LAND-COVER AND LAND-USE MAPPING

Gerd Eiden
LANDSIS, Groupement Européen d'Intérêt Economique, Luxembourg

Keywords: land cover, land use, mapping, remote sensing, aerial photographs, area frame sampling

Contents

Summary

The paper illustrates different data-collection tools available for gathering primary data on land cover and land use. Emphasis is placed on technical aspects of remote-sensing imagery, aerial-photo interpretation, and area frame sampling surveys.

The paper describes successively the basic principles, underlying concepts, and possible outputs, as well as different methodologies and approaches. These technical explanations are necessary for assessing both the potential application of the tools and the quality of the information return.

1. Introduction

Land-cover and land-use information are required for many different kinds of spatial planning, from urban planning at a local level up to regional development. They play an important role in agricultural policy making. Moreover, land-cover data are used as basic information for sustainable management of natural resources; they are increasingly needed for the assessment of impacts of economic development on the environment. Hence, they are fundamental for guiding decision making at various geographical levels.

Various tools and methods for collecting land-cover and land-use information have been developed to satisfy the user requirements and the information demand.

2. Space Remote-Sensing Imagery

The advent of the first satellite images in the 1970s pioneered an innovative observation of Earth. Many projects demonstrated the usefulness of remote sensing, particularly for land-cover mapping.

The Canadian Center for Remote Sensing (1999) has defined remote sensing as "the science (and to some extent, art) of acquiring information about Earth's surface without actually being in contact with it." This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. Since the 1980s, a vast number of satellite missions have been dedicated to the observation of Earth, and these have demonstrated the great variety of potential applications of remote-sensing imagery, far beyond the simple mapping of land cover.

2.1. Principles

In order to understand properly the use of satellite images, it is necessary to explain the basic principles of remote sensing, which can briefly be summarized as follows. Earth's surface is illuminated by a wide spectrum of electromagnetic radiation coming from the sun. Table 1 shows different parts of the electromagnetic spectrum ranging from the ultraviolet part up to the far infrared region.

Spectral range		Wavelength in μm
Ultraviolet		<0.3
Visible part of the spectrum	Violet	0.4–0.446
	Blue	0.446–0.500
	Green	0.500–0.578
	Yellow	0.578–0.592
	Orange	0.592–0.620
	Red	0.620–0.7
reflected infradred		0.7–3.0
thermal infrared		3.0–100

Table 1. The electromagnetic spectra

All objects on Earth's surface (targets) are interfering with radiation as targets reflect, transmit, or absorb the incoming electromagnetic waves. The process that takes place depends on the physical and chemical structure of the target and on the wavelength involved. The reflected part of the spectrum is the most important for remote-sensing applications dealing with land. Over the different wavelengths, targets reflect in a specific, and in some cases unique, way (Figure 1). This characteristic spectral response of objects enables their identification by means of remote sensing. Comparing the response patterns of different features of Earth's surface in different spectral ranges makes the different objects distinguishable.

Green Vegetation: Chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Therefore, leaves appear green in the summer, when their chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionally more reflection of the red wavelengths, making the leaves appear red or yellow. The internal structure of healthy leaves acts as a strong reflector of near-infrared wavelengths. The near-IR/red ratio is the basis for many vegetation indices, used for vegetation monitoring. The specific reflection properties of each plant enable the identification and differentiation of different plants.

