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Dedicated to my parents

Shri. Ram Pratap Dwivedi
Mrs. Kapoora Devi

Foreword

More than five decades ago a combination of new advances in science and technology became available to Earth scientists. A new approach for observing the entire surface of the Earth every eighteen days by multispectral sensors on polar-orbiting satellites provide human observers possibilities never available before for observing Earth surface features and temporal changes in these features.

The U.S. National Aeronautics and Space Administration (NASA) launched its first Land Satellite, Landsat 1, in July 1972. A few years prior to the launch of Landsat 1, NASA made research grants to three different state universities in the U.S. to provide their engineering, agriculture, forestry, and earth sciences skills in the design of spectral sensors and computer algorithms for analyzing quickly vast amounts of satellite sensor data.

It was obvious from the first multispectral images of the Earth surface transmitted to Landsat Receiving Stations that a new era was beginning for man's use of multispectral images for observing, managing and conserving man's use of land and water resources on the Earth surface. In their recommendations to NASA, university scientists and engineers proposed that two different sensor systems be installed on Landsat 1. One sensor was a four-spectral band (two visible bands, and two near-infrared bands) transmitted in digital format to receiving stations; the second sensor was an analogue scanner with three cameras, each covering a different portion of the visible spectrum.

Examination of original data received from each sensor indicated that images from the multispectral digital scanner were far superior to images from the analogue scanner. One explanation is that the "signal-to-noise" ratio is far better with digital data than it is with analogue data in transmission from the high-altitude satellite to receiving stations on the Earth surface.

Multispectral images of the Earth surface from the satellite-borne sensor on Landsat 1 provided the challenge of relating quantitatively the multispectral images in different spectral bands to the current Earth surface categories. The basic challenge was to relate the spectral features to colour, chemical properties, physical features, organic properties, and temporal changes in these features on succeeding Landsat passes. Of particular interest was the spectral identification of specific crops and indications of stage of growth and/or indications of crop quality, different agricultural crops, features of cities, lakes, salt water, forests, desert lands, and other features. As the research progressed with the analysis of Landsat multispectral data, it became necessary to design sensors with narrower spectral band-widths. As researchers defined the use of the multispectral sensors for identifying changes in Earth surface features and conditions, what came to be known as “precision farming” was developed so that spectral and other sensors mounted on tractors, planters and harvesters could be used to control the quantity of seeds, fertilizer or pesticides tobe applied.

In the early stages of computer software development for the analysis and interpretation of the vast quantities of multispectral data from scanners on the Earth-orbiting satellites, it became imperative to develop an efficient system for “ground observation” sampling to define and identify “ground truth”. Such ground truth was essential for defining the wide range of spectral classes as specific earth surface features—kinds and conditions of agricultural crops, eroded soils, flooded lands, types and conditions of forests, and many other changing conditions of lands and water.

During the 40 plus years since the launch of Landsat 1, on average each five years a new Landsat with improved sensors has been launched into polar orbit. Scientific research to define the spectral reflectance and emittance properties of Earth-surface features of human interest has increased dramatically with research institutions in many countries. An excellent example of such research is in India where Dr. Ravi Shankar Dwivedi has provided an excellent contribution in his extensive review of relevant literature. Dr. Dwivedi provides many past and current references to the broad field of remote sensing and gives many examples of the applications of these technologies, especially in the management of soils and agricultural land use throughout the world.

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Preface

The intimate knowledge of soils with regard to their nature, extent, spatial distribution, potential and limitations is a prerequisite for sustainable development of natural resources and environmental management. In the backdrop of global environmental change quantitative information on soil properties is required to comprehend the role soil plays in the biophysical and biogeochemical functioning of the planet. Soil surveys which were carried out using traditional methods until recently, provide such information. The soil scientists world over have graduated from traditional soil surveys to using aerial photographs during the period 1930s to 1960s, and ultimately to satellite data for deriving information on soil resources since early 1970s, and to study their potentials and limitations for intended usage for various purposes including agriculture, forestry, urban development, soil and water conservation, etc. Apart from generating information on soil resources, spectral measurements made from space platforms have also been found to be very effective in deriving information on soil degradation, soil fertility and soil moisture, and inputs for precision agriculture.

