Chapter 3. Optical Remote Sensing

3.1 Introduction

In the chapter 1 “Introduction Remote Sensing” the recording of energy by the sensor was described in short. In this chapter, we will take a closer look at this component of the remote sensing process by examining the characteristics of remote sensing platforms and sensors and the data they collect in greater detail. In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable platform at some distance from the target or surface being observed. Platforms for remote sensors may be situated on the ground, on an aircraft or balloon (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere.

Ground-based sensors are often used to record detailed information about the surface, which is compared with information collected from aircraft or satellite sensors. In some cases, this can be used to better characterise the target, which is being imaged by these other sensors, making it possible to better understand the information in the imagery. Aerial platforms are primarily stable wing aircraft, although drones are more and more being used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time. In space, remote sensing is sometimes conducted from the international space station or, more commonly, from satellites. Satellites are objects that revolve around another object - in this case the Earth. For example, the moon is a natural satellite, whereas man-made satellites include those platforms launched for remote sensing, communication, and telemetry (location and navigation) purposes. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. Cost is often a significant factor in choosing among the various platform options.

3.2 Satellite characteristics: orbits and swaths

We learned in the previous section that remote sensing instruments could be placed on a variety of platforms to view and image targets. Although ground-based and aircraft platforms may be used, satellites provide a great deal of the remote sensing imagery commonly used today. Satellites have several unique characteristics, which make them particularly useful for remote sensing of the Earth's surface.

The path followed by a satellite is referred to as its orbit. Satellite orbits are matched to the capability and objective of the sensor(s) they carry. Orbit selection can vary in terms of altitude (their height above the Earth's surface) and their orientation and rotation relative to the Earth. Satellites at very high altitudes, which view the same portion of the Earth's surface at all times have geostationary orbits. These geostationary satellites, at altitudes of approximately 36,000 kilometres, revolve at speeds that match the rotation of the Earth so they seem stationary, relative to the Earth's surface. This allows the satellites to observe and collect information continuously over specific areas. Weather and communications satellites commonly have these types of orbits. Due to their high altitude, some geostationary weather satellites can monitor weather and cloud patterns covering an entire hemisphere of the Earth. Many remote sensing platforms are designed to follow an orbit (basically north-south) which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time. These are near-polar orbits, so named for the inclination of the orbit relative to a line running between the North and South poles. Many of these polar
Satellite orbits are also sun-synchronous such that they cover each area of the world at a constant local time of day called local sun time. At any given latitude, the position of the sun in the sky as the satellite passes overhead will be the same within the same season. This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. This is an important factor for monitoring changes between images or for mosaicking adjacent images together, as they do not have to be corrected for different illumination conditions.

As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the swath. Imaging swaths for spaceborne sensors generally vary between tens and hundreds of kilometres wide. As the satellite orbits the Earth from pole to pole, its east-west position would not change if the Earth did not rotate. However, as seen from the Earth, it seems that the satellite is shifting westward because the Earth is rotating (from west to east) beneath it. This apparent movement allows the satellite swath to cover a new area with each consecutive pass. The satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits.

### 3.3 Multispectral scanning principle

Cameras and their use for aerial photography are the simplest and oldest of sensors used for remote sensing of the Earth's surface. Cameras are framing systems (Figure 3.1a), which acquire a near-instantaneous "snapshot" of an area of the Earth’s surface. Camera systems are passive optical sensors that use a lens (or system of lenses collectively referred to as the optics) to form an image at the focal plane, the “aerial image plane” at which an image is sharply defined.

Many electronic (as opposed to photographic) 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. Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. A scanning system used to collect data over a variety of different wavelength ranges is called a multispectral scanner (MSS), and is the most commonly used scanning system. There are two main modes or methods of scanning employed to acquire multispectral image data - across-track scanning, and along-track scanning.

Across-track scanners scan the Earth in a series of lines (Figure 3.1b). The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath). Each line is scanned from one side of the sensor to the other, using a rotating mirror. As the platform moves forward over the Earth, successive scans build up a two-dimensional image of the Earth’s surface. So, the Earth is scanned point by point and line after line. These systems are referred to as whiskbroom scanners. The incoming reflected or emitted radiation is separated into several spectral components that are detected independently. A bank of internal detectors, each sensitive to a specific range of wavelengths, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing.
Along-track scanners also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction (Figure 3.1c). However, instead of a scanning mirror, they use a linear array of detectors (so-called charge-coupled devices, CCDs) located at the focal plane of the image formed by lens systems, which are "pushed" along in the flight track direction (i.e. along track). These systems are also referred to as pushbroom scanners, as the motion of the detector array is analogous to a broom being pushed along a floor. A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded.

