UNIT 1: REMOTE SENSING

1.1 Introduction

"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." In much of remote sensing, ***the process*** *involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Note, however that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.*

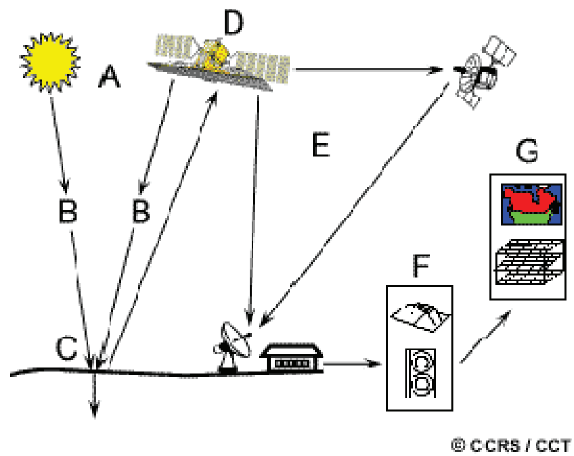


Fig 1.1: Remote sensing

1. Energy Source or Illumination (A) *– the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.*

2. Radiation and the Atmosphere (B) *– as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.*

3. Interaction with the Target (C) *- once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.*

4. Recording of Energy by the Sensor (D) *- after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.*

5. Transmission, Reception, and Processing (E) *- 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).*

6. Interpretation and Analysis (F) *- the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.*

7. Application (G) *- the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.*

These seven elements comprise the remote sensing process from beginning to end. We will be covering all of these in sequential order throughout the five chapters of this tutorial, building upon the information learned as we go. Enjoy the journey!

1.1.1 Electromagnetic Radiation

As was noted in the previous section, the first requirement for remote sensing is to have an ***energy source to illuminate the target*** *(unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation.*

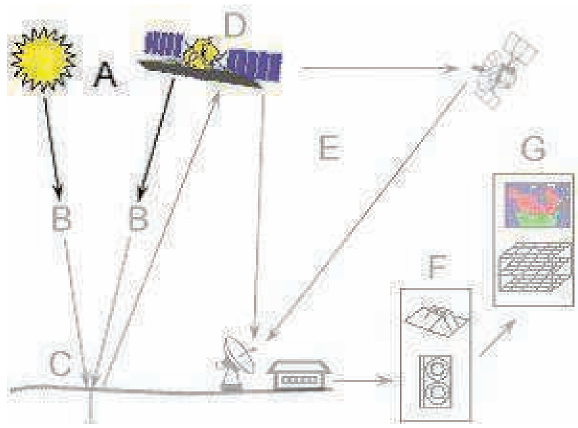


Fig 1.2: Electromagnetic radiation

All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. ***Electromagnetic radiation*** *consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c). Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the* ***wavelength and frequency.***

