Aerospace Remote Sensing Systems

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Unofficial material

A. De Vivo

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INTRODUCTION

Remote sensing can be defined as the measurement and the analysis of the electromagnetic radiation coming from a given surface we want to study, by using a device (a sensor) that is not in contact with this surface or, in general, with the object we want to analyze (it is in a remote location). In steps, what we have is:

1. measurement of the *electromagnetic radiation* (in other words, of the energy);
2. transformation of the measurement into information and, then, in applications which can be considered of practical usefulness.

The term "remote sensing" is strictly related to the observation of the Earth; the term **astrophysics** is, instead, used when this electromagnetic radiation comes from stars; **planetology** is used when we are measuring electromagnetic radiation coming from planets or asteroids.

Remote sensing was originally born as a military discipline; civilian applications were developed something like 40 years ago (for *cartography* and *meteorology*). Anyway, military and defense remote sensing systems are still characterized by improved performance, since they are forced to get information from much smaller objects and with higher frequency. Examples of civilian applications could be:

- weather observations and atmospheric conditions;
- monitoring of the environment (global warming);
- monitoring of geophysical parameters (Earth magnetic field, gravity);
- monitoring of land surfaces;
- monitoring of the oceans;
- monitoring of snow and ice.

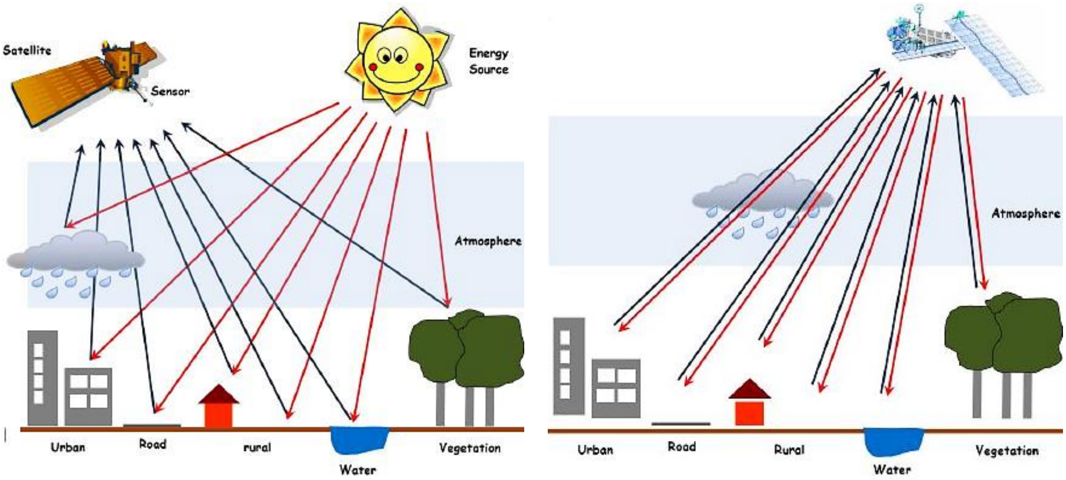
In terms of mass of orbiting satellites around the Earth, remote sensing satellites represent the second class of satellites just after the telecommunication ones.

The sensor used for Earth observation is typically located on a satellite or on a plane.
A useful way to present and analyze remote sensing problems is to interpret remote sensing as a **system** made up of some sub-systems, or **items** (logical units); each item is important and essential for the understanding of the entire system. These logical units are:

1. the energy **source**. Since we want to measure electromagnetic radiation (energy), there must be somewhere a source which is generating this energy. In our problems, we will consider as source:

- the **Sun**, that is the most common one for our problems. For example, if we take a picture of a landscape, we are actually collecting the energy coming from the Sun which reflects on the Earth and reaches the camera.
- The **Earth**. It is a warm body, so it is able to emit a particular amount of energy (much weaken than the one coming from the Sun).
- The **instrument** itself (for example the flash of the camera). Examples of sensors that emit radiation are *lasers* and *radars.*

We will talk about **passive remote sensing** when the instrument collects the radiation generated by a different and separated source (Earth or Sun), and **active remote sensing** when the instrument is also the source of the radiation (*radar* or *laser*).

