Remote Sensing and GIS

3rd Edition

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PREFACE TO THE THIRD EDITION

Given the high demand for the revision of *Remote Sensing and GIS* from teachers and students community, I am presenting the third edition after working on it for almost two years and having accommodated all the fundamentals and some advanced topics.

Additional material and colour illustrations have been moved to online platform—'Oxford Areal'. I am sure this new edition will be accepted widely by the teacher and student community as the earlier editions. The CD has been discontinued in this edition as the software PCI Geomatica has lost its popularity and it can now be downloaded from their website.

NEW TO THE THIRD EDITION

The book has been revised to keep the practical aspects in mind. Several changes have been made to give emphasis on practical applications. This edition:

- Discusses new launches of remote sensing satellites and their sensors (e.g., Landsat-8, Sentinel series, and several others)
- Includes information on UAV (drone) based remote sensing (including practical guide), UAV policy in India
- Describes advancement in GNSS technology (Galileo, BeiDou, NavIC, etc.) with additional details on GNSS signals, and detailed discussion on triangulation and trilateration
- Provides practical guide on surveying
- Helps with selection of appropriate data for a specific application
- Includes deriving surface reflectance from DNs, topographic correction, enhanced accuracy assessment, several DIP flowcharts, and new image indices
- Discusses Geodatabase concept
- Has a new chapter—Chapter 21—to discuss change detection and geosimulation in detail; because change detection is the most frequently performed operation and it embraces many techniques
- Comes with additional theory for the analysis of urban growth
- Includes entirely revised Appendix-B, to accommodate many new mathematical topics
- Offers new exercises in each chapter

CONTENT AND COVERAGE

Divided into two parts the book comprises 21 chapters and two appendices. **Part I** comprises Chapters 1 through 12 that explain remote sensing techniques, its history, ground truth, photogrammetry, visual and digital analysis, remote sensing applications and its 'multi' approaches. This part concentrates principally upon Indian remote sensing satellites, LANDSAT, and where appropriate on SPOT, but also draws upon a variety of sensors operating from land and sea satellites launched by various government and private industries. Most of these observe in the visible, reflective infrared and microwave spectral intervals, but images from several thermal systems are also included as examples of common space data sets.

Part II comprises Chapters 13 through 21 that explain the basics of GIS, spatial and attribute data model, the process of GIS, analysis of geospatial data, planning/ implementation/management of GIS, the modern trends of GIS, and change detection and geosimulation.

The chapterwise details of the text are as follows:

Chapter 1: Concept of Remote Sensing Covers the basic concepts of remote sensing, brief outline of remote sensing process and fundamentals of electromagnetic radiation. It also covers advantages and limitations of remote sensing.

Chapter 2: Types of Remote Sensing and Sensor Characteristics Provides an in-depth explanation of sensor resolutions, geometry, and orbital characteristics. It also includes classification of remote sensing (from multiple perspectives); their respective advantages and limitations. Orbital characteristics of satellite have been explained in the light of Keplerian motion and Newton's law of gravitation. A brief description of remote sensing satellite with appropriate line diagram will help the students to understand its functionality.

Chapter 3: History of Remote Sensing and Indian Space Program Talks about the developmental history of remote sensing and the Indian space program. It also includes new Indian launches since January 2008.

Chapter 4: Photographic Imaging Deals with the photographic imaging techniques and allied matters such as camera, filter, and film. It also includes sections on film size, film resolution, geometry of aerial photograph, and scale of photograph.

Chapter 5: Digital Imaging Describes digital imaging techniques in the ultraviolet through infrared region of electromagnetic spectrum with detail of related sensors. This chapter clarifies the concepts of framing and scanning system, spectrometer, and spectroradiometer. It covers a series of robust remote sensing satellites (GeoEye-1, WorldView-1, Cartosat-2A/2B/3, Oceansat-2, Landsat-8, Resourcesat-2/2A, Sentinel series, HysI WorldView-2,3, 4) and their sensors have been described. Thermal remote sensing has been explained thoroughly (radiant versus kinetic temperature, Stefan-Boltzmann law, Wien's displacement law, temperature mapping). LiDAR is discussed in detail with various illustrations.

Chapter 6: Microwave Remote Sensing Introduces microwave remote sensing and related matters. Various illustrations and mathematical equations make the discussions more comprehensive, especially resolution of real aperture radar and synthetic aperture radar. It has a separate section that compares airborne radar and space-borne radar. Discussion on Satellite RISAT-1/2B is also included.

Chapter 7: Ground-Truth Data and Global Navigation Satellite System Describes ground truth data and GNSS in detail. Includes IRNSS satellites (1A, 1B, 1C, 1D, 1E, 1F, 1G) and signals.

Chapter 8: Photogrammetry Discusses principles of modern digital photogrammetric techniques in detail. Several geometric distortions have been discussed in detail with illustrations. Stereoscopic viewing in analog photogrammetry (lens and mirror stereoscopes) has been included, and radargrammetry has been explained with illustrations.

Chapter 9: Visual Image Interpretation The chapter is aimed to develop visual interpretation skills. It covers all of the interpretation elements for optical, thermal and microwave images with lot of B&W and colour images. It also includes a discussion on marginal information of air photo with illustrations. Interpretation keys have been discussed and a very comprehensive interpretation table has been furnished for LISS sensors. Influence of antenna pattern on radar imagery has also been covered.

Chapter 10: Digital Image Processing It covers many pre-processing, enhancement, transformation, and classification techniques. Includes elaborated discussion on Sun angle and topographic corrections, top of atmosphere and surface reflectance, addresses practical aspects, and covers indices (e.g., hydrothermal composite, normalized difference built-up index, normalized burn index, normalized difference infrared index, etc.). It covers unsupervised and supervised classification, and subpixel classification. The accuracy assessment section discusses Kappa statistics and rule-based rationality evaluation. It also explains sample size determination, reference plot size determination, sampling method, etc.

Chapter 11: Data Integration, Analysis, and Presentation Includes remote sensing data integration with ground truth and other ancillary data, and integration of transformed data. Process of remote sensing data analysis has also been discussed. This chapter also adds some important issues like level of detail for data analysis, and limitations of remote sensing data analysis.

Chapter 12: Applications of Remote Sensing Describes the applications of remote sensing. It has been tried to accomplish this by presenting a very large number of remote sensing products as images which are described in a running text that explains their characteristics and utility. It covers applications on land-use/land-cover, agriculture, forestry, geology, urban growth, geomorphology, hydrology, ocean and coastal, mapping applications, and so on. Various illustrations for geological, geomorphological, and urban applications are also shown in this chapter.

Chapter 13: Concept of Geographic Information Systems and **Chapter 14: Functions and Advantages of GIS** Describe the basic concepts of GIS, its functions and advantages over other systems like CADD, conventional DBMS, AM/FM, or other mapping systems. Chapter 13 includes an exclusive section to discuss the distinction among GIS and other related terms.

Chapter 15: Spatial Data Model Discusses spatial data model in detail. It covers several data models, such as, run length encoding, chain encoding, block encoding, quadtree/binary-tree encoding for raster, and spaghetti, vertex dictionary, dual independent map encoding for vector.

Chapter 16: Attribute Data Management and Metadata Concept Provides a clear understanding of attribute data model and its management with a detailed discussion on metadata.

Chapter 17: Process of GIS Sketches the entire process to be followed to prepare a GIS.

Chapter 18: Geospatial Analysis Covers a significant number of geospatial analysis techniques in a very structured manner with appropriate examples and illustrations. It also discusses Geostatistics.

Chapter 19: Planning, Implementation, and Management of GIS Explains how to plan, implement, and manage GI systems.

Chapter 20: Modern Trends of GIS Highlights the modern and future trends of GIS which will essentially impress upon the reader the power and reach of geospatial technology. It includes advancements in WebGIS and also discusses Mobile Mapping.

Chapter 21: Change Detection and Geosimulation Covers change detection and geosimulation in detail with various illustrations.

Appendices are given at the end of the book. **Appendix A** focuses on the basic concepts of map, coordinate system, and projection. **Appendix B** comprises the mathematical topics required to understand digital image processing. These will help the beginners to understand geospatial technology better.

A very rich glossary and bibliography at the end are for the benefit of the students.

Acknowledgements

First of all I would like to express my thanks to those teachers and students who have accepted and popularized this book in the last 13 years. I would like to acknowledge the feedback and suggestions given by many teachers and students to improve the quality of the book.

I express my gratitude to my colleagues for their co-operation. I am also thankful to my wife and daughter who missed me a lot while I was working on this new edition. I am also grateful to Oxford University Press, India for giving me enough time to work on this edition and bringing out the revised edition in a very elegant format.

I would like to add that every effort has been made to contact the copyright holders of the assets used in this title. We, the publishers and I, would be pleased to rectify any omissions in the subsequent editions of this title should they be drawn to our attention.

Any comments and suggestions for further improvement of the book are welcome; please send them at basubhatta@gmail.com.

B. Bhatta

PREFACE TO THE FIRST EDITION

We normally observe the earth from a more or less horizontal viewpoint while living on its surface. From an altitude or from a vertical perspective, our impression of the surface below is notably different. Remote sensing enables us to view the spectral and spatial relations of observable objects and materials at a distance, typically from above, using instruments or sensors. Remote sensing is most often practised from platforms such as airplanes and spacecrafts with onboard sensors that survey and analyse surface features over extended areas unencumbered by the immediate proximity of the neighbourhood. It is a practical, orderly, and cost-effective way of maintaining and updating information about the world around us.

The advancements in computer-based image processing have made robotic and manned platform observations accessible to universities, resource-responsible agencies, environmental companies, and even individuals in their personal computers. Initially, remote sensing was controlled and sponsored by the governments of various countries but recently, commercial vendors have also involved themselves in this emerging field.

Geographical Information System (GIS) is a computer-assisted information management system of geographically referenced data. A GIS differs from conventional computer-assisted mapping and attribute data analysis systems. Although computer-assisted cartographic systems emphasize map production and presentation of spatial data, they cannot analyse spatially defined attribute data. Attribute data analysis systems, on the other hand, analyse aspatial data. A GIS blends these into a more powerful analytical tool. Its proponents highlight its capacity to produce a comprehensive and timely analysis of complex database and its potential to improve data collection, analysis, and presentation process. Today, it is possible to make conventional GIS over the Internet, sharing various data for the use of the whole world. From the perspective of information science, the growing interest in GIS is fascinating.

GIS provides an exceptional means for integrating timely remote sensing data with other spatial and thematic data types. It is a concept that originated in Canada four decades ago, is now being applied by several application sectors as the demand increases for information and analysis on the relationship between people and their environment. Now that many commercially available GIS software packages are becoming increasingly user friendly, and can be run on personal computers, this important tool is being actively explored all over the world for various applications.

Remote sensing and GIS were initially recognized as supporting tools for planning, monitoring, and managing the appropriate utilization of the earth resources. However, due to their multidisciplinary applications and integration with numerous other scientific and technological fields, in the recent years they have become a distinct field of study.

The rapid progress, and increased visibility, of remote sensing and GIS since the 1990s has been made possible by a paradigm shift in computer technology, computer science, and software engineering, as well as airborne and space observation technologies. As a result a new field of study named geomatics engineering or geospatial technology or geoinformatics is now in its maturity. The term 'geoinformatics' is fairly young and is commonly used to define the tools and techniques used inland surveying, remote sensing, GIS, global navigation satellite systems (GNSS), and related forms of the earth mapping.