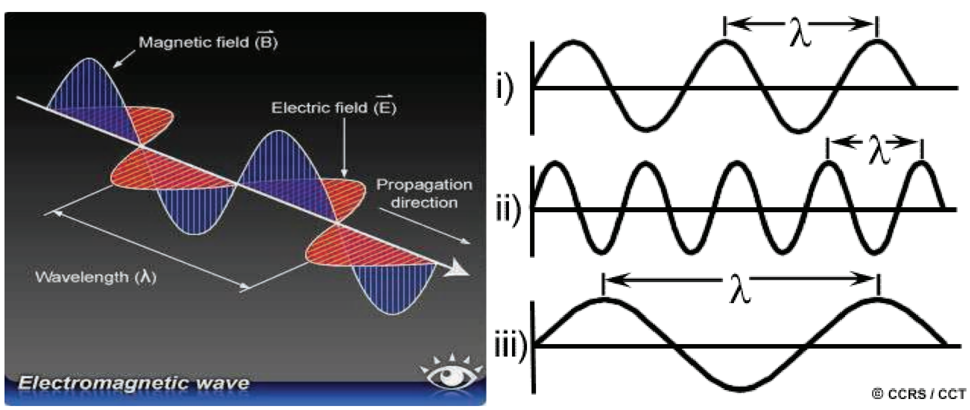


Fig 1.3: wavelength and frequency

The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of metres such as ***nanometres*** *(nm, 10-9 metres),* ***micrometres*** *(μm, 10-6 metres) (μm, 10-6 metres) or centimetres (cm, 10-2 metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in* ***hertz*** *(Hz), equivalent to one cycle per second, and various multiples of hertz. Wavelength and frequency are related by the following formula:*

$$c = \lambda \nu$$

where:

λ = wavelength (m)
ν= frequency (cycles per second, Hz)
c =speed of light (3×10^8 m/s)

Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency. Understanding the characteristics of electromagnetic radiation in terms of their wavelength and frequency is crucial to understanding the information to be extracted from remote sensing data. Next we will be examining the way in which we categorize electromagnetic radiation for just that purpose.

1.2 Electromagnetic Spectrum

The ***electromagnetic spectrum*** *ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum which are useful for remote sensing.*

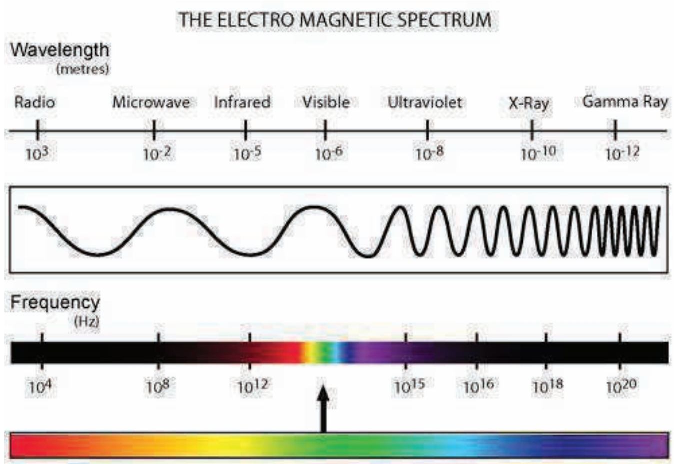


Fig 1.4: Electromagnetic spectrum

For most purposes, 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 Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.*

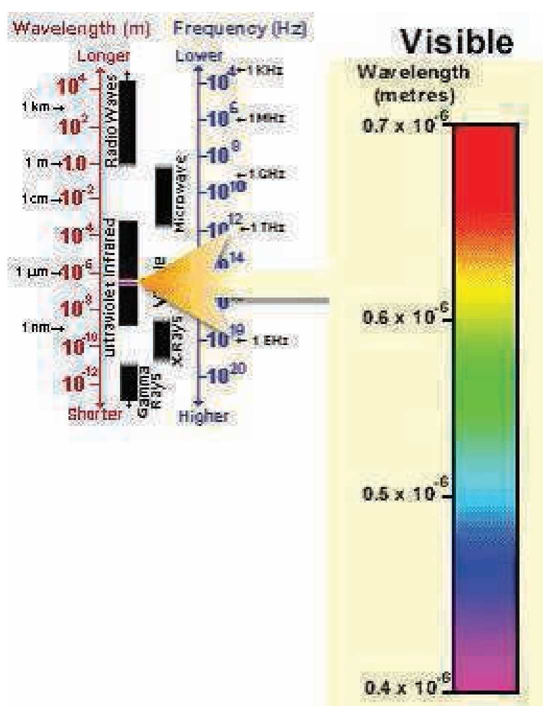


Fig. 1.5: Electromagnetic spectrum

The light which our eyes - our "remote sensors" - can detect is part of the ***visible spectrum****. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. The visible wavelengths cover a range from approximately 0.4 to 0.7 µm. The longest visible wavelength is red and the shortest is violet. Common wavelengths of what we perceive as particular colours from the visible portion of the spectrum are listed below. It is important to note that this is the only portion of the spectrum we can associate with the concept of* ***colours****.*