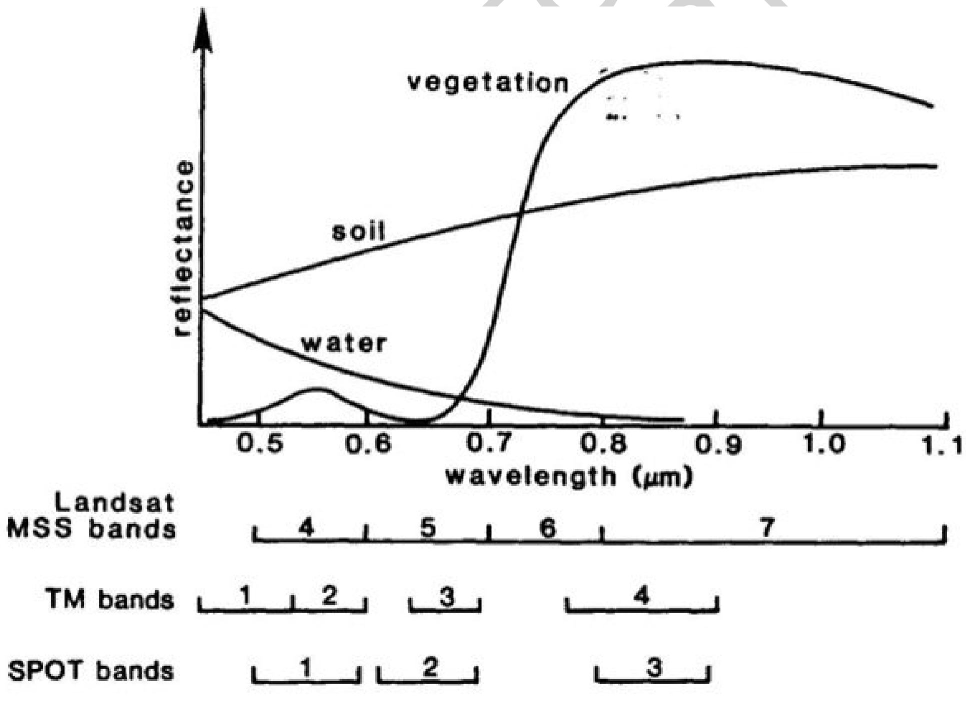

Figure 1. Spectral response of some common surfaces and spectral bands of satellite sensors

Water: Water absorbs the longer wavelengths in the visible range and the near infrared radiation more 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 near infrared wavelengths. If there is suspended sediment present in the upper layers of the water body, then this will allow a better reflectivity and brighter appearance of the water.

Soil and Minerals: The reflection patterns of soils exhibit stronger spectral features. The reflection depends mainly on the mineral composition, the grain size, the water, and the organic content of the soil. The drier, purer soils have a lower emission in this range of the spectrum.

The spectral response can be quite variable, even for the same target type, and can also vary with time and location. In addition, the spectral response is influenced by the atmospheric conditions during image acquisition because the radiation transfer strongly depends on the water and dust content in the atmosphere. Knowing where to "look" spectrally and understanding the factors influencing the spectral response of the features of interest are crucial for the correct interpretation of remotely sensed images and their results.

Remote sensors acquire data using scanning systems, which employ a sensor with a narrow field of view that sweeps over the terrain to build up and produce a two-dimensional image of the surface (raster image, Figure 2).