About the Book

This book begins with the fundamentals of remote sensing and GIS. As readers go through the chapters of this book, they will learn how remote sensing and GIS can be applied for studying the land, sea, air, and biotic communities that comprise our planet's environment.

The first part of this book describes the role of space science and technology for using remote sensing to monitor planetary bodies; while the second part demonstrates the role of information technology to monitor and to manage the earth resources by means of GIS. Not only will readers gain an insight into the applications of remote sensing imagery, they will also develop skills in interpreting these visual displays and data sets by direct inspection and by computer processing. This book provides a clear idea of how remote sensing and GIS can be used to analyse the data and to solve complex management problems. Students will also be able to apply this newly acquired knowledge by doing their own analysis using the software provided in the online resource centre.

Each chapter in the book commences with an introduction, which briefly outlines the topics covered in the chapter, and ends with exercises which help the students to assess their comprehension of the subject matter studied in the chapter. The chapters also contain numerous black and white and colour illustrations that complement the text.

The primary purpose of this book is to be a learning resource for college and university students, as well as for individuals now in the industry who require indoctrination in the basics of remote sensing and GIS. It is hoped that this survey of environmental remote sensing and GIS will attract and inspire a few individuals who might consider a specialized career in this field or in the broader fields allied with Earth System Science (ESS) and the environment.

B. Bhatta

About the Author

Basudeb Bhatta is currently the Course Coordinator of Computer Aided Design Centre, Jadavpur University, Kolkata. A PhD in engineering from Jadavpur University, he has more than 25 years of industrial, teaching, and research experience in remote sensing, GNSS, and GIS. He has published many research papers, monographs, and textbooks in Geoinformatics. He is the life member of several national and international Geoinformatics societies.

Dr Bhatta has been instrumental in initiating a large number of courses on Geoinformatics and related field. He is also attached with several other universities to flourish the Geoinformatics education. He is the person who had introduced first formal Geoinformatics course in the Eastern India from Jadavpur University. Other than Geoinformatics, he also has remarkable contributions in the field of CADD.

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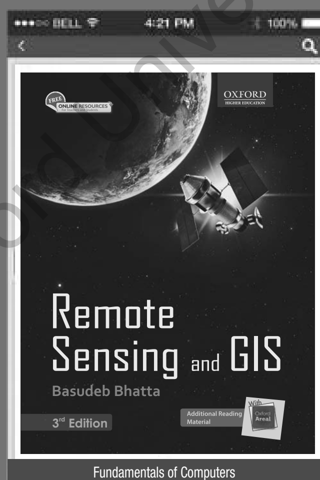

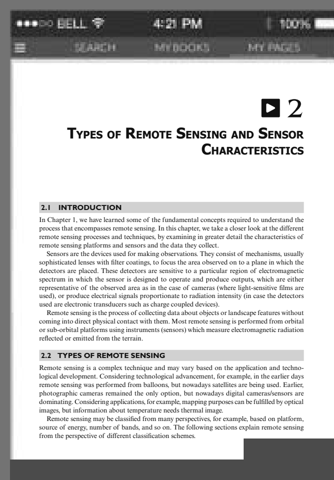

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TYPES OF REMOTE SENSING AND SENSOR CHARACTERISTICS

2.1 INTRODUCTION

In Chapter 1, we have learned some of the fundamental concepts required to understand the process that encompasses remote sensing. In this chapter, we take a closer look at the different remote sensing processes and techniques, by examining in greater detail the characteristics of remote sensing platforms and sensors and the data they collect.

Sensors are the devices used for making observations. They consist of mechanisms, usually sophisticated lenses with filter coatings, to focus the area observed on to a plane in which the detectors are placed. These detectors are sensitive to a particular region of electromagnetic spectrum in which the sensor is designed to operate and produce outputs, which are either representative of the observed area as in the case of cameras (where light-sensitive films are used), or produce electrical signals proportionate to radiation intensity (in case the detectors used are electronic transducers such as charge coupled devices).

Remote sensing is the process of collecting data about objects or landscape features without coming into direct physical contact with them. Most remote sensing is performed from orbital or sub-orbital platforms using instruments (sensors) which measure electromagnetic radiation reflected or emitted from the terrain.

2.2 TYPES OF REMOTE SENSING

Remote sensing is a complex technique and may vary based on the application and technological development. Considering technological advancement, for example, in the earlier days remote sensing was performed from balloons, but nowadays satellites are being used. Earlier, photographic cameras remained the only option, but nowadays digital cameras/sensors are dominating. Considering applications, for example, mapping purposes can be fulfilled by optical images, but information about temperature needs thermal image.

Remote sensing may be classified from many perspectives, for example, based on platform, source of energy, number of bands, and so on. The following sections explain remote sensing from the perspective of different classification schemes.

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- Deriving ToA Radiance and Reflectance for Landsat Sensors

Chapter 11
- Selection of Data for Remote Sensing Researches/Applications

Chapter 12
- Measurement and Analysis of Urban Growth

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Part I

REMOTE SENSING AND IMAGE ANALYSIS

Chapter 1	Concept of Remote Sensing
Chapter 2	Types of Remote Sensing and Sensor Characteristics
Chapter 3	History of Remote Sensing and Indian Space Programme
Chapter 4	Photographic Imaging
Chapter 5	Digital Imaging
Chapter 6	Microwave Remote Sensing
Chapter 7	Ground-Truth Data and Global Positioning System
Chapter 8	Photogrammetry
Chapter 9	Visual Image Interpretation
Chapter 10	Digital Image Processing
Chapter 11	Data Integration, Analysis, and Presentation
Chapter 12	Applications of Remote Sensing

1

Concept of Remote Sensing

1.1 INTRODUCTION

Normally, if one comes across the term *remote sensing*, one wonders 'what does it mean'. 'Remote' means far away, and 'sensing' means believing or observing or acquiring some information. Remote sensing means acquiring information of things from a distance. Of our five senses, we use three as remote sensors when we

(a) watch a cricket match from the stadium (sense of sight)
(b) smell freshly cooked curry in the oven (sense of smell)
(c) hear a telephone ring (sense of hearing)

Then what are our other two senses and why are they not used 'remotely'?

(d) try to feel the smoothness of a desktop (sense of touch)
(e) eat a mango to check the sweetness (sense of taste)

In the last two cases, we are actually touching the object by our organs to collect the information about the object.

In the world of geospatial science, remote sensing, also known as *earth observation*, means observing the earth with sensors from high above its surface. Sensors are like simple cameras except that they not only use visible light but also other bands of the electromagnetic spectrum such as infrared, microwave, and ultraviolet regions. They are so high up that they can take images of a very large area. Nowadays, remote sensing is mainly performed from space using satellites.

1.2 DISTANCE OF REMOTE SENSING

Remote sensing occurs at a distance from the object or area of interest. Remarkably, there is no clear definition about this distance. It could be 1 m, 1,000 m, or greater than 1 million metres from the object or area of interest. In fact, virtually all astronomy is based on remote sensing. Many of the most innovative remote sensing systems, and visual and digital image processing methods were originally developed for remote sensing of extraterrestrial landscapes such as the Moon, Mars, Saturn, and Jupiter (Jensen 2004).

Remote sensing techniques may also be used to analyse inner space. For example, an electron microscope and its associated hardware may be used to obtain photographs of extremely small objects on the skin, in the eye, etc. Similarly, an X-ray device is a remote sensing instrument to examine bones and organs inside the body. In such cases, the distance is less than 1 m.

However, it is important to realize that the term 'remote sensing' is applied in a different sense in case of earth observation. In this instance, remote sensing actually means acquiring information about the features of earth-surface (by using some instruments) without going to the site for which the information is being collected. Instruments are generally placed on aeroplanes and satellites. One can now realize the distance of remote sensing for earth observation, and can distinguish other remote sensing processes from earth observation.

1.3 DEFINITION OF REMOTE SENSING

A formal and comprehensive definition of applied remote sensing, as given by the National Aeronautics and Space Administration (NASA), is as follows:

The acquisition and measurement of data/information on some property(ies) of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature(s) under surveillance; techniques involve amassing knowledge pertinent to environments by measuring force fields, electromagnetic radiation, or acoustic energy employing cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, seismographs, magnetometers, gravimeters, scintillometers, and other instruments.

Jensen (2004) has given two definitions of remote sensing:

1. Maximal definition: *Remote sensing is the acquiring of data about an object without touching it*. This definition is short, simple, general, and memorable. Unfortunately, it excludes little from the domain of remote sensing of the earth's environment. It encompasses virtually all remote sensing devices, including cameras, optical-mechanical scanners, linear and area arrays, lasers, radio-frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, X-ray, and other medical applications.

2. Minimal definition: *Remote sensing is the non-contact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or spacecraft, and the analysis of acquired information by means of visual and digital image processing*.

Robert Green at NASA's Jet Propulsion Laboratory suggested the use of the term *remote measurement* because the data obtained using new hyperspectral remote sensing systems (Chapter 5) are so accurate (Robbins 1999).

1.4 REMOTE SENSING: ART OR SCIENCE OR TECHNOLOGY

Many of the literature prefers to define remote sensing as "science and art of obtaining and interpreting information …" (Jensen 2006). However, remote sensing is a perfect blend of science, technology, and art. Lillesand et al. (2007) stated, "Remote sensing is the science, technology, and art of obtaining information …”. Science is a system of acquiring knowledge based on the scientific methods, as well as the organized body of knowledge gained through such research. Technology is applying the outcome of scientific principles to innovate and improve the man-made things in the world. The output of technology is a new or better entity or mechanism. Art is the product or process of deliberately arranging items in a way that influences and affects one or more of the senses, emotions, and intellect. In simple words, art is the expression or application of human creative skill and imagination.

According to (Jensen 2006), “Remote sensing is a tool or technique similar to mathematics. Using sophisticated sensors to measure the amount of electromagnetic energy exiting an object or geographic area from a distance, and then extracting valuable information from the data using mathematically and statistically based algorithms is a scientific and technologic activity. It functions in harmony with other spatial data collection techniques or tools of the mapping sciences, including cartography and Geographic Information System (GIS). The synergism of combining scientific knowledge with real-world analyst experience allows the interpreter to develop heuristic rules of thumb to extract valuable information from the imagery. It is a fact that some image analysts are much superior to others because they: (1) understand the scientific principles better, (2) are more widely travelled and have seen many landscape objects and geographic areas first hand, and (3) can synthesize scientific principles and real-world knowledge to reach logical and correct conclusions.” Humans are equipped with intellect by which they can percept their surrounding world.

Automatic image processing techniques (by using computers) remain inadequate for remote sensing data analysis (Friedl et al. 1988). The human must be in the ‘loop’; since the human, unlike the computer, can perceive and can form and reform concepts (Hoffman and Markman 2001). It is important to note that a human interpreter can derive very little information using a point-by-point approach. Many of the original interpretations depended not only on the imagery itself but also on the skill and experience of the interpreter (Campbell 1996). Therefore, it is evident that remote sensing is a blend of science, technology, and art. The important thing one should understand is that information extracted from remote sensing data may vary from analyst to analyst to some extents and achieving one hundred percent accuracy is never possible.