Violet: *0.4 - 0.446 µm*

Blue: *0.446 - 0.500 µm*

Green: *0.500 - 0.578 µm*

Yellow: *0.578 - 0.592 µm*

Orange: *0.592 - 0.620 µm*

Red: *0.620 - 0.7 µm*

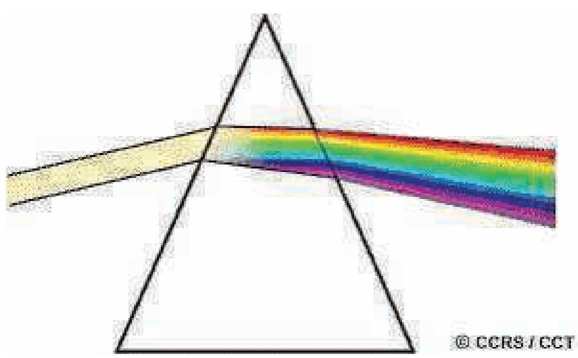


Fig. 1.6: Visible spectrum

Blue*,* ***green****, and* ***red*** *are the* ***primary colours*** *or wavelengths of the visible spectrum. They are defined as such because no single primary colour can be created from the other two, but all other colours can be formed by combining blue, green, and red in various* *proportions. Although we see sunlight as a uniform or homogeneous colour, it is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum. The visible portion of this radiation can be shown in its component colours when sunlight is passed through a* ***prism****, which bends the light in differing amounts according to wavelength.*

The next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 µm to 100 µm - more than 100 times as wide as the visible portion! The infrared region can be divided into two categories based on their radiation properties - the ***reflected IR****, and the emitted or* ***thermal IR****.*

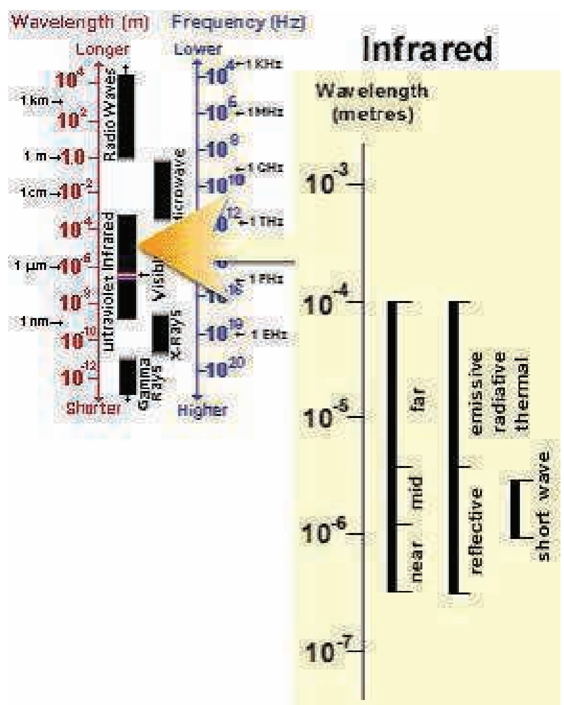


Fig. 1.7: Infrared

Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion. The reflected IR covers wavelengths from approximately 0.7 µm to 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. The thermal IR covers wavelengths from approximately 3.0 µm to 100 µm.