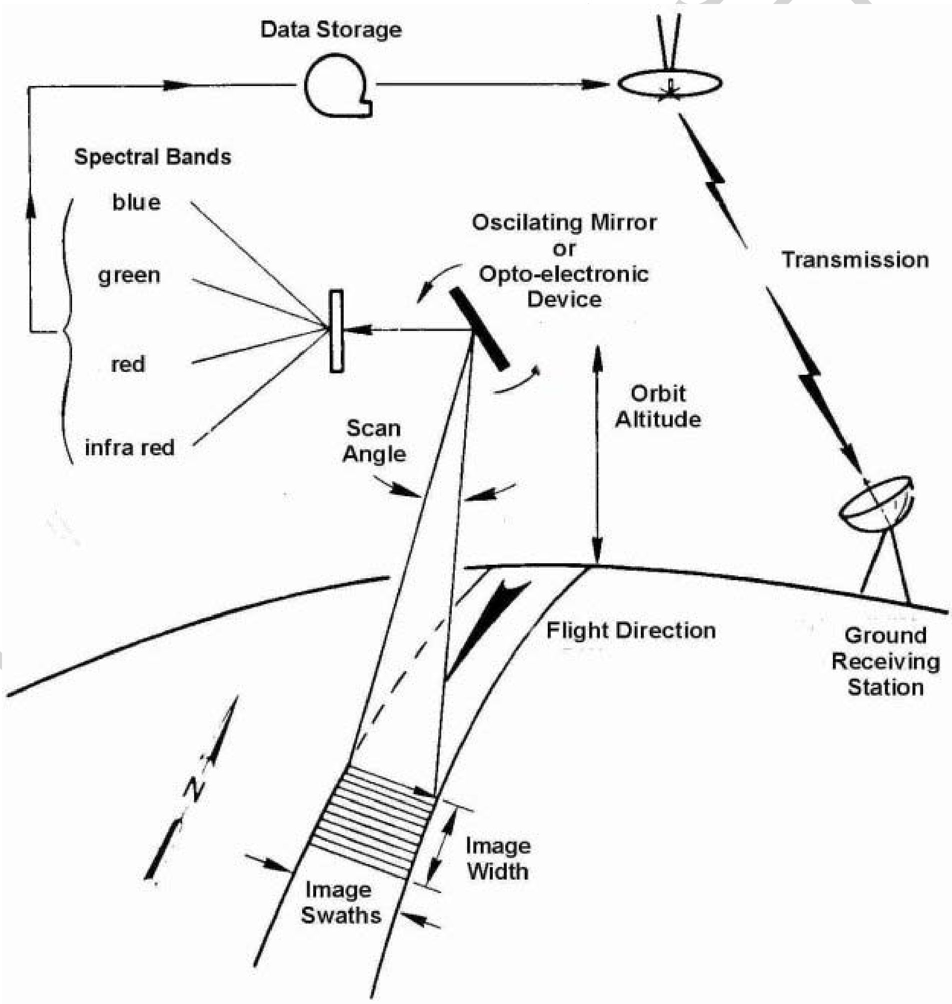

Figure 2. Principle of data recording, scanning process

Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. The scanning systems measure the reflected (or emitted) energy simultaneously over a variety of different wavelength ranges (spectral bands). Both, the size of the raster cells (or Picture Elements or pixels) and the wavelength ranges measured depend on the technical specification of the sensor (spatial and spectral resolution).

A scanning system has several advantages over photographic systems. The spectral range of photographic systems is restricted to the visible and near-infrared regions while a multispectral scanner can extend this range to the thermal infrared. They are also capable of much higher spectral resolution than photographic systems. Multispectral photographic systems use separate lens systems to acquire each spectral band simultaneously. Photographic systems record the energy detected on an emulsion on film by means of a photochemical process that is difficult to measure and to make consistent. Because scanner data are recorded electronically, it is easier to determine the specific amount of energy measured, and they can record greater range of values in a digital format.

2.2. Satellite Platforms

Several satellite platforms equipped with specific imaging sensors are in operation. In the following section a brief overview of the most commonly used satellites is given.

LANDSAT: Since 1972, the American satellite Landsat delivers multispectral imagery of Earth's surface. Landsat Satellites 1–3, operational until 1983, were equipped with the Multispectral Scanner (MSS) with the following specifications: four bands, image size 185 km × 185 km, pixel size 80 m × 80 m. Landsat 4 (launched 1982) and Landsat 5 (launched 1984) carried in addition to the Multispectral Scanner the Thematic Mapper sensor (TM), characterized by seven spectral bands, image size of 185 km × 185 km, pixel size 30 m × 30 m). The payload of Landsat 7, operational since April 1999, consists of an Enhanced Thematic Mapper sensor (ETM). In addition to the multispectral bands, similar to those of Landsat 5, the ETM sensor scans Earth in a panchromatic band with a pixel size of 15 m × 15 m. During the operational phase of the Landsat satellite program an extensive archive of satellite images was created, which offers a retrospective view and the analysis of changes.

SPOT: The French SPOT satellites (Système Probatoire d'Observation de la Terre) were initiated in 1986 with SPOT 1, followed by SPOT 2 in 1990 and SPOT 3 in 1993. The HRV (Haute Résolution Visible) sensor on board delivers imagery within three spectral bands with a pixel size of 20 m × 20 m and a panchromatic band with 10 m × 10 m pixel size taken from an orbit altitude of 830 km. The SPOT 4, launched in 1998, carries also the so-called “vegetation instrument” producing imagery with four bands (blue, red, near infrared, and shortwave infrared) with a pixel size of 1 km × 1 km and a width of 2250 km. The launch of SPOT 5 with a sensor producing panchromatic images with 5 m × 5 m pixel size is planned.

IRS: The first Indian Remote-sensing satellite (IRS-1A) was launched in 1988. The sensors carried by the most recent IRS-1D platform produce a panchromatic image with a 5.8 m × 5.8 m pixel size, a four-band imagery with 23.5 m × 23.5 m pixel size (LISS) and a two-band imagery with 188 m × 188 m pixel size (WiFS).

IKONOS: The IKONOS satellite, the first commercial high-resolution satellite, is operational since the end of 1999. The satellite, flown at an altitude of 681 km, carries two independent sensors, scanning Earth's surface in a strip of 11 km width and up to 1000 km length. With a ground resolution of 1 m × 1 m (panchromatic) and 4 m × 4 m (multispectral), the sensor provides high-quality images that are close to aerial photography, enabling new applications of satellite remote-sensing imagery in a wide field of subjects.

