Proc. Indian Acad. Sci. (Engg. Sci.), Vol. 6, Pt. 2, June 1983, pp. 97–107.

Introduction to remote sensing

P R PISHAROTY
Physical Research Laboratory, Ahmedabad 380009, India

Abstract. Remote sensing consists of gathering information about objects and features without placing instruments in contact with them. The sensors are placed on aircraft or spacecraft platforms and the earth's surface surveyed for its natural resources. Electromagnetic radiation (EMR) in the visible, infrared and microwave bands are employed, mostly solar radiation or natural emissions. The interactions of EMR with the objects are impressed as "signatures" on the reflected, scattered, transmitted or emitted EMR. The sensors employed are (i) cameras with normal or special films sensitive to infrared, (ii) electro-optical systems in the scanning mode using solid state detectors, (iii) imaging tubes and devices and (iv) microwave systems which can gather data even when clouds intervene. The data gathered with the sophisticated systems are converted into imagery or directly processed on electronic computers. The processed data are then interpreted in terms of known ground truths or 'EMR signatures' of the objects. Remote sensing has wide applications in agriculture, forestry, geology, hydrology cartography and oceanography.

Keywords. Remote sensing; earth resource surveys; sensor systems; image processing.

1. Introduction

Remote sensing is the technique of gathering information about objects and features without placing measuring instruments in contact with them. The human eye with its muscular controls and the retina, is perhaps the best example of a remote sensing system. It may be recalled that astronomy and astrophysics developed through the analysis of *visible* radiations emitted by remote celestial objects and sensed by ground-based spectrographs and spectrophotometers. With the development of sensitive detectors for infrared radiations and centimetre radio waves, new branches of astronomy known as infrared astronomy and radio astronomy have come into existence. If instead of viewing celestial objects with sensors on a ground-based platform, objects and features on land, sea, and within the atmosphere are sensed with instruments on aircraft and spacecraft platforms we have the modern technology of remote sensing. This is an efficient method of surveying earth's resources; what is lost in detail is gained in the area covered by, and the time required for, the survey.

The acquisition of data on earth's resources by remote sensing represents either a logical extension of existing capabilities for solutions of problems in a quicker time-scale, or a completely new approach capable of many useful variations and innovative approaches. Modern remote sensing devices include passive and active systems and employ different bands in the visible spectrum, in the near infrared, as well as in the centimetre radiowaves. Fortunately, the atmosphere is almost completely transparent to all these radiation-bands when cloud-free and nearly so to the radiowaves when clouded. The reflectivity and emissivity of the terrestrial objects in the lithosphere, hydrosphere or biosphere in the various bands of the electromagnetic spectrum are quantitatively registered by the sensitive sensing devices. Recordings in about ten bands—visible and invisible—over a ten stage intensity scale, can provide ideally ten billion combinations, or fingerprints of terrestrial (land, sea and air) features.

During the early stages of remote sensing technology, the data were gathered in the form of photographic imagery. Various techniques were evolved in deducing useful information from simple black and white as well as multi-band photo imagery. However, modern remote sensor systems on aircraft and spacecraft collect vast quantities of data. These are increasingly collected in the form of electrical signals mostly as trains of digital pulses. Their transmission, reception and recording are problems of electric engineering. But the translation of these signals into intelligible images for visual interpretation, or processing them in electronic computers for automatically deducing various kinds of useful information is a fairly new discipline—image processing/automatic data processing. It is in a rapidly advancing state of development, to which contributions can still be made by innovative minds in India.

India, particularly the National Remote Sensing Agency, Hyderabad, has *all* the modern equipment necessary for the acquisition and processing of remote sensor data for earth's resources.

Detection and processing of electromagnetic signals do not provide directly useful information. The reflectance, emission and absorption of an object in the visible and invisible parts of the electromagnetic spectrum are characteristics of that object—whether it be a snow pack, a water body, a cloud, a crop, a tree, a patch of soil, a mineral-bearing rock, an oil slick, seawaves, sea plankton or aerosols, gases and vapours in the atmosphere. These can be collectively called interaction mechanisms. A thorough knowledge of these mechanisms is necessary to interpret the data generated through the processing of the electromagnetic signals, either as imagery or as other kinds of computer outputs.

