Chapter 7
Fundamentals of Remote Sensing

"Know the weather, know the terrain, and your victory will be complete"

Sun Tzu ($\approx$500 BC)

7.1 Basic Concept

Remote sensing is defined as the art, science and technology through which the characteristics of object features/targets either on, above or even below the earth's surface are identified, measured and analyzed without direct contact existing between the sensors and the targets or events being observed, see e.g., (Jensen 2009; Lillesand et al. 2010; Richards 1994; Murai 1999) etc. This allows for *information* about such object features to be obtained by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.

Electromagnetic radiation is normally used as the *information carrier* in remote sensing. Such electromagnetic radiation that is either reflected or emitted from targets normally constitutes remote sensing data. This can be detected by a sensor usually on-board airborne (e.g., aircraft or balloon) or space-borne (e.g., satellites and space shuttles) platforms. A comprehensive survey of airborne and space-borne missions and sensors for observing the earth is given in Kramer (2002). As an analogy, of the five basic human senses, three of them namely; sight, hearing and smell may be considered forms of "remote sensing", where the source of information is at some distance away from the sensors, in this case the eyes, ears and nose respectively. In contrast, however, the other two human senses (i.e., taste and touch) rely on direct physical contact with the source of information.

As shown in Fig. 7.1, the process of remote sensing is characterized by various stages and interactions summarized as follows: (a) an energy source or illumination is used to provide electromagnetic energy to the target of interest, (b) interactions

J. L. Awange and J. B. Kyalo Kiema, *Environmental Geoinformatics*,
Environmental Science and Engineering, DOI: 10.1007/978-3-642-34085-7_7,

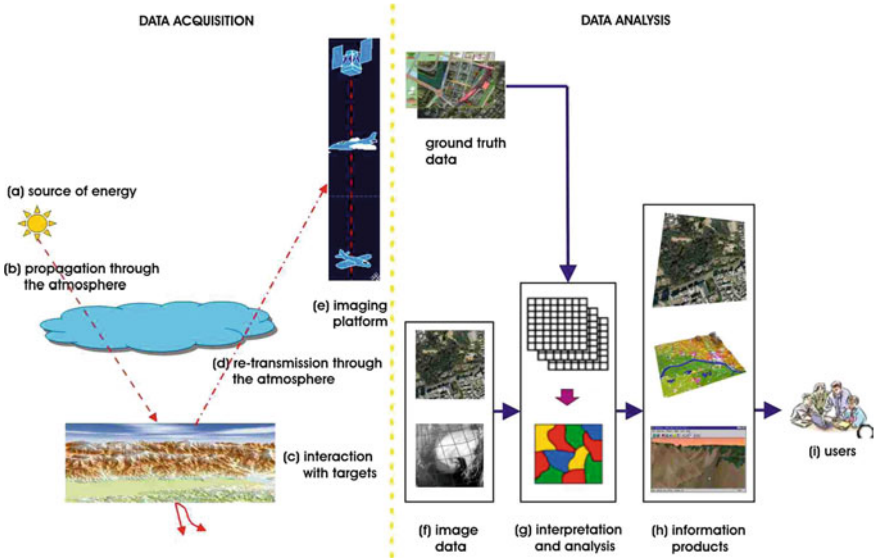

Fig. 7.1 Remote sensing process

between the electromagnetic radiation and the atmosphere, (c) interaction between the target and the electromagnetic radiation, (d) recording of reflected and emitted energy from the target by the sensor, (e) transmission, reception and processing of recorded energy into an image, (f) interpretation and analysis of image to extract desired information and (g) application of the information about the object or target in order to better understand it, reveal some new information, or assist in solving a particular problem.

Although it is now possible to expand the object feature base in image interpretation beyond the traditional spectral domain to include spatial and other dimensions, the practice of remote sensing still relies heavily on the spectral characteristics of objects. Accordingly, each object has a unique spectral signature of reflection or emission dependent on the sun, climate, atmosphere, ground condition, sensor among other factors. This allows the discrimination of the object *type*, *class*, *rank* or *density* to be made through image processing and analysis as illustrated in Fig. 7.2.

