Chapter 1. What is Sensing?

"Remote sensing is the science (and to some extent, art) of acquiring information about the 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".
(Source: CCRS Tutorial "Fundamentals of remote sensing")

1.1 Introduction

Remote sensing (RS), also called earth observation, refers to obtaining information about objects or areas at the Earth's surface by using electromagnetic radiation (light) without being in direct contact with the object or area. So, remote sensing is day to day business for people. Reading the newspaper, watching cars driving in front of you, looking at a lecturer during a course are all remote sensing activities. The human eyes register the solar light reflected by these objects and your brains interpret the colours, the grey tones and intensity variations. Next, these data are translated into useful information. The human eye, however, is limited to a small part of the total electromagnetic spectrum i.e. approximately 400 to 700 nm. In remote sensing various kinds of tools and devices are used to make electromagnetic radiation outside this range from 400 to 700 nm visible to the human eye, especially the near-infrared, middle-infrared, thermal-infrared and microwaves. Increasingly, remote sensing is used to acquire information about environmental processes such as agricultural crop growth, land cover changes, deforestation, vegetation dynamics, water quality dynamics, urban growth, etc. In this chapter we provide a brief historic sketch and summarise the basic concepts of remote sensing.

1.2 Historic overview

In 1859 Gaspard Tournachon took an oblique photograph of a small village near Paris from a balloon. With this picture the era of earth observation and remote sensing had started. His example was soon followed by other people all over the world. During the Civil War in the United States aerial photography from balloons played an important role to reveal the defence positions in Virginia. Likewise other scientific and technical developments this Civil War time in the United States speeded up the development of photography, lenses and applied airborne use of this technology. Although the space era of remote sensing was still far away after the Civil War, already in 1891 patents were granted in Germany to successful designs of rockets with imaging systems under the title: 'new or improved apparatus for obtaining bird's eye photographic views of the Earth'. The design comprised a rocket propelled camera system that was recovered by a parachute. Table 1.1 shows a few important dates in the development of remote sensing.

The next period of fast development took place in Europe and not in the United States. It was during World War I that aeroplanes were used on a large scale for photo reconnaissance. Aircraft proved to be more reliable and more stable platforms for Earth observation than balloons. In the period between World War I and World War II a start was made with the civil use of aerial photos. Application fields of airborne photos included at that time geology, forestry, agriculture and cartography. These developments lead to much improved cameras, films and interpretation equipment. The most important developments of aerial photography and photo interpretation took place during World War II. During this time span the development of other imaging systems such as near-infrared photography, thermal sensing and radar took place. Near-infrared photography and thermal-infrared proved very valuable to separate real vegetation from camouflage. The first successful airborne imaging radar was not used for civilian purposes but proved valuable for nighttime bombing. As such the system was called by the military 'plan position indicator' and was developed in Great Britain in 1941.

Table 1.1: Milestones in the History of Remote Sensing

1800	Discovery of Infrared by Sir W. Herschel
1839	Beginning of Practice of Photography
1847	Infrared Spectrum Shown by J.B.L. Foucault
1859	Photography from balloons
1873	Theory of Electromagnetic Spectrum by J.C. Maxwell
1909	Photography from Airplanes
1916	World War I: Aerial Reconnaissance
1935	Development of Radar in Germany
1940	WW II: Applications of Non-Visible Part of the electromagnetic spectrum
1950-	Military Research and Development
1959	First Space Photograph of the Earth (Explorer-6)
1960	First TIROS Meteorological Satellite Launched
1970	Skylab Remote Sensing Observations from Space
1972	Launch Landsat-1 (ERTS-1): MSS sensor
1972-	Rapid Advances in Digital Image Processing
1982	Launch of Landsat-4: New Generation of Landsat Sensors: TM
1986	French Commercial Earth Observation Satellite SPOT
1986	Development Hyperspectral Sensors
1990-	Development High Resolution Spaceborne Systems
	First Commercial Developments in Remote Sensing
1991	Launch of the first radar satellite ERS-1 by ESA
1992	Launch of radar satellite JERS-1 by Japan
1995	Launch of Radarsat by Canada
1995	Launch of ERS-2 by ESA
1999	Launch EOS: NASA Earth Observing Mission 'Terra' with MODIS and ASTER
1999	Launch of IKONOS, very high spatial resolution sensor system
2001	Launch of QuickBird, very high spatial resolution sensor system
2002	Launch of 'Aqua' with MODIS by NASA
2002	Launch of Envisat-1 with optical and radar instruments by ESA
2008	Launch of GeoEye
2009	Launch of WorldView-2 by DigitalGlobe
2013	Launch of Landsat-8 by NASA/USGS
2015	Launch of Sentinel-1 by ESA
2016	Launch of Sentinel-2 by ESA
2016	Launch of Sentinel-3 by ESA