1.5 DATA

The collection of data may take place directly in the field, or at some remote distance from the object or area of interest. Data that is collected directly in the field is termed as *in situ data*, and the data collected remotely called *remote sensing data*.

1.5.1 In Situ Data

One form of in situ data collection involves the scientist going out in the field and examining the phenomena of interest. Conversely, a scientist may elect to use a transducer or other in situ measurement device at the study site to make measurements. Transducers are the devices that convert variations in a physical quantity (such as pressure or brightness) into an electrical signal, or vice versa. Many different types of transducers are available. For example, a scientist could use a thermometer to measure the temperature of the air, soil, or water; spectrometer to measure the spectral reflectance; anemometer to measure the speed of the wind; or a psychrometer to measure the humidity of the air. The data recorded by the transducer may be an analog signal with voltage variations related to the intensity of the property being measured. Often these analog signals are transformed into digital values using analog-to-digital (A to D or A/D) conversion procedures.

It is necessary to understand that we can collect in situ data by using instruments which are not required to be used in direct contact with the object, but essentially we are required to go to the study site or the ground for which data is to be collected; for instance, collecting in situ data by using a spectrometer that measures very narrow wavelengths of the electromagnetic radiation (EMR) radiated or reflected by earth's surface. In this case, though we are using the instrument without touching the object, it is not remote sensing (for the earth observation), as the data is being collected by travelling to the study site.

1.5.2 Remotely Sensed Data

It is also possible to collect information about an object or geographic area using specialized instruments without direct contact with the object or area of interest and also without going to the study area. In remote sensing, the transfer of information is accomplished by the use of EMR. EMR is a form of energy that reveals its presence by the observable effects it produces when it strikes the matter. Receiving this energy for interpretation is called sensing. The EMR reflected or emitted from an object is the common source of remote sensing data, though other types of force fields may be used in place of EMR. The majority of remotely sensed data collected for earth resource applications are the result of sensors that record electromagnetic energy.

This remote data collection was originally performed using aerial cameras on photographic films. But nowadays, satellites are the main platforms for measuring physical/biophysical properties (land cover, elevation, temperature, etc.) of the earth, digitally by using electronic sensors.

1.6 REMOTE SENSING PROCESS

Figure 1.1 explains the elements (A to G) that comprise the most common remote sensing process from beginning to end. It is important to mention that remote sensing may be performed in a variety of forms and techniques. The form that has been explained in this section is the most widely used and is known as *passive optical remote sensing*. Other forms will also be discussed later.

Radiation by energy source The first requirement for remote sensing is to have an energy source that illuminates or radiates electromagnetic energy to the target of interest.

Interaction of energy with atmosphere As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. When the energy source is the sun, then first of all the energy passes through vacuum where no interaction happens before interacting with the earth's atmosphere.

Interaction of energy with target Once the energy makes its way to the target (on the earth's surface) through the atmosphere, it interacts with the target depending on the properties of

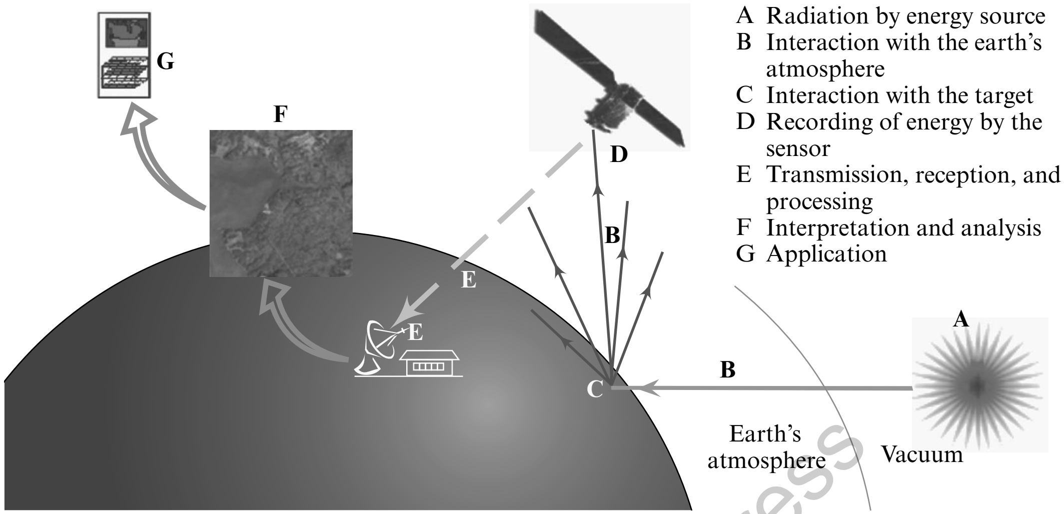

Fig. 1.1 Remote sensing process (Visit ORC; Plate 1)

both the target and the incident (incoming) energy. Some amount of incident energy is then reflected from the target.

Interaction of energy with atmosphere again As the reflected energy travels from the target to the sensing or imaging device, it interacts with the atmosphere once again.

Recording of energy by sensor After the energy has been reflected by the target, a sensor (remote, not in contact with the target) is used to collect and record the EMR.

Transmission, reception, and processing The energy recorded by the sensor is transmitted, often in electronic form, to a receiving and processing station on the ground where the data is processed into an image.

Interpretation and analysis The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target of interest.

Application Finally, we apply the information we have been able to extract from the imagery about the target to better understand it, reveal some new information, or assist in solving a particular problem.

Passive optical remote sensing can be performed from both aeroplanes and satellites. The process described in this section is for satellite remote sensing. Though aerial remote sensing is similar, transmission and reception are not required because the aircraft comes back to the ground. However, processing is required to generate interpretable imagery.

1.7 SOURCE OF ENERGY

As was noted earlier, the first requirement for remote sensing is to have an energy source to illuminate the target; unless the remotely sensed energy is being emitted by the target itself. Just as our eyes need objects to be illuminated by light so that we can see them, sensors also need a source of energy to illuminate the earth's surface. The sun is the natural source of energy.

Artificial energy sources are also used in remote sensing. Whether the energy is radiated from an external (natural or artificial) source or emitted from the object itself, it is in the form of EMR. The following subsections explain principles of EMR.

1.7.1 Concept of Energy

Energy is the ability to do work. In the process of doing work, energy is often transferred from one body to another or from one place to another. The three basic ways in which energy can be transferred include *conduction*, *convection*, and *radiation*. Conduction occurs when one body (molecule or atom) transfers its energy to another by colliding with it. For example, a metal pan is heated by a hot burner on a stove. In convection, the energy of bodies is transferred from one place to another by physically moving the bodies. A good example is the heating of the air near the ground in the morning hours. The warmer air near the surface rises, and from there the cool air comes to the surface. This process continues and thus the entire environment warms up. The transfer of energy by radiation is the primary interest to remote sensing science because it is the only form of energy transfer that can take place in vacuum such as the region between the sun and the earth.

1.7.2 Electromagnetic Radiation

To understand how EMR is produced, how it propagates through space, and how it interacts with other matter, it is useful to describe the electromagnetic energy using two different models: *wave model* and *particle model*.

1.7.2.1 Wave Model

In the 1860s, James Clerk Maxwell conceptualized EMR as an electromagnetic energy or wave that travels through space at the speed of light, that is 299,792.46 km/s or 186,282.03 miles/s (commonly rounded off to 3×10^8 m/s or 186,000 miles/s). The electromagnetic wave consists of two fluctuating fields—one electric and the other magnetic (Fig. 1.2). These two fluctuating fields are at right angles (90°) to one another, and both are perpendicular to the direction of propagation. Both have the same amplitudes (strengths) which reach their maxima–minima at the same time. Unlike other wave types that require a carrier (e.g., sound waves), electromagnetic waves can transmit through vacuum (such as in space). Electromagnetic radiation is generated whenever an electrical charge is accelerated.

Wavelength and frequency are the two important characteristics of EMR which are particularly important for understanding remote sensing. The *wavelength* is the length of one complete wave cycle, which can be measured as the distance between two successive crests (Fig. 1.2). A *crest* is the point on a wave with the greatest positive value or upward displacement in a cycle. A *trough* is the inverse of a crest. The wavelength of the EMR depends upon the length of time that the charged particle is accelerated. It is usually represented by the Greek letter lambda (λ). It is measured in metres (m), or some factor of metres such as nanometres (nm, 10^{-9} m), micrometres (µm, 10^{-6} m), or centimetres (cm, 10^{-2} m). *Frequency* refers to the number of cycles of a wave passing a fixed point per unit of time. It is usually represented by the Greek letter

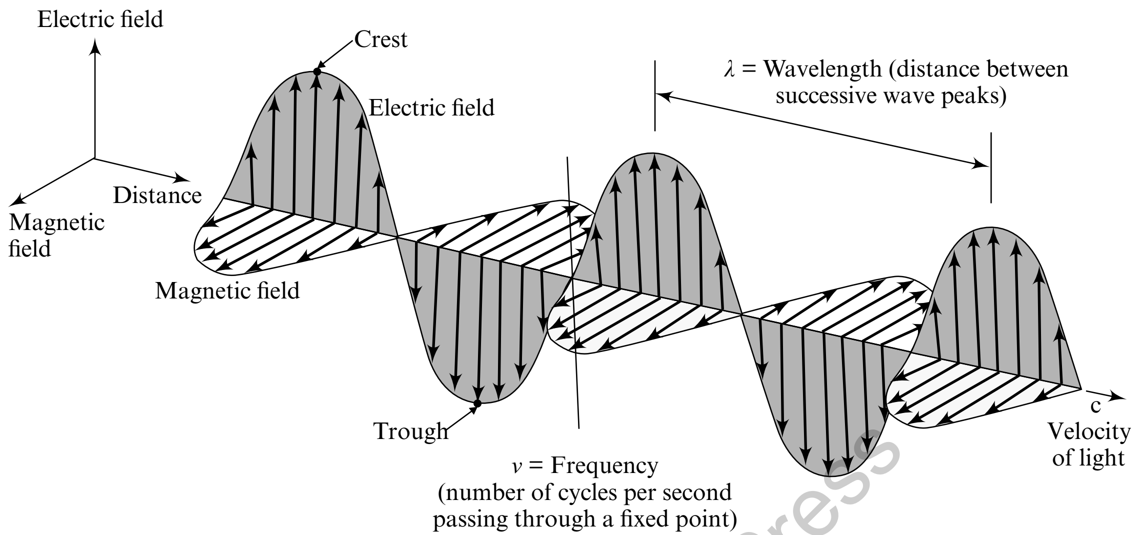

Fig. 1.2 Electromagnetic wave (composed of both electric and magnetic fields at 90° angle to one another)

Table 1.1 Standard units of measurement for wavelength and frequency

Wavelength (λ)	
Kilometre (km)	1,000 m
Metre (m)	1.0 m
Centimetre (cm)	0.01 m = 10^{-2} m
Millimetre (mm)	0.001 m = 10^{-3} m
Micrometre (μm)	0.000001 m = 10^{-6} m
Nanometre (nm)	0.000000001 m = 10^{-9} m
Angstrom (Å)	0.0000000001 m = 10^{-10} m
Frequency (ν)	
Hertz (Hz)	1 cycle per second
Kilohertz (kHz)	1,000 = 10^3 cycles per second
Megahertz (MHz)	1,000,000 = 10^6 cycles per second
Gigahertz (GHz)	1,000,000,000 = 10^9 cycles per second

nu (ν). It is normally measured in hertz (Hz), equivalent to one cycle per second. A wave that completes one cycle in every second is said to have a frequency of one cycle per second, or one hertz (1 Hz). Frequently used measures of wavelength and frequency are shown in Table 1.1.