In using the eye as a remote sensing system in day-to-day life, the common man has acquired the necessary skills through experience—a continuous process of observation, inference and validation. One sees a cow, distinguishes it from a bull, deduces that it can yield milk, deduces whether this particular cow is starved or well-fed, etc. A physician looks at the x-ray photograph of the chest of a patient and infers much about the state of his lungs, heart, ribs etc. and the most probable causes for the abnormalities observed in the shadows of the different organs inside the chest. Here he uses his knowledge of the interaction between the x-ray band of the electromagnetic spectrum and the human lungs, heart, ribs, cancerous patches, tubercular growths etc. He has gained confidence in his inferences through validations of his past inferences, by surgery conducted by him, his seniors, his teachers or others and subsequently published in literature. Such an experience is required in remote sensing of earth's resources with sensors located on aircraft and spacecraft platforms. The components of such an experience are: (i) a knowledge of the interaction of the different parts of the electromagnetic spectrum with terrestrial objects and features; (ii) determinations of the ground truths corresponding to the recorded data; and (iii) their validation.

2. Platforms for remote sensing

Just as the eye is located on the head, man-made remote sensors are located on different kinds of platforms. They are free-lift balloons, aircraft and spacecraft.

Historically the first aerial photographs were taken in 1858 from a balloon which floated over Paris. In 1862, during the American civil war, similar balloon-based photographs were taken for military purposes. Balloons can still be used for remote sensing. India with its decentralised living conditions, will do well to explore all the possibilities of remote sensing especially for agriculture, using sophisticated instrumentation on balloon platforms.

Aerial photography using simple band cameras as well as multiband cameras has been extensively used for aerial mapping, in war and peace. In fact the term remote sensing was first used in literature in 1962, as a more convenient term for a US naval project on the study of aerial photographs.

Conventional aircraft currently used for remote sensing vary in size from small single engine piston-powered aircraft to the large four engine jet-powered modified Boeing 707. Very high altitude aircraft types with ceilings of 18·3, 21·3 and even 107 km are also employed for remote sensing work, not in India, but elsewhere. The usual aircraft are to be modified for taking on the sensors, some of which need open ports under the fuselage. Some of the sensors have large power requirements. Systems are needed to provide corrections for the yaw, pitch and roll of the aircraft. Special navigational equipment are often necessary to precisely pinpoint the areas flown on the imagery obtained and to avoid area overlaps. The National Remote Sensing Agency, Hyderabad has a satisfactory flight facility, with three aircraft of two different types.

With the advent of space systems a new dimension has been added to remote sensing. 'Bhaskara' satellites fabricated in India are very junior members of this category. All weather satellites, beginning with television infrared observation station (TIROS I) launched in April 1960, gather information on cloud cover and other atmospheric parameters; they are remote sensing satellites. The satellites specially designed for earth resource surveys, carry multi-spectral imaging systems (vidicons and scanners) and other *auxiliary* equipment to collect information needed to utilise the data. These are near polar-orbiting satellites, passing over the different geographical areas at the same local time (sun-synchronous), and giving full earth coverage (outside the poles) every 18 days; they have a ground resolution of about 70 km (40 km in the later satellites). For meteorological purposes, the geo-synchronous satellites (hovering over the same point of the equator all the time) have come into vogue.

3. Electromagnetic radiation

Electromagnetic radiation is a propagating form of energy manifest through its interaction with matter. This energy is propagated in free space with a velocity of 3×10^8 m/s; and visible light is such a form of energy. Maxwell showed it to be a wavemotion in the electric and magnetic force-fields. Therefore the interaction between these waves and matter depends upon both the magnetic and electric properties of the matter. And this is the reason why electromagnetic radiation acts as a powerful tool in remote sensing.

The additional advantage is that when this electrical-cum-magnetic wavemotion propagating in a direction, mingles with another similar wavemotion, the resultant wavemotion has an amplitude which is the sum of the amplitudes of the two wavemotions. It is easy to detect either of them, separately, without distortion using a suitable detector. As this form of energy can be propagated through long distances in empty space, the message imprinted on them by interaction with matter, is also carried over long distances of empty space without distortion.