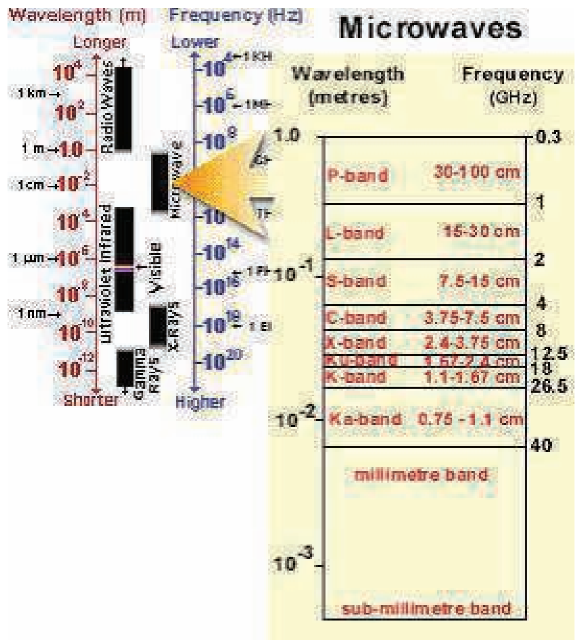


Fig. 1.8: Microwave

The portion of the spectrum of more recent interest to remote sensing is the ***microwave region*** *from about 1 mm to 1 m. This covers the longest wavelengths used for remote sensing. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts. Because of the special nature of this region and its importance to remote sensing in Canada, an entire chapter (Chapter 3) of the tutorial is dedicated to microwave sensing.*

1.2.1 Interactions with the Atmosphere

Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of ***scattering*** *and* ***absorption****.*

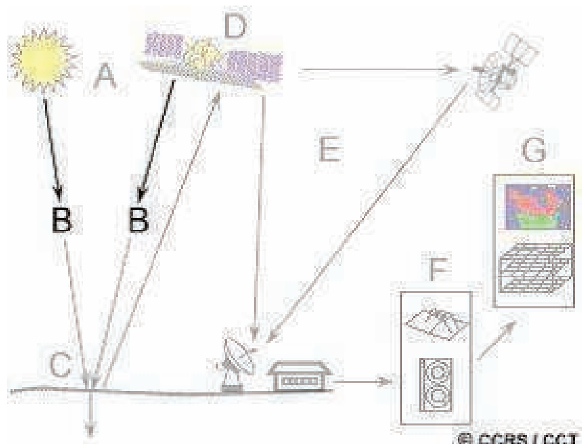


Fig. 1.9: Interactions with the Atmosphere

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. How much scattering takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere. There are three (3) types of scattering which take place.*

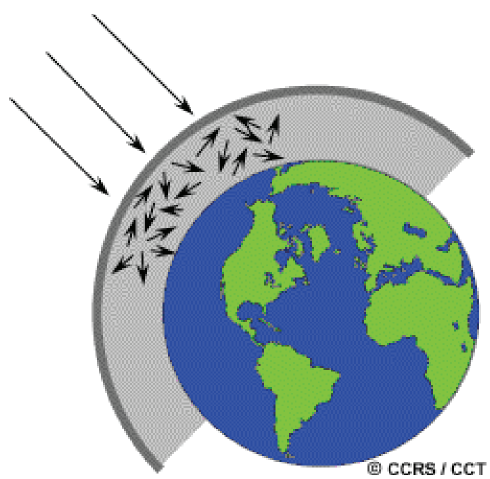


Fig. 1.10: Scattering

Rayleigh scattering *occurs when particles are very small compared to the wavelength of the radiation.*

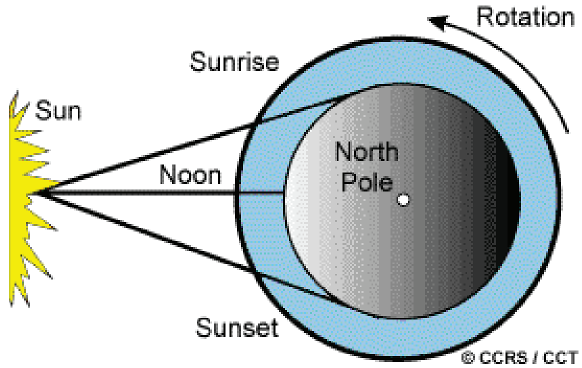


Fig. 1.11: Rayleigh scattering

These could be particles such as small specks of dust or nitrogen and oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during the day is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. At ***sunrise and sunset*** *the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.*