The availability of Landsat-MSS data with coarse spatial resolution in 1972 could afford generation of only reconnaissance level information on soils. With the increased availability of spatial data (satellite digital data with improved spatial and spectral resolution digital elevation model), the development of data-mining tools and GIS, on-site geophysical instrumentation, viz. electromagnetic induction (EMI), ground penetrating radar (GPR), portable X-ray fluorescence (PXRF), etc., the availability of computing power for processing data, and the development of statistical and geostatistical techniques have greatly enhanced our ability to collect, analyze, and predict spatial information on soils.

The book essentially aims at addressing the applications of remote sensing techniques in the studies on soils.

In pursuance of the objective, the book initially provides an introduction to various elements and concepts of remote sensing, and associated technologies, namely Geographic Information System (GIS), Global Positioning System (GPS) in Chap. 1. An overview of the sensors used to collect remote sensing data and important Earth observation missions is provided in Chap. 2. The processing of satellite digital data (geometric and radiometric corrections, feature reduction, digital data fusion, image enhancements and analysis) are dealt with in Chap. 3. In the chapter to follow the interpretation of remote sensing data, very important and crucial step in deriving information on natural resources including soils resources, is discussed. An introduction to soils as a natural body with respect to their formation, physical and chemical properties used during inventory of soils, and soil classification is given in Chap. 5. The spectral response patterns of soils including hyperspectral characteristics—fundamental to deriving information on soils from spectral measurements, and the techniques of soil resources mapping are discussed in Chaps. 6 and 7, respectively. Furthermore, the creation of digital soil resources database and the development of soil information systems, a very important aspect of storage and dissemination of digital soil data to the end users are discussed in Chap. 8. Lastly, the applications of remote sensing techniques in soil moisture estimation and soil fertility evaluation are covered in Chaps. 9 and 10, respectively.

In order to make the soil survey and mapping techniques popular to the readers having not much exposure to pedology and soil surveys using remote sensing an attempt has been made by the author to provide (i) the basic concepts and techniques for interpreting/analyzing the remote sensing data, and (ii) the basic information on soils including soil classification. It is hoped that the soil survey practitioners, researchers and academicians may find the book quite helpful in pursuing their endeavour.

Hyderabad, India Ravi Shankar Dwivedi

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Contents

Chapter 1
An Introduction to Remote Sensing

1.1 Introduction

The term remote sensing is derived from two Latin words: *remotus*, meaning far away or distant in time or place, and *sensus* meaning to detect a stimulus by means of any of the five senses. Putting together these two words: *remote* plus *sensus*, remote sensing refers to detecting an object/feature/phenomenon with an observation device that is not in intimate physical contact with the object/feature/phenomenon in question. Essentially, the term 'remote sensing' in its broadest sense merely means '**reconnaissance at a distance**' (Colwell 1966). Remote sensing thus differs from in situ or proximal sensing in the way information is gathered about an object/feature or phenomenon. While the instruments are immersed in, or physically touch the objects of measurement in proximal sensing or in situ measurements, the sensing device is invariably not in physical contact in case of remote sensing. In practice, remote sensing is the use of a variety of devices for gathering information on a given object or area. According to Buiten and Clevers (1993) remote sensing, also called Earth observation, refers in 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 from that surface.

At initial stages, the term 'remote sensing' was confined to the development of different components of photography, i.e. various types of films, camera, film processing and printing systems, interpretation techniques and photogrammetry. By the early 1960s, many new types of remote sensing devices were being introduced that could detect electromagnetic radiation in spectral regions far beyond the range of visible spectrum or human vision and photographic film. During this period, several natural resources scientists were visualizing the Earth observations from

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orbiting satellites on a routine basis. To encompass these concepts, Evelyn L. Pruitt, a geographer formerly with the Office of Naval Research, coined the term '*remote sensing*' to replace the more limiting terms '*aerial*' and '*photograph*'.

