PHYSICS OF REMOTE SENSING

Introduction

Definition

Remote sensing means acquiring information about a phenomenon, object or surface while at a distance from it. This name is attributed to recent technology in which satellites and spacecraft are used for collecting information about the earth's surface. This was an outcome of developments in various technological fields from 1960 onward.

Principle of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount and kind of energy in different bands of the electromagnetic spectrum, incident upon it. This unique property depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy.

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching etc. All these technologies are integrated to act as one complete system in itself, known as Remote Sensing System. There are a number of stages in a Remote System, working as links in a complete, and each of them is important for successful operation.

Stages in Remote Sensing

1. Emission of electromagnetic radiation, or **EMR** (sun/self- emission)
2. Transmission of energy from the source to the surface of the earth, as well as absorption and scattering
3. Interaction of **EMR** with the earth's surface: reflection and emission
4. Transmission of energy from the surface to the remote sensor
5. Sensor data output
6. Data transmission, processing and analysis

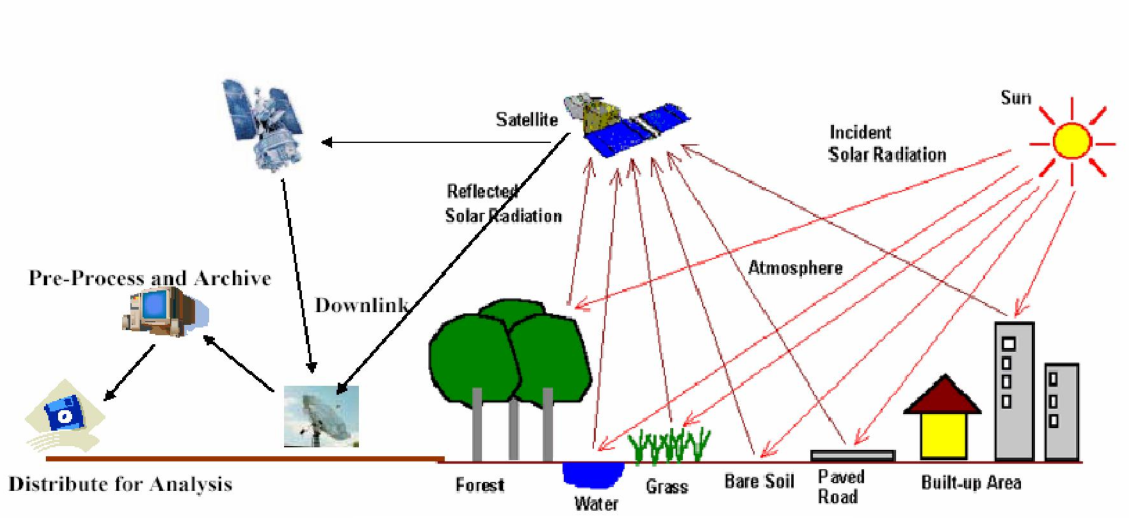


Fig.1 Stages in Remote Sensing

What We See

At temperature above absolute zero, all objects radiate electromagnetic energy by virtue of their atomic and molecular oscillations. The total amount of emitted radiation increases with the body's absolute temperature and peaks at progressively shorter wavelengths. The sun, being a major source of energy, radiation and illumination, having a sharp power peak around 0.5 µm, allows capturing reflected light with conventional (and some not-so-conventional) cameras and films.

The basic strategy for sensing electromagnetic radiation is clear. Everything in nature has its own unique distribution of reflected, emitted and absorbed radiation. These spectral characteristics, if ingeniously exploited, can be used to distinguish one thing from another or to obtain information about shape, size and other physical and chemical properties. In so far as we know the spectral characteristics, we can pick an appropriate detector to make the desired measurement, remembering that for a given collector's diameter we get our greatest spatial resolution where wavelengths are shortest and energies greatest, and that these energies decrease at longer wavelengths and distances.

Modern Remote Sensing Technology versus Conventional Aerial Photography

The use of different and extended portions of the electromagnetic spectrum, development in sensor technology, different platforms for remote sensing (spacecraft, in addition to aircraft), emphasis on the use of spectral information as compared to spatial information, advancement in image processing and enhancement techniques, and automated image analysis in addition to manual interpretation are points for comparison of conventional aerial photography with modern remote sensing system.