Mie scattering *occurs when the particles are just about the same size as the wavelength of the radiation.*

Fig. 1.12: Mie scattering

*Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast. The final scattering mechanism of importance is called **nonselective scattering**. This occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue+green+red light = white light).*

***Absorption** is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths.*

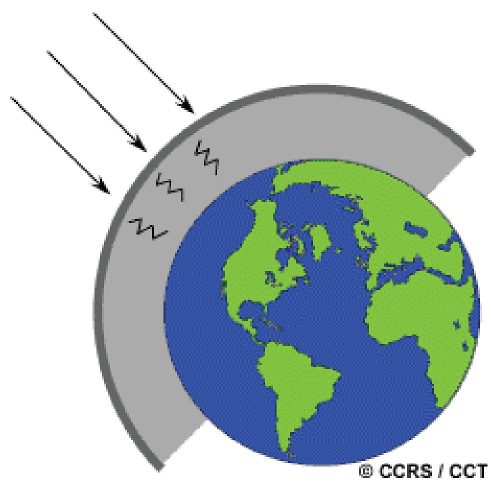


Fig. 1.13: Absorption

*Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation. **Ozone** serves to absorb the harmful (to most living things) ultraviolet radiation from the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight. You may have heard **carbon dioxide** referred to as a greenhouse gas. This is because it tends to* *absorb radiation strongly in the far infrared portion of the spectrum - that area associated with thermal heating - which serves to trap this heat inside the atmosphere. Water vapour in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation (between 22μm and 1m). The presence of water vapour in the lower atmosphere varies greatly from location to location and at different times of the year. For example, the air mass above a desert would have very little water vapour to absorb energy, while the tropics would have high concentrations of water vapour (i.e. high humidity).*

Because these gases absorb electromagnetic energy in very specific regions of the spectrum, they influence where (in the spectrum) we can "look" for remote sensing purposes.

Those areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors, are called ***atmospheric windows****. By comparing the characteristics of the two most common energy/radiation sources (the sun and the earth) with the atmospheric windows available to us, we can define those wavelengths that we can use* ***most effectively*** *for remote sensing.*

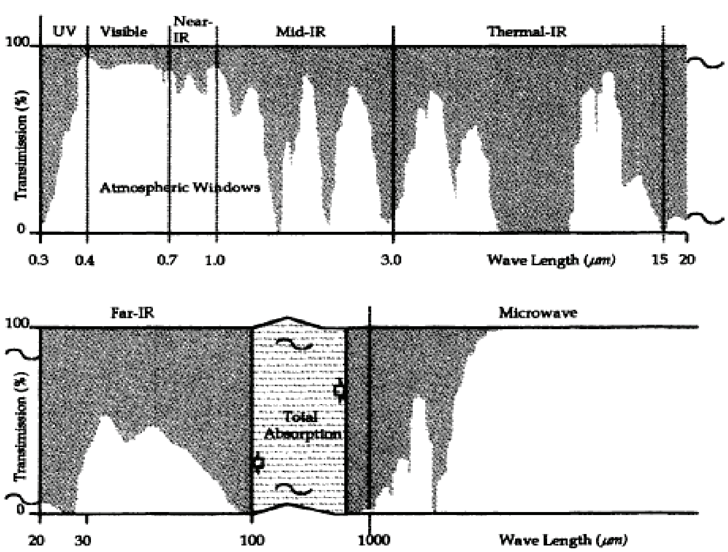


Fig. 1.14: Atmospheric windows

Atmospheric windows (unshaded). Vertical axis is atmospheric transmission (%). Horizontal axis is the logarithm of the wavelength in micrometres