Even though the invention of classical photography can be traced way back to around 1860 and balloon photography was pioneered in 1900, strictly speaking, the technology of remote sensing evolved gradually into a scientific discipline only after World War II. Like most other mapping technologies, the early developments in remote sensing were mainly driven by military use, with civilian applications emerging much later. Today, the range of remote sensing applications varies from archeology, agricure, cartography, civil engineering, meteorology and climatology, coastal studies, emergency response, forestry, geology, geographic information systems, hazards, land use and land cover, natural disasters, oceanography, water resources etc. Furthermore, the introduction of high spatial resolution sensors and the

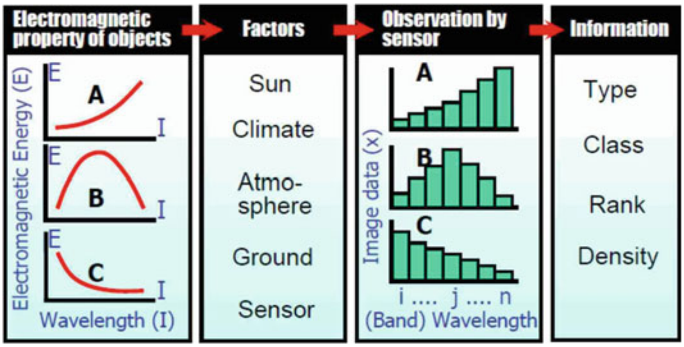

Fig. 7.2 Flow of remote sensing. *Source* Murai (2004)

development of new image analysis algorithms, has given an impetus to new applications in non-conventional areas like urban mapping, disaster management, location-based services, car and pedestrian navigation etc.

7.2 Principles of Electromagnetic Radiation

7.2.1 Electromagnetic Spectrum

Electromagnetic radiation, whose major source is the Sun, is fundamentally a carrier of electromagnetic energy. The electromagnetic radiation which travels in the form of waves at the speed of light (denoted as c and equals to $3 \times 10^8\ \text{ms}^{-1}$) is known as the electromagnetic spectrum. The waves propagate through time and space oscillating in all directions perpendicular to their direction of travel. According to the quantum wave theory, electromagnetic radiation propagates as a traverse wave comprising of both an electric field (E) and a magnetic field (H). These two fields are located at right angles to each other and travel at the speed of light.

Electromagnetic radiation is defined by four basic elements namely; *frequency* or *wavelength*, *transmission direction*, *amplitude* and *plane of polarization*. It is these four elements which influence the kind of information that can be extracted from electromagnetic radiation. They also effectively determine the characteristics of remote sensing data or images cues such as colors, tones or geometric shape of objects. The wavelength (λ) is defined as the distance between successive crests of the waves. The frequency (μ) is the number of oscillations completed per second. On the other hand, the amplitude defines the maximum positive displacement from the undisturbed position of the medium to the top of a crest. The plane of polarization represents the plane of the electric field and is important in microwave remote sensing (described in Chap. 9).

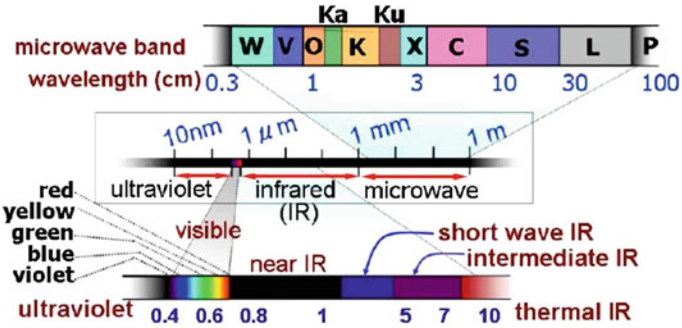

Fig. 7.3 Bands used in remote sensing. *Source* Murai (2004)

By scientific convention, the *electromagnetic spectrum* is divided into different portions. The major divisions of the electromagnetic spectrum ranging from short-wavelength, high-frequency waves to long-wavelength, low-frequency waves, include gamma rays, X-rays, ultraviolet (UV) radiation, visible light, infrared (IR) radiation, microwave radiation, and radio waves. Because of the spectral absorption characteristic of atmospheric molecules in certain regions of the atmosphere, otherwise referred to as the *blocking effect*, only certain parts of the electromagnetic spectrum are useful in remote sensing. These regions represent the *principal atmospheric windows* and define the bands employed in remote sensing as shown in Fig. 7.3.

