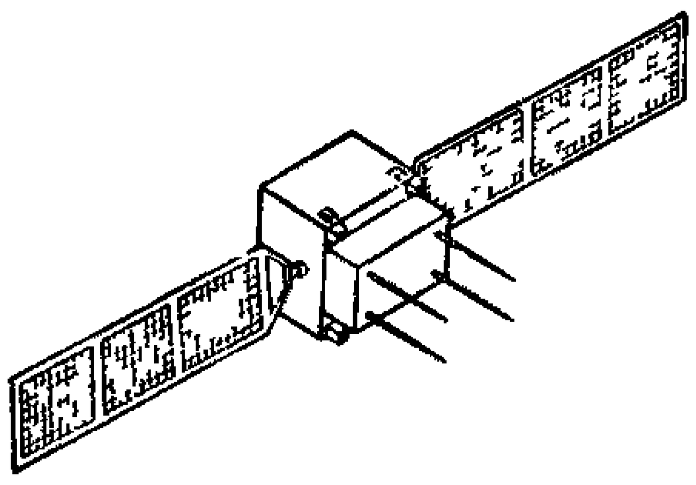

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Science of Remote Sensing

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ABSTRACT: *Remote Sensing is the science of deriving information about an object from measurements made at a distance from the object, and without the sensor actually coming into contact with it. The observation is made on the reflected/scattered or self-emitted electromagnetic energy from the earth in different wavelength bands. The reflectance/emittance pattern under different spectral/polarisation/temporal, etc., conditions provides signatures specific to a land cover class, which forms the basis for data interpretation. The paper describes the basic principles involved in remote sensing.*

INTRODUCTION

Remote Sensing is a multi-disciplinary activity which deals with the inventory, monitoring and assessment of natural resources through the analysis of data obtained by observations from a remote platform. In other words, Remote Sensing is the science of deriving information about an object from measurements made at a distance from the object without actually coming in contact with it. The observations are synoptic, provide repetitive coverage of large areas and the data is quantifiable. In this context, any force field-gravity, magnetic or electromagnetic could be used for remote sensing, covering various disciplines from astronomy to laboratory testing of materials. However, currently the term remote sensing is used more commonly to denote identification of earth features by detecting the characteristic electromagnetic radiation that is reflected/emitted by the earth's surface. Every object reflects/scatters a portion of the electromagnetic energy incident on it depending on its physical properties. In addition, objects emit radiation depending on their temperature and emissivity. The reflectance/emittance of any object at different wavelengths follows a pattern which is characteristic of that object, known as 'spectral signature'. Proper interpretation of the spectral signature leads to the identification of the object.

If the observation is made based on the electromagnetic radiation from the sun or the self emitted radiance, it is called passive remote sensing. It is also possible to produce electromagnetic radiation of a specific wavelength or band of wavelengths to illuminate the terrain. The interaction of this radiation can then be studied by sensing the scattered radiance from the target. This is called active remote sensing.

The different stages in Remote Sensing are:

- Origin of electromagnetic energy (sun, transmitter carried by the sensor).
- Transmission of energy from the source to the surface of the earth and its interaction with the intervening atmosphere.
- Interaction of energy with the earth's surface (reflection/absorption/transmission) or self-emission.
- Transmission of the reflected/emitted energy to the remote sensor placed on a suitable platform.
- Detection of the energy by the sensor converting it into photographic image or electrical output.
- Transmission/recording of the sensor output.
- Preprocessing of the data for generation of the data products.
- Collection of Ground Truth and other collateral information.
- Data processing and interpretation.

Thus, the remote sensing system consists of a sensor to collect the radiation, and a platform, which can be satellite, rocket, aircraft, balloon, automobiles or even a ground-based stand on which a sensor can be mounted. The information received by the sensor is suitably manipulated and transported back to the earth – may be telemetered as in the case of unmanned spacecraft, or brought back through films, magnetic tapes, etc., as in aircraft or manned-spacecraft systems. The data are reformatted and processed on the ground to produce either photographs, or computer compatible magnetic tapes (CCTs). The photographs/CCTs are interpreted visually/digitally to produce thematic maps and other resources information.

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 thermal IR (3 to 5 μm and 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. The maximum radiation occurs around 0.55 μm which is in the visible region. However, the solar radiation reaching the surface of earth is modified by the atmospheric effects. All bodies at temperatures above zero degrees absolute emit electromagnetic radiation at different wavelengths,as per Planck's Law. The earth can be treated as a blackbody at 300 K emitting electromagnetic radiation with a peak emission at around 9.7 μm. Figure 1 shows the spectral distribution of reflected solar and self-emitted thermal radiation. 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.