1.2.2 Radiation - Target Interactions

Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface. There are three (3) forms of interaction that can take place when energy strikes, or is ***incident (I)*** *upon the surface. These are:* ***absorption (A)****;* ***transmission (T)****; and* ***reflection (R)****. The total incident energy will interact with the surface in one or more of these three ways. The proportions of each will depend on the wavelength of the energy and the material and condition of the feature.*

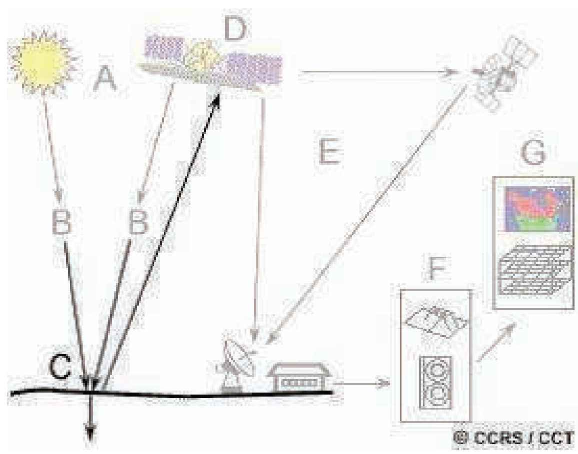


Fig. 1.15: Target interaction

Absorption (A) occurs when radiation (energy) is absorbed into the target while transmission (T) occurs when radiation passes through a target.

Fig. 1.16: Reflection

Reflection (R) occurs when radiation "bounces" off the target and is redirected. In remote sensing, we are most interested in measuring the radiation reflected from targets. We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: ***specular reflection*** *and* ***diffuse reflection****.*

When a surface is smooth we get ***specular*** *or mirror-like reflection where all (or almost all) of the energy is directed away from the surface in a single direction.* ***Diffuse*** *reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions.*

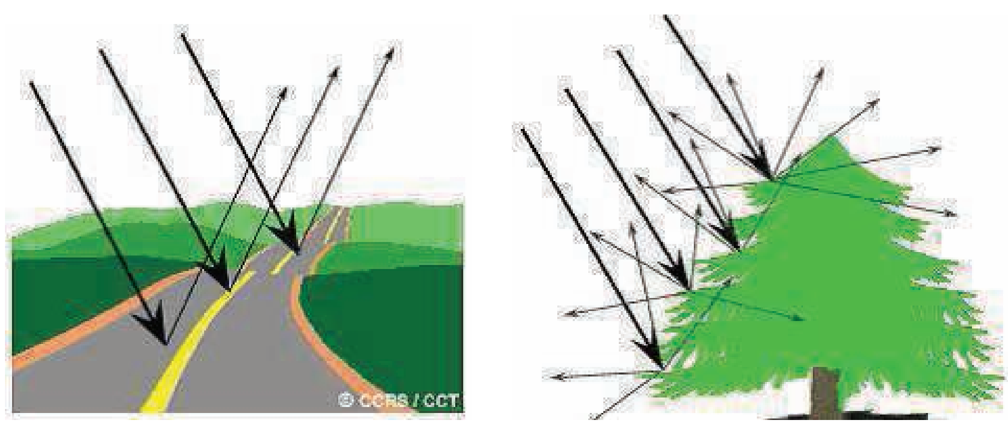


Fig. 1.17: Diffusion

Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors. Whether a particular target reflects specularly or diffusely, or *somewhere in between, depends on the surface roughness of the feature in comparison to the wavelength of the incoming radiation. If the wavelengths are much smaller than the surface variations or the particle sizes that make up the surface, diffuse reflection will dominate. For example, finegrained sand would appear fairly smooth to long wavelength microwaves but would appear quite rough to the visible wavelengths. Let's take a look at a couple of examples of targets at the Earth's surface and how energy at the visible and infrared wavelengths interacts with them.*