During early half of twentieth century, aerial photos were used in military surveys and topographical mapping. Main advantage of aerial photos has been the high spatial resolution with fine details and therefore they are still used for mapping at large scale such as in route surveys, town planning, construction project surveying, cadastral mapping etc. Modern remote sensing system provide satellite images suitable for medium scale mapping used in natural resources surveys and monitoring such as forestry, geology, watershed management etc. However the future generation satellites are going to provide much high-resolution images for more versatile applications.

Historic overview

In 1859 Gaspard Tournachon took an oblique photograph of a small village near Paris from a balloon. With this picture the era of earth observation and remote sensing had started. His example was soon followed by other people all over the world. During the Civil War in the United States aerial photography from balloons played an important role to reveal the defence positions in Virginia (Colwell, 1983). Likewise other scientific and technical developments this Civil War time in the United States speeded up the development of photography, lenses and applied airborne use of this technology. Table 1 shows a few important dates in the development of remote sensing.

The next period of fast development took place in Europe and not in the United States. It was during World War I that aeroplanes were used on a large scale for photoreconnaissance. Aircraft proved to be more reliable and more stable platforms for earth observation than balloons. In the period between World War I and World War II a start was made with the civilian use of aerial photos. Application fields of airborne photos included at that time geology, forestry, agriculture and cartography. These developments lead to much improved cameras, films and interpretation equipment. The most important developments of aerial photography and photo interpretation took place during World War II. During this time span the development of other imaging systems such as near-infrared photography; thermal sensing and radar took place. Near-infrared photography and thermal-infrared proved very valuable to separate real vegetation from camouflage. The first successful airborne imaging radar was not used for civilian purposes but proved valuable for nighttime bombing. As such the system was called by the military 'plan position indicator' and was developed in Great Britain in 1941.

After the wars in the 1950s remote sensing systems continued to evolve from the systems developed for the war effort. Colour infrared (CIR) photography was found to be of great use for the plant sciences. In 1956 Colwell conducted experiments on the use of CIR for the classification and recognition of vegetation types and the detection of diseased and damaged or stressed vegetation. It was also in the 1950s that significant progress in radar technology was achieved.

Table1: Milestones in the History of Remote Sensing

1800	Discovery of Infrared by Sir W. Herschel
1839	Beginning of Practice of Photography
1847	Infrared Spectrum Shown by J.B.L. Foucault
1859	Photography from balloons
1873	Theory of Electromagnetic Spectrum by J.C. Maxwell
1909	Photography from Airplanes
1916	World War I: Aerial Reconnaissance
1935	Development of Radar in Germany
1940	WW II: Applications of Non-Visible Part of EMS
1950-	Military Research and Development
1959	First Space Photograph of the Earth (Explorer-6)
1960	First TIROS Meteorological Satellite Launched
1970	Skylab Remote Sensing Observations from Space
1972	Launch Landsat-1 (ERTS-1): MSS sensor
1972-	Rapid Advances in Digital Image Processing
1982	Launch of Landsat-4: New Generation of Landsat Sensors: TM
1986	French Commercial Earth Observation Satellite SPOT
1986	Development Hyperspectral Sensors
1990-	Development High Resolution Spaceborne Systems
	First Commercial Developments in Remote Sensing
1998-	Towards Cheap One-Goal Satellite Missions
1999	Launch EOS: NASA Earth Observing Mission
1999	Launch of IKONOS, very high spatial resolution sensor system

Remote Sensing in India

Indian remote sensing programme was started in late seventies with Indian built Bhaskara-I and Bhaskara-II satellites launched from Soviet Union in June 1978 and November 1981 respectively. Indigenous launch capabilities have also been developed to launch 1000 Kg. Remote Sensing Satellite into polar orbit. The Department of Space (DOS)/ Indian Space Research Organisation (ISRO) has been actively engaged in development of state of art remote sensing capabilities along with other related activities. ISRO Satellite Center (ISAC), Bangalore is responsible for design, development and management of remote sensing satellites. Space Application Center (SAC), Ahmedabad is engaged in development of sensors (cameras & scanners) & data processing software, analysis of remote sensing data, and related research. National Remote Sensing Agency (NRSA), Hyderabad is responsible for acquisition, processing and dissemination of remote sensing data, analysis of data for different applications and training of users. The National Natural Resources Management System (NNRMS) is responsible for execution of application projects through the establishment of a no. of Regional Remote Sensing Service Center (RRSSC) throughout the country. Many user agencies, Govt. Departments, State Governments, and academic institutes have also established remote sensing infrastructure for various applications.

