Chapter 1
Basics of Remote Sensing

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1.1 Introduction

In July 1972 the first earth observation satellite was launched by the United States. In 1972 this satellite was called Earth Resources Technology Satellite-1 (ERTS-1), a name that held until January 1975 when it was renamed into Landsat-1. This first earth observation satellite held a four waveband multi-spectral scanning system (MSS) aboard in two visible and two near-infrared spectral bands and three return beam vidicon (RBV) television cameras. This sensor wrote history as it proved to be of great importance to give remote sensing worldwide recognition as an important environmental technique (Harper, 1983).

Remote sensing refers to obtaining information about objects or areas by using electromagnetic radiation (light) without being in direct contact with the object or area. So, remote sensing is day-to-day business for people. Reading the newspaper, watching cars driving in front of you, looking at a lecturer during classes are all remote sensing activities of the human eye. The human eyes register the solar light reflected by these objects and your brains interpret the colours, the grey tones and intensity variations. Next, these data are translated into useful information. The human eye however is limited to a small part of the total electromagnetic spectrum i.e. approximately 400 to 700 nm. In remote sensing various kinds of tools and devices are used to make electromagnetic radiation outside this range visible to the human eye, especially the near infrared, middle infrared, thermal infrared and microwaves. Remote sensing now plays an important role in a wide range of environmental disciplines such as geography, geology, zoology, agriculture, forestry, botany, meteorology, oceanography and civil engineering.

Since that first launch of an earth observation satellite remote sensing is increasingly used to acquire information about environmental processes such as agricultural crops, land cover, vegetation dynamics, water quality, urban growth, seabed topography etc. Remote sensing helped us to increase our understanding of the ecological system of the earth. Remote sensing helped us to measure the size of the ozone hole in the atmosphere, to notice the differences of atmospheric ozone concentrations between the southern and northern hemisphere and to understand the dynamics of ozone concentration in the atmosphere. Remote sensing is playing a key role in our efforts to understand the complex dynamics of ocean circulation such as El Niño, El Niña and the NAO: the Northern Atlantic Oscillation and to assess their effects on global and regional climates and extreme events. Long-term remote sensing observations of the Sahel region made us at least partly understand the complex cyclic pattern

S.M. de Jong and F.D. van der Meer (eds.),
Remote Sensing Image Analysis: Including the Spatial Domain, 1–15.

of the advancing and withdrawing Sahara desert. The European Union is successfully using Earth observation images collected throughout the growing season of crops to control their subsidies on agricultural crops. Remote sensing is used in precision agriculture practices to follow crop development and to detect water or nutrient deficits. Remote sensing is used to collect information necessary for the maintenance of forests and to monitor nature reserves. Next, there is of course the role of remote sensing in our society as an instrument enabling us to monitor the activities of neighbouring, and maybe hostile states as shown during the first and the second gulf wares in the middle east.

1.2 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. Other people all over the world soon followed his example. 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. Although the space era of remote sensing was still far away after the Civil war, already in 1891 patents were granted in Germany to successful designs of rockets with imaging systems under the title: 'new or improved apparatus for obtaining bird's eye photographic views of the earth'. The design comprised a rocket propelled camera system that was recovered by a parachute. Table 1.1, modified from Campbell, 1996) shows a few important dates in the development of remote sensing.

The next period of fast developments in earth observation took place in Europe and not in the United States. It was during World War I that airplanes were used on a large scale for photoreconnaissance. Aircrafts proved to be more reliable and more stable platforms for earth observations 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 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 war efforts (Lillesand & Kiefer, 2000; Colwell, 1983; Harper, 1983). Colour infrared photography (CIR) 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. Two types of radar were developed at that time: SLAR: side-looking airborne radar and SAR: Synthetic Aperture Radar. Either development aimed at the acquisition of images at the highest possible resolution. Crucial to the SAR development was the ability to finely resolve the Doppler frequencies using a frequency analyses algorithm on the returning radar signal by the US Air Force research centre.

In the early 1960s the US started placing remote sensors in space for weather observation and later for land observations. TIROS (Television Infrared Observation Satellite) was the first meteorological satellite. A long series of meteorological satellites followed this one. 1960 was also the beginning of a famous US military space imaging reconnaissance program called Corona (McDonald, 1995). Unfortunately, much of this programme remained classified until 1995. In 1970 the TIROS programme was renamed into NOAA (National Oceanic and Atmospheric Administration). Until today the NOAA Advanced Very High Resolution Radiometer (AVHRR) is orbiting the globe and collecting information on weather patterns in visible, near infrared and thermal wavelengths. NOAA-17 was launched on June 24, 2002. The 1950s and 1960s were also important for the organisational development of remote sensing. Various civil research organisations and universities became highly interested in these new technologies. This resulted in the start of various professional organisations and the publishing of remote sensing journals such as the IEEE Transactions on Geoscience and Remote Sensing, International Journal of Remote Sensing, Remote Sensing of Environment and Photogrammetric Engineering & Remote Sensing. Today remote sensing is not only taught at the university level but also at high schools.