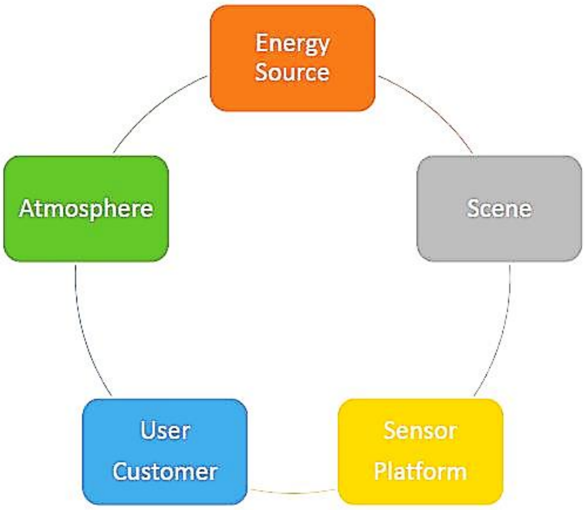


2. The **atmosphere**. Since we are performing measurements from a remote location, the signal always has to pass across the atmosphere twice. The atmosphere is able to change the characteristics of the energy we are measuring, so we need to model and characterize these effects on the energy propagation in order to isolate them and to keep in the data only the information relevant to the scene.
3. The **scene**. It is something that is placed over Earth surface we want to study. Scene must be quantitatively characterized through the parameters that must be measured (surface temperature, biomass, target size, etc.).
4. The **sensor** and the **platform** on which it is placed. Most of remote sensing devices are not able to work without motion of the platform, that is why we study them at the same time (<u>platform motion affects the data collected by the sensors</u>). Different platforms can be selected: small UAV, large airplanes, satellites, etc.

   When we talk about sensors/platforms, it is important to discuss the trade-off between **coverage** (the size of the area we are observing) and **data granularity** (the minimum level of detail from a geometrical point of view that we are able to sense); they are conflicting requirements.

Platform	Coverage	Granularity
Satellite	10s km – 1000s km	1 m – 100s m
Airplanes	1 km – 10s km	10 cm – 1 m
Small UAV	< 1km	<10 cm

5. **Users/customer**. User is the set of people that will actually use the data, while customer is the person or group that actually buy the remote sensing system. This is the most important item: all the other items exist simply because there are applications, there are users and there are customers. Usually users are politicians or private investors, so, typically, they do not know anything about the first four items; they only want to get data.



The first three items are typically referred to a **physical branch**, because they involve the knowledge of the radiation and of energy propagation.

N.B. The role of an engineer is on the fourth item. He/she:

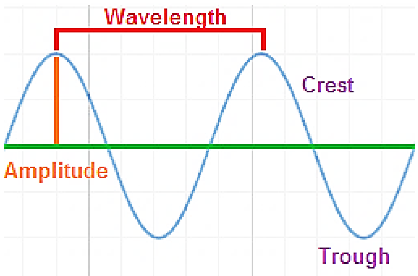
- designs both the sensor and the platform;
- performs assessment;
- develops software-based data analysis and digital processing.

1. MENTION TO THE PHYSICAL BRANCH

1.1 Electromagnetic spectrum

We start introducing the *electromagnetic spectrum*. The problem is that different forms of energy exist: visible light, X-rays, UV-rays, Radio waves, etc. All these different forms of energy are actually similar, because they radiate in accordance with **basic wave theory**: any form of energy propagates as a harmonic or sinusoidal wave that travels through the space at the *speed of light* ($c = 3 \cdot 10^8\ m/s$).

A travel wave is characterized by two main parameters:



- **wavelength** ($\lambda = [L]$): it is the distance between two consecutive homologous points along the wave. The most useful unit for measuring the wavelength is the **micrometer** ($1\mu m = 10^{-6} m$), or **micron**.
- **Frequency** ($\upsilon = [t^{-1}]$): is the number of abscissae x passing at a fixed location in space per unit time.

There is a relation between these parameters:

$$c = \lambda \upsilon$$

(increasing the wavelength, the frequency is decreasing).

After this simple introduction, we can define what is the *electromagnetic spectrum*: it is a one-dimensional diagram over which we organize all different forms of energy, classifying them as a function of the wavelength.