After the wars in the 1950s remote sensing systems continued to evolve from the systems developed for the war effort. Colour infrared photography (CIR) was found to be of great use for the plant sciences. In 1956 experiments were conducted by Colwell on the use of CIR for the classification and recognition of vegetation types and the detection of diseased and damaged or stressed vegetation. It was also in the 1950s that significant progress in radar technology was achieved. Two types of radar were developed at that time: SLAR: side-looking airborne radar, and SAR: Synthetic Aperture Radar. Either development aimed at the acquisition of images at the highest possible resolution. Crucial to the SAR development was the ability to finely resolve the Doppler frequencies using a frequency analyses algorithm on the returning radar signal by the US Air Force research centre.

1.3 The space era

In the early 1960s the US started placing remote sensors in space for earth observations. TIROS (Television Infrared Observation Satellite) was the first meteorological satellite. A long series of meteorological satellites followed this one. 1960 was also the beginning of a famous US military space imaging reconnaissance program called Corona. Unfortunately, much of this programme remained classified until 1995. In 1970 the TIROS programme was financed by and renamed into NOAA (National Oceanic and Atmospheric Administration). Until today the NOAA Advanced Very High Resolution Radiometer (AVHRR) is orbiting the globe and collecting information on weather patterns in visible, near-infrared and thermal wavelengths. NOAA-19 was launched on 6 February 2009. It may also be used for other (monitoring) applications. The 1950s and 1960s were also important for the organisational development of remote sensing. Various civil research organisations and universities became highly interested in these new technologies. Today remote sensing is not only taught at the university level but also at high schools.

In the early 70s the first satellite specifically designed to collect data of the Earth's surface and its resources was developed and launched: ERTS-1 Earth Resources Technology Satellite (later in 1975 this programme was renamed into Landsat). This first earth resources satellite was in fact a modified Nimbus weather satellite carrying two types of sensors: a four waveband multi-spectral scanner (MSS) and three return beam vidicon television cameras (RBV). The sensors aboard this satellite proved to be able to collect high quality images with a reasonable detail. These images gave remote sensing a world-wide recognition as a valuable technology. The main advantages recognized at that time were: ready availability of images for most of the world, lack of political, security and copyright restrictions, low cost, repetitive multi-spectral coverage and minimal image distortion.
Landsat 2 and 3 were launched in 1975 and 1978, respectively, and carried the same payload as the first satellite of this series. The payload was changed in 1982 with Landsat 4. The RBV was replaced by the technically more advanced Thematic Mapper (TM) sensor. An improved design of the TM, the ETM+ (Enhanced Thematic Mapper) was mounted aboard Landsat 7 and launched in 1999. The Landsat series is a very successful programme, various MSS and TM sensors exceeded by far its design life time and its imagery is probably the most widely used data in the Earth sciences. One black spot on its history record is the 'failure upon launch' of Landsat 6 in 1993.
Finally, on 11 February 2013 the Landsat programme was continued with the launch of Landsat 8. Originally called the Landsat Data Continuity Mission, it has a two-sensor payload, the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS). Respectively, these two instruments collect image data for nine shortwave bands and two longwave thermal bands.