The *ultraviolet* or UV portion of the spectrum has the shortest wavelengths which are practical for remote sensing. This radiation is just beyond the violet portion of the visible wavelengths, hence its name. Some rocks and minerals fluoresce or emit visible light when illuminated by UV radiation. The visible spectrum is a very narrow band whose wavelength ranges from between 0.3 and 0.7 μm. However, it is a very important part of the electromagnetic spectrum that is particularly critical in photogrammetry and satellite remote sensing. In addition, the light which our eyes—"ur remote sensors"—can detect is part of the visible spectrum.

The *infrared* (IR) region can be divided into two categories based on their radiation properties—the *reflected IR* and the *emitted or thermal IR*. Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion as shown in Fig. 7.4a. The reflected IR covers wavelengths from approximately 0.7 and 3.0 μm. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the earth's surface in the form of heat (see Fig. 7.4b).

The thermal IR covers wavelengths from approximately 3.0 and 100 μm. The principle of black body radiation is relevant in understanding the operation of thermal remote sensing and is articulated in most classical remote sensing literature, see e.g., Lillesand et al. (2010), Richards (1994) etc. While reflected IR images can yield important information on the health status of crops and vegetation, thermal IR sensors have been employed to support rescue operations in disaster events like earthquakes, fires etc.

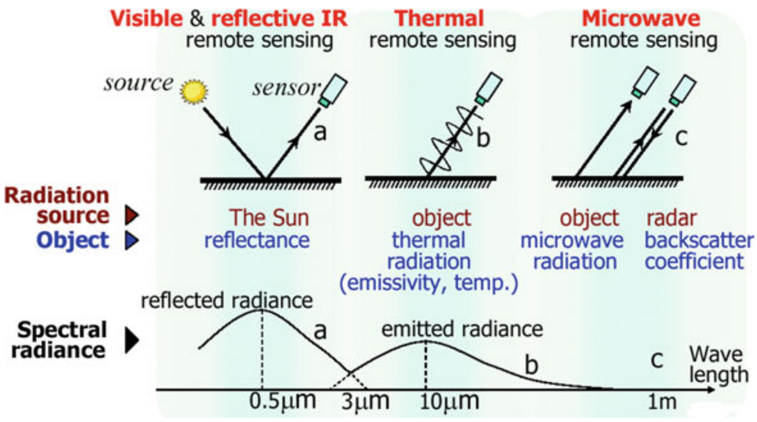

Fig. 7.4 Types of remote sensing. *Source* Murai (2004)

The *microwave regions* represent the portion of the electromagnetic spectrum that has raised most interest to remote sensing in recent times. It covers a vast wavelength region that extends in wavelength from about 1 mm to 1 m (see Fig. 7.4c). The microwave region is further subdivided into several other bands like P, L, C, X and K bands. Microwave remote sensing uses microwave in both passive and active modes. Microwaves can be emitted from the earth, from objects such as cars and planes, as well as from the atmosphere.

These microwaves can be detected to provide information, such as the temperature of the target that emitted the microwave. Most passive microwave sensors are characterized by low spatial resolution. Active microwave sensing systems such as RAdio Detection And Ranging (RADAR) provide their own source of microwave radiation that is fired in the form of a radar pulse towards the targets. They are then able to detect and record the energy that is backscattered from the targets as shown in (Fig. 7.4c). More detailed discussion on microwave remote sensing is presented in Chap. 9.

7.2.2 Interaction with the Atmosphere and Targets

As the electromagnetic energy travels through the atmosphere from either the energy source or the target, some *absorption and/or scattering* will inevitably take place. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb electromagnetic radiation. As mentioned above, it is only in those regions of the electromagnetic spectrum where no or slight absorption occurs, otherwise referred to as the *principal atmospheric windows*, where meaningful remote sensing can be practiced.