The relationship between the wavelength (λ) and frequency (ν) of EMR is based on the following formula:

$$c = \lambda\nu$$

or

$$\nu = c/\lambda \text{ or } \lambda = c/\nu$$

where c is the velocity of light.

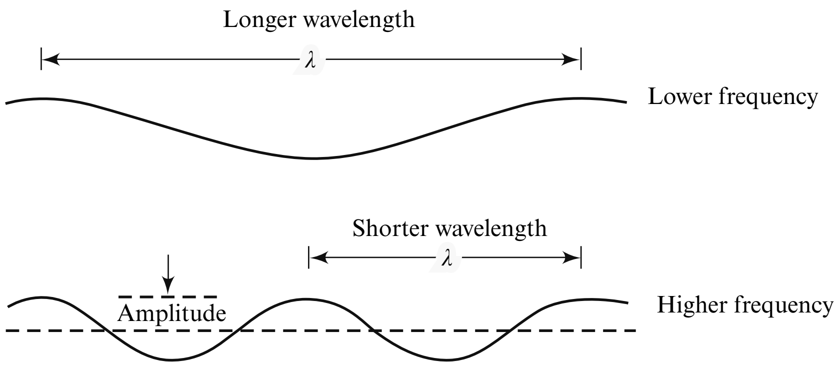

Fig. 1.3 Longer wavelength with lower frequency and shorter wavelength with higher frequency

Note that frequency is inversely proportional to wavelength. This relationship is shown diagrammatically in Fig. 1.3, the longer the wavelength, the lower the frequency; the shorter the wavelength, the higher the frequency. When the EMR passes from one medium to another, then the speed of light and the wavelength change while the frequency remains constant.

1.7.2.2 Particle Model

The rate of transfer of energy from one place to another (e.g., from the sun to the earth) is termed the flux of energy. Flux means 'flow'. Light is a stream flow of particles called photons, which in most respects are similar to subatomic particles such as protons and neutrons. The quantum theory of EMR states that energy is transferred in discrete packets called *quanta* or *photons*. Photons move at the speed of light, i.e., 299,792.46 km/s. Thus, from the point of view of quantum mechanics, EMR is both a wave and a stream of particles.

Photons, as quanta, show a wide range of discrete energies. The amount of energy characterizing a photon is determined using Planck's general equation:

$$Q = \mathrm{h}\nu$$

where Q is the energy of a quantum measured in joules (J), h is the Planck's constant (6.6260×10^{-34} J), and ν is the frequency of the radiation. Referring to the following equation:

$$\lambda = \mathrm{c}/\nu$$

we can multiply c/ν with h/h without changing its value

$$\lambda = \mathrm{hc}/\mathrm{h}\nu$$

By substituting Q for hν, we can express the wavelength associated with a quantum of energy as

$$\lambda = \mathrm{hc}/Q$$

$$\text{or} \quad Q = \mathrm{hc}/\lambda$$

Thus, we see that the energy of a quantum is inversely proportional to its wavelength. Photons travelling with shorter wavelengths (that means at higher frequencies) are therefore more energetic.

Note Consult a physics text for detailed study. Or, read the chapter on 'The Nature of Electromagnetic Radiation' in the *Manual of Remote Sensing*, second edition, published by the American Society of Photogrammetry and Remote Sensing (ASPRS). From that chapter, the NASA has suggested to read the following useful topics that explain some of the terminology and the concepts they represent as used by specialists in the remote sensing field:

Radiant energy (*Q*) is the quantity of energy carried by EMR, transferred as photons, is said to emanate in short bursts (wave train) from a source in an excited state. This stream of photons moves along lines of flow (also called rays) as a flux (Φ) which is defined as the rate at which the energy *Q* passes a spatial reference (in calculus terms dQ/dt). The unit is either joules (or ergs) per second (1 J/s = 1 W). The flux concept is related to power, defined as the rate of doing work or expending energy. The nature of the work can be one, or a combination, of these: changes in motion of particles acted upon by force fields; heating; physical or chemical change of state. Depending on circumstances, the energy spreading from a point source may be limited to a specific direction (a beam) or can disperse in all directions.

Radiant flux density is just the energy per unit volume (cubic metres or cubic centimetres). It is proportional to the squares of the amplitudes of the component waves. Flux density as applied to radiation coming from an external source to the surface of a body is referred to as irradiance (*E*); if the flux comes out of that body, its nomenclature is exitance (*M*) or sometimes as 'emittance' (now obsolete). Thus, the sun, a source, irradiates the earth's atmosphere and its surface.

Thus, the amount of radiant flux incident per unit area of a surface in specific wavelength (λ):

$$E_\lambda = \frac{\Phi_\lambda}{A}$$

and the amount of radiant flux leaving per unit area of the surface in specific wavelength (λ):

$$M_\lambda = \frac{\Phi_\lambda}{A}$$

Both equations are usually measured in watts per metre square (W/m^2), where Φ_λ is the total radiant flux and *A* is the total area.

Radiance is the most precise remote sensing radiometric measurement. It is the radiant flux per unit solid angle leaving an extended source in a given direction per unit of projected source area in that direction. It is measured in watts per meter square per steradian ($W/m^2/sr$). Steradians defined as a cone angle in which the unit is radian (1 radian = 57°17′44″). One way of visualizing the solid angle is to consider what we would see if we were in an airplane looking through a telescope at the ground. Only the energy that exited the terrain and came up to and through the telescope in a specific solid angle (measured in steradians) would be intercepted by the telescope and viewed by our eyes. Therefore, the solid angle is like a three-dimensional cone (or tube) that funnels radiant flux from a specific point source to the terrain (in case of irradiance), or from the terrain towards the sensor system (in case of exitance).

The concept of radiance is best understood by evaluating Fig. 1.4. First, for a surface at a distance R from a point source, the radiant intensity I is the flux Φ flowing through a cone of solid angle ω on to the circular area A at that distance, and is given by $I = \Phi/(A/R^2)$. Note that the radiation is moving in some direction or pathway relative to a reference line (normal to the source or target surface) as defined by the angle θ.

From this is derived a fundamental EMR entity known as radiance (commonly noted as '*L*'). In the *Manual of Remote Sensing*, radiance is defined as the radiant flux per unit solid angle leaving an extended source (of area *A*) in a given direction per unit projected surface area in that direction.

Thus, consider the radiant flux levels from the surface area in a specific direction towards the remote sensor. We are not concerned with any other radiant flux that might be leaving the source area in any other direction. We are only interested in the radiant flux in certain wavelengths (L_λ) leaving the projected source area within a certain direction ($A \cos \theta$) and solid angle (ω).

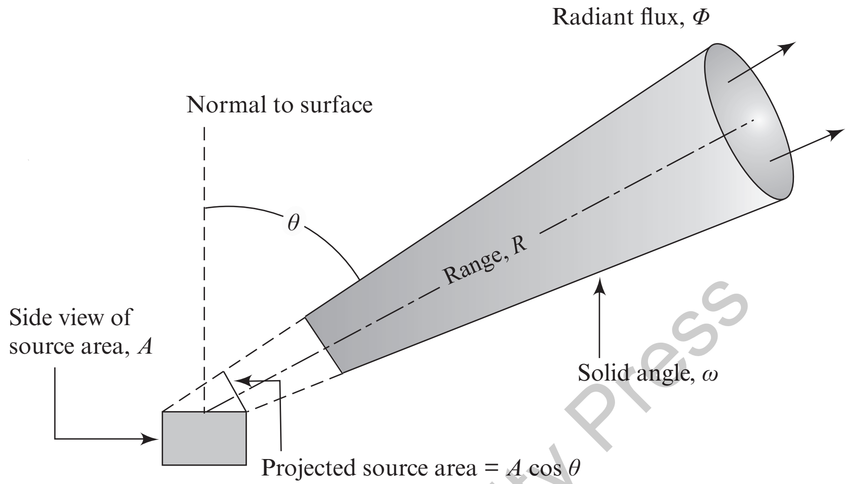

Fig. 1.4 Concept of radiance

$$L_\lambda = \frac{\phi/\omega}{A\cos\theta}$$

These, rather abstract, sets of ideas and terminology are important to the theorist. Inclusion of this synopsis is mainly to familiarize with these radiometric quantities in the event we encounter them in other reading.

1.7.3 Electromagnetic Spectrum

As noted earlier, EMR extends over a wide range of energies or wavelengths or frequencies. A narrow range of EMR (extending from 0.4 μm to 0.7 μm), the interval detected by the human eye, is known as the visible region (also referred to as *light* by common people, but physicists often use the term *light* to include radiation beyond the visible region). White light contains a mix of all wavelengths in the visible region. It was Sir Isaac Newton who in 1666 first carried out an experiment that showed visible light to be a continuous sequence of wavelengths that represented the different colours that the eye can see. He passed white light through a glass prism and concluded that 'white light is a mixture of several other lights'.

The principle supporting this result is that as radiation passes from one medium to another, it bends according to a number called the *index of refraction* (Section 1.8.3). This index of refraction is dependent on wavelength, so that the angle of bending varies systematically from red (longer wavelength; lower frequency) to violet (shorter wavelength; higher frequency). The process of separating the constituent colours in white light is known as *dispersion*.

The distribution of the continuum of all radiant energies can be plotted either as a function of wavelength or of frequency in a chart known as the electromagnetic spectrum (Fig. 1.5).

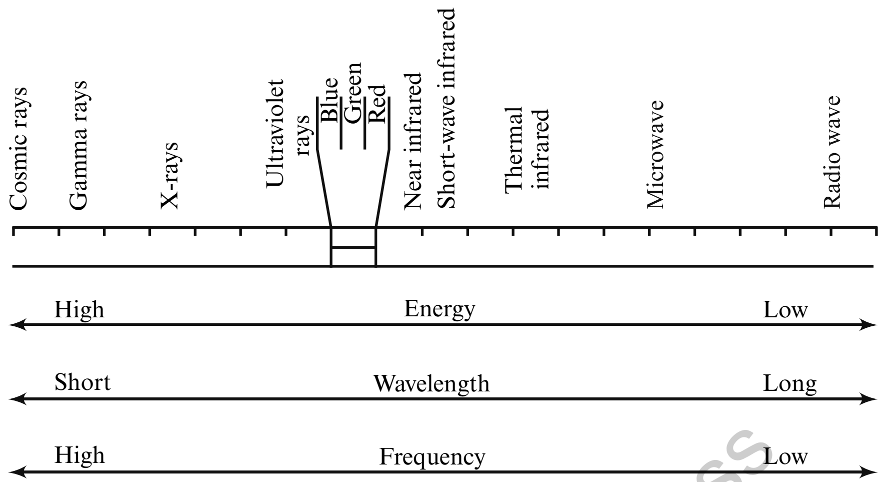

Fig. 1.5 Electromagnetic spectrum

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and X-rays) to the longer wavelengths (including microwaves and broadcast radio waves). Using spectroscopes and other radiation detection instruments, over the years, scientists have arbitrarily divided the EM spectrum into regions or intervals and applied descriptive names to them (Fig. 1.6). These regions or intervals are commonly termed as *bands* or *channels*.