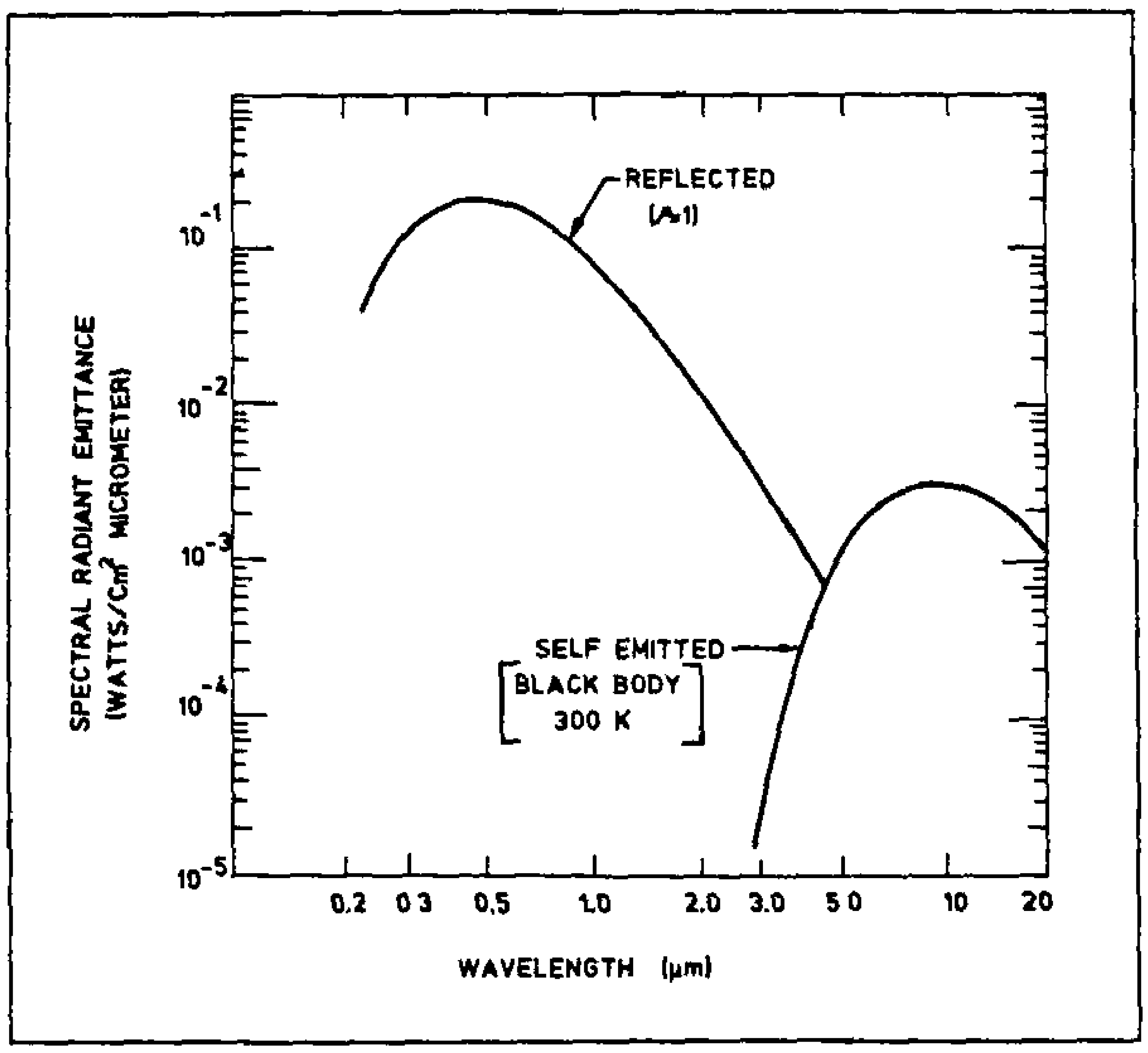

Figure 1. Energy available for remote sensing (atmospheric absorption not considered and microwave regions not shown).

Atmospheric Effects

In passing through the atmosphere, electromagnetic radiation is scattered and absorbed by gases and particulates. The strongest absorption occurs at wavelengths shorter than 0.3 μm primarily due to ozone. On the other hand, certain spectral regions of the electromagnetic radiation pass through the atmosphere without much attenuation. These are called atmospheric windows (Figure 2). Remote

