Remote Sensing

1. Basics and Applications

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Rangnath R Navalgund, after working for more than two decades at the Space Applications Centre (ISRO), Ahmedabad has moved over to the National Remote Sensing Agency, Department of Space, Hyderabad, as its Director since May, 2001. Definition of Indian spaceborne remote sensing missions and formulation of remote sensing applications programme in the country are his areas of work.

Remote sensing refers to the science of identification and classification of Earth surface features using electromagnetic radiation as a medium of interaction. Space borne remote sensing is fast emerging as a front running provider of information on natural resources in a spatial format. This article briefly discusses the physical basis of remote sensing, how information is extracted from images and various applications of remote sensing.

What is Remote Sensing?

Remote Sensing (RS) refers to the branch of science which derives information about objects from measurements made from a distance i.e. without actually coming into contact with them. Conventionally remote sensing deals with the use of light i.e. electromagnetic radiation as the medium of interaction. RS refers to the identification of Earth features by detecting the characteristic electromagnetic radiation that is reflected/emitted by the earth surface. Every object reflects/scatters a portion of the electromagnetic radiation incident on it depending upon its physical properties. In addition, objects also emit electromagnetic radiation depending upon their temperature and emissivity. Reflectance/emittance pattern at different wavelengths for each object is different. Such a set of characteristics is known as spectral signature of the object. This enables identification and discrimination of objects. Visual perception of objects is the best example of remote sensing. We see an object by the light reflected from the objects falling on the human eye. Here, eye is the sensor and the nervous system carries data to the brain, which interprets the information in terms of the identification and location of the objects seen. Modern remote sensing is an

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extension of this natural phenomenon. Apart from visible light, the electromagnetic radiation extending from the ultraviolet to the far infrared (IR) and the microwave regions are also used for remote sensing of the Earth.

Remote sensing, as we understand today, is the opposite of astronomy. An astronomer looks from the Earth towards heavenly bodies to understand and gain more insight about them. He builds instruments to measure 'light coming from these bodies' to understand their movements, evolution, etc. On the other hand, remote sensing refers to going up in the sky and looking downwards towards the Earth to learn more about the place we have inhabited.

Remote sensing system broadly comprises the platform, the sensors, the data acquisition, preprocessing and data interpretation (*Figure* 1). The platform can be a spacecraft, aircraft, balloon, a tower or even a tripod. The platform houses the sensor(s) required for detecting reflected/emitted radiation from the earth surface features. The data acquisition system comprises broadly a receiving antenna and associated electronics. Preprocessing involves radiometric and geometric correction of raw data. Data analysis refers to interpretation of data for identifying different features on the basis of their signatures,

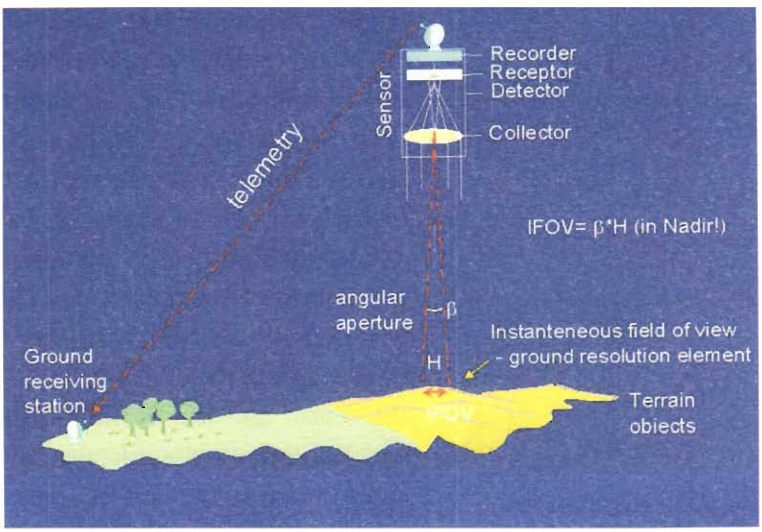

Figure 1. Shows schematically the principle of remote sensing.