The Landsat programme was followed by various other successful earth observation missions carried out by other countries. In 1978, the French government decided to develop their own

earth observation programme. This programme resulted in the launch of the first SPOT satellite in 1986. To the original SPOT design of three spectral bands a new sensor called Vegetation was added aboard SPOT-4 in 1998. In 2002 SPOT-5 has been launched. Spatial resolution was increased to either 2.5 or 5 m panchromatic imagery, 10 m in the visible and near-infrared and 20 m in the middle-infrared. SPOT-6 (launched 9 September 2012) and SPOT-7 (launched 30 June 2014) have 4 multispectral bands at 6 m and a panchromatic band at 1.5 m.
Other earth observation missions are the Indian Remote Sensing Programme (IRS) that started in 1988, the Russian Resurs series, first launched in 1985, and the Japanese ADEOS (Advanced Earth Observing Satellite) put in orbit in 1996. The European Space Agency (ESA) launched its first remote sensing satellite (ERS-1) in the year 1991. ERS carries various types of sensors aboard among which the AMI, a C-band (5 cm radar) active microwave instrument. The main focus of the ERS programme is oceanographic applications although it is also widely used for monitoring tropical forests. In 1995, ERS-2 was successfully launched. In March 2002, ESA launched Envisat-1, an earth observation satellite with an impressive payload of 10 instruments such as a synthetic aperture radar (ASAR) and a Medium Resolution Imaging Spectrometer (MERIS). More recently, ESA moved to more operational missions within the Copernicus programme, called the Sentinels. Sentinel-1A was launched on 3 April 2014 as a radar mission and is considered a continuation on the ASAR sensor on Envisat. Sentinel-2A is an optical mission launched on 23 June 2015 as a continuation of the Landsat programme. Its Multi Spectral Instrument (MSI) covers the VNIR/SWIR spectral region in 13 bands and incorporates two new spectral bands in the red-edge region. It carries 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m (the latter for atmospheric corrections). Finally, Sentinel-3A, launched 16 February 2016, is a continuation of the MERIS sensor on Envisat.

An important development has been the launch of Ikonos in 1999. Ikonos has a multispectral system collecting information in 4 bands (blue, green, red and near-infrared) at a spatial resolution of 4 m. Ikonos has also a panchromatic mode (0.45-0.90 μm) with a spatial resolution of 1 m. In 2001, QuickBird was launched with similar bands as Ikonos, but with a spatial resolution of 2.44 m and 0.61 m, respectively. OrbView-3, launched in 2003, is very similar to Ikonos. GeoEye, launched in 2008, operates even at spatial resolutions of 1.64 m and 0.41 m, respectively. In 2009 WorldView-2 has been launched, having an increased number of spectral bands: 8 multispectral bands at 1.8 m and a panchromatic band at 0.46 m. WorldView-3 (launched on 13 August 2014) and WorldView-4 (launched on 11 November 2016) have multispectral bands at 1.24 m and a panchromatic band at 0.31 m. With these commercial systems, spaceborne remote sensing approaches the quality of airborne imaging.

1.4 Concepts of remote sensing

Remote sensing (RS) refers in a general sense to the instrumentation, techniques and methods used to observe (sense) the surface of the Earth, usually by the formation of an image in a position – stationary or mobile – at a distance remote from that surface (after Buiten & Clevers, 1993). In remote sensing electromagnetic (EM) radiation coming from an object (in case of earth observation: the Earth’s surface) is being measured and translated into information about the object or information on processes related to the object. In the measurement phase the following components are relevant:
(A) the source of the EM radiation;
(B) the path through the atmosphere;

(C)	the interaction with the object;
(D)	the recording of the radiation by a sensor.
These comprise the remote sensing system as illustrated in Figure 1.1.