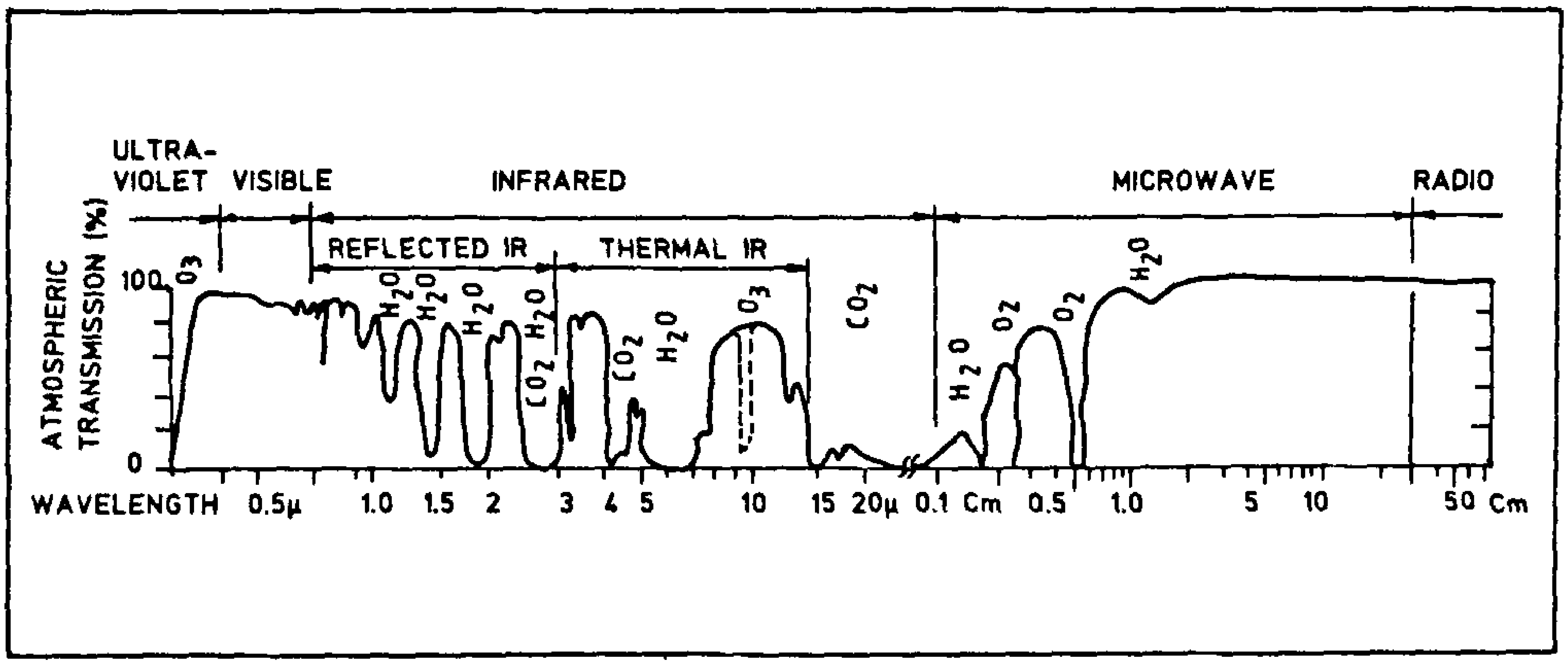

Figure 2. Atmospheric windows, gases responsible for absorption are indicated (adapted from [7]).

sensing of the earth's surface is generally confined to these wavelength regions, which 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 regions of atmospheric windows, the scattering by the atmospheric constituents produce spatial redistribution of energy. There are three scattering mechanisms, namely Rayleigh scattering, Mie scattering and non-selective scattering. When the diameter of the scattering particles is significantly less than the wavelength of radiation, the scattering is inversely proportional to the fourth power of wavelength (Rayleigh scattering). Because of this, information collected in blue band is most affected. Non-selective scattering occurs when the scattering particle size is much larger than the wavelength. This phenomenon is independent of wavelength and occurs when the atmosphere is heavily dust laden. White appearance of scattering from fogs caused due to large diameter of water particles is an example of this kind. In case of Mie scattering, the amount of scattering is a varying function of wavelength. Mie scattering leads to general degradation of multispectral images under conditions of heavy atmospheric haze. The scattered/diffused radiance reaching the sensor field of view, other than that from the target of interest, is called path radiance. The path radiance reduces the image contrast, and thereby the visual sharpness of the image is reduced. In addition, it produces radiometric error, since the information characteristic to target is corrupted. Thus, the apparent radiance of the ground targets, as measured by a remote sensor, differs from the intrinsic surface radiance because of the intervening atmosphere. Since the aerosol concentration in the atmosphere varies with position and time, the amount of correction to be applied also varies. In principle, the added radiance could be removed if the concentration and optical properties of aerosol are known throughout the image. A number of methodologies have been developed to provide at least approximate corrections[1,2].