The light which our eyes—our 'remote sensors'—can detect is part of the visible spectrum. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There are lots of radiations around us which are invisible to our eyes, but can be detected by other remote sensing instruments, and used to our advantage. The visible wavelengths cover a range from approximately 0.4 μm to 0.7 μm.

Although the electromagnetic spectrum is spread from cosmic rays to radio waves, remote sensing is generally performed within the range of ultraviolet to microwave region. Different bands of electromagnetic spectrum are used for different types of remote sensing. Often these bands are overlapping (Fig. 1.6). Table 1.2 describes these bands briefly.

1.8 INTERACTION WITH ATMOSPHERE

Once EMR is generated, it is first propagated through the vacuum almost at the speed of light in vacuum and then through the earth's atmosphere. EMR passes through the vacuum without having any interaction or modification. However, while passing through the earth's atmosphere, four different types of interactions take place: absorption, scattering, refraction, and reflection.

1.8.1 Absorption

Absorption is the process by which radiant energy is absorbed and converted into other forms of energy. The absorption of the incident radiant energy may take place in the atmosphere and on the terrain. An absorption band is a range of wavelengths (or frequencies) in the electromagnetic

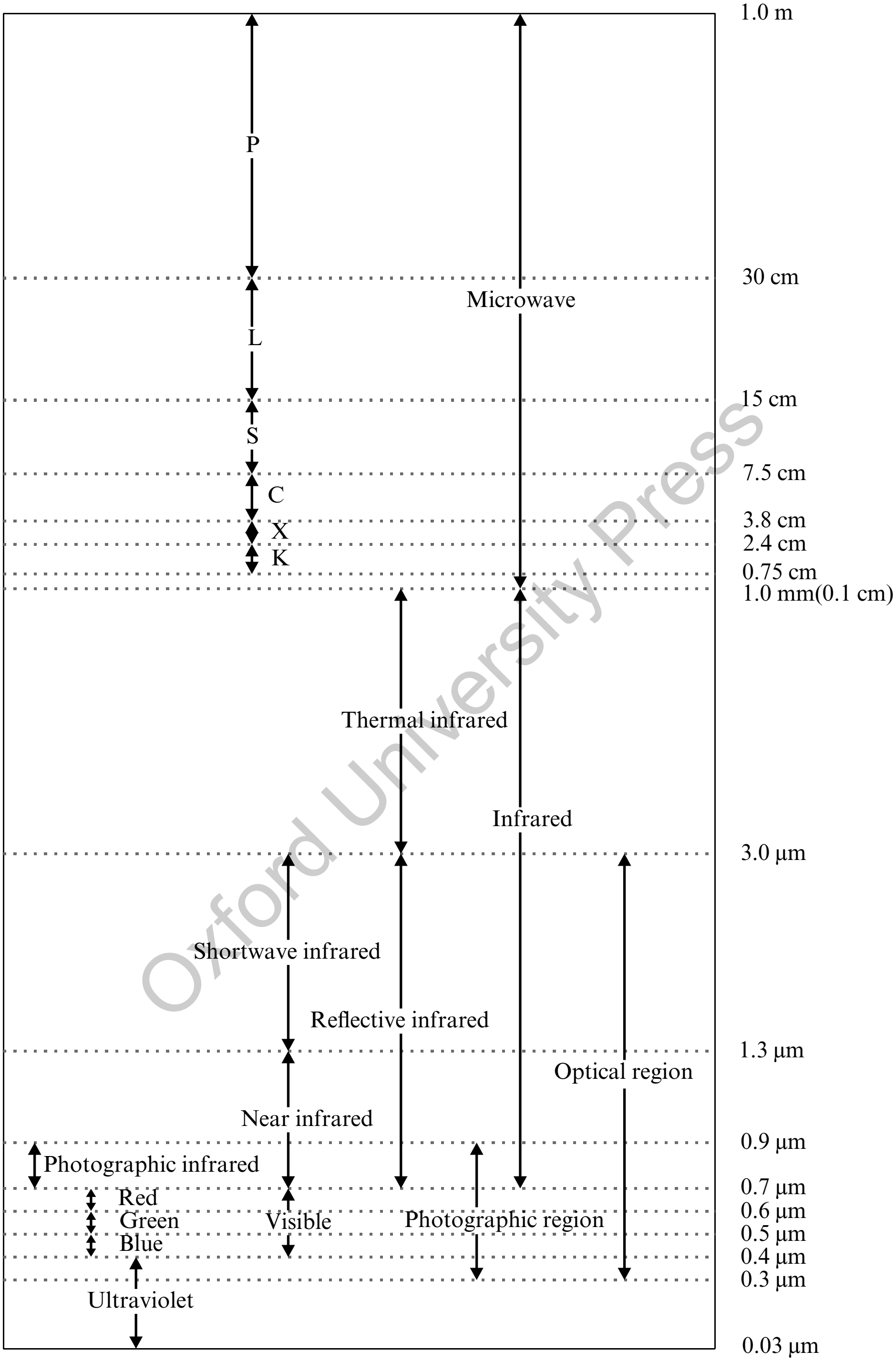

Fig. 1.6 Different bands of electromagnetic spectrum

Table 1.2 Different bands that are used in remote sensing

Band	**Dimension**	**Description**
Optical	0.3–3.0 μm	Optical region is rather a wide band that includes 0.3–15.0 μm. However, significant energy for reflection remains only within the wavelength range from about 0.3–3.0 μm. Optical devices such as lens and mirrors can handle this band.
Ultraviolet	0.3–0.4 μm	Wavelengths of ultraviolet rays are very small and highly affected by the atmosphere. Further these rays are absorbed by the ozone layer of the atmosphere. Therefore this band is not suitable for remote sensing. Although the ultraviolet band ranges from 0.03–0.4 μm, only 0.3–0.4 μm is used in few instances.
Visible	0.4–0.7 μm	This region can be detected by the human eye. *Blue* (0.4–0.5 μm), *green* (0.5–0.6 μm), and *red* (0.6–0.7 μm) are three sub-regions in it.
Infrared (IR)	0.7 μm–1.0 mm	This region has two main sub-regions—*reflective infrared* and *thermal infrared*.
Reflective (or optical) infrared	0.7–3.0 μm	Reflective infrared comes within the optical region. EMR within this region can be reflected from an object. It has two sub-regions—*near infrared* and *shortwave infrared*.
Near infrared (NIR)	0.7–1.3 μm	A subset (0.7-0.9 μm) of this region is known as *photo-graphic infrared*.
Shortwave infrared (SWIR)	1.3–3.0 μm	This region is also known as *mid infrared*.
Thermal infrared (TIR)	3.0 μm–1.0 mm	This region is also known as *far infrared*. Energy in this region cannot be reflected from an object, rather it is emitted by the object. Although thermal infrared region is very wide, two narrow bands within this region can be used for remote sensing: (1) 3–5 μm and (2) 8–14 μm. The region at 22 μm–1 mm is called *no transmission band*. This region may be referred to as *no remote sensing zone* because atmospheric molecules absorb the entire energy at this region. Therefore, energy cannot be transmitted through the atmosphere; as a result remote sensing is not possible.
Photographic	0.3–0.9 μm	EMR within the photographic region can be recorded on photographic film (as well as on digital media). EMR outside of this region cannot be recorded on film; must be recorded on digital media. This region includes the entire visible band and some portions of ultraviolet and infrared. The infrared energy within this region is called *photographic infrared*.
Photographic infrared	0.7–0.9 μm	Only this portion of infrared energy can be recorded on photographic film. This band is a subset of near infrared.
Microwave	1 mm–1 m	Microwave band is again subdivided into several sub-regions. Chapter 6 will address this band in greater detail.

spectrum within which radiant energy is absorbed by a substance. The cumulative effect of the absorption by the various constituents can cause the atmosphere to close down completely in certain regions of the spectrum. This is not desired for remote sensing as no energy is available to be sensed.

Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents that absorb radiation. Ozone serves to absorb the harmful (to most living things) ultraviolet radiation from the sun. Without this protective layer in the atmosphere, our skin would burn when exposed to sunlight.

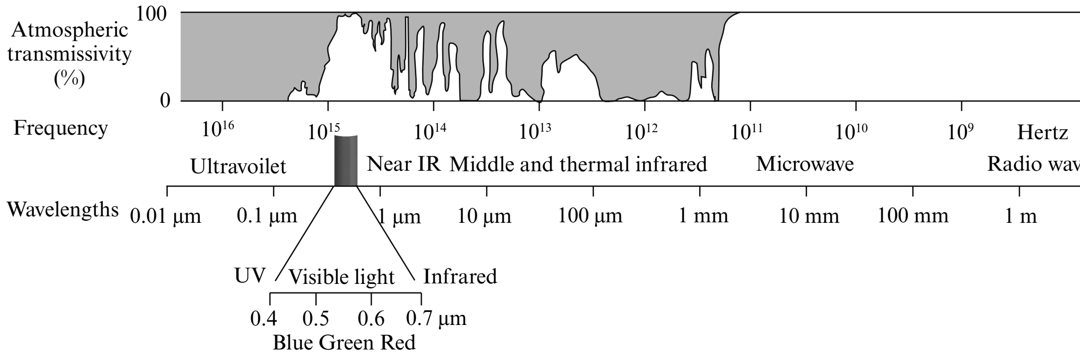

Fig. 1.7 Atmospheric window for various wavelengths of EMR

Carbon dioxide is referred to as a *greenhouse gas*. This is because it tends to absorb radiation strongly in the far infrared (thermal infrared) portion of the spectrum—area associated with thermal heating—which serves to trap this heat inside the atmosphere. Water vapour in the atmosphere absorbs much of the incoming longwave (thermal) infrared and shortwave microwave radiations. The presence of water vapour in the lower atmosphere varies greatly from location to location and at different times of the year. For example, the air mass above a desert would have very little water vapour to absorb energy, while the tropic regions would have high concentrations of water vapour (i.e., high humidity).

The atmospheric gases absorb electromagnetic energy in different specific regions of the spectrum, they influence where (in the spectrum) we can 'look' for remote sensing purposes. Those areas of the spectrum which are not severely influenced by atmospheric absorption and, thus, are useful to remote sensors are called *atmospheric windows*. All spectral regions are affected to some extent by absorption in the atmosphere but some regions are less affected and nearly transparent. These regions are called atmospheric windows and are useful in remote sensing.

Figure 1.7 is a generalized diagram showing relative atmospheric radiation transmission of different wavelengths. Grey zones marked in Fig. 1.7 show the minimal passage of incoming and/or outgoing radiation, whereas white areas denote atmospheric windows, in which the radiation does not interact much with air molecules and hence is not absorbed. Most remote sensing instruments on air or space platforms operate in one or more of these windows by making their measurements with detectors tuned to specific frequencies (wavelengths) that pass through the atmosphere. However, some sensors, especially those on meteorological satellites, directly measure absorption phenomena, such as those associated with carbon dioxide and other gaseous molecules.