Electromagnetic Radiation and the Electromagnetic Spectrum

EMR is a dynamic form of energy that propagates as wave motion at a velocity in space, i.e. c = 3 x 10^{10} cm/sec. The parameters that characterize a wave motion are wavelength (λ), frequency (ν) and velocity (c). The relationship between them is

$$c = \nu\lambda.$$

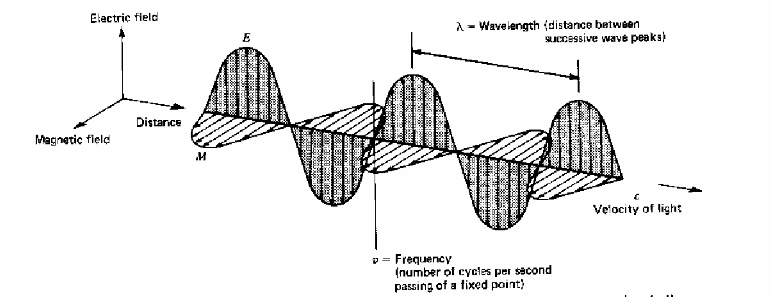


Fig.2 Electromagnetic wave. It has two components, Electric field E and Magnetic field M, both perpendicular to the direction of propogartion

Electromagnetic energy radiates in accordance with the basic wave theory. This theory describes the EM energy as traveling in a harmonic sinusoidal fashion at the velocity of light. Although many characteristics of EM energy are easily described by wave theory another theory known as particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that EMR is composed of many discrete units called photons/quanta. The energy of quantum is

$$Q = h\, c / \lambda = h\, c\nu$$

where Q is the energy of quantum, h = Planck's constant

Table: Principal Divisions of the Electromagnetic Spectrum

Division	**Wavelength**
Gamma rays	(10^{-11} cm $< \lambda <$ 10^{-8} cm)
X-rays	(10^{-8} cm $< \lambda <$ 10^{-6} cm)
Ultraviolet light	(10^{-6} cm $< \lambda <$ 4×10^{-5} cm)
Visible light	(4×10^{-5} cm $< \lambda <$ 7.6×10^{-5} cm)
Infra-red light	(8×10^{-5} cm $< \lambda <$ 10^{-1} cm)
Microwaves	(10^{-1} cm $< \lambda <$ 10^{2} cm)
Radiowaves	(10^{2} cm) $< \lambda$

Electromagnetic Radiation Quantities: Nomenclature, Definition and Units

Radiant Energy (Q): Radiant energy is the energy carried by EMR. Radiant energy causes the detector element of the sensor to respond to EMR in some appropriate manner. Unit of Radiant Energy Q is Joule.

Radiant Flux (ϕ) (Phi) is the time rate of flow of radiant energy. Unit of Radiant flux is Joule/second or watt (W).

Irradiance (E): Radiant flux intercepted by a plane surface per unit area of the surface. The direction of the flux is not specified. It arrives at the surface from all directions within a hemisphere over the surface. Unit of Irradiance E is W/m^2 or Wm^{-2} (Watt per square meter).

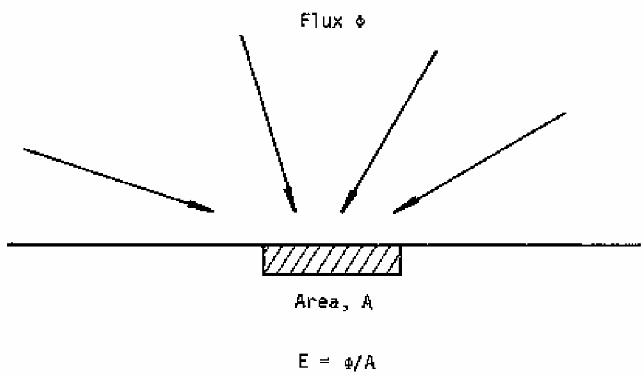


Fig.3 - Concept of Irradiance

Exitence/ emittance (M); is radiant flux leaving a surface per unit area of the surface. The flux may leave the surface in any or all directions within a hemisphere over the surface.