The atmosphere including haze and clouds, is much more transparent to microwave than to optical and infrared region. Hence, microwave remote sensing using active sensors like Side Looking Airborne Radar (SLAR), Synthetic Aperture Radar (SAR), etc., have an all-weather capability. However, emission from atmosphere can affect the brightness temperatures of the elements of the target, even in the microwave region. It is worth mentioning that the atmospheric absorption can be advantageously used to derive information on atmospheric constituents and the vertical temperature profile.

Interaction of Radiation with Matter

The electromagnetic radiation when incident on the earth, either gets reflected, absorbed, reradiated or transmitted through the material depending upon the nature of the object and the wavelength. When the surface is smooth compared to the wavelength of the 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 reflection. 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 leads to the identification of an object and/or its condition is termed signature. Spectral, spatial, temporal and polarisation 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. Colour of objects is a manifestation of spectral variation in reflectance in the visible region.

Spatial arrangements of terrain features providing attributes, such as shape, size and texture of objects which lead to their identification 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 to distinguish crops which may have similar spectral reflectances, but whose growing cycles may not be the same. A plot of spectral reflectance *vs* growth-stages of a crop provides a phenologic pattern, which is characteristic of a crop, even at the species level. Therefore, remote sensing data acquired over the same area at different times can make use of the temporal characteristics to discriminate them in a better way.

Polarisation variations relate to the changes in the polarisation of the radiation reflected or emitted by an object. The degree of polarisation is a characteristic of the object and hence can help in distinguishing the object. Such observations 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.

SPECTRAL RESPONSE OF SOME NATURAL EARTH SURFACE FEATURES

Vegetation

The spectral reflectance of vegetation (Figure 3) 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. In the near infrared, there is high (45%) reflectance, transmittance of similar magnitude and absorptance of only about five to ten per cent. This is essentially controlled by the internal cellular structure of the leaves. As the leaves grow, inter-cellular air spaces and the reflectance increases markedly. As vegetation becomes stressed or senescent, chlorophyll absorption decreases and red reflectance increases, accompanied by decrease in inter-cellular air spaces. This results in decreased 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[3].