1.8.2 Scattering

Atmospheric scattering is the unpredictable diffusion of radiation by particles in the atmosphere. It occurs when particles or large gas molecules present in the atmosphere interact with and cause the EMR to be redirected from its original path. How much scattering takes place depends on several factors including the wavelength of the radiation, the diameter of particles or gaseous molecules, and the distance the radiation travels through the atmosphere.

The amount of scattering is inversely proportional to the fourth power of wavelength of radiation. For example, ultraviolet light at 0.3 μm is scattered approximately 16 times more than red light at 0.6 μm. Scattering is responsible for the blue appearance of the sky. The shorter violet and blue wavelengths are more efficiently scattered than the longer green and red wavelengths. That is why most remote sensing systems avoid detecting and recording wavelengths in the ultraviolet and blue portions of the spectrum.

1.8.3 Refraction

When EMR encounters substances of different densities, like air and water, refraction takes place. *Refraction* refers to the bending of light when it passes from one medium to another. Refraction occurs because the media are of different densities and the speed of EMR is different in each medium (Fig. 1.8). The index of refraction (n) is a measure of the optical density of a substance. This index is the ratio of the speed of light in vacuum, c (3×10^8 m/s), to the speed of light in a substance such as the atmosphere or water, c_n:

$$n = \frac{c}{c_n}$$

The speed of light in a substance can never reach the speed of light in vacuum. Therefore, its index of refraction must always be greater than 1. For example, the index of refraction for the atmosphere is 1.0002926.

Refraction can be described by Snell's law, which states that for a given frequency of light (we must use frequency since, unlike wavelength, it does not change when the speed of light changes), the product of the index of refraction and the sine of the angle between the ray and a line normal to the interface is constant:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Serious errors in location due to refraction can occur in images formed from energy detected at high altitude or at acute angle. However, these location errors are predictable by Snell's law and can be reduced. If one knows the index of refraction of medium-1 and -2 (n_1 and n_2) and the angle of incidence (θ_1) of the energy to medium-1, it is possible to predict the amount of refraction that will take place in medium-2.

Within the atmosphere, there is a continuous movement of air. An effect produced by the movement of masses of air with different refractive indices is called *atmospheric shimmer*. The effect of shimmer can be most easily detected in the twinkling of stars. Shimmer results in blurring in remotely sensed images.

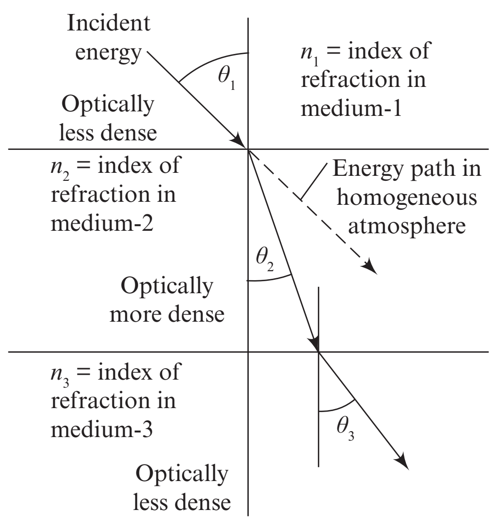

Fig. 1.8 Atmospheric refraction

1.8.4 Reflection

Reflection is the process whereby radiation 'bounces off' an object like the top of a cloud or the terrestrial earth. However, here we are discussing atmospheric reflection, not reflection on the terrain. Reflection differs from scattering in the way that the direction of reflection is predictable whereas in case of scattering it is unpredictable.

A considerable amount of incident radiant flux from the sun is reflected from the top of clouds and other materials in the atmosphere. This results in recording of some extra amount of energy by the sensor in addition to the reflected energy from the terrain (target). Blurred images and appearance of clouds on the imagery are the main problems associated with atmospheric reflection.

1.9 INTERACTION WITH TARGET

Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the earth's surface. There are three forms of interaction that can take place when energy strikes, or is incident upon the earth's surface. They are absorption, transmission, and reflection. The proportions of each will depend on the wavelength of the energy and the material and condition of the terrain (Fig. 1.9).

The amount of radiant energy onto, off of, or through a surface per unit time is called *radiant flux* (Φ) and is measured in watts (W). The characteristics of the radiant flux and what happens to it as it interacts with the earth's surface is of critical importance in remote sensing. In fact, this is the fundamental focus of much remote sensing research. By carefully monitoring the exact nature of the incoming (incident) radiant flux in selective wavelengths and how it interacts with the target, it is possible to learn important information about the target. Various radiometric quantities have been identified that allow us to keep a careful record of the incident and exiting radiant flux. We begin with the simple radiation budget equation, which states that the total amount of radiant flux in specific wavelengths (λ) incident to the terrain ($\Phi_{i\lambda}$) must be accounted by evaluating the amount of energy reflected from the surface (ρ_λ), the amount of energy absorbed by the surface (α_λ), and the amount of radiant energy transmitted through the surface (τ_λ):

$$\Phi_{i\lambda} = \rho_\lambda + \tau_\lambda + \alpha_\lambda$$

It is important to note that these radiometric quantities are based on the amount of radiant energy incident to a surface from any angle in a hemisphere (i.e., a half of a sphere).

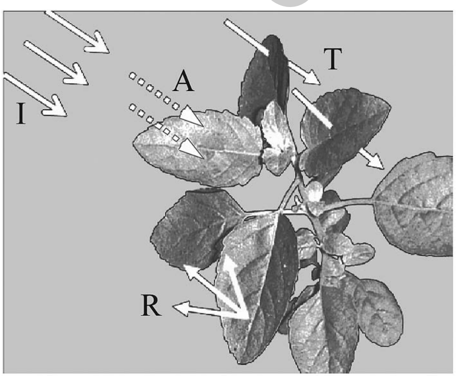

Fig. 1.9 Incident energy (I) is being ab sorbed (A), transmitted (T), and reflected (R) by vegetation leaf

1.9.1 Hemispherical Absorptance, Transmittance, and Reflectance

Radiant energy must be conserved, that is, it is either returned by reflection, transmitted through a material, or absorbed and transformed into some other form of energy. The net effect of absorption of radiation by most substances is that the energy is converted into heat, causing a subsequent rise in the substance's temperature.

Hemispherical absorptance is the ratio of the energy that is absorbed by the surface (Φ_{absorbed}) (in specific wavelengths (λ)) and the radiant flux incident to the terrain ($\Phi_{i\lambda}$):

$$\alpha_\lambda = \frac{\Phi_{\text{absorbed}}}{\Phi_{i\lambda}}$$

Hemispherical transmittance is the ratio of energy that is transmitted through the surface ($\Phi_{\text{transmitted}}$) (in specific wavelengths (λ)) and the radiant flux incident to the terrain ($\Phi_{i\lambda}$):

$$\tau_\lambda = \frac{\Phi_{\text{transmitted}}}{\Phi_{i\lambda}}$$

Hemispherical reflectance is the ratio of energy that is reflected by the surface ($\Phi_{\text{reflected}}$) (in specific wavelengths (λ)) and the radiant flux incident to the terrain ($\Phi_{i\lambda}$):

$$\rho_\lambda = \frac{\Phi_{\text{reflected}}}{\Phi_{i\lambda}}$$

These radiometric quantities are useful for producing general statements about the spectral reflectance, absorption, and transmittance characteristics of terrain features. In fact, if we take the simple hemispherical reflectance equation and multiply it by 100, we obtain an expression for *percent reflectance* ($p_{r\lambda}$):

$$p_{r\lambda} = \frac{\Phi_{\text{reflected}}}{\Phi_{i\lambda}} \times 100$$

This is often used in remote sensing research to describe the spectral reflectance characteristics of various phenomena.

The amount and properties of reflection will depend on the wavelength of the energy and the material and condition of the feature. Surface of the material plays a vital role in this case and needs to be discussed.

There are two general types of reflecting surfaces which interact with EMR: *specular* (smooth) and *diffuse* (rough) (Fig. 1.10). These terms are defined geometrically, not physically. The Rayleigh criterion is used to determine surface roughness with respect to radiation

$$h \leq \lambda/8 \cos\theta$$

where h is the surface irregularity height (measured in Å), λ is the wavelength (also in Å), and θ is the angle of incidence (measured from the normal to the surface). If λ is less than h, the surface acts as a diffuse reflector; if greater than h, the surface is specular. For example, a sandy beach is 'smooth' to longer-wavelength radio wave, but 'rough' to the visible light.

Specular reflection occurs when the surface from which the radiation is reflected is essentially smooth (i.e., the average surface profile height is several times smaller than the wavelength of radiation striking the surface). Several features, which have a flat surface, act like near-perfect specular reflectors (Fig. 1.10).

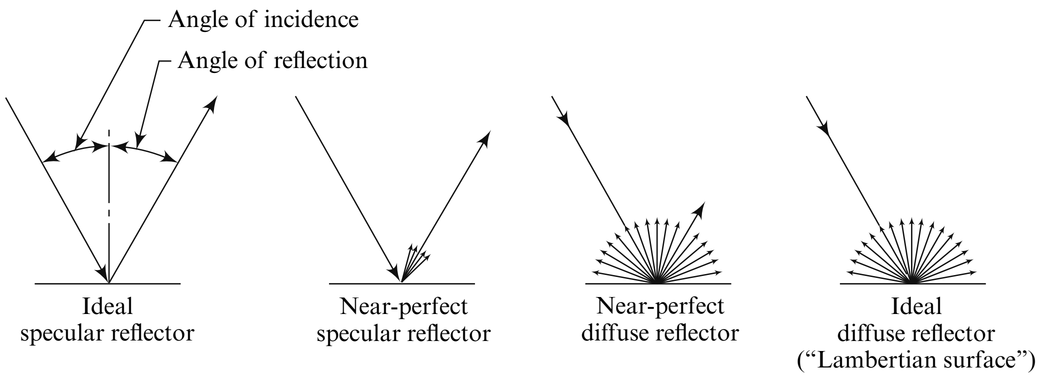

Fig. 1.10 Nature of specular and diffuse reflection

If the surface has a large surface height variation compared to the size of the wavelength of the incident energy, the reflected rays go in many directions, depending on the orientation of reflecting surfaces. This diffuse reflection does not yield a mirror image, but instead produces diffused radiation. Rough surfaces act like diffuse reflectors. If any diffuse reflector reflects in such a manner so that the radiant flux leaving the surface is constant for any angle of reflectance then the reflector is called ideal diffuse reflector or *Lambertian surface*.

We have used the term 'hemispherical' to measure the reflectance, absorptance, and transmittance. Hemispherical measurements account for all energy contained within a hemisphere above a surface or object of interest. For example, diffuse reflection is hemispherical, whereas specular reflection is directional. Directional measurements account for the measurement in a particular direction of illuminating or viewing. In remote sensing, we are generally interested in measuring the hemispherical (diffuse) reflectance properties of terrain features. Because in directional (specular) reflectance, the energy is reflected in a single direction and the sensor must be placed in that specific direction; otherwise the object will appear as black (no light to record by the sensor).