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path resulting in attenuation of the electromagnetic radiation. Scattering is mainly caused by nitrogen (N_2) and oxygen (O_2) molecules, aerosols, fog particles, cloud droplets, and raindrops. The type of scattering that results is influenced by the relative size of the atmospheric molecules and particles *vis á vis* the wavelength of the incident energy and will thus vary from one atmospheric region to the other. Three different types of scattering can be distinguished: *Rayleigh scattering*, *Mie scattering* and *Non-selective scattering* in the upper, mid and lower atmospheric regions respectively. Whereas Rayleigh scattering is the reason why the sky appears blue, non-selective scattering is the reason for fog and clouds appearing white.

Different types of interactions will occur when the incident electromagnetic radiation finally hits or connects with the targets. The specific type of interaction will depend on the properties of both the target and the wavelength of the incident electromagnetic radiation. *Reflection* occurs when radiation bounces off the target and is then redirected. When the target surface is smooth, *specular reflection* results, where all (or almost all) of the energy is directed away from the surface in a single direction. When the target surface is rough, the energy is reflected almost uniformly in all directions, in which case *diffuse reflection* occurs. Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors.

Absorption occurs when electromagnetic radiation is absorbed by the target. *Transmission* occurs when electromagnetic radiation passes through a target. For any given material, the amount of solar radiation that reflects, absorbs, or transmits varies with wavelength. As discussed in Sect. 7.1, it is this important characteristic of matter that makes it possible to identify different substances or features and distinguish between them on the basis of their *spectral signatures* (spectral curves) in remote sensing.

For demonstration purposes, Fig. 7.5 shows the *spectral reflectance curves* for vegetation, water and dry and wet soils. While vegetation has a unique pattern, the spectral reflectance for soil varies depending on the moisture content with dry soil

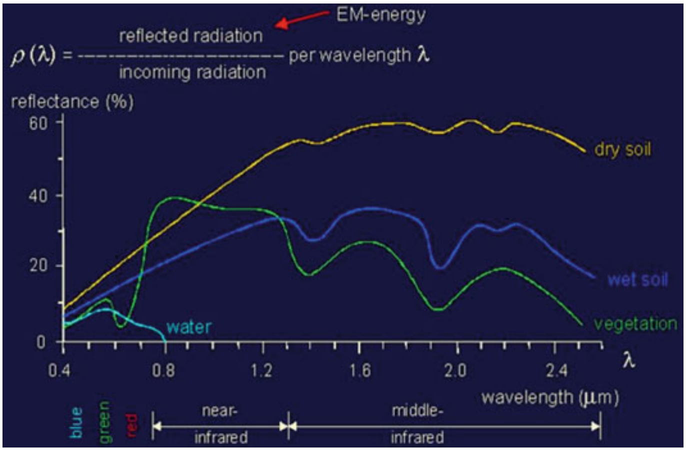

Fig. 7.5 Spectral curves for some features. *Source* CCRS (2012)

exhibiting higher reflectance than wet soil. The main part of water, except for shorter wavelength is absorbed with less reflection. Furthermore, Fig. 7.5 also shows that the near infra-red band represents the best region within which to distinguish between vegetation and most other object features like water.

7.3 Passive Versus Active Remote Sensing

On the basis of the scope of application and type of electromagnetic radiation employed, remote sensing may be divided into Weng (2010): (a) *satellite remote sensing* (when satellite platforms are employed), (b) *photogrammetry* (when photographic images are used to record reflected visible energy as discussed in Chap. 11), (c) *thermal remote sensing* (when the thermal infrared portion of the electromagnetic spectrum is used), (d) *microwave remote sensing* (when microwave wavelengths are employed as described in Chap. 9). and (e) *LiDAR* or *laser scanner remote sensing* (when laser pulses are directed toward the target and the distance between the sensor and the target is estimated premised on either the return time for pulse ranging or the phase difference for side tone (continuous wave) ranging as described in Sect. 8.4.