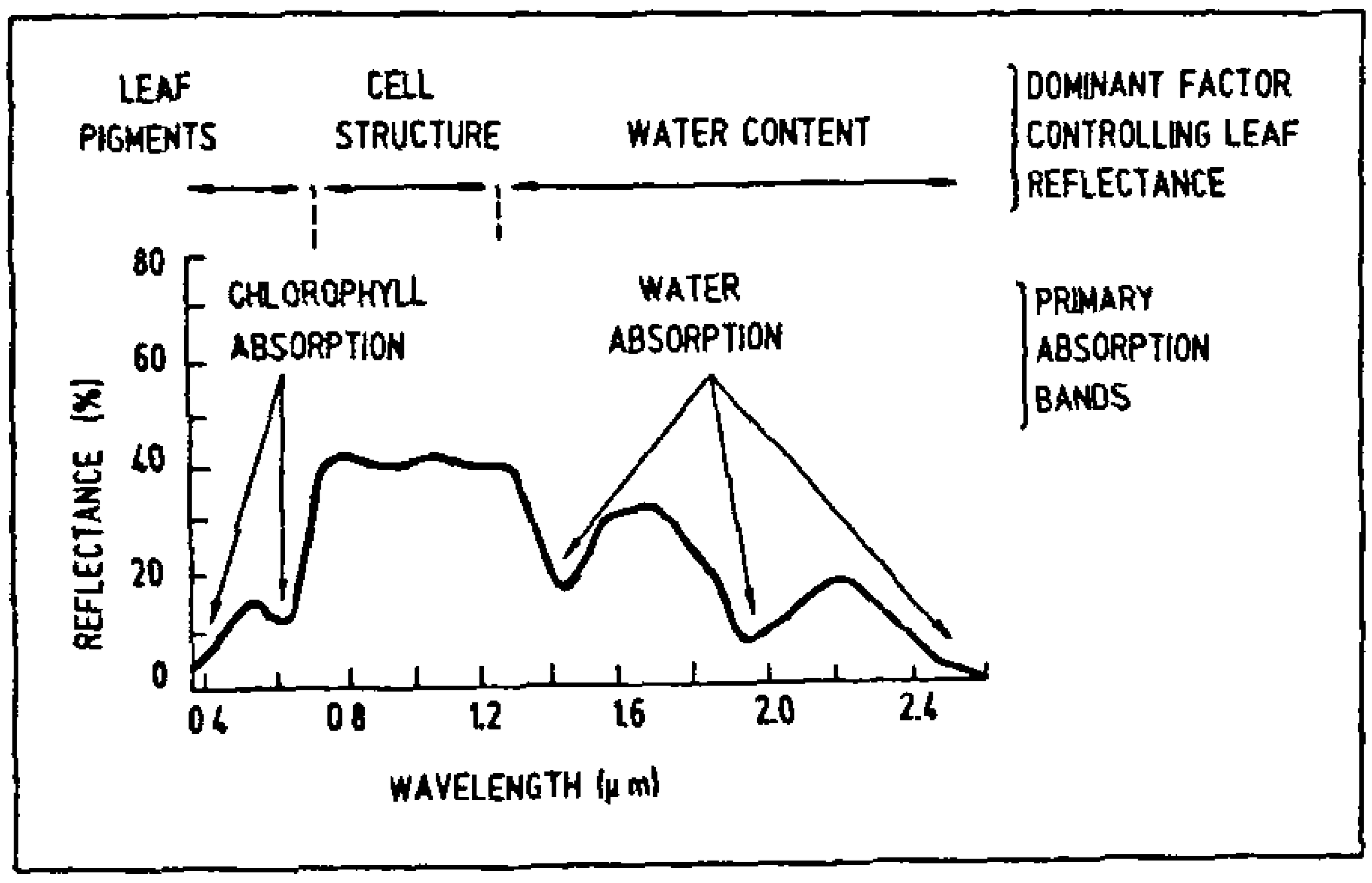

Figure 3. Typical vegetation reflectance spectrum (adapted from [8]).

Soil

Typical soil reflectance curve shows a generally increasing trend with wavelength in the visible and near infrared regions. Some of the parameters which influence soil reflectance are the moisture content, the amount of organic matter, iron oxide, relative percentages of clay, silt and sand, and the roughness of the soil surface. As the moisture content of the soil increases, the reflectance in the optical IR region decreases; 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.

Water

Water absorbs most of the radiation in the near infrared and middle infrared regions. This property enables easy delineation of even small water bodies. Turbidity in water generally leads to an 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 change in the spectral response of water.

Snow and Clouds

Snow has a very high reflectance up to 0.8 µm and then decreases rapidly afterwards. In case of clouds, there is non-selective scattering, which makes them appear uniformly bright throughout the range of 0.3 to 3 µm. The cloud tops and snow generally have the same temperature and hence it is not easily possible to separate these in the thermal infrared region. For these reasons, the two atmospheric windows in the middle infrared wavelength regions (around 1.6 and 2.2 µm) are important for snow cloud discrimination.