The wave properties of this radiation are prominent when the wavelengths are long—more than a few μm ($\mu = 10^{-6}$) upto several hundreds of metres. However, such properties are much less manifest, when the wavelengths are very small, of the order of a hundred nm (n $= 10^{-9}$) or less, like ultraviolet rays, x-rays, γ-rays etc. In the case of visible light (400–700 nm), it is a mixed behaviour. A large part of remote sensing technology uses electromagnetic radiation in this visible band.

At the very short wavelengths indicated above, the generation of electromagnetic radiation occurs in bursts of short wavetrains, each wavetrain carrying an amount of energy E in ergs given by the relation:

$$E = h\nu = hC/\lambda,$$

where h is the Planck's constant $6{\cdot}626 \times 10^{-27}$ erg. s, ν is the frequency in numbers/s., C is the velocity of propagation 2.998×10^{10} cm/s and λ is the wavelength in vacuo in cm.

The radiant energy carried by these bursts of wavetrains is not delivered to the receiver as if it were spread evenly between the waves in the train but is delivered in a single shot, a quantum or a photon, on a probability basis. The probability of the delivery of the quanta over an area, depends upon the flux density of the incident radiation. However, when the flux density is large, that is when there are numerous quanta, *the time average of the rate of delivery* of the wave energy is the same as the average power in the wavefront. This is the quantum behaviour of electromagnetic radiation in a non-mathematical language.

This quantum or photon concept becomes necessary and useful in dealing with modern types of solid-state detectors, where the minimum intensity detected is limited by the random thermal fluctuations occurring in the detector—called photon-noise.

All objects, at temperatures above 0°K, emit electromagnetic radiation. In the ideal case of a black body, the intensity of the radiation emitted versus the wavelength is given by the well-known Planck's law of radiation. The intensity at each wavelength and the general shape of the curve of radiation versus wavelength, depends on the temperature of the body. According to Stefan's law, the total radiation emitted by a black body is proportional to the fourth power of the absolute temperature. According to the Wien's displacement law, the wavelength at which the emitted energy is maximum is inversely proportional to the absolute temperature. When the wavelengths are large, of the order of centimetres or more, the energy emitted per unit area is proportional to the temperature and inversely proportional to the fourth power of the wavelength—known as Rayleigh–Jeans formula. All the above are derivable from Planck's formula

$$E_\lambda \, d\lambda = 2hC^2 \lambda^{-5} (\exp hC/\lambda kT - 1)^{-1} \, d\lambda,$$

where E is the spectral radiant emittance in ergs/s; h is the Planck's constant $6{\cdot}626 \times 10^{-27}$ erg.s; C is the velocity of light in vacuo $2{\cdot}998 \times 10^{10}$ cm/s, λ is the wavelength in cm; k is the Boltzmann constant $1{\cdot}381 \times 10^{-16}$ ergs/°K and T is the absolute temperature in °K. Being transverse waves, electromagnetic waves are plane-polarised waves. But, during emission individual wave trains are emitted with random planes of polarisation, so that the available radiation behaves as unpolarised radiation. However, in the case of radio waves it is possible to generate waves with their plane of polarisation in a given plane chosen by the experimenter. And their interaction with matter depends on the plane of polarisation; this is an additional advantage when radio waves are used in remote sensing.

Electromagnetic waves also experience the so-called Doppler shift, when the real source (or the effective source in reflected waves) has a velocity with a component in the direction of propagation. For the relatively low velocities encountered in remote sensing, the increase in frequency $\Delta\nu$ is given by U/C, where U is the component of the relative velocity towards the observer or the recording instrument. This principle is also made use of in special systems of measurements using active microwave systems.

4. Interaction mechanisms

The processes and details of the interaction between electromagnetic radiation and material surfaces form a field of intense current scientific activity. The electromagnetic radiation incident on a material surface is reflected either specularly or diffusely or is transmitted into the surface, absorbed by the sub-surface and partially reradiated or scattered. Reflection and emission are not purely surface phenomena, they involve some penetration of the radiation into the medium below the surface. And all these interactions depend upon the electrical and magnetic properties of the substances of various geometries and extents, such as buildings, crops, rough soils, geological features of land, ocean surfaces with waves, biomass content of the waters, temperature of the surfaces, composition of atmospheric gases etc.