In the early 70s the first satellite specifically designed to collect data of the earth's surface and its resources was developed and launched: ERTS-1 Earth Resources Technology Satellite. Later, in 1975, this programme was renamed into Landsat. This first earth resources satellite was in fact a modified Nimbus weather satellite carrying two types of sensors: a four waveband multi-spectral scanner (MSS) and three return beam vidicon television cameras (RBV). The sensors aboard this satellite proved to be able to collect high quality images at a reasonable spatial resolution. These images gave remote sensing a worldwide recognition as a valuable technology. The main advantages recognized at that time were (Curran, 1985): ready availability of images for most of the world, lack of political, security and copyright restrictions, low cost, repetitive multi-spectral coverage and minimal image distortion.
Landsat 2 and 3 were launched in 1975 and 1978, respectively, and carried the same payload as the first satellite of this series. The payload was changed in 1982 with Landsat 4. The technically more advanced Thematic Mapper (TM) sensor replaced the RBV. An improved design of the TM, the ETM+ (Enhanced Thematic Mapper) was mounted aboard Landsat 7 and launched in 1999. The Landsat series is a very successful programme, various MSS and TM sensors exceeded by far its design life time and its imagery is probably the most widely used data in the Earth sciences. One black spot on its history record is the 'failure upon launch' of Landsat 6 in 1993.

Various other successful earth observation missions carried out by other countries followed the Landsat programme. In 1978 the French government decided to develop their own earth observation programme. This programme resulted in the launch of the first SPOT satellite in 1986. To the original SPOT design of three spectral bands a new sensor called Vegetation was added aboard SPOT-4 in 1998. Other earth observation missions are the Indian Remote Sensing Programme (IRS) started in 1988, the Russian Resurs series first launched in 1985 and the Japanese ADEOS (Advanced Earth Observing Satellite) put in orbit in 1996. The European Space Agency (ESA) launched its first remote sensing satellite, ERS-1, in the year 1991. ERS carries various types of sensors aboard among which the AMI, a C-band (5 cm radar) active microwave instrument. The main focus of the ERS programme is oceanographic applications although it is also widely used for monitoring tropical forests. In 1995 ERS-2 was successfully launched. In March 2002 ESA launched Envisat-1, an earth observation satellite with an impressive payload of 13 instruments such as a synthetic aperture radar (ASAR) and a Medium Resolution Imaging Spectrometer (MERIS). An important recent development is the launch of high-resolution earth observation systems such as IKONOS and QuickBird. These systems have multi-spectral systems collecting information in 4 bands (blue, green, red and near-infrared) at a spatial resolution of 4 meters or better. IKONOS has also a panchromatic mode (0.45-0.90 μm) with a spatial resolution of 1 m. With IKONOS, QuickBird and similar systems, space borne remote sensing approaches the quality of airborne photography.

Table 1.1 – Milestones in the history of remote sensing (modified from Campbell, 1996).

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
1971	Launch of Landsat-1 (ERTS-1): MSS sensor
1972-	Rapid Advances in digital image processing
1978	Launch of Seasat (first spaceborne L-band radar)
1982	Launch of Landsat-4: new Generation of Landsat sensors TM
1986	French Commercial Earth Observation Satelliet SPOT
1986	Development Hyperspectral Sensors
1990-	Development High Resolution Spaceborne Systems
	First Commercial Developments in Remote Sensing
1991	Launch of the first European Remote Sensing Satellite ERS1 (active radar)
1998	Towards Cheap One-Goal Satellite Missions
1999	Launch of EOS-TERRA: NASA Earth Observing Mission
1999	Launch of IKONOS, very high spatial resolution sensor system
2001	Launch of Landsat-7 with new ETM+ sensor
2001	Launch of QuickBird, very high spatial resolution sensor system
2002	Launch of ESA's Envisat with 10 advanced instruments

1.3 Concepts of Remote Sensing

Remote sensing, also called earth observation, refers in a general sense to the instrumentation, techniques and methods used to observe, or sense, the surface of the earth, usually by the formation of an image in a position, stationary or mobile, at a certain distance remote from that surface (after Buiten & Clevers, 1993). In remote sensing electromagnetic radiation coming from an object, in case of earth observation this object is the earth's surface, is being measured and translated into information about the object or into processes related to the object. In the former measurement phase the following components are relevant:

- the source of the electromagnetic radiance
- the path through the atmosphere
- the interaction with the object
- the recording of the radiation by a sensor.

These comprise the remote sensing system as illustrated in figure 1.1. The second phase can be considered to cover the following components:

- transmission, reception and (pre)processing of the recorded radiance
- interpretation and analysis of the remote sensing data
- creation of the final product.

The individual components will be briefly described in the next sections.