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Solar and Terrestrial Radiation

Electromagnetic radiation spans a large spectrum of wavelengths right from very short wavelength gamma rays (10^{-10}m) to long radio waves (10^{6}m). In remote sensing, the most useful regions are the visible (0.4 to 0.7 μm), the reflected IR (0.7 to 3 μm), the middle infrared (3 to 5 μm), the thermal (8 to 14 μm) and the microwave regions (0.3 to 300 cm). The Sun is the important source of electromagnetic radiation used in conventional optical remote sensing. The Sun may be assumed to be a blackbody with surface temperature around 6000 K. The Sun's radiation covers ultraviolet, visible, IR and radio frequency regions and the maximum emission occurs around 0.55 μm, which is in the visible region (green). However, the solar radiation reaching surface of the Earth is modified by the atmospheric effects. It is observed that all bodies at temperatures above zero degrees absolute emit electromagnetic radiation at different wavelengths, as per Planck's law.

$$E(\lambda,T)=\frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}$$

h=6.625 × 10^{-27} erg-sec (Planck constant)
k=1.38 × 10^{-16} erg/K (Boltzmann constant)
c=3 × 10^{10} cm/sec (speed of light).

The Earth can be treated as a blackbody at ~300 K emitting electromagnetic radiation with peak emission at around 9.7 μm. According to Planck's law, the radiation emitted by the Earth (300 K) is much less at all wavelengths compared to that emitted by the Sun (6000 K). However, at the Earth's surface because of the great distance between the Sun and the Earth, the energy in the 7.0 to 15 μm wavelength region is predominantly due to thermal emission of the Earth.

Atmospheric Effects

In passing through the atmosphere, electromagnetic radiation is

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scattered and absorbed by gases and particulates. Besides the major atmospheric gaseous components such as molecular nitrogen and oxygen, other constituents like methane, hydrogen, helium, and nitrogen compounds play an important role in modifying the incident radiation energy spectrum. The strongest absorption occurs at wavelengths shorter than 0.3 μm primarily due to ozone. There are certain spectral regions where the electromagnetic radiation is passed through without much attenuation. These are called atmospheric windows. Remote sensing of the Earth's surface is generally confined to these wavelength regions. Atmospheric windows used for remote sensing are 0.4-1.3, 1.5-1.8, 2.2-2.6, 3.0-3.6, 4.2-5.0, 7.0-15.0 μm and 10 mm to 10 cm wavelength regions of the electromagnetic spectrum. Even in the atmospheric window regions, scattering by the atmospheric constituents produces spatial redistribution of energy. The three important scattering mechanisms are the Rayleigh scattering, Mie scattering and non-selective scattering.

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Interaction of Radiation with Matter

The electromagnetic radiation when incident on the Earth either gets reflected, absorbed, reradiated or gets transmitted through the material depending upon the nature of the object and wavelength. When the surface is smooth compared to the wavelength of incident radiation, it gets reflected in the forward direction called specular reflection. When the surface is rough, the incident energy is reflected uniformly in all directions, which is termed as diffused. It may be noted that fine sand, which appears rough in the visible region is smooth in the microwave region. Reflective/emissive properties of various surfaces at different wavelengths termed as spectral signatures are important in remote sensing since they provide information about the objects.

Concept of Signatures

Any set of observable characteristics, which directly or indirectly lead to the identification of an object and/or its condition, is termed 'signature'. Spectral, spatial, temporal and polarization variations are four major characteristics of the targets, which facilitate discrimination. Spectral variations are the changes in the reflectance or emittance of objects as a function of wavelength. Spatial arrangements of terrain features, providing attributes such as shape, size and texture of objects, which lead to the identification of objects, are termed as spatial variations. Temporal variations are the changes of reflectivity or emissivity with time. They can be diurnal and/or seasonal. The variation in reflectivity during the growing cycle of a crop helps distinguish crops which may have similar spectral reflectances but whose growing cycles may not be same. Polarisation variations relate to the changes in the polarization of the radiation reflected or emitted by an object. The degree of polarization is a characteristic of the object and hence can help in distinguishing the object. Such studies have been particularly useful in microwave region. Signatures are not, however, completely deterministic. They are statistical in nature with a certain mean value and some dispersion around it.