NOAA–AVHRR: The Advanced Very High Resolution Radiometer (AVHRR) on board the NOAA (National Oceanic and Atmospheric Administration) satellites was originally designed for meteorological purposes. Therefore the technical specifications are quite different from those satellites developed for land applications (like Landsat, SPOT, or IRS). The AVHRR sensor is recording the spectral reflectance in the red and near infrared wavelength and the emitted energy (temperature) in the middle and long infrared region. Information about temperature, particularly of clouds, is of specific interest for meteorologists. The broad spatial resolution of the AVHRR sensor of 1.1 km and the wide scan angle of 55° enable a synoptic view of huge areas of ~2000 km width (Landsat TM: 185 km). The technical properties and the fact that at least two satellites are in operation at the same time, enables the provision of a daily coverage of the entire Earth and allows a continuous monitoring, which is of particular importance for weather forecasts and other meteorological subjects.

RADARSAT, ERS: From the conceptual and technical point of view, radar satellite systems are quite different from those mentioned so far. In contrast to sensors, measuring radiance coming from the sun and reflected or emitted from Earth's surface (passive systems), radar sensors actively send their own signals and record the reflected proportion of that signal. The structural properties of the targets determine the way of the reflection, thus enabling their identification. The advantage of radar systems is the capability to penetrate clouds, so that the image acquisition is independent from the atmospheric conditions. Radar systems are of minor importance for land-cover/land-use mapping applications and therefore not exhaustively treated here. They are more frequently used for geological purposes, sea ice, or oil-spill detection. The Canadian RADARSAT and the European ERS-1 and -2 satellites are two radar satellite systems working operationally.

2.3. Remote-Sensing Image Properties

The technical specifications of the sensors and the orbit characteristics of the satellite platforms mainly determine the capabilities and the potential mapping applications of remote-sensing images. The most relevant issues are explained in the following chapter.

2.3.1. Spectral Resolution

As mentioned above, features or targets of Earth's surface can be characterized and distinguished by the spectral reflectance over a variety of wavelengths. Satellite sensors are measuring the reflected radiation of the surface in different spectral intervals, so-called spectral bands or channels, in order to capture these differences. The capability of a satellite sensor to identify targets on Earth's surface depends to a great extent on the number of spectral bands, the so-called spectral resolution.

Sensor	**Spectral resolution**		**Spatial resolution**	**Recommended maximum working scale (approximate)**
	Channel	**Wavelength Range (in μm)**		
Landsat MSS	MSS 1	0.5–0.6 (green)	80 × 80 m	1:500.000
	MSS 2	0.6–0.7 (red)		
	MSS 3	0.7–0.8 (near infrared)		
	MSS 4	0.8–1.1 (near infrared)		
Landsat TM/ ETM	TM 1	0.45–0.52 (blue)	30 × 30 m	1:200.000
	TM 2	0.52–0.60 (green)		
	TM 3	0.63–0.69 (red)		
	TM 4	0.76–0.90 (near IR)		
	TM 5	1.55–1.75 (short wave IR)		
	TM 6	10.4–12.5 (thermal IR)	120 × 120 m	
	TM 7	2.08–2.35 (short wave IR)		
Landsat ETM	Panchromatic	0.52–0.9	15 × 15 m	1:100.000
SPOT Pan	Panchromatic	0.51–0.73 (blue-green-red)	10 × 10 m	1:50.000
SPOT XS Multispectral	Band 1	0.50–0.59 (green)	20 × 20 m	1:100.000
	Band 2	0.61–0.68 (red)		
	Band 3	0.79–0.89 (near infrared)		
SPOT Vegetation	Channel 1	0.50–0.59 (green)	1000 × 1000 m	1:1.5 Mio
	Channel 2	0.61–0.68 (red)		
	Channel 3	0.79–0.89 (near infrared)		
	Channel 4	1.58–1.75 (short wave IR)		
IRS Pan	Panchromatic	0.5–0.75 (blue-green-red)	5.8 × 5.8m	1:15.000
IRS LISS	Band 2	0.52–0.59 (green)	23.5 × 23.5 m	1:100.000
	Band 3	0.62–0.68 (red)		
	Band 4	0.77–0.86 (near infrared)		
	Band 5	1.55–1.7 (short wave IR)		
IRS WiFS	Band 3	0.62–0.68 (red)	188 × 188 m	1:500.000
	Band 4	0.77–0.86 (near infrared)		
NOAA AVHRR	Channel 1	0.58–0.68 (red)	1100 × 1100 m	1:1.5 Mio
	Channel 2	0.725–1.1 (near IR)		
	Channel 3	3.55–3.93 (middle IR)		
	Channel 4	11.3–11.3 (thermal IR)		
	Channel 5	11.4–12.4 (thermal IR)		
IKONOS	Panchromatic	0.45–0.90	1 × 1 m	1:5000
Multispectral	Channel 1	0.45–0.52 (blue)	4 × 4 m	1:15.000
	Channel 2	0.52–0.60 (green)		

	Channel 3	0.63–0.69 (red)		
	Channel 4	0.79–0.90 (near IR)		

Table 2. Spatial resolution, spatial resolution and recommended working scale (approximation) of common remote-sensing instruments.