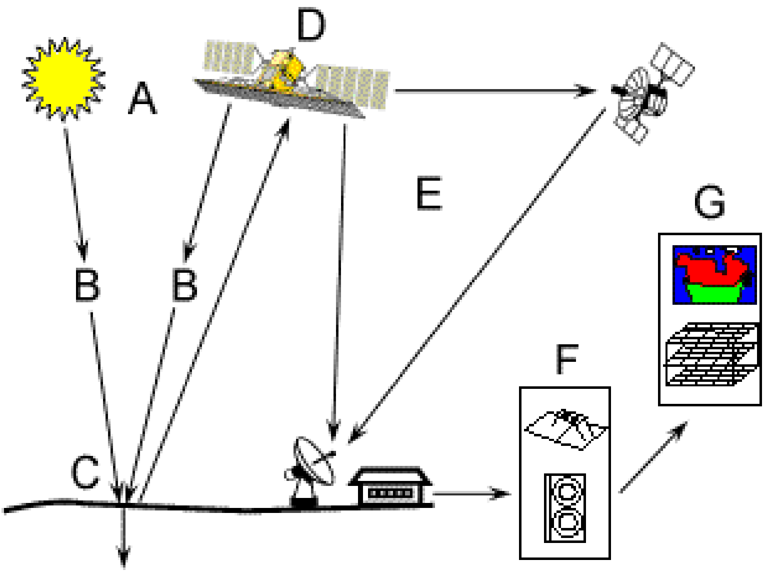

Figure 1.1: The remote sensing system (see text for explanation of letters).

The second phase can be considered to cover the following components:
(E)	transmission, reception end (pre)processing of the recorded radiation;
(F)	interpretation and analysis of the remote sensing data (mostly using a computer);
(G)	creation of the final product, which is mostly stored as a GIS layer.
The individual components will be briefly described in the next sections.

1.4.1 Source of EM radiation

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

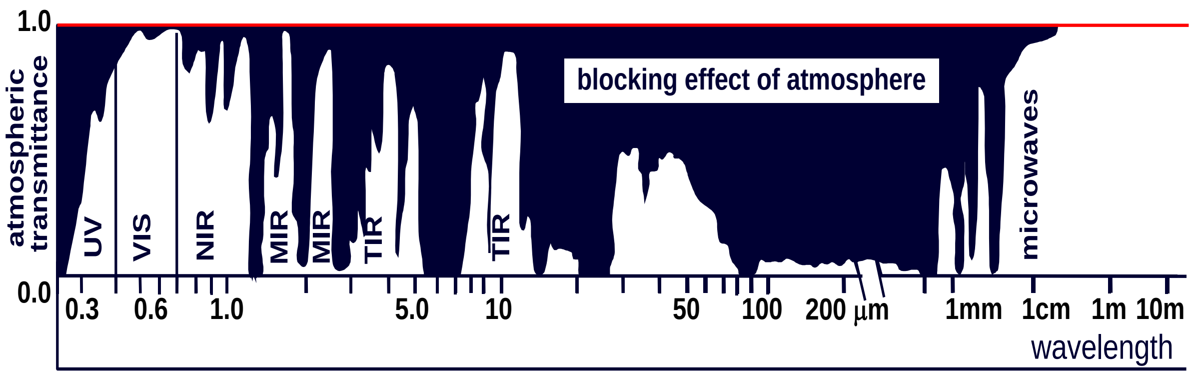

Figure 1.2: Atmospheric transmittance for radiation as a function of the wavelength.