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Spectral Response of Some Natural Earth Surface Features

Vegetation: The spectral reflectance of vegetation (*Figure* 2) is quite distinct. Plant pigments, leaf structure and total water content are the three important factors which influence the spectrum in the visible, near IR and middle IR wavelength regions, respectively. Low reflectance in the blue and red regions corresponds to two chlorophyll absorption bands centered at 0.45 and 0.65 μm, respectively. A relative lack of absorption in the green region allows normal vegetation to look green

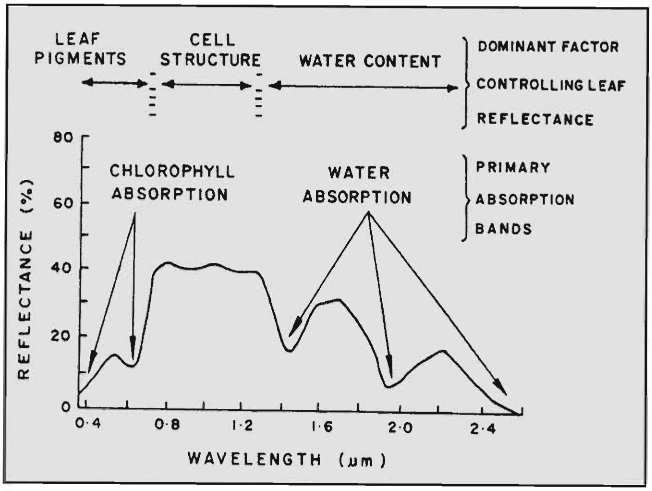

Figure 2. Spectral reflectance of vegetation.

to ones eyes. In the near infrared, there is high (~45 per cent) reflectance, transmittance of similar magnitude and absorptance of only about five per cent. This is essentially controlled by the internal cellular structure of the leaves. As the leaves grow, inter-cellular air spaces increase and so the reflectance increases. As vegetation becomes stressed or senescent, chlorophyll absorption decreases, red reflectance increases and also there is a decrease in intercellular air spaces, decreasing the reflectance in the near IR. This is the reason why the ratio of the reflectance in the near IR to red or any of the derived indices from this data are sensitive indicators of vegetation growth/vigour. In the middle IR reflectance peaks occur at 1.6 and 2.2 μm. It has been shown that total incident solar radiation absorbed in this region is directly proportional to the total leaf water content.

Soil: Typical soil reflectance curve shows a generally increasing trend with wavelength in the visible and near IR regions. Some of the parameters which influence soil reflectance are the moisture content, the amount of organic matter, iron oxide, relative percentage of clay, silt and sand, and the roughness of the soil surfaces. As the moisture content of the soil increases, the reflectance decreases and more significantly at the water absorption bands. In a thermal IR image moist soils look darker compared to the dry soils. In view of the large differences in dielectric constant of water and soil at microwave frequencies, quantification of soil moisture becomes possible.

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Water: Water absorbs most of the radiation in the near IR and middle IR regions. This property enables easy delineation of even small water bodies. In the visible region, the reflectance depends upon the reflectance that occurs from the water surface, bottom material and other suspended materials present in the water column. Turbidity in water generally leads to increase in its reflectance and the reflectance peak shifts towards longer wavelength. Increase in the chlorophyll concentration leads to greater absorption in the blue and red regions. Dissolved gases and many inorganic salts do not manifest any changes in the spectral response of water.

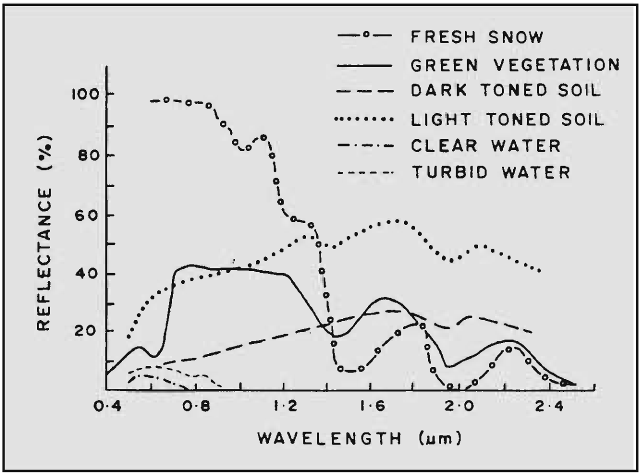

Figure 3. Typical spectral responses of vegetation, soil, water and snow.