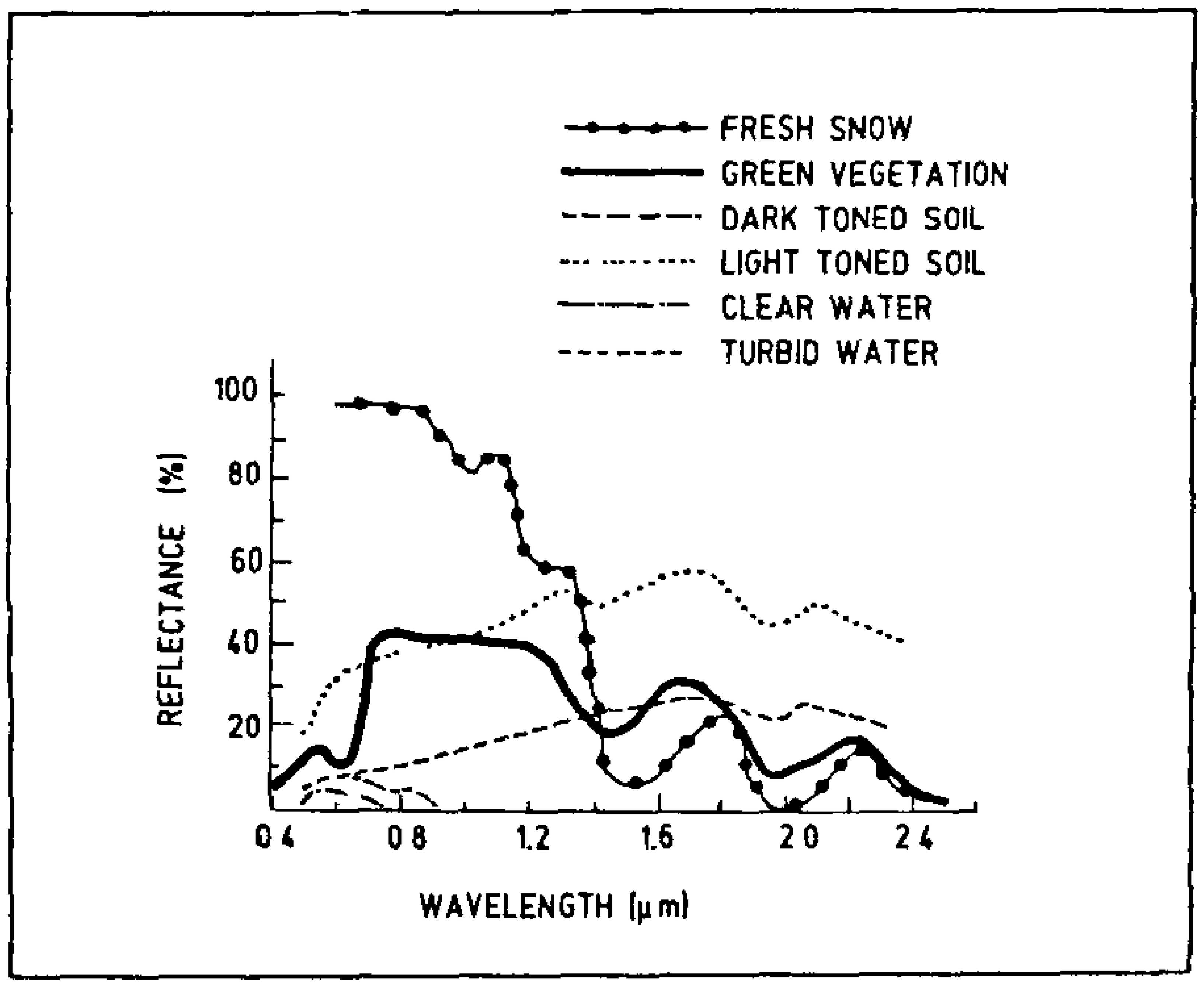

Figure 4. Comparison of reflectance spectra of a few land covers (adapted from [9]).

Typical spectral responses of vegetation, soil, water, and snow are given in figure 4.

DATA PRODUCTS GENERATION

The data acquired by a sensor invariably suffers from a number of errors. These errors occur due to various reasons, such as (i) imaging characteristics of the sensor, (ii) stability and orbit characteristics of the platform, (iii) scene surface characteristics, (iv) motion of the earth, and (v) atmospheric effects. Preprocessing is carried out to correct these errors to the maximum extent so that the inherent quality of the original information of the scene (such as geometry, radiometry and information content) is brought out in an optimal way. The outputs of the preprocessing, which are available in standardised formats, either in photographic or digital are known as data products.

Preprocessing is carried out for (i) eliminating geometric distortion in the imagery, (ii) eliminating radiometric distortion in the imagery, and (iii) enhancing the contrast in the data so that certain features of interest come out best in the photograph. Normally, standard data products in digital form are generated by applying geometric and radiometric corrections only; leaving the enhancement to application scientists.

The procedures employed for geometric correction generally treat distortions in two groups, viz. those which are systematic (or predictable) and those which are essentially random. Systematic errors are corrected by applying formulas derived by mathematical modelling of the expected distortions. A typical example of systematic distortions is the correction required for earth rotation. Earth rotation correction is applied on line scan images (for optomechanical and LISS type of sensors). The satellite images the earth in its south bound pass in the case of descending node acquisition. The image is made up of individual scan lines and since the earth is rotating from west to east, each successive scan line has thus to be displaced westward to correct for the relative motion between the satellite and the earth. The effect of this correction is to skew the image. Other systematic distortions include the earth curvature, deviations from nominal altitude and attitude, variation of the above deviations during the imaging of a scene, etc. Random errors arise from the uncertainty in the measurement/estimation of these parameters and modelling limitations. Geometric distortions, if left uncorrected, result in relative positional distortion over the scene as well as absolute positional errors in latitude and longitude. To a first approximation these distortions can be corrected from the measured/estimated parameters leaving the random errors uncorrected. The correction process proceeds by first defining the transformation equations, which relate the corrected image co-ordinates to the uncorrected data, using the different error models and measured system parameters. The transformation equations are then applied to a selected grid of points over the scene. For the remaining points interpolation is carried out. As the transformation results in fractional scanline/pixel values in the uncorrected data, a resampling procedure is adopted to determine the gray values at these locations.

Radiometric distortion arises due to nonlinearity of the detector response, responsivity variation between the detectors, radiation pattern of antenna line and pixel drop outs. Correction factors for sensor related radiometric errors are normally generated by extensive calibration measurements during laboratory tests. When inflight calibration techniques are employed, such information is also used for correcting post launch sensor degradation, if any. When more than one detector is used for a band, which is usually the case (6 detectors for Landsat MSS, 2048 detector elements for IRS LISS CCDs), and if the response of the detectors is not normalised by radiometric correction, one finds stripes on the image.

Image enhancement is a radiometric transformation on the pixels to enhance visual discrimination of low contrast image features. For this, the first step is to generate an image histogram, which describes statistical distribution of grey levels in an image in terms of the number of pixels comprising each grey level. One simple way to increase contrast is to expand the original grey level to fill the total dynamic range of the recording/display system. This may be achieved by substracting a bias grey value and then increasing the grey level range with a gain factor, or by 'saturating' the lower and upper extreme of the grey values and expanding the middle range. There are a number of other linear/non-linear transformation techniques. Such enhancements are useful only for visual analysis and generally there is no advantage for digital classification.