Solid Angle: is the cone angle subtended by the portion of a spherical surface at the center of the sphere. It is equal to the area of the spherical surface divided by the square of the radius of the sphere. Its unit is steradian (sr) and it is denoted by omega (ω).

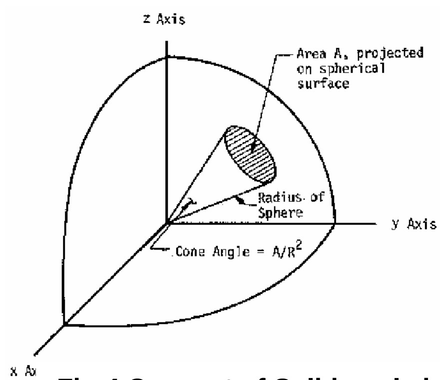


Fig.4 Concept of Solid angle in angular measurement

Radiant Intensity (I): of a point source in a given direction is the radiant flux per unit solid angle leaving the source in that direction. Unit of Radiant Intensity is Watts/ sr

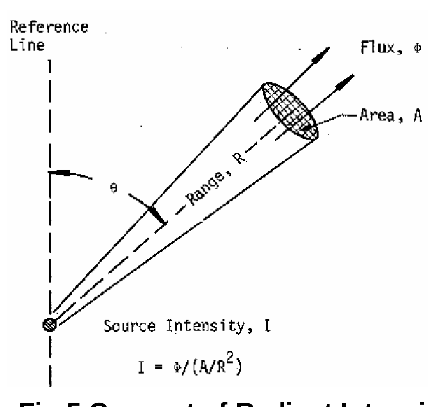


Fig.5 Concept of Radiant Intensity

Radiance (L): is defined as the radiant flux per unit solid angle leaving an extended source in a given direction per unit projected area of the source in that direction. The concept of radiance is intended to correspond to the concept of brightness. The projected area in a direction that makes an angle θ (Theta) with the normal to the surface of area A is A Cosθ

The relationship between radiant intensity and radiance is

$$I = L.A. \cos\theta \qquad \text{Unit for Radiance is W } m^{-2} sr^{-1}$$

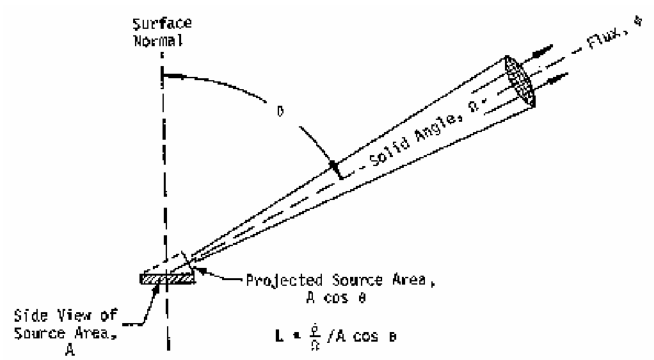


Fig.6 Concept of Radiance

Lambertian Surface: The plane source or surface for which the radiance L does not change as a function of angle of view is called Lambertian (perfectly diffused).

- The irradiance in the retinal image does not change with viewing angle for a lambertian panel, and
- The existence and radiance are related by
  Existence M = π * radiance L (where π = 3.1415927)

Thermal Emission of Radiation

All objects at all temperatures emit electromagnetic radiation at all wavelengths. The thermal emission of radiation is due to the conversion of heat energy, which is the kinetic energy of the random motion of the particles of the matter, into electromagnetic energy.

Thermal emission of radiation depends upon two parameters:

- Absolute Temperature (T), and
- Emissivity (ε)

The total thermal radiation from a body increases with fourth power of T. The absolute temperature is given by T (in units of degrees Kelvin) = 273 + temperature (in degrees centigrade).