Studies in this area are of such an expanding nature, and of an intensely local variety, that Indian scientists can and have to make substantial contributions of relevance to our country.

(i) The emissity of a surface in the different wavelengths is not that given by Planck's law for a black body. Natural surfaces emit only a fraction of it. This fraction, called the emissivity, is dependent on wavelength, on temperature and the geometry of the surface, besides the composition of the surface.

(ii) The reflectance or scattering effected by a surface is also a fraction of the intensity of the incident radiation. This fraction again is a characteristic of the electric and magnetic properties of the substance constituting the surface, the geometry of the surface, the wavelength and the temperature. As mentioned earlier, the reflectance depends upon the plane of polarisation of the incident beam particularly in the radio wave band.

(iii) The absorption of electromagnetic radiation by the gases in the atmosphere is another form of interaction. Such absorptions are highly wavelength-dependent and are characteristic of the gases involved—ozone, water vapour, oxygen, oxides of nitrogen, etc. Some absorption bands are in the infrared, others in the centimetre radio waves, and yet others in the ultraviolet.

Except in rare cases it has not been possible to theoretically compute the emission, reflection, and absorption coefficients. Most of the values have been and have to be determined experimentally. The field is very vast. A gist of the work done in this field is given in ASP (1975) together with a list of about 360 references. The reader is referred to this mass of material for further information.

5. The remote sensors

5.1 *Photographic systems*

Photographic systems are extensively used for reconnaissance, cartography and for identifying objects imaged through their spectral signatures determined earlier by laboratory and field experiments. Aerial black and white films are generally used. Aerial "false colour" films are sensitive to the near infrared and the corresponding radiations are recorded in the film as crimson red on development; the normal red radiation appears as green, and the normal green as blue. Due to the abundance of infrared radiation reflected from crops and other green foliage, healthy vegetation and forest canopy appear as crimson red. Hence such films are used for remote sensing in agriculture and forestry. Unhealthy vegetation shows up through significant fall in their infrared reflectance, even before the visible radiations record a change.

Single band and multi-spectral optical cameras have been extensively used. When employed on spacecraft, the cameras are of the television type.

5.2 *Electro-optical sensors*

Electro-optical remote sensors with appropriate optical systems have been a relatively recent development, exclusively for remote sensing of terrestrial objects. Electro-optical systems as radiation detectors are those which transform electromagnetic radiation (visible, infrared or ultraviolet) into electrons or other detectable electric signals and thereby convey image information of the viewed scene. Since the output voltage is a direct analog of the radiation falling on the detectors, any operation performed on the incident radiation, such as varying its intensity, is imparted to the output signal. Thus it is possible to optically encode the signal to facilitate electronic handling, or conversely it is possible to enhance a signal which has been degraded or distorted by the optical sub-systems. Wolf (1965) has given a comprehensive picture on the subject.

Detection can be broadly divided into thermal and quantum detectors. The latter can be sub-classified as photo-emissive, photo-conductive and photo-voltaic (photo-diodes) depending upon the basic mechanism of the detection process.

It is feasible, in principle, to scan an image with a single electro-optical detector. Consequently, most of the remote-sensor systems operate this way. The serious difficulty is the very short dwell-time on each image element, especially when the sensor is carried on a fast moving aircraft or on a spacecraft. The difficulty is partially overcome by using detector arrays. The charge-transfer device is a recent development in photo-diode arrays.

The spectral responses of most of the photoconductive photo-diode detectors are peaked in the near, intermediate or far infrared. At noon temperatures, the thermal phonons cause signals similar to those generated by the incidence of photons on the detector, called thermal noise. Their suppression needs cooling of the detector to liquid nitrogen or even liquid hydrogen temperatures. All these make modern remote sensing a sophisticated branch of electronic engineering. The author is deliberately not reproducing diagrams of the various systems, their spectral responses, cooling arrangements, etc. as these may be given in other articles of this volume.