1.3.1 Sources of electromagnetic radiation

In remote sensing we restrict ourselves to the use of electromagnetic radiation as a characteristic of numerous physical processes. All materials with a temperature above 0K have the power to emit electromagnetic energy. Objects on or near the earth's surface are able to reflect or scatter incident electromagnetic radiation emitted by a source, which may be artificial, e.g., flash light, laser or microwave radiation, or natural, such as the sun. In the visible, near-infrared (NIR) and middle-infrared (MIR) part of the electromagnetic spectrum, we are measuring solar radiation reflected by objects at the earth's surface. In the thermal-infrared (TIR) part, particularly in the atmospheric window at about 10 μm (see figure 1.2), we are measuring emitted radiation by objects at the earth's surface, be it that this radiation is originating from the sun. In the microwave part of the spectrum, both reflection of solar light and emission occur at very low energy rates. As a result, radiation mostly is transmitted to the earth's surface by an antenna on board the remote sensing system and, subsequently, we measure the amount of radiation that is reflected (backscattered) towards the same antenna. The latter type of system is generally referred to as an active remote sensing system.

1.3.2 The atmosphere

Before solar radiation reaches the earth's surface, the atmosphere will influence it. In addition, the atmosphere will influence reflected solar radiation or emitted radiation by an object at the earth's surface before an airborne or space borne sensor detects it (Van der Meer & De Jong, 2001). The atmosphere consists mainly of molecular nitrogen and oxygen (clean dry air). In addition, it contains water vapour and particles (aerosols) such as dust, soot, water droplets and ice crystals. The changes of the radiation can vary with wavelength, condition of the atmosphere and the solar zenith angle (Slater, 1980). The most important processes here are scattering (Herman et al., 1993) and absorption (LaRocca, 1993). Scattering effects

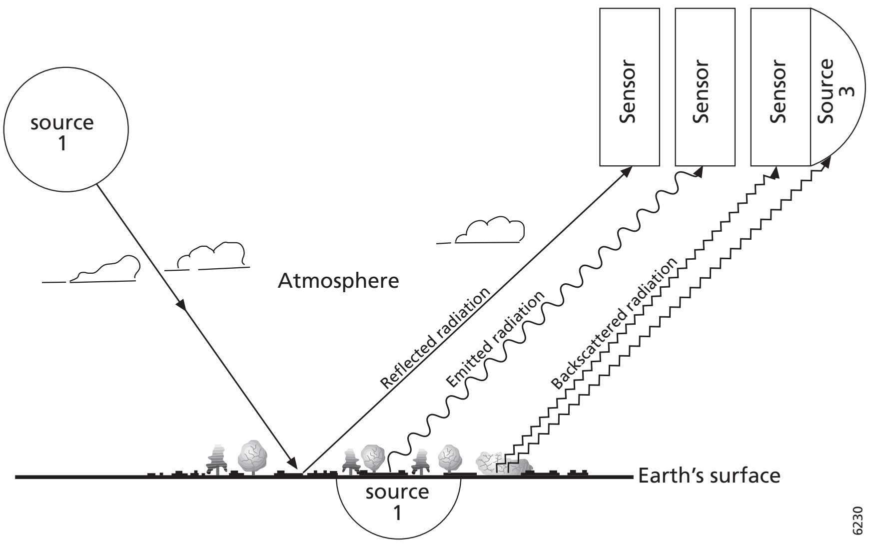

Figure 1.1 – The remote sensing system (modified from Curran, 1985).

can be divided into Rayleigh, Mie and non-selective scattering. These processes lead to the formation of diffuse radiation. A portion of the diffuse radiation goes back to space and a portion reaches the ground. The radiation, which has not been scattered, is called direct radiation. Absorption is caused, for example, by the presence of water vapour in the atmosphere. Scattering and absorption in the atmosphere cause an attenuation of the solar radiation before it reaches the earth's surface. This is illustrated in figure 1.2 for the entire electromagnetic spectrum used for Earth observation techniques. In parts of the electromagnetic spectrum the atmosphere is not or hardly transparent, these parts are not suitable for remote sensing. Those parts of the spectrum where the atmospheric transmittance is high are useful for remote sensing and they are called atmospheric windows. Figure 1.3 illustrates the effects of scattering and absorption in the optical part of the spectrum between 400 and 2500 nm as computed by the atmospheric transmission model Modtran (Wolfe and Zissis, 1993). Most of the absorptions are due to water in figure 1.3. Absorption due to oxygen occurs at 760 nm, carbon dioxide at 2005 and 2055 nm.

1.3.3 Object – radiation interaction

When electromagnetic radiation hits an object at the earth's surface, it can be transmitted, absorbed or reflected. The mutual magnitude of these processes is determined by the properties of the object. In remote sensing we can measure the amount of reflected solar radiation as a function of wavelength, called spectral reflectance. Figure 1.4 illustrates the spectral reflectance of some typical objects. Water absorbs most of the incoming radiation and reflects only a small amount of radiation particularly in the visible part of the spectrum, at longer wavelengths water does not reflect any significant amount of radiation. Soils exhibit quite a smooth spectral reflectance curve. Distinct spectral features are found in narrow spectral bands caused by absorption by minerals and iron oxide and can be detect by imaging spectrometers (Van der Meer and De Jong, 2001). Broader features occur at about 1400 nm

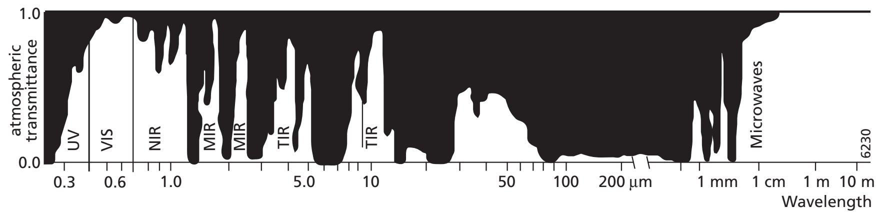

Figure 1.2 – Atmospheric transmittance for radiation as a function of the wavelength (modified from Lillesand and Kiefer, 2000).