The spectrum is organized in intervals or different ranges of wavelength/frequency, corresponding to different forms of energy:

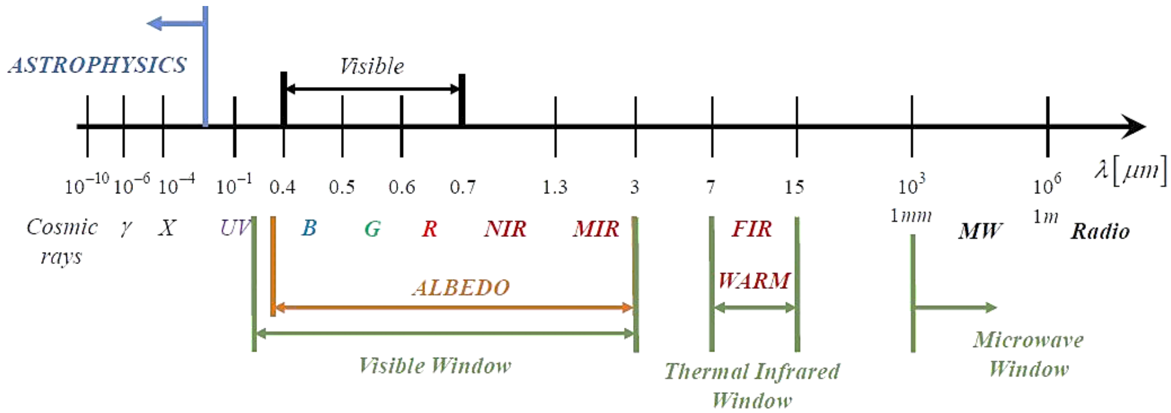
- The shorter wavelengths refer to:
  - **cosmic rays** ($10^{-10}\ \mu m$);
  - **γ-rays** ($10^{-6}\ \mu m$);
  - **x-rays** ($10^{-4}\ \mu m$);

  This part of the spectrum cannot be used for remote sensing because the energy at these wavelengths is stopped by the atmosphere (*ozone*). They are of interest for **astrophysics**.

- With the increasing wavelengths:
  - **ultra-violet radiations** ($10^{-1}\ \mu m$);
  - **visible light** ($0.4 - 0.7\ \mu m$). This is the only region of the spectrum which can be sensed by human eyes. It can be further divided in colors:
    - **blue** ($0.4 - 0.5\ \mu m$);
    - **green** ($0.5 - 0.6\ \mu m$);
    - **red** ($0.6 - 0.7\ \mu m$);
  - **infrared radiation** ($0.7 - 15\ \mu m$). It can be further divided in:
    - **near infrared** (**NIR**) ($0.7 - 1.3\ \mu m$);
    - **middle infrared** (**MIR**) or **reflected infrared** ($1.3 - 3\ \mu m$);
    - **far infrared** (**FIR**) or **thermal infrared** (**TIR**) ($7 - 15\ \mu m$);

  N.B. The region from $0.38\ \mu m$ to $3\ \mu m$ is often called **reflective region** of the spectrum because it includes the radiation of the Sun which is reflected from Earth surface (**albedo radiation**).

  N.B. The last portion of infrared region (TIR) is where warm bodies at ambient temperature emit their energy. This region can be also defined **Long Wave Infrared** (LWIR), while the one which includes NIR and MID is also called **Short Wave Infrared** (SWIR).
- The last part of the spectrum is characterized by much longer wavelengths:
  - **microwave region** ($10^3\ \mu m = 1\ mm$);
  - **radio waves** ($\lambda > 10^6\ \mu m = 1\ m$).



The energy along the spectrum is not entirely available for remote sensing; there exist the so-called **atmospheric windows**, that represent regions of the spectrum in which the energy is not absorbed by the elements of the atmosphere.

- *Ozone* (O_3) absorbs all the energy up to a significant fraction of UV;
- *carbon dioxide* (CO_2) absorbs energy in the infrared region (*Greenhouse effect*).

Three main windows can be qualitatively defined:

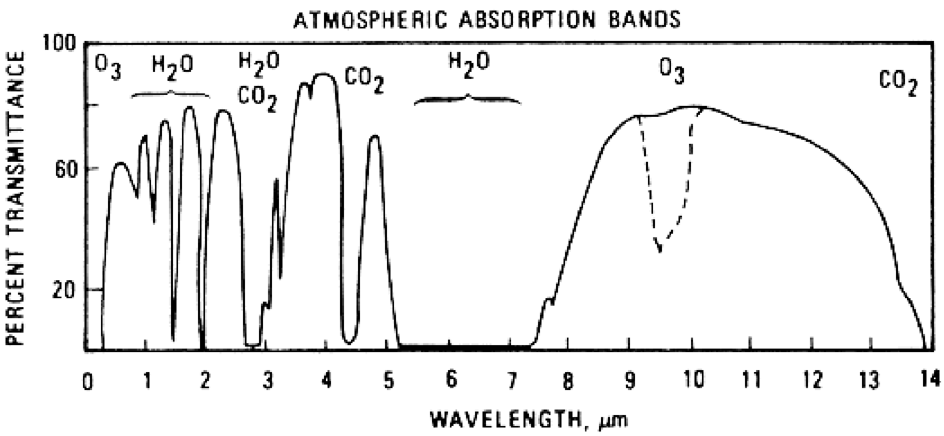
- **visible window** ($0.3 - 3\ \mu m$), where we measure albedo radiations;
- **IR window** ($7 - 15\ \mu m$);
- **MW window** ($\lambda > 1\ mm$).