The emissivity factor (ε) is the characteristics of the material, a measure of its capability to emit radiation due to thermal energy conversion. The emissivity of a substance is related to its absorptive ability. Good absorbers are good radiators, whereas poor absorbers are poor radiators. For an ideal thermal emitter (called a blackbody), ε = 1.

Characteristics of Solar Radiant Energy

The sun is the strongest and most important source of radiant energy for remote sensing. The solar spectrum extends approximately from 0.3 µm to 3.0 µm. The maximum irradiance occurs at 0.47 µm. The visible band from 0.40 µm to 0.76 µm receives about 46 per cent of the total solar energy.

The rate at which the total solar radiant energy flows across a unit area normal to the direction of propagation located at a mean distance of the earth from the sun is called the solar constant. The value of this constant is 1,353 w/m^2 with an error of + 21 $watts/m^2$. The solar constant can be calculated from the blackbody temperature of the sun ($T = 5,800^oK$) and the mean angular radius of the sun from the earth (4.6×10^{-3} radians).

Radiation Principles

Planck's Law

The spectral exitance for a blackbody is given by Planck's Law.

$$M = C1\ \lambda^{-5}\ [\exp. (C2/ T) - 1]^{-1}$$

C1 and C2 are constant, is the wavelength and T is the absolute temperature.

The spectral exitance of a blackbody is not the same at all wavelengths. The spectral exitance is low for very short and very long wavelengths. It reaches the maximum value for some wavelengths in between, depending on the temperature of the blackbody. A blackbody at higher temperature emits more radiation than a blackbody at lower temperature at all the wavelengths.

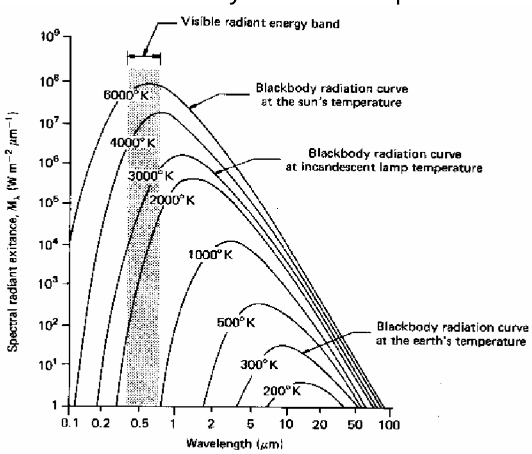


Fig6. Spectral distribution of energy radiated from black bodies of various temperatures (note that spectral radiant exitance M_λ is the energy emitted per unit wave length interval. Total radiant exitance M is given by the area under the spectral radiant exitance curves

The Stephen-Boltzman Law

The total radiation emitted by a blackbody in the entire electromagnetic spectrum is obtained by integrating the area under Planck's distribution curve. It is given by the Stephen-Boltzman law.

$$M\ (\text{blackbody}) = \sigma T^4$$

Where $\sigma = 5.67 \times 10\text{-}8\ W/m2\ (^oK)^4$

Wien's Displacement Law

The wavelength for which the spectral exitance has its maximum value is given λ_m (in microns) = 2,898/T.

For a blackbody at T = 300^{o}K, the peak in spectral emission occurs at λ_m = 10 μm. Hence, objects at ambient temperature emit in the infrared region of the spectrum. As the temperature of the object is raised, the peak emission shifts toward the shorter wavelength side. The radiation in the infrared portion of the spectrum is often referred to as heat rays, as it produces the sensation of heat. At T = 6,000^{o}K, about the temperature of the sun, the peak emission occurs in the visible region of the spectrum (λ_m = 0.5 μm). The production of light by heating and the shift of intensity toward shorter wavelengths by increasing the temperature is illustrated by passing a current through a blackened platinum wire in a dark room. As the magnitude of the current is increased, the wire becomes hot, glows red initially, then the colour of the emitted radiation changes to orange, then to yellow and ultimately to white.

Spectral Emissivity and Kirchoff's Law

The three radiation laws mentioned above hold good for blackbody radiation only. All other substances are characterized by their spectral emissivity (ε), defined as the ratio of spectral existence of the material to the spectral existence of a blackbody at the same temperature.