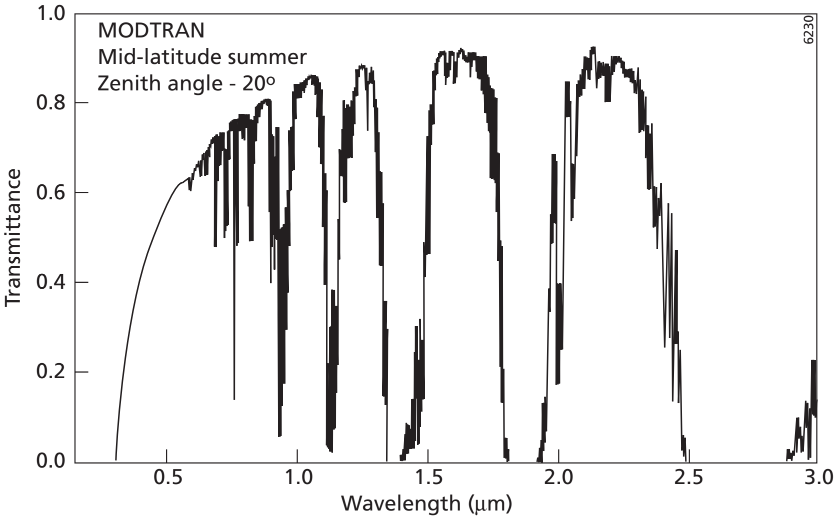

Figure 1.3 – Modtran modelled atmospheric transmittance, visible to near infrared. Most of the absorptions are due to water. Oxygen occurs at 0.76 µm, carbon dioxide at 2.0 and 2.06 µm. (source: http://speclab.cr.usgs.gov/index.html).

and at about 1900 nm, due to absorption by water. The absorption by water also causes the gradually decreasing reflectance with increasing wavelength in the mid-infrared region. The moisture content of the soil causes the spectral reflectance of a wet soil to be lower than that of a dry soil. Vegetation, on the other hand, shows a very characteristic reflectance curve. The reflectance in the visible part of the spectrum is low due to absorption of this radiation by the chlorophyll in the green plant parts. In the NIR region hardly any absorption occurs, and reflectance is determined by the amount of transitions between cell walls and air vacuoles in the leaf tissue. As a result, NIR reflectance of green vegetation is high, and a steep slope occurs in the curve at about 700 nm, the so-called red-edge region (Clevers and Jongschaap, 2001; Kumar et al., 2001). In the MIR region we observe a similar influence of water as observed for soils.

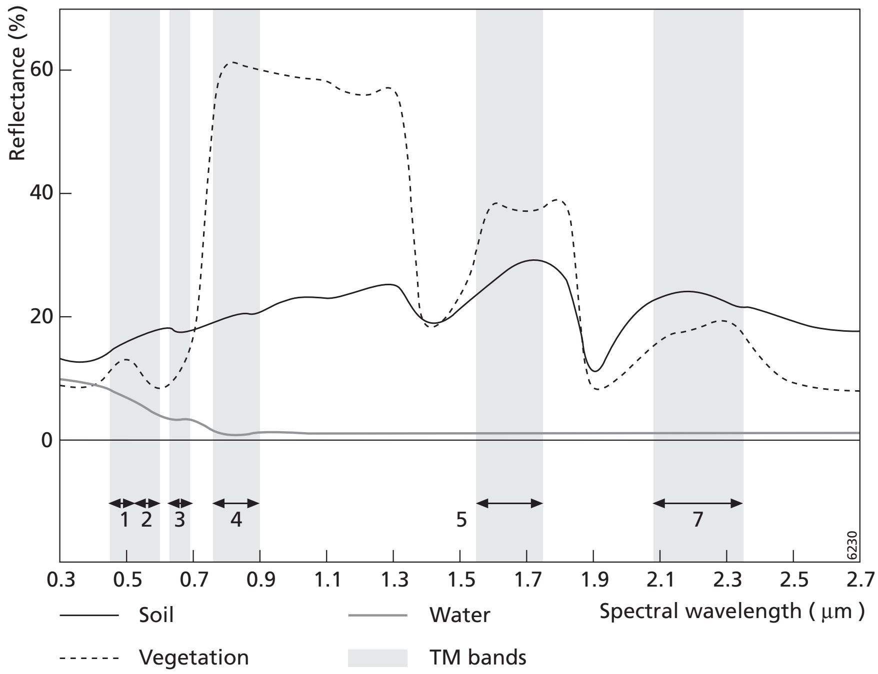

Figure 1.4 – Typical spectral reflectance curves for water, soil and vegetation.