Other additions to the remote sensing systems are the imaging tubes and devices—like the image orthicon, the vidicon and its modifications like the return beam vidicon, the plumbicon, the isocon, the secondary electron conduction vidicon, etc. A large amount of literature has accumulated on these topics, to which the interested reader can refer.

6. Microwave systems

All the above refer to the optical region of the spectrum. The microwave region of the spectrum has also been found to be very useful for remote sensing.

Microwave (wavelengths 1 mm to a few cm) sensors can measure through cloud cover and some rain—a very great advantage over the optical systems. Microwave responses are functions of the frequency (or wavelength), *polarisation* and look-angles. Polarisation is often used as a discriminant in the microwave region because microwave detection antennas are easily built with a single polarisation direction. The geometry of radar range measurement encourages the use of observational angles well away from the vertical and produce significant shadow effects, thereby revealing orographic features better than normal optical pictures.

Active microwave sensors provide their own illumination, while passive systems measure radiation originating from the scene, and not necessarily dependent on scattered sunlight as the optical sensors do.

The field is comparatively recent, but is developing rapidly. It is felt that microwave systems may be found to be more suitable in the Indian conditions of weather and small-size land holdings, than in the developed countries of the middle latitudes. But we shall not go into great details.

7. Data processing

Processing the data received through remote sensors for obtaining information operationally useful in the various disciplines like agriculture, forestry, hydrology, geology, oceanography, etc., is a colossal task. It is one thing to say that they can be processed, but quite a different thing to have them processed expeditiously to be useful for operational *i.e.* decision-making, processes. And when the information is not available in time for making decisions or even for short-term planning, the value of the information to the Governments who pay for collection of data by remote sensing systems, comes down considerably.

Hence it is essential that we should lay greater emphasis on information processing than information gathering. However sophistcated, information gathering is demonstrable engineering and therefore easily appreciated. It is not sufficient to have the final output of data processing as a hard copy imagery similar to a photographic print. The print has to be further interpreted.

7. Conclusions

As stated earlier, availability of a good x-ray picture of the chest of a patient is not

Table 1. A brief summary of remote sensor systems

Sensor	Spectral region	Remarks
Cameras (single & multiband) with conventional black and white and colour films	400–700 nm (visible)	
Cameras (single & multiband) with infra-red black and white and false colour films	600–900 nm	
Infrared radiometers (bolometers)	Thermal 1 R 2.4 to 14 μm (total radiation)	Imagery obtained by scanning techniques.
Scanning spectrometers	Narrow special regions in the visible, near ultraviolet and near infra-red.	Imagery can be produced.
Solid state detectors Single detectors Linear arrays Matrices	1 μm to 1 mm Scanners	Air-borne and space-borne systems Imagery can be produced.
Scanners with photomultipliers Image orthicons Vidicons Return beam vidicons		Air borne and space-borne systems Imagery can be produced.
Microwave radiometers	1 mm to 80 cm	All weather passive systems Imagery produced.
Side-looking airborne radars (SLAR)	1 mm to 80 cm	All weather active systems. Imagery can be produced.
Lidar (laser radar)	400–1100 nm	Monochromatic active systems for measuring atmospheric aerosols

Table 2. Important characteristics of some infrared detectors

Detector material	Operating mode	Useful wave-length range (μm)	Wavelength of peak response. (μm)	Time const. (μs)	D* in cm $Hz^{1/2}$ w^{-1} at indicated frequency (in Hz)
Operation at room temperature					
Lead sulphide (PbS)	PC	0·6–3·0	2·3–2·7	50–500	$1–7 \times 10^8$ (800)
Indium arsenide (InAs)	PV	1–3·7	3·2	1	$1–3 \times 10^8$ (900)
Operation at 195°K					
Lead sulphide (PbS)	PC	0·5–3·3	2·6	800–4000	$0·7–7 \times 10^9$ (800)
Indium antimonide (InSb)	PC	0·5–6·5	5·1	1	1×10^9 (800)
Operation at 77°K					
Lead sulphide (PbS)	PC	0·7–3·8	2·9	500–3000	$3–8 \times 10^9$ (800)
Indium antimonide (InSb)	PC	0·7–5·9	5·3	1–10	$3–10 \times 10^9$ (800)
Mercury cadmium telluride (HgCdTe)	PV	6–15	10·6	0·01	$10^9–10^{10}$ (900)
Operation below 50°K					
Mercury-doped germanium (Ge:Hg) 30°K	PC	3–14	1	1	$3–9 \times 10^9$ (900)
Copper-doped germanium (Ge:Cu) 4·2°K	PC	6–29	23	1	$5–10 \times 10^9$ (1800)