$\varepsilon(\lambda) = M$ (material, ^{o}K) / M_λ (blackbody ^{o}K)

Knowing the spectral emissivity of a body, its spectral exitance, total exitance and the wavelength of peak emission can be determined.

Kirchoff's law states that the spectral emissivity of a material is equal to its spectral absorptivity, i.e. $\varepsilon(\lambda) = \alpha(\lambda)$.

This implies that if a body is capable of emitting certain radiation, it will absorb that radiation when exposed to it.

The emissivity characteristics of material can be summarized as follows.

- Blackbody: $\varepsilon = 1$ at all wavelengths.
- Grey body : $0 < \varepsilon < 1$ (does not depend upon wavelength)
- Imperfect blackbody (perfect reflector): $\varepsilon = 0$
- All other bodies: $\varepsilon = \varepsilon(\lambda)$ is a function of wavelength.

The relationship between reflectance, absorptivity and transmittance was given by

$$\rho(\lambda) + \alpha(\lambda) + \tau(\lambda) = 1.$$

It can now be written as

$$\rho(\lambda) + \varepsilon(\lambda) + \tau(\lambda) = 1.$$

For opaque substances, $\tau(\lambda) = 0$; hence, emissivity and reflectance are related by

$$\varepsilon(\lambda) = 1 - \rho(\lambda)$$

Interaction of EMR with the Earth's Surface

Radiation from the sun, when incident upon the earth's surface, is either reflected by the surface, transmitted into the surface or absorbed and emitted by the surface. The **EMR**, on interaction, experiences a number of changes in magnitude, direction, wavelength, polarization and phase. These changes are detected by the remote sensor and enable the interpreter to obtain useful information about the object of interest. The remotely sensed data contain both spatial information (size, shape and orientation) and spectral information (tone, color and spectral signature).

From the point of view of interaction mechanisms, the wavelengths (visible and infrared) from 0.3 μm to 16 μm can be divided into three regions. The spectral band from 0.3 μm to 3 μm is known as the reflective region. In this band, the radiation sensed by the sensor is that due to the sun, reflected by the earth's surface. The band corresponding to the atmospheric window between 8 μm and 14 μm is known as the thermal infrared band. The energy available in this band for remote sensing is due to thermal emission from the earth's surface. Both reflection and self-emission are important in the intermediate band from 3 μm to 5.5 μm.

In the microwave region of the spectrum, the sensor is radar, which is an active sensor, as it provides its own source of **EMR**. The **EMR** produced by the radar is transmitted to the earth's surface and the **EMR** reflected (back scattered) from the surface is recorded and analyzed. The microwave region can also be monitored with passive sensors, called microwave radiometers, which record the radiation emitted by the terrain in the microwave region.

Reflection

Of all the interactions in the reflective region, surface reflections are the most useful and revealing in remote sensing applications. Reflection occurs when a ray of light is redirected as it strikes a non-transparent surface. The reflection intensity depends on the surface refractive index, absorption coefficient and the angles of incidence and reflection.

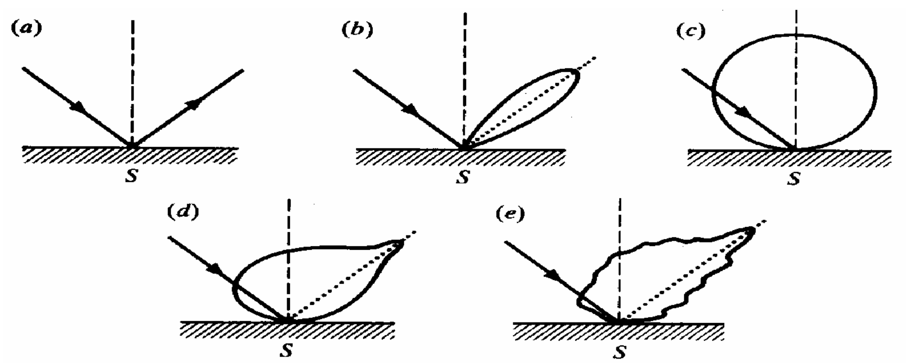


Fig.7 Different types of scattering surfaces (a) Perfect specular reflector (b) Near perfect specular reflector (c) Lambertain (d) Quasi Lambertian (e) Complex.