1.4.2 The atmosphere

Before solar radiation reaches the Earth's surface, the atmosphere will influence it (Figure 1.1). In addition, the atmosphere will influence reflected solar radiation or emitted radiation by an object at the Earth’s surface before an airborne or spaceborne sensor detects it. The atmosphere consists mainly of molecular nitrogen and oxygen (clean dry air). In addition, it contains water vapour and particles (aerosols) such as dust, soot, water droplets and ice crystals. The changes of the radiation can vary with wavelength, condition of the atmosphere and the position of the sun. The most important processes influencing the radiation in the atmosphere are scattering and absorption. Scattering effects can be divided into Rayleigh, Mie and non-selective scattering. These processes lead to the formation of diffuse radiation. A portion of the diffuse radiation goes back to space and a portion reaches the ground. The radiation, which has not been scattered, is called direct radiation. Absorption is caused, for example, by the presence of water vapour in the atmosphere. Scattering and absorption in the atmosphere cause a transmission loss of the solar radiation before it reaches the Earth's surface. This is illustrated in Figure 1.2. In parts of the EM spectrum the atmosphere is not or hardly transparent, thus these parts are not suitable for remote sensing. Those parts of the spectrum where the atmospheric transmittance is high, are useful for remote sensing and they are called “atmospheric windows”.

1.4.3 Object – radiation interaction

When EM radiation hits an object at the Earth’s surface, it can be transmitted, absorbed or reflected. The mutual magnitude of these processes is determined by the properties of the object. In remote sensing we can measure the amount of reflected solar radiation as a function of wavelength, called spectral reflectance. Figure 1.3 illustrates the spectral reflectance of some typical objects. Water absorbs most of the incoming radiation and reflects only a small amount of radiation (particularly in the visible part of the spectrum; at longer wavelengths water does not reflect any significant radiation). Soils exhibit quite a smooth spectral reflectance curve. Distinct features are found in narrow spectral bands caused by absorption by minerals and iron oxide. Broader features occur at about 1.4 µm and at about 1.9 µm, due to absorption by water. The absorption by water also causes the gradually decreasing reflectance with increasing wavelength in the MIR region. The moisture content of the soil causes the spectral reflectance of a wet soil to be lower than that of a dry soil. Vegetation, on the other hand, shows a very characteristic reflectance curve. The reflectance in the visible part of the spectrum is low due to absorption of this radiation by the chlorophyll in the green plant parts. In the NIR region hardly any absorption occurs, and reflectance is determined by the amount of transitions between cell walls and air vacuoles in the leaf tissue. As a result, NIR reflectance of green vegetation is high, and a steep slope occurs in the curve at about 0.7 µm (the so-called red-edge region). In the MIR region we observe a similar influence of water as observed for soils (see further chapter 2 on "Spectral Signatures").

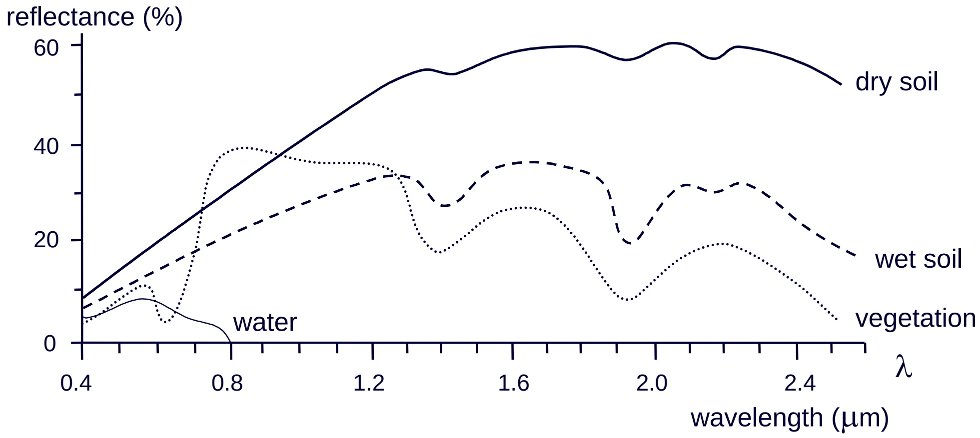

Figure 1.3: Typical spectral reflectance curves for water, soil and vegetation.