In the thermal infrared part of the spectrum the amount of emitted radiation is measured. This amount can be related to the temperature of the feature observed. This provides information on, e.g., the (evapo)transpiration of the surface and thus gives relevant information for energy balance studies. An important property of the long wavelengths used in the microwave region is that they are not susceptible to atmospheric scattering. As a result they can penetrate through cloud cover, haze and all but the heaviest rainfall. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties of the emitting object. Since the amounts of emitted energy generally are very small, a passive microwave sensor is therefore characterised by a low spatial resolution.

Active microwave sensors provide their own source of illumination. They are called radars and measure the amount of energy scattered back towards the radar antenna. The radar echo is depending on the properties of the radar system like frequency, polarisation and the viewing geometry, and on the properties of the object like the roughness and electrical properties. So, with radar we get information on object properties like the geometry (terrain topography), roughness (height variations in relation to the applied wavelength) and moisture (determining the electrical properties of a soil or vegetation). An in-depth description of microwave remote sensing is given in volume 3 of this book series on 'Remote Sensing and Digital Image Processing' by Kozlov et al. (2001) or can be found in Henderson and Lewis (1998).

1.3.4 Sensors

Instruments capable of measuring electromagnetic radiation are called sensors. They can be classified as follows:

1. Passive sensors do not have their own source of radiation. They are sensitive only to radiation from a natural origin, usually reflected sunlight or the energy emitted by an earthly object. The classical example of a passive imaging sensor is the camera, which records the distribution of radiation from an object on a photosensitive emulsion spread out on a film. Other examples are the multi-spectral scanner, the thermal scanner and the microwave radiometer. Both sensor and object are passive.
2. Active sensors have a built-in source of radiation. The object is passive. Examples are radar (radio detection and ranging) and lidar (light detection and ranging).

Radiation can be recorded in an analogue form, the aerial photograph is a particular example, or radiation can be stored in a digital arrangement, a set of signal values on a magnetic device CD-rom or DVD, as in most remote sensing records at present. Visualized images (pictures) may be derived from digital data of imaging sensors. Before proceeding it is advisable to indicate which properties permit the observation and recognition of an object. 5 Main classes can summarize the many object characteristics:

1 Shape and size of the object; the spatial or geometric resolution is important for the sensor. In general, the size of the pixels (in terrain dimensions) is used as a measure.

2 Reflective and/or emissive properties of the object, the dynamic range and the radiometric resolution are important for the sensor. This dynamic range is defined as the number of digital levels in which the observed reflection or emission can be stored.

3 Spectral properties (wavelength, frequency, colour) of the object, the wavelength or frequency bands and the spectral resolution (i.e. the band width) are important for the sensor.

4 The effects of polarization of the object; the selection of polarization is important for the sensor, viz. (HH) horizontally polarized transmission and reception; (VV) vertical polarization and (HV) or (VH) cross polarization. This applies particularly to the microwave region.

5 Temporal effects (changes in time or location) of the object; the temporal resolution concerning a possible time interval between successive remote sensing surveys of the same region is important for remote sensing.

It is clear that the design and use of remote sensing systems should be preceded by many considerations depending on specific applications.

1.3.5 Transmission, reception and (pre-)processing

The energy recorded by the sensor has to be transmitted, in electronic form, to a receiving and processing station where the data are processed into an image (digital and/or hardcopy). Generally, the provider of the image data will already apply some pre-processing. Pre-processing operations are intended to correct for sensor- and platform-specific radiometric and geometric distortions of data. Radiometric corrections may be necessary due to variations in scene illumination and viewing geometry, atmospheric conditions, and sensor noise and response. Each of these will vary depending on the specific sensor and platform used to acquire the data and the conditions during data acquisition. Also, it may be desirable to convert and/or calibrate the data to known (absolute) radiation or reflectance units to facilitate comparison between data.

1.3.6 Image analysis and interpretation

The outstanding advantage of digital recordings is that numerous manipulations can be applied to the observational data according to the methods of digital image processing and pattern recognition. A very extended set of algorithms can be applied in an automatic way by using one of the various software packages for image analysis that are on the market. In principle, three categories of information can be derived from remote sensing:

1. The assignment of class labels to the individual pixels or objects in an image, called classification creating, e.g., a thematic land cover map;
2. The estimation of object properties from remote sensing e.g. assessing the amount of biomass of agricultural crops or forest types;
3. The monitoring of the thematic class labels named under 1) or the object properties named under 2) over time.

Observing, for example, the properties of vegetation, one has to pay attention to numerous variables. Examples of these are the irradiance, the direction of the radiation source, the condition of the atmosphere and its influence on the detected radiation, the presence of surrounding objects, the viewing angle of the sensor and, last but not least, the variations pertinent to the vegetation such as growing stage, moisture content, leaf area index, number of leaf layers and soil background. In summary, information about the earth's surface and its features may be obtained from images by detection on the basis of:

- Spectral characteristics (wavelength or frequency, reflective or emissive properties);
- Spatial characteristics (viewing angle of the sensor, shape and size of the object, position, Site, distribution, texture);
- Temporal characteristics (changes in time and position);
- Polarization characteristics (object effects in relation to the polarization conditions of the transmitter and receiver).