Standard data products are generated from the corrected and formatted data by photowriting to produce photographic products in the form of black and white or colour transparencies or prints of different bands or combination of bands. Enlargements are generated to provide images at a specific usable scale. Digital information is provided in specific formats in computer compatible tapes. The products generated will have other auxiliary information required for data interpretation, such as longitude and latitude marks, sun azimuth and elevation, date of acquisition and other relevant sensor related information.

DATA ANALYSIS

The two major methods of data analysis for extracting resource-related information from data products, either independently or in some combination with other collateral information, are visual interpretation and digital image processing techniques.

Visual Analysis

Traditionally, visual interpretation methods have been followed for extracting information on various natural resources. Tone/colour, texture, shadow, shape, size, etc. and their association are some of the basic image characteristics on which visual interpretation is based. Some of the advantages of this approach are (i) familiarity of the users with aerial photo-interpretation, (ii) images depicting the scene as though one is observing the area from a point at high altitude, and (iii) the display of spatial relations among surface features are in the same context as in maps. However, visual interpretation techniques suffer from some shortcomings. The range of grey values recorded on a film or print is limited; the number of colour tones recognised by the human brain is quite large but still limited. The interpreter is likely to be subjective in discerning subtle differences in tones. It is difficult to be quantitative. It is also difficult to achieve precise registration of multi-band and multi-temporal images.

Digital Techniques

In digital classification the computer analyses the spectral signature so as to associate each pixel with a particular feature of imagery. The reflectance value measured by a sensor for the same feature, say wheat field, will not be identical for all pixels, such response variation within a class is to be expected for any earth surface cover due to various reasons. Therefore, the radiance value for a class will have a mean and a variance. Figure 5 shows a two dimensional plot of radiance in two wavelengths for three classes, viz., for wheat, mustard and corn. This is called feature space. If we use n spectral bands we get n dimensional feature space. One finds a natural clustering of classes in three groups indicating the signature differences. When the clusters corresponding to different ground covers are distinct, it is easy to associate localised regions of the feature space with specific ground covers. However, such distinct clustering does not always happen in real life situations, and there could be some data set, which is not as obvious as others about which class it belongs. The digital classification technique essentially partitions this feature space in some fashion so that each pixel in the feature space can be uniquely associated with one of the classes. The decision to classify a pixel into any particular class from a set of data, as mentioned earlier, is a statistically intelligent 'guess', which has some associated probability of error. Several classification algorithms have been developed in an attempt to minimise this error[6].