N.B. It is not true that these windows are completely available: within each window there are very short bands in which the energy is absorbed.

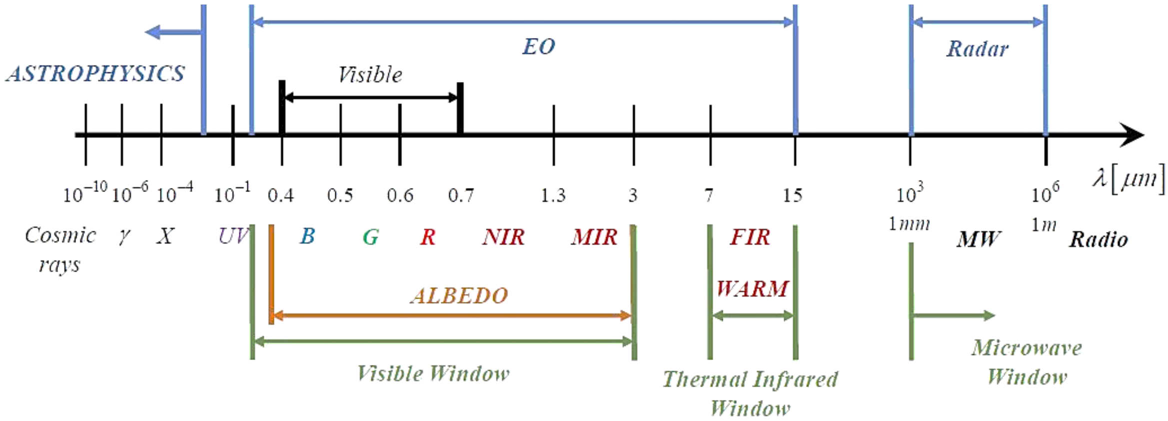
N.B. The possibility to get information from these windows and the amount of energy that passes through a window is also a function of local metrological conditions (humidity, smog, clouds can hinder the energy from passing). In this sense, we can state that "atmospheric windows are not always opened".

There are specific components in the atmosphere which absorb specific ranges:

- in the portion of the spectrum between $10^{-10}\mu m$ and $10^{-1}\mu m$ energy is absorbed by *ozone* (O_3) (it is a portion of interest for astrophysics). This energy is very dangerous for human health.
- In the region from 3 μm up to 7 μm energy is absorbed by *carbon dioxide* CO_2 and *water vapour* $H_2 0$;
- the region between 15 μm and $10^3\mu m$ is also absorbed by the atmosphere.



At the very beginning of remote sensing we used **films** as sensitive elements; they were sensitive to the region of the spectrum from 0.4 μm up to 1 μm. Now we have **electro-optical sensors** (**EO**), that are digital, and that are sensitive to all the energy from 0.3 μm (also a portion of UV) up to 15 μm (such sensors are similar to human eyes, but they extend the capabilities of human eye to small portion of UV and to the infrared region). Another class of sensors we use in remote sensing starts to $10^3 \mu m$: they are **radar** and **microwave sensors**. In this case data we receive are very different from images, so it is more difficult to interpret them (that is why the market of these sensors was typically limited to military applications; now there are more “user friendly” radars). On the contrary to some electro-optical sensors, with radars we can have information even if there is no light (radars are considered **all-weather/all-time** sensors).



1.2 Radiometric terminology and units

Radiation is measured in radiometric units. The choice of correct terms and units depends on the aspect of the radiation under analysis, on the angular nature, the temporal nature, the behaviour as a function of wavelength, and so on.

Symbol	Parameter	Unit	Description
Q	Radiant energy	J	It is the energy carried by a wave that is propagating into the space.
$\Phi = \frac{\partial Q}{\partial t}$	Radiant flux	$W = \frac{J}{s}$	It is the amount of energy transmitted, emitted or received per unit time.
$\frac{\partial \Phi}{\partial A} = \frac{\partial Q}{\partial t\, \partial A}$	Radiant flux density	$\frac{W}{m^2}$	It is the radiant flux per unit area. The flux can be incident or can leave the surface.