The spectral resolution describes the ability of a sensor to distinguish between fine wavelength intervals. Remote-sensing systems record reflected proportions of radiation in several separate wavelength ranges (so-called spectral bands or channels) at various spectral resolutions. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band, the better different objects can be detected and distinguished. Advanced multispectral sensors, called hyperspectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near infrared, and mid-infrared portions of the electromagnetic spectrum. Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.

Table 2 shows the spectral resolution of common sensors used for land applications. With seven spectral bands, the Landsat Thematic Mapper sensor enables the best discrimination of objects, while SPOT and IRS are operating only with three and four spectral bands, respectively.

SPOT, IRS, and the latest Landsat ETM sensors are operating also in a panchromatic mode, scanning Earth in a broad wavelength range (visible spectrum) and with a higher spatial resolution than the multispectral bands.

-
-
-

Bibliography

Albertz J. (1991). Grundlagen der Interpretation von Luft- und Satellitenbildern: Eine Einführung in die Fernerkundung. Wissenschaftliche Buchgesellschaft Darmstadt [This is a basic textbook for the interpretation of remote-sensing data.]

Canadian Center for Remote Sensing (1999). Fundamentals of Remote Sensing Tutorial. <http://www.ccrs.nrcan.gc.ca.ccrs/eduref/ref/glosndxe.html>.

Cochran W.G. (1977). *Sampling Techniques.* Third edition, 428 pp. New York: Wiley [(This book gives a good overview of the various sampling techniques.]

Cotter J. and Nealon J. (1987). *Area Frame Design for Agricultural Surveys*. 67 pp. Washington, DC: United States Department of Agriculture, National Agricultural Statistics Service, Research and Applications Division

Drury S.A. (1990). *A Guide to Remote Sensing*, 199 pp. Oxford: Oxford Press [This book provides an overview of what can be done with remote-sensing techniques.]

FAO (Food and Agriculture Organization of the United Nations) (1996). Multiple Frame Agricultural Surveys. Current Surveys Based on Area and List Frame Sampling Methods. FAO Statistical Development Series, Vol. 1. 119 pp. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations) (1998). *Multiple Frame Agricultural Surveys. Agricultural Survey Programs Based on Area Frame or Dual Frame (Area and List) Sample Designs.* FAO Statistical Development Series Vol. 2. 242 pp. Rome: FAO.

Gallego F.J. (1995): *Sampling Frames of Square Segments*. 72 pp. Luxembourg: Office for Official Publications of the European Communities. [This is a guide on sampling techniques.]

Lillesand T.M. and Kiefer R.W. (1994). *Remote Sensing and Image Interpretation*. Third edition. 750 pp. New York: Wiley. [This is a basic textbook on the interpretation of remote-sensing data.]

NASA Goddard Space Flight Applied Information Sciences Branch Center (1999). *Remote Sensing and Photo Interpretation Tutorial*. <http://rst.gsfc.nasa.gov/TofC/table.html>.

Sabins F.F. (1987). *Remote Sensing Principles and Interpretation*, second edition, 449 pp. San Francisco: W.H. Freeman & Co. [This is another basic textbook.]

Weissel, J. (1999). *Glossary. Lamont-Doherty Earth's Observatory of Columbia University*. <http://rst.gsfc.nasa.gov/Glossary/glossary.html>.

Biographical Sketch

Gerd Eiden (PhD, MSc in physical geography) is project manager at LANDSIS g.e.i.e. in Luxembourg. His main job is the development of methods and tools for gathering information on land cover and land use within the statistical framework of the European Commission. He is currently working on the exploitation of land-use and land-cover data for environmental indicators, particularly focusing on the assessment of land-cover and land-use change and the impact on landscapes at European level. Formerly, he was a consultant on natural resource assessment and desertification monitoring using remote-sensing data and GIS techniques in developing countries.