These information-extraction algorithms can generally only be applied to earth observation images when the images are radiometrically processed i.e. converted from raw digital numbers into physical units such as radiance or reflectance. Such correction should account for sensor characteristics, terrain topography and atmospheric conditions. Details about radiometric processing can be found in Van der Meer et al. (2001). Furthermore, images must be geometrically corrected for the effects of scanner distortions of the image, orbital geometry and figure of the earth. Details on methods for geocoding and distortion correction are given in Schowengerdt (1997).

1.3.7 The final product

The output from remote sensing can be in various forms and often is information that is used as input for further analysis, e.g. in a geographical information system (GIS). On the one hand, information present in a GIS can help in the analysis and interpretation of remote sensing data. On the other hand, the results of a remote sensing analysis can be stored in a GIS. Subsequently, this information can be combined with other types of information for various types of studies or applications. As an example, a land cover map can be considered as an 'end product' of a remote sensing analysis. It can be used as input in a study towards groundwater pollution by combining it with various spatial and statistical data.

1.4 The chapters in this book

Conventionally used spectral classification methods of remote sensing images work on a pixel-by-pixel basis and ignore the useful spatial information surrounding the pixel. In this book we bring together a range of new and advanced image analysis methods aiming at quantitatively capturing that spatial information in earth observation images and use it effectively for applications such as land cover mapping, natural vegetation survey, soil mineral mapping, hydrocarbon seepage mapping and urban issues. In chapter 1 the basic concepts of remote sensing and the historic developments are briefly presented. The quintessence of the other chapters is briefly presented below. We are aware that there is some kind of overlap between a number of chapters, especially with respect to the basics of geostatistics and the basics of earth observation. We believe that this small degree of overlap is not harmful to the contents of the book but will allow the reader to consult the chapters individually.

Chapter 2 starts by presenting and discussing traditional approaches in geography, ecology, hydrology, geology and other disciplines of handling spatial variability in their mapping and surveying efforts of complex natural landscapes. Basic forms of earth observation such as black and white aerial photographs have played an important role in these mapping efforts since they were available. Next, we look at how sensors register reflected radiance from the earth surface and how the pixels, regularized or gridded sampling of the landscape, are imperfect capturings of the natural patterns that occur in the surrounding landscape. We then review a number of statistical and geostatistical models and how they can help us to quantitatively characterize spatial structures.

In chapter 3 Foody put emphasis on the fact that pure pixels in remote sensing images do not exist and hence, a pixel will never represent a single thematic class complicating the production of accurate land cover maps. Recognizing the fact that each remote sensing image has a certain degree of mixed pixels, methods are required to analyse images at the sub-pixel level. Foody reviews two methods to estimate sub-pixel composition, the linear mixture model and the soft or sub-pixel classification method. Next he identifies a number of current and future research topics such as the extraction of sub-pixel scale thematic information using support vector machines.

In chapter 4 Atkinson presents an overview of the meaning of terms such as spatial resolution, pixel size, up- and downscaling. Next the issue of scale, support and pixel size, spatial resolution and spatial extent is considered followed by an outline of geostatistics. Variograms, variogram models and kriging are summarized. Furthermore, Atkinson discusses a number of methods for downscaling i.e. increasing the spatial resolution of an already acquired data set and hence providing a representation of the data set at finer spatial resolution (super-resolution). Various methods for super-resolution mapping are presented such as sub-pixel classification, the Hopfield neural network approach and a pixel swapping method. The concepts and ideas presented in this chapter form a good basis for the later chapters in the book dealing with related techniques, methods and practical applications.

In chapter 5 Hay and Marceau presents a new and advanced multiscale approach for landscape analysis MOSA. MOSA stands for Multiscale Object-Specific Analysis. Hay and

Marceau claim that it is now widely recognized that landscapes are complex systems that are characterized by a large number of heterogeneous spatial components, non-linear interactions, emergence, self-organization, adaptation through time, and scale multiplicity. The later property refers to the fact that landscapes exhibit distinctive spatial patterns associated to different processes at different scales. Since there is no way of defining a priori what are the appropriate scales associated to specific patterns, and because there is a need to derive adequate rules for transferring information through multiple scales, it is imperative to develop a multiscale approach that allows dominant patterns to emerge at their characteristic scales of expression. In this chapter Multiscale Object-Specific Analysis (MOSA) is described as a multiscale approach for landscape analysis that has been developed for the particular spatial sampling context of remote sensing data where each pixel is considered as part of an image-object. This approach reduces the effect of the modifiable area unit problem (MAUP) and explicitly takes into account the hierarchical organization of the landscape. MOSA represents an integration of Object-Specific Analysis (OSA), Object-Specific Up scaling (OSU) and Marker-Controlled Segmentation (MCS) that allows for the generation of data at a range of scales from which objects can be detected, and for the delineation of individual objects as they emerge and evolve through scale. In chapter 5, a detailed description of MOSA is given, provide new information on the OSA kernel, and discuss improved methods for using MCS as a feature detector. This is followed by an application using an IKONOS-2 (Geo) dataset acquired over a highly fragmented agro-forested landscape in southwest Quebec, Canada.