1.9.2 Spectral Reflectance Curve

Spectral reflectance curve shows the relationship of electromagnetic spectrum (distribution of the continuum of radiant energies plotted either as a function of wavelength or of frequency) with the associated percent reflectance for any given material. It is plotted in a chart that represents wavelengths along the horizontal axis and percent reflectance along the vertical axis (Fig. 1.11).

For any given material, the amount of solar radiation that is reflected, absorbed, or transmitted varies with wavelength. This important property of matter makes it possible to identify different substances or classes and separate them by their spectral signatures (or spectral curves), as shown in Fig. 1.11.

In the example shown in Fig. 1.11, at some wavelengths, dry soil reflects more energy than green vegetation but at other wavelengths it absorbs more (reflects less) than what the vegetation does. In principle, we can recognize various kinds of surface materials and distinguish them from each other by these differences in reflectance.

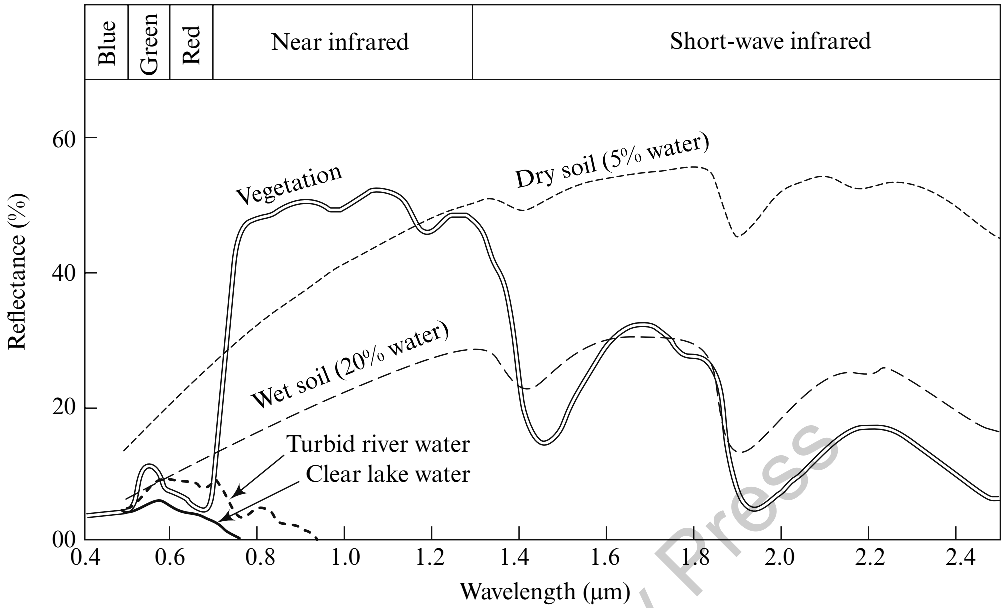

Fig. 1.11 Example of laboratory-tested spectral reflectance curves (Source: Jet Propulsion Laboratory, NASA)

When we use more and more wavelengths, the plots tend to show more separation among the materials. This improved ability to distinguish materials due to extra wavelengths is the basis for multi-spectral and hyper-spectral remote sensing (discussed in Chapter 5).

Let us consider examples of targets at the earth's surface and how energy at the visible and infrared wavelengths interacts with them.

Vegetation leaves A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths, but reflects green wavelengths. Leaves appear 'greenest' to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths). The internal structure of healthy leaves act as excellent diffuse reflectors of reflective infrared (especially NIR) wavelengths. If our eyes were sensitive to near-infrared wavelengths, trees would appear extremely bright to us at these wavelengths. In fact, measuring and monitoring the NIR reflectance is one way that scientists can determine how healthy (or unhealthy) the vegetation may be. Healthy vegetation reflects more NIR light than unhealthy vegetation.

Water Longer-wavelength visible and NIR radiation is absorbed more by water than shorter visible wavelengths. Thus, water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or NIR wavelengths. If there is suspended sediment present in the upper layers of the water body, then this will allow better reflectivity and a brighter appearance of the water. The apparent colour of the water will show a slight shift to longer wavelengths. Suspended sediment can be easily confused with shallow (but clear) water, since these two phenomena appear very similar. Chlorophyll in algae absorbs more of the blue wavelengths and reflects the green, making the water appear greener in colour when algae are present. The topography of the water surface (rough, smooth, floating materials, etc.) can also lead to complications for water-related interpretation due to potential problems of specular reflection and other influences on colour and brightness.

We can see from these examples that depending on the complex make-up of the target that is being looked at and the wavelengths of radiation involved, we can observe different responses to the mechanisms of absorption, transmission, and reflection. By measuring the energy that is reflected (or emitted) by targets on the earth's surface over a variety of different wavelengths, we can build a spectral response for that object. By comparing the response patterns of different features in different wavelengths, we may be able to distinguish between them, where we might not be able to, if we compared them at one wavelength only. For example, water and vegetation may reflect somewhat similarly in the red band but are almost always separable in the near infrared. Spectral response can be quite variable, even for the same target type; and can also vary with time and location. For example, the 'greenness' of a vegetation species may differ in different season; it may also differ in different location because the health and condition may vary with the change of soil type and weather. Knowing where to 'look' spectrally and understanding the factors that influence the spectral response of the features of interest are critical for correctly interpreting the interaction of EMR with the surface.

The nature of interaction of EMR with an object can lead to identifying the object. The basic property by which an object can be identified is called *signature*. As we know, a person can be identified by his/her signature. All the properties of an object help us to identify it. For example, golden colour of a wheat field indicates that the crop is matured. In remote sensing, spatial, spectral, and temporal variations (signatures) are the major characteristics to identify an object.

Spatial signatures are the arrangements of terrain features like shape, size, texture, etc. (see Chapter 9). Spectral signature indicates the change in reflectance of object with different wavelengths (Fig. 1.11). Temporal signature is the change in reflectance with time (diurnal/seasonal). Therefore, by proper investigation of these three signatures one can get a clear understanding about the object type and its condition.

1.10 INTERACTION WITH THE ATMOSPHERE AGAIN

The radiant flux reflected or emitted from the earth's surface once again enters the atmosphere, where it interacts with various gases, water vapour, and particulates. Thus, atmospheric scattering, absorption, reflection, and refraction influence the radiant flux (as described in Section 1.8) once again before the energy is recorded by the remote sensing system, which need not be discussed again.

1.11 RECORDING OF ENERGY BY SENSOR

So far, we have mainly considered the nature and characteristics of EMR in terms of sources and behaviour when interacting with materials and objects. It was stated that the bulk of the radiation sensed is either reflected or emitted from the target, generally through air until monitored by a sensor. The subject of what sensors consist of and how they perform (operate) is important and wide ranging which is beyond the scope of this chapter and will be discussed in Chapters 4, 5, and 6.

However, it should be mentioned that additional energy–matter interactions take place when the energy reaches the remote sensor (Fig. 1.12).

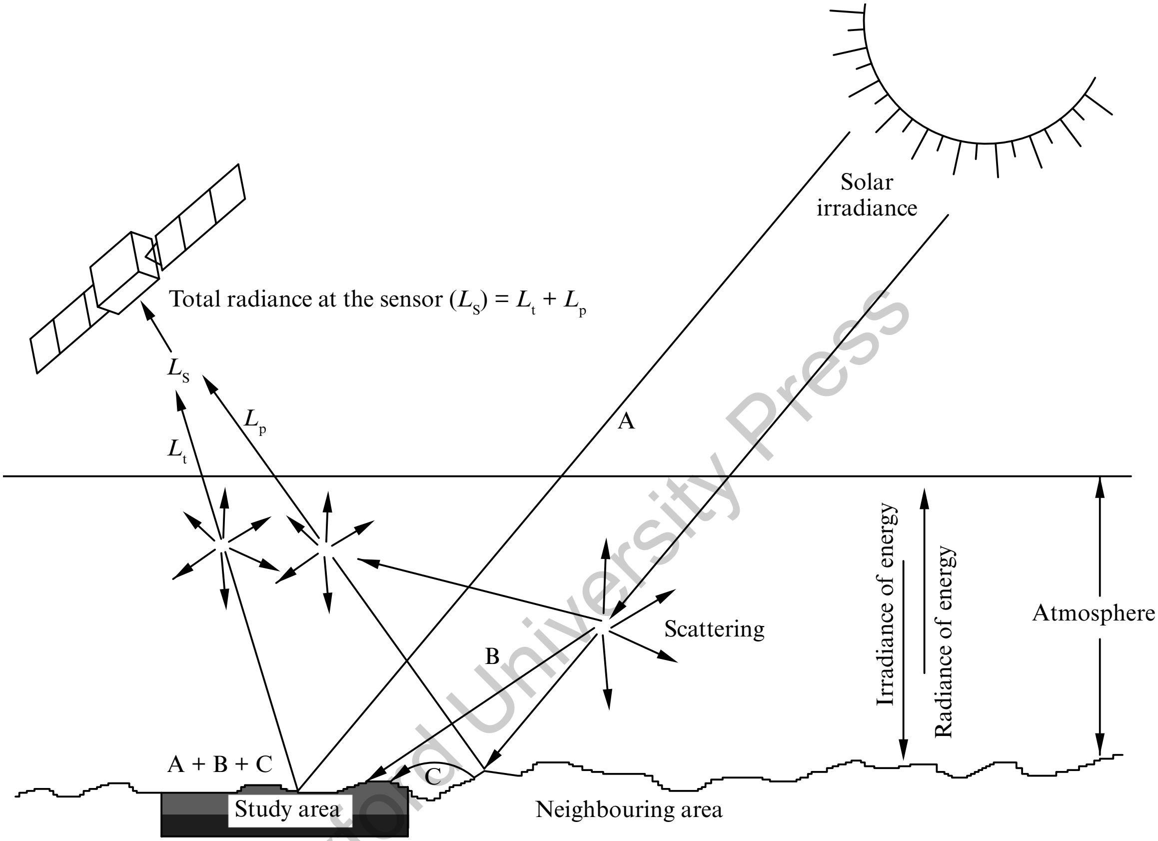

Fig. 1.12 Additional energy–matter interactions take place when the energy reaches the remote sensor

1.11.1 Target and Path Radiance

Ideally, the radiant energy recorded by the camera or detector is a true function of the amount of radiance leaving the terrain at a specific solid angle. Unfortunately, other radiant energy may enter the field of view from various other paths such as atmospheric interaction, solar irradiance, sky irradiance, and scattering, and introduce confounding noise into the remote sensing process. Furthermore, the light from a target outside the field of view of the sensor may be scattered into the field of view of the sensor. This effect is known as *adjacency effect*. Near to the boundary between two regions of different brightness, the adjacency effect results in an increase in the apparent brightness of the darker region while the apparent brightness of the brighter region is reduced.

Only a small amount of total radiance at the sensor is actually reflected by the terrain in the direction of the sensor system. It would be wonderful if the total radiance recorded by the sensor (L_s) equalled the radiance returned from the area of interest (L_t). Unfortunately, $L_s \neq L_t$, because there are some additional radiance from different paths which may fall within the field of view of the sensor system. This is often called path radiance (L_p). Thus, the total radiance recorded by the sensor becomes

$$L_s = L_t + L_p$$

This path radiance generally introduces unwanted radiometric noise in the remotely sensed data and complicates the image interpretation process. A great deal of research has gone into developing methods to remove the contribution of path radiance, some of which will be discussed in the chapter on digital image processing (Chapter 10).