Snow and Clouds: Snow has very high reflectance, up to 0.8 μm, and then decreases rapidly afterwards. In case of clouds, there is non-selective scattering and they appear uniformly bright throughout the range of 0.3 to 3 μm. The cloud tops and snow generally have same temperature and hence it is not possible to separate these easily in the thermal infrared region. Hence, the two atmospheric windows in the middle infrared wavelength regions 1.55 to 1.75 and 2.11 to 2.35 μm are important for snow cloud discrimination. Typical spectral responses of vegetation, soil, water, and snow are given in *Figure* 3.

Figure 4 shows images of a typical Earth surface taken in blue, green, red and near infrared regions. Vegetation is seen in dark tone in the red image while it manifests a bright tone in near infrared as discussed earlier. Water bodies show dark tone in NIR region meaning all radiation in that region gets absorbed by the water molecules. Since eyes are not sensitive to NIR region, concept of false colour composite is introduced. In this, the NIR image is assigned red colour; red image, the green colour; green image, the blue colour. Hence, vegetation with high reflectance in NIR region is seen in red tone. One could construct a normal colour composite without NIR, however it would have less ability to distinguish objects, in particular the vegetation.

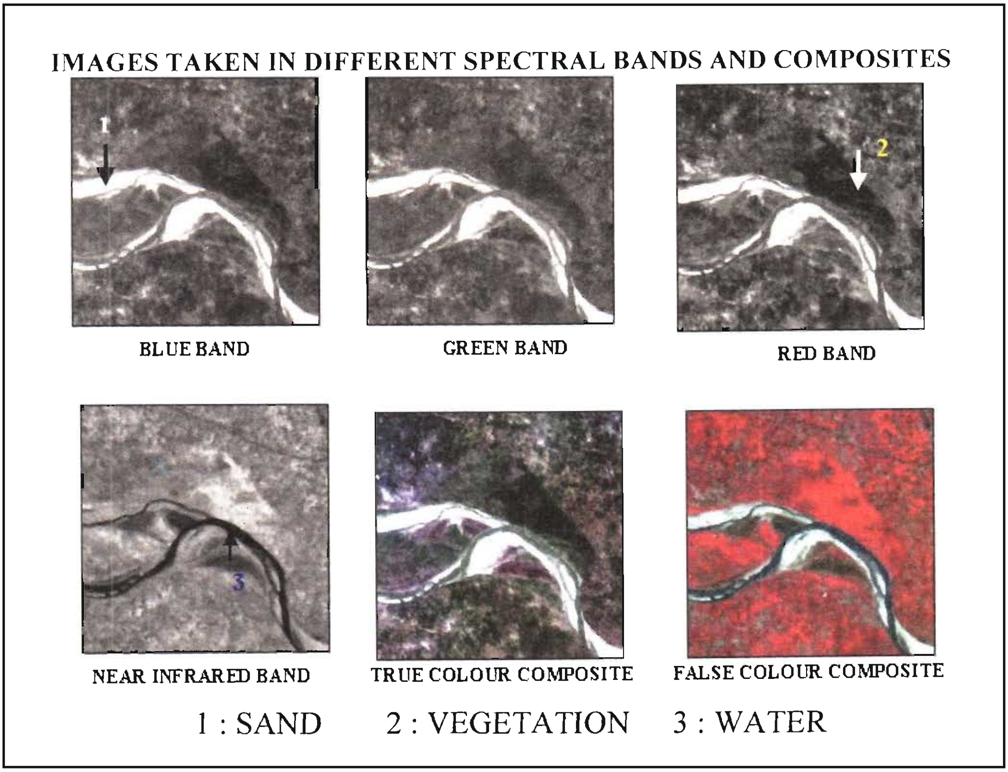

Figure 4. Images taken in different spectral bands and composites.