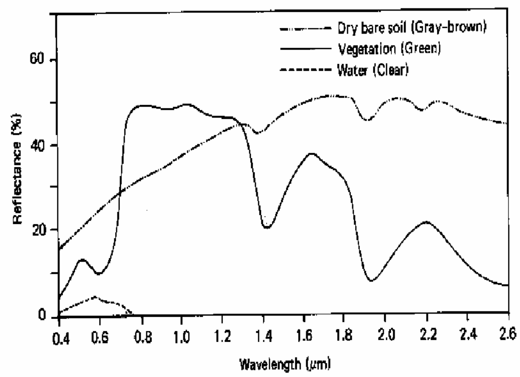
Transmission

Transmission of radiation occurs when radiation passes through a substance without significant attenuation. For a given thickness, or depth of a substance, the ability of a medium to transmit energy is measured as transmittance (τ).

$$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}$$

Spectral Signature

Spectral reflectance, (ρ(λ)), is the ratio of reflected energy to incident energy as a function of wavelength. Various materials of the earth's surface have different spectral reflectance characteristics. Spectral reflectance is responsible for the color or tone in a photographic image of an object. Trees appear green because they reflect more of the green wavelength. The values of the spectral reflectance of objects averaged over different, well-defined wavelength intervals comprise the spectral signature of the objects or features by which they can be distinguished. To obtain the necessary ground truth for the interpretation of multispectral imagery, the spectral characteristics of various natural objects have been extensively measured and recorded. Figure 8 shows a typical reflectance curves for three basic types of earth surface features, healthy vegetation, dry bare soil (gray-brown and loamy) and clear lake water.



Typical spectral reflectance curves for vegetation, soil, and water. (Adapted from [55].)

Fig.8 Typical Spectral reflectance curves for vegetation, soil and water

Interactions with the Atmosphere

The sun is the source of radiation, and electromagnetic radiation (EMR) from the sun that is reflected by the earth and detected by the satellite or aircraft-borne sensor must pass through the atmosphere twice, once on its journey from the sun to the earth and other time after being reflected by the surface of the earth back to the sensor. Interactions of the direct solar radiation and reflected radiation from the target with the atmospheric constituents interfere with the process of remote sensing. This is called as " Atmospheric Effects".

The interaction of EMR with the atmosphere is important to remote sensing for two main reasons. First, information carried by EMR reflected/ emitted by the earth's surface is modified while traversing through the atmosphere. Second, the interaction of EMR with the atmosphere can be used to obtain useful information about the atmosphere itself.

The atmospheric constituents scatter and absorb the radiation modulating the radiation reflected from the target by attenuating it changing it's spatial distribution and introducing (into field of view) radiation from sunlight scattered in the atmosphere and some of the energy reflected from nearby ground area. Both scattering and absorption vary in their effect from one part of the spectrum to the other.

The solar energy is subjected to modification by several physical processes as it passes the atmosphere viz.

1. Scattering
2. Absorption
3. Refraction

Atmospheric Scattering.

Scattering is the redirection of EMR by particles suspended in the atmosphere or by large molecules of atmospheric gases. Scattering not only reduces the image contrast but also changes the spectral signature of ground objects as seen by the sensor. The amount of scattering depends upon the size of the particles, their abundance, the wavelength of radiation, depth of the atmosphere through which the energy is traveling and the concentration of the particles. The concentration of particulate matter varies both in time and over season. Thus the effects of scattering will be uneven spatially and will vary from time to time.