In the TIR part of the spectrum the amount of emitted radiation is measured. This amount can be related to the temperature of the feature observed. This provides information on, e.g., the (evapo)transpiration of the surface and thus gives relevant information for energy balance studies.

An important property of the long wavelengths used in the microwave region is that they are not susceptible to atmospheric scattering. As a result they can penetrate through cloud cover, haze and all but the heaviest rainfall. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture properties (e.g., soil) of the emitting object. Since the amounts of emitted energy generally are very small, a passive microwave sensor is therefore characterised by a low spatial resolution (typically 50 km).

Active microwave sensors provide their own source of illumination. They are called radars and measure the amount of energy scattered back towards the radar antenna. The radar echo is depending on the properties of the radar system (like frequency, polarisation and the viewing geometry) and on the properties of the object (like roughness and electrical properties). So, with radar we get information on object properties like the geometry (terrain topography), roughness (height variations in relation to the applied wavelength) and moisture (determining the electrical properties of a soil or vegetation).

1.4.4 Sensors

Remote sensing instruments capable of measuring EM radiation are called sensors. They can be classified as follows:

(1) Passive sensors do not have their own source of radiation. They are sensitive only to radiation from a natural origin, usually reflected sunlight or the energy emitted by an object on Earth. The classical example of a passive imaging sensor is the photographic camera, which records the distribution of radiation from an object on a photosensitive emulsion spread out on a film. Other examples are the multispectral scanner, the thermal scanner and the microwave radiometer. Both sensor and object are passive.

(2) Active sensors have a built-in source of radiation. The object measured by the sensor is passive. Examples are the radar (radio detection and ranging) and lidar (light detection and ranging).

Radiation can be recorded in an analogue form (the aerial photograph is a particular example) or in a digital arrangement (a set of signal values on a magnetic tape or disk, as in most RS sensors at present). Visualised images (pictures) may be derived from digital data of imaging sensors. Before proceeding it is advisable to indicate which properties permit the observation and recognition of an object. They are as follows:

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

(2) Reflective and/or emissive properties of the object; the dynamic range and the radiometric resolution are important for the sensor. This dynamic range is defined as the number of digital levels in which the observed reflection or emission can be stored (e.g., 0 – 255).

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

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

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

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

1.4.5 Transmission, reception and (pre-) processing

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

1.4.6 Image analysis and interpretation

The outstanding advantage of digital recordings is that numerous manipulations can be applied to the observational data according to the methods of digital image processing and pattern recognition. A very extended set of algorithms can be applied in an automated way by using one of the various software packages for image analysis that are on the market. In principle, three categories of information can de derived from remote sensing (see also chapter 6 on "Digital Image Processing"):

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

Observing, for example, the properties of vegetation, one has to pay attention to numerous variables. Examples of these are the irradiance, the direction of the radiation source, the condition of the atmosphere and its influence on the detected radiation, the presence of surrounding objects, the viewing angle of the sensor and, last but not least, the variation of the vegetation itself. In summary, information about the Earth's surface and its features may be obtained by detection on the basis of:

- spectral characteristics (wavelength or frequency, reflective or emissive properties);
- spatial characteristics (viewing angle of the sensor, shape and size of the object, position, site, distribution, texture);
- temporal characteristics (changes in time and position).

1.4.7 The final product

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

1.5 Data integration

In the early days of analogue remote sensing when the only remote sensing data source was aerial photography, the capability for integration of data from different sources was limited. Today, with most data available in digital format from a wide array of sensors, data integration is a common method used for interpretation and analysis. Data integration fundamentally involves the combining or merging of data from multiple sources in an effort to extract better and/or more information (Figure 1.4). This may include data that are multitemporal, multiresolution, multisensor, or multi-data type in nature.