Remote Sensing Applications

Remotely sensed data have been extensively used in making an inventory of natural resources, knowing their condition, and studying changes over time. RS data have also been used in deriving geophysical and biophysical parameters of different ecosystem components, which in turn are used to understand Earth system processes and phenomena. Some of the major areas in which RS data have been extensively used are agriculture, forestry, water resources, landuse, urban sprawl, geology, environment, coastal zone, marine resources, snow and glaciers, etc. Multispectral and multi temporal RS data facilitate identification of crops, estimating their area, inferring the possible yield and hence production forecasts before harvest. Extent of forest cover, their types and density are discernible. Identification of surface water bodies and their spread, mapping ground water prospect zones, estimating snow cover and possible melt, retreat of glaciers over time period, sedimentation in reservoirs are some applications related to water resources that are routinely being done. Identification of wastelands, their culturable status to facilitate their development is another use. Monitoring urban sprawl, preparing development plans and studying impact of urbanisation are some other examples. Preparation and updation of existing maps at various scales is an important application of RS data. Mono and stereo data are useful in identifying geological structures, possible mineralized zones etc. Environmental impact assessment has been another major application area. RS data in conjunction with collateral data has greatly facilitated integrated development of land and water resources on watershed basis leading to sustainable development.

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Disaster monitoring, damage assessment and mitigation has been a main beneficiary of spaceborne remote sensing. Sequential images taken from both near Earth and geosynchronous orbits help track cyclones and indicate their landfall point. Multitemporal RS data help in identifying and monitoring flood inundated areas, consequent damage assessment and in relief measures. Monitoring drought and its severity assessment through indicators derived from RS data is another example. Preparation of landslide hazard zonation maps, forest fire prone areas, vulnerability/risk maps for many disasters in GIS environment has been greatly benefited from RS data. Use of thermal data helps monitoring impending volcanic eruption. Ability of microwave radar data to see through clouds has been particularly useful in flood and cyclone related studies since they are generally accompanied by cloud cover. Detection and monitoring of oil spills in oceans is another application. International co-operation of nations in evolving integrated global observation for disaster studies is getting in place.

Evolution of Remote Sensing in India

Identification of coconut trees affected by the root-wilt disease on the colour infrared images obtained from a helicopter in 1970 heralded remote sensing in its present sense in India. This was followed by many studies conducted using aerial data and also data available from Landsat series of satellites from 1972. Launching of two experimental Earth observation satellites, Bhaskara I and II in 1979 and 1981 carrying both optical and microwave payloads provided the initial thrust to learning process. Design, development and successful launching of Indian remote sensing satellites (IRS-1A and 1B) carrying state-of-the-art sensors providing data at two different spatial resolutions but in identical spectral bands brought Indian remote sensing to international forefront. IRS-1C/ 1D carrying a unique set of three sensors, viz., WiFS, LISS-III and PAN camera have made significant impact on the remote sensing scene internationally. Till recently, PAN camera providing 5.8 m resolution data was the highest spatial resolution offered in civilian domain. While, IRS-1A/ 1B/ P2/ 1C/ ID addressed data needs of land observations, IRS-P3 and IRS-P4 carrying ocean colour sensors and microwave radiometer (IRS-P4) provided measurements for the study of ocean biology and atmosphere.

While there was advancement in building space technology capabilities, it should be emphasized, it was always driven by application needs. A unique concept of National Natural Resources Management System has been evolved and institutionalised in the country. It envisages use of RS data as a cornerstone for the survey and management of natural resources in the country along with other collateral data. There are several state, central government agencies, academic institutes and voluntary organizations who are engaged in utilizing space technology in the country. Parallely, infrastructure for training and education has been established in the country. Various centres for providing infrastructure facilities for data analysis and value added services have also been established. RS data is being routinely used in many areas of survey and management of natural resources.

Suggested Reading

[1] R R Navalgund and K Kasturirangan, The Remote Sensing Satellite - A Programme Overview, *Proc. Ind. Acad. of Sciences; Engg Sciences - Remote Sensing-III*, Vol. 6, pp. 313-336, 1983.

[2] George Joseph and R R Navalgund, Remote Sensing: Physical basis and its evolution, in *Glimpses of Science in India* (ed. U S Srivastava), Malhotra Publ. Home, pp 357- 383, 1991.

[3] R R Navalgund, A Sarkar and K K Mohanty, *Satellite oceanography: physical basis, status and new development in ocean science; trends and future perspectives* (ed. BLK Somayajulu) INSA, New Delhi, pp. 247- 274, 1999.

[4] F F Sabins, *Remote Sensing: Principles and Interpretation*, W H Freeman & Company, 1987.

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