In chapter 6 Chica-Olmo and Abarca-Hernández present texture-based and variogram-based methods to analyse and express quantitatively the spatial properties of remotely sensed imagery. Texture is a feature that has received great attention in image processing particularly in remote sensing applications. Valuable information can be extracted from textural analysis, about the spatial arrangement of the objects, thematic classes, in the image and their relationship with the environment. From a geostatistical point of view, diverse procedures can be developed for textural analysis of images. All of them use the variogram function as a powerful tool to analyse the spatial variability of digital values. This vector function locally represents the spatial variance of the data within a window and, consequently, can serve as an operator to create texture images calculated at a local level. The variogram offers wide possibilities to calculate textural operators or measures, on the basis of the different uni- or cross variant variogram estimators. In such cases, the measures are calculated for specific lag distances in a local neighbourhood, obtaining as the final result a set of geostatistical texture images. A second case analysed is the joint use of the variogram function with the well-known geostatistical estimation method of kriging through cross validation. The validation or experimental errors obtained in moving windows offer another interesting way to derive textural images. In an applied context, this textural information concerning the geostatistical analysis of the image, added to the spectral bands, plays an important role as contextual information for classifying remotely sensed images, in order to increase digital classification accuracy. A geological example to map important classes for mineral prospecting in South-east Spain is given.

In chapter 7 Berberoglu and Curran present the use of traditional land cover classifiers such as the maximum likelihood approach and the use of artificial neural networks to classify remotely sensed images. Next they provide a thorough overview of methods how to assess texture from images by first and second order statistics, by geostatistics i.e. various types of variograms and by fractals and they discuss the pros and cons of a pixel-based classification versus a per-field approach. The previously discussed methods are applied to an IKONOS image of a study area located on the Cukurova plain in Turkey. This case study illustrates a method how to integrate spectral and spatial information captured by an image in two different classification methods: the widely used maximum likelihood approach and artificial neural networks. The increase of classification accuracy is presented and discussed together with the pros and cons of the various texture measures.

In chapter 8 Gong and Xu review the use of contextual information for urban areas and they stress the importance of contextual approaches to characterize spatial structural differences in high spatial resolution images of urban regions. Contextual spatial approaches are not only useful for panchromatic images but can also successfully be applied to multi-spectral data. Gong and Xu introduce the frequency-based contextual classifier (FBC). FBC creates frequency tables of pixel values in neighbouring cells within a kernel and assigns these values to the centre pixel. An important advantage is that frequency tables contain more spatial information than first-order statistical measures such as mean and standard deviation. The choice of the window size is crucial for the successful application of FBC. Example applications to a multi-spectral SPOT image, a CASI image and samples of an IKONOS image are presented and discussed.

In chapter 9 Van der Meer presents a geological application of a contextual image analysis method on hyperspectral HyMap imagery of the Cuprite dataset in Nevada by producing images of spectral absorption band parameters. Van der Meer describes that spectral reflectance in the visible and near infrared offers a rapid and inexpensive technique for determining the mineralogy of samples and obtaining information on chemical composition. Absorption-band parameters such as the position, depth, width, and asymmetry of the feature have been used to quantitatively estimate composition of samples from hyperspectral field and laboratory reflectance data. The parameters have also been used to develop mapping methods for the analysis of hyperspectral image data. This has resulted in techniques providing surface mineralogical information (e.g., classification) using absorption-band depth and position. However no attempt has been made to prepare images of the absorption-band parameters. A simple linear interpolation technique is proposed in order to derive absorption-band position, depth and asymmetry from hyperspectral image data. AVIRIS data acquired in 1995 over the Cuprite mining area (Nevada, US) are used to demonstrate the technique and to interpret the data in terms of the known alteration phases characterizing the area. Next we turn to look at stratified approaches. It is demonstrated that vegetation indices, red edge index and carter stress indices are highly correlated with lithology as shown in the analysis of Probe (HyMap) data from Santa Barbara (CA). This area is renown for oil and gas seeps. The analysis is a statistical data integration leading to mapping of oil and gas seeps from the relation between vegetation anomalies, soil mineralogical anomalies and the lithology. The last part of the chapter is devoted to contextual analysis. Here we introduce data inversion techniques that incorporate geologic prior knowledge. An example is shown on Hymap data from a sedimentary sequence. We exploit the systematic facies changes to outperform standard mapping approaches.