Theoretically scattering can be divided into three categories depending upon the wavelength of radiation being scattered and the size of the particles causing the scattering. The three different types of scattering from particles of different sizes are summarized below

Scattering process	**Wavelength**	**Approximate dependence particle size**	**Kinds of particles**
Selective			
I) Rayleigh	λ^{-4}	< 1 µm	Air molecules
ii) Mie	λ^{o} to λ^{-4}	0.1 to 10 µm	Smoke, haze
Non-selective	λ^{o}	> 10 µm	Dust, fog, clouds

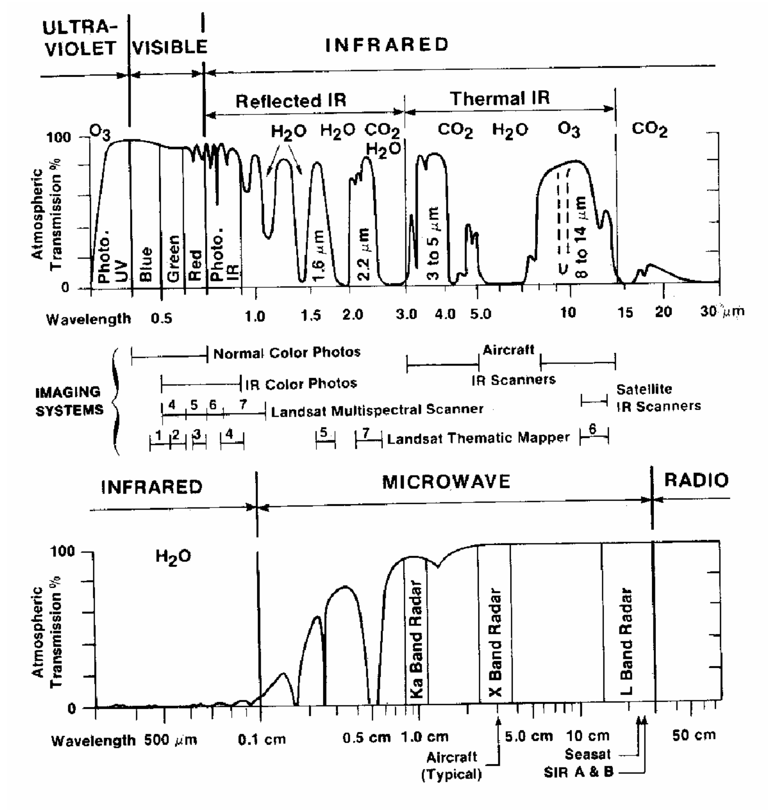
Occurrence of this scattering mechanism gives a clue to the existence of large particulate matter in the atmosphere above the scene of interest which itself is a useful data. The effects of the Raleigh component of scattering can be eliminated by using minus blue filters. However, the effects of heavy haze, when all the wavelengths are scattered uniformly, cannot be eliminated by using haze filters. The effects of haze are less pronounced in the thermal infrared region. Microwave radiation is completely immune to haze and can even penetrate clouds.

Atmospheric Absorption

The gas molecules present in the atmosphere strongly absorb the EMR passing through the atmosphere in certain spectral bands. Mainly three gases are responsible for most of absorption of solar radiation viz. ozone, carbon dioxide and water vapor. Ozone absorbs the high energy, short wavelength portions of the ultraviolet spectrum (λ < 0.24µm) thereby preventing the transmission of this radiation to the lower atmosphere. Carbon dioxide is important in remote sensing as it effectively absorbs the radiation in mid and far infrared regions of the spectrum. It strongly absorbs in the region from about 13- 17.5 µm, whereas two most important regions of water vapour absorption are in bands 5.5 - 7.0 µm and above 27 µm. Absorption relatively reduces the amount of light that reaches our eye making the scene look relatively duller.

Atmospheric Windows

The general atmospheric transmittance across the whole spectrum of wavelengths is shown in figure. The atmosphere selectively transmits energy of certain wavelengths. The spectral bands for which the atmosphere is relatively transparent are known as atmospheric windows. Atmospheric windows are present in the visible part (.4 µm - .76 µm) and the infrared regions of the EM spectrum. In the visible part transmission is mainly effected by ozone absorption and by molecular scattering. The atmosphere is transparent again beyond about λ= 1mm, the region used for microwave remote sensing.



Refraction

The phenomenon of refraction that is bending of light at the contact between two media also occurs in the atmosphere as the light passes through the atmospheric layers of varied clarity, humidity and temperature. These variations influence the density of atmospheric layers, which in turn causes the bending of light rays as they pass from one layer to another. The most common phenomena are the mirage like apparitions sometimes visible in the distance on hot summer days.

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