Based on how energy is used and detected, one can distinguish between two different forms of remote sensing (i) passive-and (ii) active remote sensing. Passive remote sensing systems record the reflected energy of electromagnetic radiation or the emitted energy from the Earth, such as cameras and thermal infrared detectors. On the other hand, active remote sensing systems send out their own energy and record the scattered energy received upon interaction with the Earth's surface, such as radar imaging systems and LiDAR.

One of the advantages of active sensors over their passive counterparts is that they can be used during both day and night or in most weather conditions. In addition, active remote sensors are also able to penetrate through cloud cover. This is unlike passive remote sensors for which sunlight is critical to their successful operation and cloud cover is an impedance and is thus undesirable. It is also possible to generate different imagery with different information content for the active remote sensors like radar imagery by simply altering the wavelength (or frequency) and the polarization of the transmitted and received signals.

7.4 Concluding Remarks

From its humble beginning, remote sensing has grown in stature over the past half century or so to influence virtually all aspects of human endeavor and the environment. Coupled with the availability of historical remote sensing (time-series) data, the reduction in data cost and increased spatial resolution, remote sensing technology appears poised to make an even greater impact on many socio-economic and political endeavors of mankind. Notably, the number of remote sensing applications is very impressive today, with many new applications emerging even in non-traditional areas like urban mapping, disaster management, location-based services, car and pedestrian navigation etc.

To realize the full potential of this mapping technology, however, it is imperative to integrate remote sensing with other related technologies that provide and deliver geospatial data and information such as *Global Navigation Satellite Systems* (GNSS), *inertial mapping units* (IMU) or other *rotation sensors*, *Geographic Information Systems* (GIS), *wireless sensor networks*, *Global System for Mobile Communication* (GSM), and the *Internet*.

In view of the multi-faceted and increasingly complex nature of most problems confronting humanity today, it is critical that the integration of the above technologies be implemented within the framework of a *decision support system* (DSS) elucidated in Sprague (1980), Bhatt and Zavery (2002), Shim et al. (2002), Power (2004) etc. Using disaster as a typical example, whereas mapping technologies like remote sensing, GNSS and GIS would provide the basic support in pre-event preparedness, response and monitoring, and post-reconstruction in disaster management, communication satellites and the Internet would help in disaster warning, relief mobilization and telemedicinal support Jayaraman et al. (1997). To leverage from these diverse technologies and to effectively respond to disasters in a coordinated, efficient and timely manner would call for building of the necessary DSS capability within a GIS platform.

References

Bhatt GD, Zavery J (2002) The enabling role of decision support systems in organizational learning. Decision Support Syst 32:297–309

CCRS (2012) Canada centre for remote sensing remote sensing tutorial. http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/. Accessed 24 July 2012

Jayaraman V, Chandrasekhar MG, Rao UR (1997) Managing the natural disasters from space technology inputs. Elsevier Science Ltd, Great Britain

Jensen, JR (2009) Remote sensing of the environment: an earth resource perspective. Prentice Hall, Saddle River

Kramer HJ (2002) Observation of the earth and its environment: survey of missions and sensors. Springer, Berlin

Lillesand TM, Kiefer RW, Chipman JW (2010) Remote sensing and image interpretation. John, Hoboken

Murai S (1999) GIS work book: fundamental and technical courses. vols 1 & 2. National Space Development Agency, New York

Murai S (2004) Remote sensing and GIS courses—distance education. Japan International Cooperation Agency (JICA)-Net

Power DJ (2004) Specifying an expanded framework for classifying and describing decision support systems. Commun Assoc Inf Syst 13:158–166

Richards JA (1994) Remote sensing digital image analysis: an introduction. Springer, Berlin

Shim JP, Warkentin M, Courtney JF, Power DJ, Sharda R, Carlsson C (2002) Past, present and future of decision support technology. Decision Support Syst 33:111–126

Sprague RH (1980) A framework for the development of decision support systems. MIS Q 4:1–26

Weng Q (2010) Remote sensing and GIS integration: theories, methods, and applications. McGraw-Hill, Boston, p 416