D* is the inverse of the noise equivalent power of a detector of unit area and frequency band width one Hz.

Table 3. Examples of the use of remote sensing

Area	Applications	Wavelengths employed
Agriculture and Forestry	Plant diseases and insect infestation	0·4–0·9 μ and 6–10 μ
	Natural vegetation, crop and fresh inventories	—do—
	Soil moisture content	0·4–0·8 μ and 3–100 mm (radar)
	Study of arable and non-arable lands	0·4–0·9 μ
	Assessment of plant growth and vigour for forecasting crop yield	0·4–0·9 μ
	Soil type and characteristics	0·4–1·0 μ
Hydrology	Glaciers, snow cover, ice accumulations and their changes	0·4–0·7 μ and 3–100 mm (radar)
	Flood control and water management	0·4–1·0 μ and 6–12 μ
	Surface water inventories	0·4–1·0 μ and 6–12 μ
	Seepage of underground water along river streams and sea coasts	6–12 μ
	Location of water wasting weeds	0·4–0·9 μ
Geology	Out-crops and mineral mapping	
	Fault lines and plate tectonics	0·4–1·0 μ, 7–12 μ and 3–100 mm (radar)
	Detection of structural features associated with hidden mineral deposits including petroleum	—do—
	Soil and rock types and conditions favourable for hidden mineral deposits	0·4–1·0 μ and 7–12 μ
	Detection of iodine gas associated with oil source rocks	0·4–0·5 μ
	Geothermal mapping	3–12 μ
	Detection of vegetation affected by mineral content of soil	0·4–0·5 μ
Cartography & Geography	Topographic mapping	0·4–1·0 μ, 7–12 μ and 3–100 mm (radar)
	Study of urban areas and areas of development	—do—
	Mapping of rivers, lakes etc.	0·4–1·0 μ and 7–12 μ
	Delineation of wet lands (marshes etc.)	0·4–1·0 μ, 2–5 μ and 3–100 mm (radar)
Environmental control	Monitoring of atmospheric pollution	0·4–12 μ
	Monitoring of sea water pollution	0·4–1·0 μ and 7–12 μ
	Study of aquatic eco-systems	0·4–1·0 μ and 7–12 μ
	Study of terrestrial eco-systems	0·3–12 μ and 3–100 mm (radar)
Oceanography	Wave-heights and thence winds	3–100 mm (radar)
	Surface temperatures and thence: Location of schools of fish; Estimation of ocean currents; Estimation of evaporation; Forecast of cyclone development	6–12 μ
	Water colour tones and thence: Coastal underwater topography; Water pollution; Estimation of biomass; Location of schools of fish etc.	0·4–1·0 μ
	Wave refraction and thence bottom topography	0·4–0·7 μ and 3–100 mm (radar)
	Oil slicks of petroleum origin or fish origin	0·4–0·7 μ
	Chlorophyll concentration (algae, plankton)	0·4–1·0 μ

sufficient. Its interpretation as to whether there is a tubercular patch or a cancerous patch or an enlarged heart, requires medical specialists. A novice in medicine can at best recognise a broken rib in the picture. The interpretation of the hard copy image of a terrestrial or oceanographic scene requires several experts, experts in different disciplines—agriculture, forestry, geology, hydrology, oceanography etc.

References

ASP 1975 *The manual of remote sensing* (Am. Soc. Photogrammetry) p. 75

Wolf 1965 *The handbook of military infrared technology*, Office of Naval Research, Dept. of Navy, Washington DC