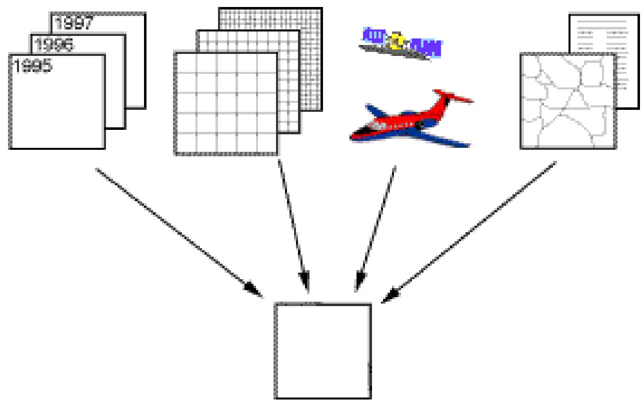

Figure 1.4: Data integration from various sources and of various types.

Applications of multisensor data integration generally require that the data are geometrically registered, either to each other or to a common geographic co-ordinate system or map base. This also allows other ancillary (supplementary) data sources to be integrated with the remote sensing data. For example, elevation data in digital form, called Digital Elevation or Digital Terrain Models (DEMs/DTMs), may be combined with remote sensing data for a variety of purposes. DEMs/DTMs may be useful in image classification, as effects due to terrain and slope variability can be included in the classification, potentially increasing the accuracy of the resultant classification. DEMs/DTMs are also useful for generating three-dimensional perspective views by draping remote sensing imagery over the elevation data, enhancing visualisation of the area imaged.

Combining data of different types and from different sources, such as we have described above, is the pinnacle of data integration and analysis. In a digital environment where all the data sources are geometrically registered to a common geographic base, the potential for information extraction is extremely wide. This is the concept for analysis within a digital Geographical Information System (GIS) database. Any data source, which can be referenced spatially, can be used in this type of environment. A DEM/DTM is just one example of this kind of data. Other examples could include digital maps of soil type, land cover classes, forest species, road networks, and many others, depending on the application. The results from a classification of a remote sensing data set in map format, could also be used in a GIS as another data source to update existing map data. In essence, by analysing diverse data sets together, it is possible to extract better and more accurate information in a synergistic manner than by using a single data source alone. Moreover, nowadays more and more long-term RS data sets are becoming available and RS data of some sensors are even directly available through the internet.

1.6 Comparison RS to traditional field observations

The human ability of observation is subjective and individual. Humans observe and process information in real time. Retrieving the images recorded in the memory is also an individual process and is time-bound.

We can list the following properties of RS (Buiten & Clevers, 1993):

- RS instrumentation makes it possible to observe the environment with EM radiation outside the visible part of the EM spectrum; the invisible becomes visible.
- RS produces measurable physical data, so that we speak of objective observations. Hence, it is possible to acquire quantitative as well as qualitative data about the Earth's surface.
- RS gives position-bound thematic information connected with the parameters "what, where, when and how", allowing for improvement and completion of existing maps.
- RS is flexible in that there is a variety of RS observation techniques and a diversity of digital image processing algorithms for searching for the optimum route to information about the Earth's surface.
- The synoptic element of RS is unequalled, giving an overview of a region as a whole; the coherence and limits of the components of the region can be distinguished and identified. In the past this coherence could only be derived from theoretical considerations or conjectured from other data.
- RS provides area-wise information making the traditional way of point-wise sampling of the Earth's surface more selective.
- RS allows for an image recording of a large area in a very short time. This advances the internal correspondence of the thematic information that is aimed at. In addition there is a high degree of actuality in comparison with the conventional methods of mapping.
- RS data disclose processes on the Earth's surface both with regard to an instantaneous reproduction as well as change detection. Hence RS can be considered to be dynamical.
- RS satellite images may open up inaccessible regions, at least they give a basis for furthering the knowledge about these regions.
- RS as a source of information may repeat, alter and improve the analysis of the images as soon as our prior knowledge is augmented or deepened. The images of the observed objects can be stored and compared with more recent images at a later time.

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