Regardless of whether the scanning system used is either of these two types, it has several advantages over photographic systems. The spectral range of photographic systems is restricted to the visible and near-infrared regions while MSS systems can extend this range into the thermal infrared. They are also capable of a much higher spectral resolution than photographic systems. Multi-band or multispectral photographic systems use separate lens systems to acquire each spectral band. This may cause problems in ensuring that the different bands are comparable both spatially and radiometrically and with registration of the multiple images. MSS systems acquire all spectral bands simultaneously through the same optical system to alleviate these problems. Photographic systems record the energy detected by means of a photochemical process which is difficult to measure and to make consistent. Because MSS data are recorded electronically, it is easier to determine the specific amount of energy measured, and they can record over a greater range of values in a digital format. Photographic systems require a continuous supply of film and processing on the ground after the photos have been taken. The digital recording in MSS systems facilitates transmission of data to receiving stations on the ground and immediate processing of data in a computer environment.
3.4 Thermal imaging

Many multispectral (MSS) systems sense radiation in the thermal infrared as well as the visible and reflected infrared portions of the spectrum. However, remote sensing of energy emitted from the Earth's surface in the thermal infrared (3 μm to 15 μm) is different from the sensing of reflected energy. Thermal sensors use photon detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation. The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions. Thermal sensors essentially measure the surface temperature and thermal properties of targets.

Thermal imagers are typically across-track scanners (like those described in the previous section) that detect emitted radiation in only the thermal portion of the spectrum. Thermal sensors employ one or more internal temperature references for comparison with the detected radiation, so they can be related to absolute radiant temperature. The temperature resolution of current sensors can reach 0.1 °C. For analysis, an image of relative radiant temperatures is depicted in grey levels, with warmer temperatures shown in light tones, and cooler temperatures in dark tones. Imagery, which portrays relative temperature differences in their relative spatial locations, is sufficient for most applications. Absolute temperature measurements may be calculated but require accurate calibration and measurement of the temperature references and detailed knowledge of the thermal properties of the target, geometric distortions, and radiometric effects.

3.5 Resolutions

3.5.1 Spectral resolution

In a previous chapter, we learned that different objects exhibit different spectral signatures. As a result, different classes of objects and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. Broad classes, like water and vegetation, can usually be separated using very broad wavelength ranges. More specific features can only be detected by using finer wavelength ranges. The spectral resolution of a remote sensing system, therefore, is an important characteristic. The spectral resolution concerns the bandwidth of the specific wavelength bands of a system (called spectral bands). In addition, the number of bands and their location in the EM spectrum is of importance. In general, the spectral resolution is defined by the sensitivity curve of a spectral band (Figure 3.2) and the bandwidth is defined as the interval where the sensitivity is more than 50% of its maximum, called the Full Width at Half Maximum (FWHM).

3.5.2 Spatial resolution

For remote sensing instruments, the distance between the target being imaged and the platform, plays a large role in determining the detail of information obtained and the total area imaged by the sensor. Sensors onboard platforms far away from their targets, typically view a larger area, but cannot provide great detail. This is a great difference between satellite images and, for instance, aerial images.
The detail discernible in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected (Figure 3.3). Spatial resolution of passive sensors (we will look at the special case of active microwave sensors later) depends primarily on their instantaneous field of view (IFOV). The IFOV is the angular aperture of the sensor (β) and determines the area on the Earth's surface (D), which is "seen" from a given altitude at one particular moment in time. The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (H). This area on the ground is called the resolution cell and determines a sensor's maximum spatial resolution.

![Figure 3.2: Sensitivity curve of a spectral band.](image)

![Figure 3.3: Definition of the spatial resolution of a passive sensor system.](image)
Most remote sensing images are composed of a matrix of picture elements, or pixels, which are the smallest units of an image. Image pixels are normally square and represent a certain area on an image. It is important to distinguish between pixel size and spatial resolution - they are not interchangeable. If a sensor has a spatial resolution of 20 metres and an image from that sensor is displayed at full resolution, each pixel represents an area of 20m x 20m on the ground. In this case the pixel size and resolution are the same. However, it is possible to display an image with a pixel size different than the resolution. Many posters of satellite images of the Earth have their pixels averaged to represent larger areas, although the original spatial resolution of the sensor that collected the imagery remains the same.

3.5.3 Radiometric resolution

While the arrangement of pixels describes the spatial structure of an image, the radiometric characteristics describe the actual information content in an image. Every time an image is acquired by a sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

Imagery data are represented by positive digital numbers, which vary from 0 to (one less than) a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2 (e.g. 1 bit = $2^1$ = 2). The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be $2^8 = 256$ digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only $2^4 = 16$ values ranging from 0 to 15 would be available. Thus, the radiometric resolution would be much less. Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data).