With the development of computer technology in 1960s and realization of the potential of integrating the information on natural resources to derive more comprehensive and meaningful information and arriving at decisions for planning and management of natural resources, a new technology called Geographical Information System (GIS) was developed. Besides, for precise location of observations and information on natural resources and to improve the spatial accuracy of thematic maps, namely minerals, forests, soils, surface and ground water resources, etc., satellite-based navigation system: Global Navigation Satellite System (GNSS) was developed. Furthermore, concomitant developments in the Internet technology and its integration with the computer technology lead to the development of personal digital assistant (PDA) devices that enabled transmitting the in situ observations on natural disasters and other phenomenon requiring real- or near-real-time field data for analysis and/or interpretation of remote sensing data. In order to accommodate a host of newly developed technologies, i.e. remote sensing, GIS, GNSS and PDAs, a new term geospatial technology or geomatics or geoinformatics was coined. Geospatial technologies are an umbrella phrase associated with a suite of technologies including remote sensing, satellite-based navigation system, Geographic Information System (GIS), information technologies and field sensors, that help in capturing/storing/processing/displaying/disseminating information on a particular location (http://baegrisk.ddns.uark.edu/kpweb/). Geoinformatics or geospatial technologies literally refer to the usage of information technology for geographic analysis. It may be defined as 'An integrated science and technology that deals with acquisition and manipulation of geographical data, transforming it into useful information using geoscientific, analytical, and visualization techniques for making better decisions" (Jaganathan 2011). Lein (2012) defines geoinformatics as a descriptive which integrates the acquisition, modelling, analysis and management of spatially referenced data.

The sensors capture reflected/emitted/backscattered electromagnetic radiation from the object/feature. These sensors/instruments are of two types, i.e. *passive sensors* and *active sensors*. Passive sensors detect natural energy (radiation) that is reflected or emitted by the object. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, charge-coupled devices and radiometers. Active sensors, on the other hand, have their own source of energy to illuminate the object or terrain and record the backscattered energy there from. Radar and Lidar are examples of active sensors where the time delay between disseminated and return radiation is measured and is used for establishing the location, height, speed and direction of an object/feature.

1.2 History of Remote Sensing

A detailed historical sketch of and the major milestones in remote sensing with respect to the development of sensors, platform and launch vehicle is available in Campbell et al. (2011) and Jensen (2007). The use of remote sensing to study Earth's environments has progressed steadily over time. This evolution reflects both advancements in sensor technology and data interpretation/analysis techniques, and the quest to develop new data collection/interpretation/analysis capabilities to address growing environmental concerns. Based on the nature of developments in the technology, Melesse et al. (2007) have identified eight distinct phases in remote sensing-based Earth observation programmes which is summarized hereafter.

Beginning with the a*irborne remote sensing* during the First and Second World Wars with the primary applications focused on surveying, reconnaissance, strategic land use mapping and military surveillance, the focus was shifted to *early space-borne systems* dominated by the launch of 'proof of concept' satellites beginning with Russia's Sputnik-1 and Explorer-1, introduced by USA in 1957 and 1958, respectively. It was followed by the e*ra of spy satellites* during peak of the cold war. The advanced meteorological satellites, viz. Television Infrared Observation Satellite (TIROS) series first in 1960 marked the fourth phase whereas the launch of the Landsat-1 in 1972 heralded the major breakthrough in Earth observation from space. Several satellites, namely Landsat-2, through-8 with the state-of-the-art sensors, namely Multispectral Scanner System (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper plus (ETM+) and Optical Line Imager (OLI) and Thermal Infrared System (TIRS) were subsequently launched. These missions have led to the operationalization of Earth observation technology. Later on *Earth Observing Systems (EOS)*, viz. Terra and Aqua satellites were launched in late nineties and early twenty-first century with several major innovations to satellite remote sensing, namely frequent repeat coverage, wider resolution capabilities and higher level of processing to address a multiplicity of environmental applications.

The next phase (New Millennium programme) is characterized by the introduction of highly advanced test concept systems. These satellite sensors represent 'next generation' systems such as Earth Observing1 (EO-1), which carried the first space-borne hyperspectral sensor 'Hyperion' and the Advanced Land Imager (ALI) into Earth orbit; a less costly superior replacement of Landsat TM technology. Commercialization of space technology facilitating private players to launch satellites and disseminate remote sensing data with very high resolution to the user community marks one of the noteworthy developments in the Earth observation programme.