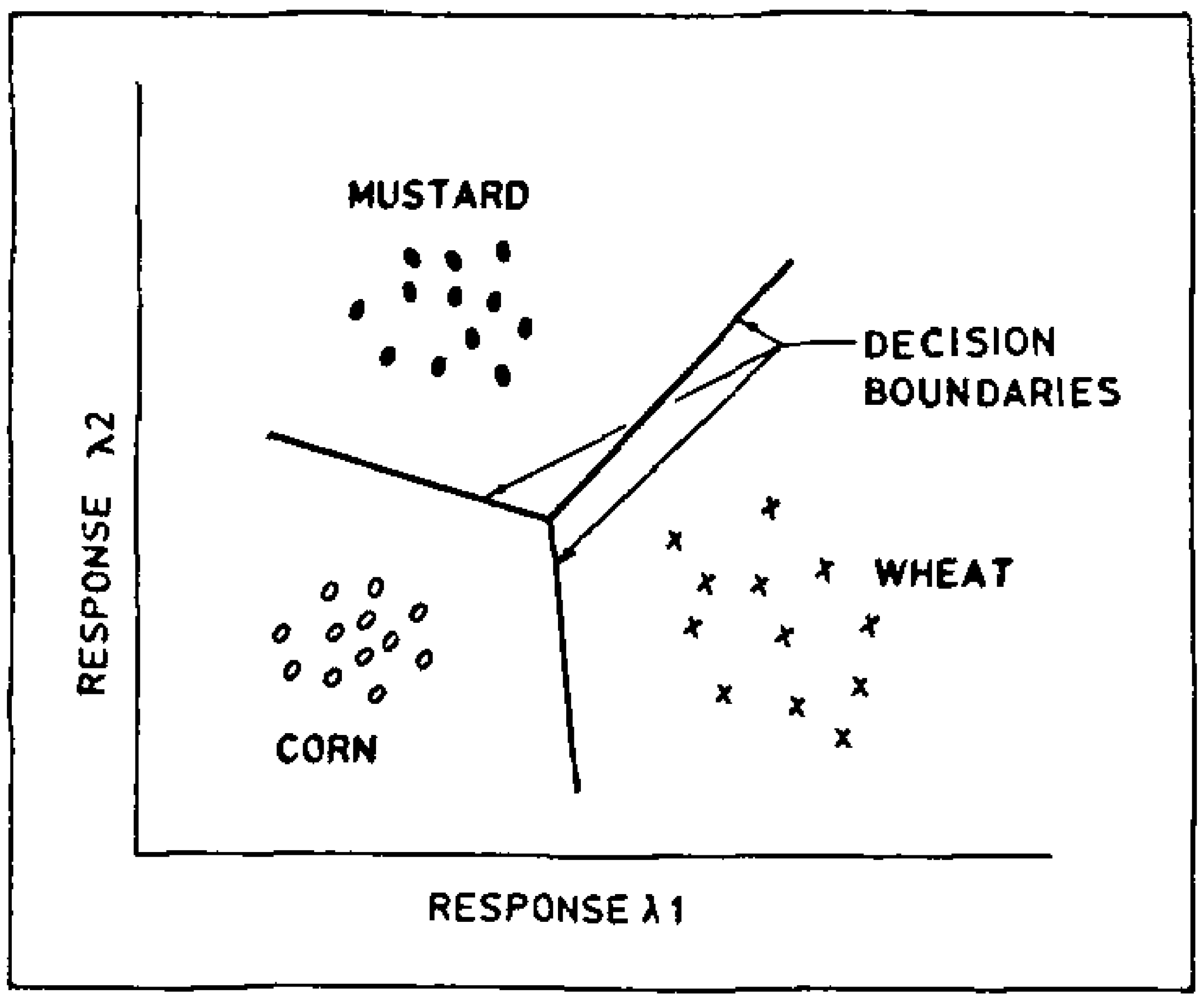

Figure 5. Two dimensional feature space (adapted from [9]).

The digital classification techniques used can be broadly categorised into (i) supervised classifier, and (ii) unsupervised classifier. In supervised classification, the analyst locates specific sites in the remotely sensed data (based on field work, analysis of aerial data, etc.) that represent homogeneous examples of various classes (like agriculture, forest, waterbody, etc.). These areas are termed as 'training sites' because the spectral characteristics of these known areas are used to 'train' the classification algorithm. For each training site, the statistical parameters like mean, variance-covariance matrix, etc. are generated, which are used in any one of a number of different classification algorithms to decide which category an unknown pixel belongs to. Each pixel is then labelled with the name of the category it resembles, or labelled "unclassified" if it is not similar to any category. If the training sites are not properly selected, the number of misclassified/unclassified pixels increases. An output image data set is then generated using the category label assigned to each pixel. Thus, the multidimensional input image is used to develop a corresponding classified image of interpreted category types.

In contrast to this procedure, unsupervised classification is based on the exploitation of the inherent tendency of different classes to form separate spectral clusters in the feature space. Unsupervised classification uses algorithms that search for natural groupings of the spectral properties of the pixels. The computer selects the class means and covariance matrix to be used in the classification. Once the data is classified into clusters each cluster is then associated with a physical category.

One of the computationally simple classifier is the minimum distance to means classification algorithm. Here the analyst provides the mean vectors in each class using the training sites. Each unknown pixel with a feature vector x is assigned to that class whose mean vector is close to x. The distance to each mean vector from each unknown pixel can be calculated using Euclidian distance. This technique though simple, has poor accuracy especially when the variance of the features are quite different and large.

Gaussian Maximum Likelihood (MXL) is one of the more commonly used supervised classifiers. Basic assumption made in this case is that the training data of any class is normally distributed. Under this assumption, the distribution of grey values of a given category can be completely described by the mean vector and the covariance matrix. Statistical probability of any given pixel being a member of a particular category is computed using these parameters. Evaluation of the probabilities of each pixel leads to assigning it to the class that has the maximum probability value. The pixel is said to be unclassified if the probability values are all below a threshold set by the analyst. The maximum likelihood classifier is computation intensive, since probability of a pixel belonging to each of the defined categories has to be computed.

Concluding remarks

Remote sensing for resources survey encompasses various disciplines of Science and Engineering. This paper has touched only a very small fraction of the various scientific principles employed in remote sensing. The advancement of remote sensing requires enhancement in the capabilities of sensors and computer processing. With higher spatial and spectral resolution, the data rate from sensors is steeply increasing, which is a challenge to the sensor designer as well as to the communication engineer. The analysis of such large volumes of data requires powerful computer systems and efficient data processing algorithm and software. The application scientists also need to reorient with new techniques and methodologies to handle a variety of data sets that will be available from the future satellites.

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