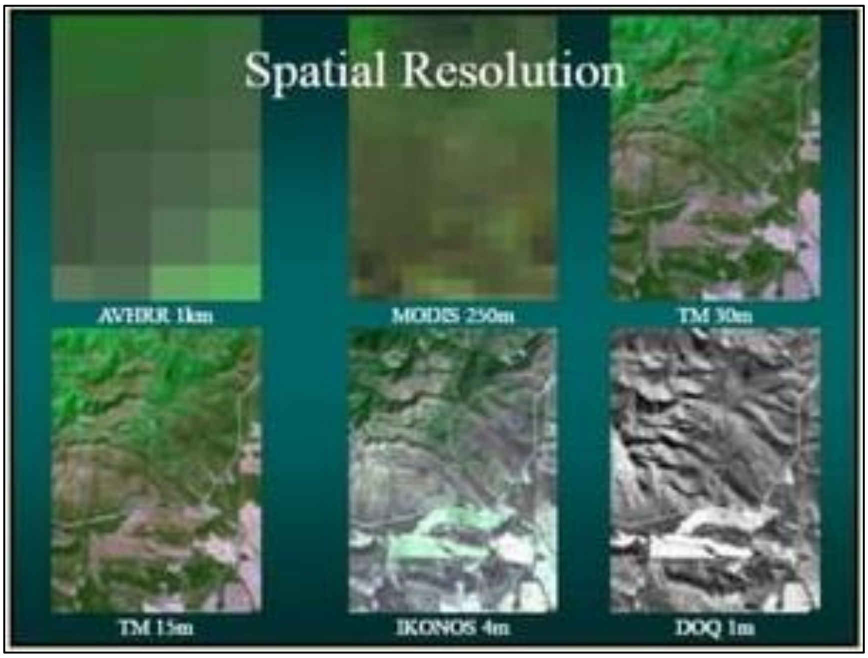

Figure 6.7: Spatial Resolution

By definition, spatial resolution is the mallest angular or linear separation between two objects that can be resolved by sensor which is determined by Instantaneous field of view (IFOV). The resolutions of today's satellite systems vary from a few centimeters (for example military usage) to kilometers.

6.6.2 Spectral Resolution:

The capacity to break down spectral features and bands into their individual components is known as spectral resolution. The level of spectral resolution needed by the analyst or researcher will depend on the application in question. It is the accuracy with which slight variations in the wavelength can be recorded. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. Different features in an image can be identified by comparing their wavelength responses. Broad classes such as water body can be identified using broad wavelength (visible and IR range), whereas more specific classes would require finer wavelength range to identify them such as type of rock. Thus, spectral resolution is the ability of the sensor to separate fine wavelength intervals. While hyperspectral imaging has hundreds or thousands of (narrower) bands (i.e., better spectral resolution), multispectral imagery often refers to 3 to 10 bands.

A single broad band known as panchromatic captures a diverse range of wavelengths.

Multispectral Sensors – MODIS – moderate spectral resolution

Hyperspectral Sensors – OMI, AIRS – High spectral resolution

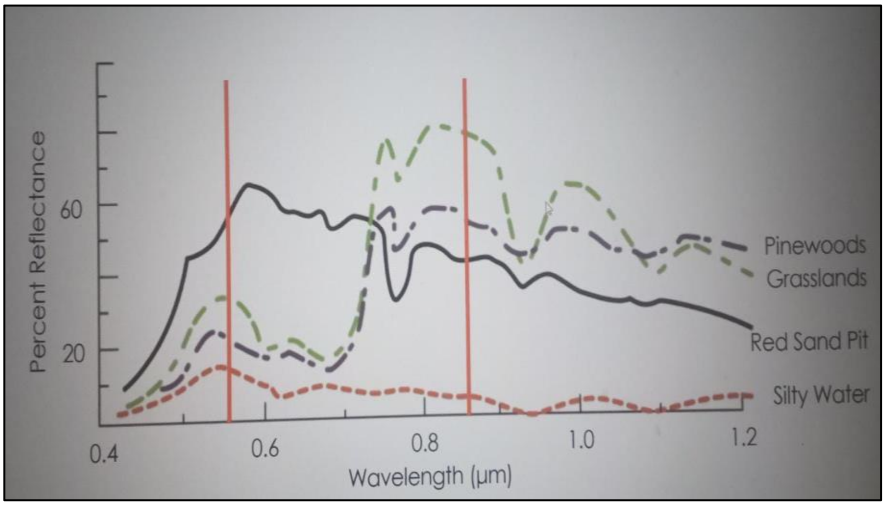

Figure 6.8: Spectral Resolution of Different Objects (Indian Institute of Science)

6.6.3 Radiometric Resolution:

It is the ability of the sensor to detect the slight variation in the EMR received. Since total EMR received is directly proportional to spatial resolution, there is an inverse relationship between spatial and radiometric resolution – low spatial resolution (large ground area) means more total energy received, so slight variations in EMR can be detected, this results in a high signal to noise ratio – conversely, if spatial resolution is high (small ground area) less total energy is received, slight variations are more difficult to detect, so lower signal to noise ratio, poorer radiometric resolution.

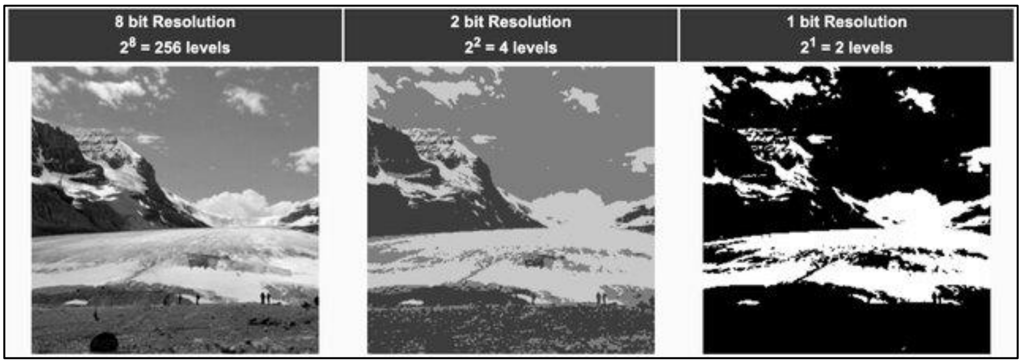

Figure 6.9: Difference in Image Having Different Bits of Radiometric Resolution.

Radiometric resolution is normally indicated by the number of quantization levels used to measure reflectance also called DN values for digital numbers. It is determined by bit format of data. It specifies how well the differences in brightness in an image can be perceived; this is measured through the number of the grey value levels. The more sensitive the sensor - the higher the radiometric resolution. If radiometric precision is high, an image will be sharp.

6.6.4 Temporal Resolution:

The frequency with which a remote sensing platform can cover a region is referred to as temporal resolution. While regular orbiting satellites can only offer data once they pass over a region, geo-stationary satellites can provide continuous sensing. In order to supply data for applications requiring more frequent sensing, remote sensing data from cameras placed on aircraft is frequently used. The data from a planned remotely sensed data system may be tampered with by cloud cover. The highest frequent temporal resolution can be obtained via remote sensors placed in fields or attached to agricultural machinery**.**

It is determined by orbital characteristics and swath width (the larger the swath, the higher the temporal resolution)

Global coverage of various satellites is.

- MODIS – 1-2 days
- OMI – 1 day
- MISR – 6-8 days
- VIIRS – 1 day
- Geostationary – 30 sec – 1 hr.

It is very difficult to obtain all resolution at higher levels at the same time.

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