In chapter 10 Scholte, Gacía-Haro and Kemper presents a special case of spectral mixture analysis of imagery: the variable multiple endmember spectral mixture analysis for mapping heavy metal contamination of soils and for mapping mud volcanism. Spectral mixture analysis is a widely used method to determine the sub-pixel abundance of vegetation, soils and other spectrally distinct materials that fundamentally contribute to the spectral signal of mixed pixels. Spectral unmixing techniques strive at finding partial least squares solutions to the (linear) mixing of spectral components in order to derive fractional abundance estimates of selected endmembers. The Variable Multiple Endmember Spectral Mixture Analysis (VMESMA) is an integrated image analysis method that extends the possibilities of multiple endmember spectral unmixing allowing variable endmember sets for different parts of an image and standardization of the data prior to unmixing. VMESMA is based on a zonal partition of the area and a zone-dependent choice of multiple candidate submodels and unmixing algorithms, each valid within a scene sub-area. By formalising knowledge of the application domain into a simple scene model, the spatial relationships between the pixels can be used to meet the user requirements. In this chapter the current state of VMESMA is discussed in terms of geologic applications such as the mapping and monitoring of residual heavy metal contamination after the Aznalcóllar mining accident in Spain and mud volcanism associated with petroleum system properties in oil mud ejecta in Azerbaijan.

In chapter 11 Van der Werff and Lucieer presents the use of hyperspectral remote sensing to detect hydrocarbon seeps at the earth surface. These seeps or leakage areas of subsurface reservoirs manifest themselves by discoloured alterations zones or by harmful effects on vegetation. The spectral differences between the spectra of the seepages and the spectra of their background and surroundings are very small. As a result the seepage areas are difficult to identify. However, the seepage areas generally have specific spatial shapes such as a halo shape or an oval shape, either around a central vent. Van der Werff and Lucieer has developed an algorithm to detect specific halo-shape spatial patterns and to determine whether the spectra in these shapes are spectrally anomalous from other image parts. The algorithm is tested on simulated images produced by using spectra of oil seeps in California. Results are promising but future work is necessary to include more spatial shapes and spectra in the algorithm.

In chapter 12 Blaschke, Burnett and Pekkarinen introduce methods to work with image segmentation and objects in an image. Especially the new generation of sensors acquiring very high spatial resolution images provide new opportunities to identify objects, groups of pixels in an image that has a meaning in the real world or to apply image segmentation methods that match ecological mapping units used in the field. In this chapter the various types and methods of image segmentation are reviewed and the authors touch upon multi-scale approaches such as multi-fractal approach. In the second part of this chapter examples are given how image segmentation approaches and object-oriented classification can be used in forest stand mapping.

In chapter 13 Carvalho, Acerbi, Fonseca, Clevers and De Jong present the use of wavelets for multi-scale image analysis. Wavelets are tools that allow us to analyze datasets over various levels of scale and in different directions by de-composing the images into details at different resolutions. In this chapter the concept of the use of wavelets for remote sensing imagery is introduced and compared with other types of filtering and spatial analysis. The decomposed images allow us to study the hierarchy of spatial information captured by a specific image or to study temporal variations at different levels of scale in time series of images. Next, the chapter provides a brief overview of applications of wavelets in remote sensing together with a reference overview. In the second part of the chapter various case studies are presented and discussed. The case studies comprise an example of the use of wavelets for image registration, a comparison of methods for feature extraction from images aiming at the fusion of images available at different spatial resolution and an application for change detection.

In chapter 14 Fuller, Smith and Thomson presents the operational use of contextual analyses of remotely sensed images for the production of land cover maps of the United Kingdom at a regular basis. This chapter examines the use of contextual procedures in pre-processing, classification and post-classification phases to produce national land cover maps from remotely sensed images. It looks first at the fairly simple contextual corrections by using kernels of variable size applied to the raster format Land Cover Map of Great Britain (LCMGB), made in 1990. It then examines the use of a geographical information system (GIS) in producing the Land Cover Map 2000 (LCM2000), an update and upgrade of the LCMGB. LCM2000 used image-segmentation and segment-based classification, wherein all pixels were classified in context. In addition around 12% of parcels required contextually based corrections to increase map accuracy. Finally, about 15% of parcels used external contextual data to extend the basic thematic classification to meet wider user needs. Contextual analyses were thus essential to the entire LCM2000 production process, controlling map structure, improving accuracy and adding thematic detail.

In chapter 15 Sluiter, De Jong, Van der Kwast and Walstra present a re-classification method called SPARK: spatial re-classification kernel. The conceptual idea behind SPARK is that the land use types of interest can be characterised by the spatial arrangement and the size of the objects in the image. These land cover types may include complex natural areas or irregular urban areas. In this chapter emphasis is put on Mediterranean types of shrub vegetation. The SPARK method starts by using a land cover map produced by any type of spectral classifier. Next spatial-based decision rules are defined using known local, spatial patterns of objects in heterogeneous and homogeneous land use types. These decision rules are then used to refine the initial classification. The SPARK concept is described in detail and a case study from an area in southern France is presented to illustrate the classification improvements and the effect of various kernel sizes. The results from SPARK differ from one vegetation type to another but most significant classification improvements are achieved for the open and complex shrub type of vegetation for kernel sizes of 3 by 3 and 5 by 5. One important conclusion is that SPARK successful identifies vegetation classes that are not distinguished at all by conventional classifiers.

The figures and graphs in this book were all reproduced in black and white to save costs. The CD-Rom enclosed in the book provides all the colour plates arranged by chapter.