1.3 Electromagnetic Radiation (EMR)

Electromagnetic energy refers to all energy that moves with the velocity of light in a harmonic wave pattern. A harmonic wave pattern consists of waves that occur at equal interval in time. The wave concept explains how electromagnetic energy propagates (moves), but this energy can only be detected as it interacts with the matter. In this interaction, electromagnetic energy EM energy behaves as though it consists of many individual bodies called photons that have such particle-like properties as energy and momentum.

Electromagnetic radiation is the means by which information is carried from an object/a feature to a remote sensor. The reviews on the nature of EM radiation and physical principles are available in Fraser and Curran (1976), Silva (1978) and Suits (1983). Electromagnetic radiation is generated by (i) acceleration of electrical charges, (ii) changes in the energy levels of electrons, (iii) decay of radioactive substances and (iv) thermal motion of atoms/molecules. Electromagnetic waves are produced whenever an electrical charge is oscillating. Therefore, as an electric charge oscillates, electrical energy will be lost and an equivalent amount of radiation will be radiated outward in the form of oscillating electric and magnetic fields. Quantum processes can also produce EM radiation, such as when atomic nuclei undergo gamma decay, and processes such as neutral pion decay (http://en.wikipedia.org/wiki/Pion). The electromagnetic radiation has been conceptualized as particles or *quanta* as well as waves.

1.3.1 Particle Model

The electromagnetic radiation (EMR) was primarily thought of as a smooth and continuous wave. Albert Einstein found that when light interacts with electrons, it has a different character. He concluded that when EMR interacts with matter, it behaves as though it is composed of many individual bodies called *photons*, which carry such particle-like properties as energy and momentum which confirms its duality.

1.3.2 Wave Model

The electromagnetic radiation has been conceptualized by as waves that travel through space at a speed of light. However, when it interacts with matter, as mentioned in Sect. 1.3.1 it is considered as particles/*quanta* or photons. It consists of two fluctuating fields—one electric (E) and the other magnetic (M) (Fig. 1.1). The two vectors are orthogonal to one another, and both are perpendicular to direction of travel. Important parameters characterizing any EMR under study are:

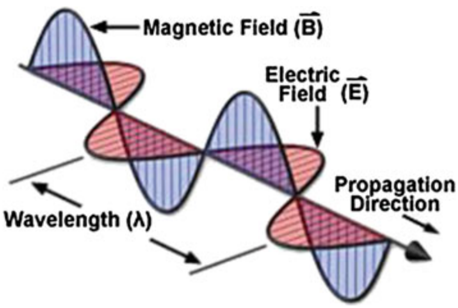

Fig. 1.1 The electromagnetic radiation

wavelength/frequency/amplitude/phase/the direction of propagation, and polarization. The wavelength (λ) of the electromagnetic radiation depends upon the length of time that the charged particles are accelerated. The frequency (υ) of a wave is its rate of oscillation and is measured in hertz, the SI unit of frequency or a multiple of it like kilo Hertz (10^3 Hz), mega Hertz (10^6 Hz) and giga Hertz (10^9 Hz). One hertz is equal to one oscillation per second. The wavelength (λ) of the electromagnetic radiation is the distance between two successive crests or troughs. It is measured in metres or a fraction thereof microns (10^{-6})/nanometres (10^{-9}). The wavelength and frequency of electromagnetic radiation are related as follows:

$$c = \lambda \upsilon, \tag{1.1}$$

where c is the velocity of light (3×10^8 m/s)

$$\upsilon = \frac{c}{\lambda} \tag{1.2}$$

and

$$\lambda = \frac{c}{\upsilon} \tag{1.3}$$

when electromagnetic radiation passes from one substance to another, the speed of the light and its wavelength change while the frequency remains the same.

1.3.3 Amplitude

The amplitude of electromagnetic waves relates to its intensity or brightness (as in the case of visible light). With visible light, the brightness is usually measured in lumens (Fig. 1.2). With other wavelengths the intensity of the radiation, which is power per unit area or watts per square metre, is used. The square of the amplitude of a wave is the intensity.