1.12 TRANSMISSION, RECEPTION, AND PROCESSING

Remotely sensed data may be collected using onboard aircraft remote sensors/cameras and/or onboard satellite remote sensors. Aircraft remote sensing system may also be referred to as sub-orbital or airborne or aerial remote sensing system. Satellite remote sensing system may also be referred to as orbital or satellite-borne remote sensing system. Aircrafts and satellites are known as sensor platforms. Data obtained during airborne remote sensing missions can be retrieved once the aircraft lands. It can then be processed and delivered to the end-user. However, data acquired from satellite platforms needs to be electronically transmitted to the earth, since the satellite continues to stay in orbit during its operational lifetime. The technologies designed to accomplish this can also be used by an aerial platform if the data is urgently needed on the surface.

There are three main ways for transmitting data acquired by satellites to the earth's surface. The data can be directly transmitted to the earth if a ground receiving station (GRS) is in the line of sight of the satellite. If this is not the case, the data can be recorded onboard the satellite for transmission to a GRS at a later time. Data can also be relayed to the GRS through the tracking and data relay satellite system (TDRSS), which consists of a series of communication satellites in geosynchronous orbit. The data is transmitted from one satellite to another until it reaches the vicinity of appropriate GRS.

In India, ISRO operates one ground receiving station at Shadnagar, 55 km away from Hyderabad, Telangana. Shadnagar covers all of India, Pakistan, Afghanistan, Bangladesh, Burma, Thailand, and portions of Iran, Oman, Cambodia, and Laos.

The data is received at the GRS in a raw digital format, which may, if required, be processed to correct systematic, geometric, and atmospheric distortions to the imagery (refer Chapter 10), and be translated into a standardized image format. The data is written to some form of storage medium such as tape, magnetic disk, and CD.

1.13 INTERPRETATION AND ANALYSIS

Data alone cannot be used for decision making. It must be interpreted or analysed before one can extract information. The analysis of remotely sensed data is performed using a variety of image interpretation and processing techniques which fall into two broad categories (Fig. 1.13):

- visual image interpretation and
- digital image processing (DIP)

(a) (b)

Fig. 1.13 Image processing: (a) visual and (b) digital

1.13.1 Visual Image Interpretation

Both analog and digital image data allow the analyst to perform scientific visualization, defined as ‘visually exploring data and information in such a way as to gain understanding and insight into the data’.

Most of the fundamental elements of image interpretation are used in visual image analysis, including size, shape, shadow, colour (tone), parallax, pattern, texture, site, and association. The human mind is amazingly adept at recognizing these complex elements in an image or photograph because we constantly process the profile view of the earth features every day and continually process images in books and magazines and on television.

How to interpret a remotely sensed image by means of visual interpretation will be discussed in Chapter 9.

1.13.2 Digital Image Processing

Scientists have made significant advances in the digital image processing (computer processing) of remotely sensed data for scientific visualization and hypothesis testing. It is commonly known that the human eye can discriminate only between 40–50 shades of grey when interpreting a grey-scale image. A computer can analyse each of the data in an image using various digital image processing techniques.

Techniques involved in digital image processing and its elements/types are explained in detail in Chapter 10.

Information derived from remotely sensed data is usually summarized as an enhanced image, image map, orthophoto map, thematic map, spatial database file, statistic, or graph. Thus the final output products often require knowledge of remote sensing, geography, cartography, geology, physics, mathematics, statistics, computer science, information technology, GIS, and obviously social science as well as the systematic science being investigated (i.e., soils, agriculture, forestry, wetland, urban, etc.). The analyst who understands the rules and synergistic relationship between the technologies can produce output products that communicate effectively.

1.14 APPLICATIONS OF REMOTE SENSING

Remotely sensed data analysed in vacuum without the benefit of other collateral information (such as soils, hydrology, agriculture, urban, etc.) is meaningless. Remote sensing may be used for numerous applications including weapon guidance system (e.g., the cruise missile), medical image analysis (e.g., X-raying a broken arm), non-destructive evaluation of machinery and products (e.g., on the assembly line), analysis of the earth's resources, etc. Earth resource information is defined as any information concerning terrestrial vegetation, soils, minerals, water, and urban infrastructure as well as certain atmospheric characteristics. This book focuses on the art and science of applying remote sensing for the extraction of useful earth resource information. Though the application of remote sensing is not limited to 10 or 15, or even 100 cases, some broad categories are described in Chapter 12.

1.15 ADVANTAGES OF REMOTE SENSING

Remote sensing has several unique advantages as well as some limitations also. It is essential to understand both the advantages and limitations of remote sensing, to use it more effectively.

Remote sensing is unobtrusive if the sensor is passively recording the electromagnetic energy reflected from or emitted by the phenomenon of interest. This is a very important consideration, as passive remote sensing (using natural source of energy, e.g., the sun) does not disturb the object or area of interest.

Remote sensing devices are often programmed to collect data systematically. This systematic data collection can remove the sampling bias introduced in some in situ investigations.

Remote sensing sensor has *synoptic view*. Synoptic view of a sensor is the ability to see large areas at the same time. This ability of the sensor can reduce the data acquisition time (and thereby cost) dramatically over a large geographic area in comparison to the traditional surveying methods.

Remote sensing from satellites can be performed repeatedly at a regular time interval. This can help in monitoring several earth-surface features continuously.

Remote sensing can be used for collecting data about areas that are physically and/or politically inaccessible.

Under carefully controlled conditions, remote sensing can provide fundamental biophysical data, including: x, y locations, z elevation or depth, biomass, temperature, and moisture content. In this sense, it is much like surveying, providing fundamental data that other sciences can use when conducting scientific investigations. However, unlike much of surveying, the remotely sensed data may be obtained systematically over very large geographic areas rather than just single-point observations.

Remote sensing is also different from the other mapping sciences such as cartography or GIS because they rely on data produced elsewhere. Remote sensing science yields fundamental scientific information. For example, a properly calibrated thermal infrared remote sensing system can provide a geometrically correct map of land or sea-surface temperature without any other intervening science. A good example is the digital elevation models that are so important in many spatially distributed GIS models. Digital elevation models are now produced almost exclusively through the analysis of remotely sensed data (Jensen 2004).

1.16 LIMITATIONS OF REMOTE SENSING

Remote sensing science has various limitations. "Perhaps the greatest limitation is that its utility is often oversold" (Jensen 2004). It is not a *panacea* that will provide all the information needed for conducting physical, biological, or social science. It simply provides some spatial, spectral, and temporal information.

Human beings select the most appropriate sensor to collect the data, specify the resolution of the data, calibrate the sensor, select the platform that will carry the sensor, determine when the data will be collected, and specify how the data is processed. Thus, human method-produced error may be introduced, as the various remote sensing instrument and mission parameters are specified (Jensen 2004).

Powerful active remote sensor system, such as lasers or radars that emit their own EMR, can be intrusive and affect the phenomenon being investigated.

Remote sensing instruments often become uncalibrated, resulting in uncalibrated remote sensing data. Finally, remote sensor data may be expensive to collect, interpret, or analyse. But the information derived from the remote sensor data is so valuable that the expense is warranted.

1.17 IDEAL REMOTE SENSING SYSTEM

Having introduced some basic concepts, we now have the necessary understanding to conceptualize an ideal remote sensing system. In doing so, we can then appreciate some of the problems encountered in the design and application of the various real remote sensing systems examined in subsequent chapters.

The basic components of an ideal remote sensing system include the following components (Lillesand and Kiefer 1994):

A uniform energy source This source will provide energy all over wavelengths, at a constant, known, high level of output, irrespective of time and place.

A non-interfering atmosphere This will be an atmosphere that will not modify the energy from the source in any manner, whether that energy is on its way to the earth's surface or coming from it. Again, ideally this will hold irrespective of wavelength, time, place, and sensing altitude involved.

A series of unique energy–matter interaction at the earth's surface These interactions will generate reflected and/or emitted signals that are not only selective in respect to wavelengths, but are also known, invariant, and unique to each and every earth surface feature type and subtype of interest.

A super sensor This will be a sensor, highly sensitive to all wavelengths, yielding spatially detailed data on the absolute brightness (or radiance) from a scene (a function of wavelength), throughout the spectrum. This super sensor will be simple and reliable, require virtually no power or space, and be accurate and economical to operate.

A real-time data handling system In this system, the instant the radiance versus wavelength response over a terrain element is generated, it will be transmitted to the ground and processed into an interpretable format and recognized as being unique to the particular terrain element from which it comes. This processing will be performed nearly instantaneously (real time), providing timely information. Because of the consistent nature of the energy–matter interactions, there will be no need for reference data in the analytical procedure. The derived data will provide insight into the physical–chemical–biological state of each feature of interest.

Multiple data users These people will have comprehensive knowledge of both—their respective disciplines and of remote sensing data acquisition and analysis techniques. The same set of data will become various forms of information for different users, because of their vast knowledge about the particular earth's resources being used.

Unfortunately, an ideal remote sensing system, as described herein, does not exist. However, the preceding understanding can help us to evaluate the real remote sensing systems—their capabilities and/or limitations.

EXERCISES

Descriptive Questions

1. What do you understand by remote sensing?
2. Briefly explain the process of passive optical remote sensing.
3. Explain wave model of EMR. What is electromagnetic spectrum?
4. Derive the relation amongst the wavelength, frequency, and the energy content of a photon.
5. Explain various interactions of incident EM energy with the atmosphere.
6. Explain interaction of EM energy with the target.
7. Explain hemispherical absorptance, transmittance, and reflectance.
8. What is spectral reflectance curve and what are its utilities in remote sensing?
9. Explain the process of transmission and reception of recorded data.
10. What do you understand by analysis and interpretation?
11. What are the advantages and limitations of remote sensing?
12. Elaborate the relative advantages of using aerial photos and satellite images over products of conventional survey.
13. What are the considerations for an ideal remote sensing system?
14. Discuss on the spectral reflectance characteristics of water and vegetation in different spectral bands.
15. Why remote sensing is considered as a blend of art, science, and technology?
16. Explain particle model of electromagnetic energy. Describe the relations among wavelength, frequency, and energy.
17. Derive the wavelength for the frequency of 40 GHz and derive the frequency for the wavelength of 1.19 cm. Consider the velocity of light as 3×10^8 m/s.
18. Calculate the energy content in the photon for the wavelength of 1.2 cm.
19. Explain absorption of electromagnetic energy by the atmosphere. What is atmospheric window?
20. Explain electromagnetic spectrum with proper illustration and designation of bands in respect of remote sensing.
21. Why water appears very dark and vegetation appears extremely bright compared to other earth surface features on the image captured in NIR band? If we have three images of a forested land captured in red, green, and blue bands, how can we identify that in which band which image has been captured?
22. Calculate the frequency and amount of radiant energy for the wavelength of 1 mm. Consider the speed of light as 3×10^8 m/s, and Planck's constant as 6.6260×10^{-34} J.

Short Notes/Definitions

Write short notes on the following topics.

1. In situ data
2. EMR
3. Wavelength
4. Frequency
5. Radiant flux
6. Atmospheric window
7. Refraction
8. Spectral signature
9. Path radiance
10. Directional reflection