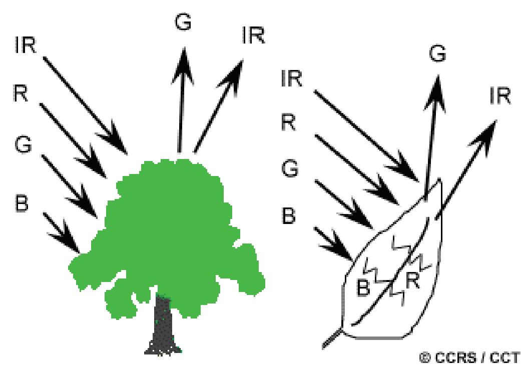


Fig. 1.18: IR interaction

***Leaves**: A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths). The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths. If our eyes were sensitive to near-infrared, trees would appear extremely bright to us at these wavelengths. In fact, measuring and monitoring the near-IR reflectance is one way that scientists can determine how healthy (or unhealthy) vegetation may be.*

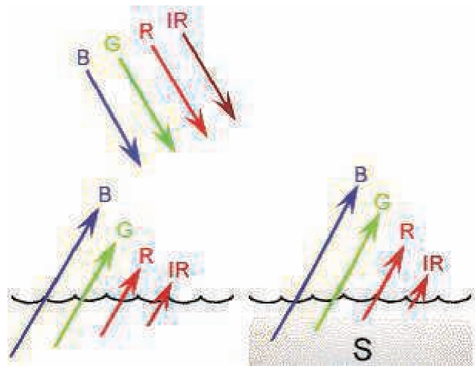


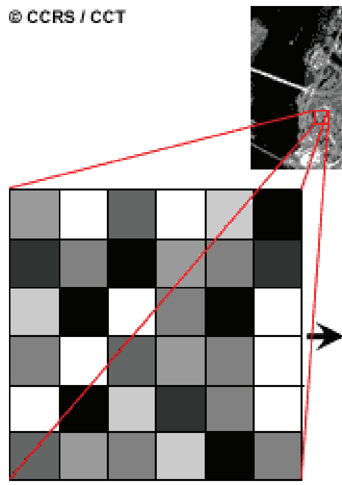
Fig. 1.19: Water

***Water**: Longer wavelength visible and near infrared radiation is absorbed more by water 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 better reflectivity and a brighter appearance of the water. The apparent colour of the water will show a slight shift to longer wavelengths. Suspended sediment (S) can be easily confused with shallow (but clear) water, since these two phenomena appear very similar. Chlorophyll in algae absorbs more of the blue wavelengths and reflects the green, making the water appear more green in colour when algae is present. The topography of the water surface (rough, smooth, floating materials, etc.) can also lead to complications for water-related interpretation due to potential problems of specular reflection and other influences on colour and brightness. We can see from these examples that, depending on the complex make-up of the target that is being looked at, and the wavelengths of radiation involved, we can observe very different responses to the mechanisms of absorption, transmission, and reflection. By measuring the energy that is reflected (or emitted) by targets on the Earth's surface over a variety of different wavelengths, we can build up a **spectral response** for that object. By comparing the response patterns of different features we may be able to distinguish between them, where we might not be able to, if we only compared them at one wavelength. For example, water and vegetation may reflect somewhat similarly in* *the visible wavelengths but are almost always separable in the infrared. Spectral response can be quite variable, even for the same target type, and can also vary with time (e.g. "green-ness" of leaves) and location. Knowing where to "look" spectrally and understanding the factors which influence the spectral response of the features of interest are critical to correctly interpreting the interaction of electromagnetic radiation with the surface.*

1.3 Component of Remote sensing

1.3.1 Introduction

An image refers to any pictorial representation, regardless of what wavelengths or remote sensing device has been used to detect and record the electromagnetic energy. A ***photograph*** *refers specifically to images that have been detected as well as recorded on photographic film. The black and white photo to the left, of part of the city of Ottawa, Canada was taken in the visible part of the spectrum. Photos are normally recorded over the wavelength range from 0.3 µm to 0.9 µm - the visible and reflected infrared. Based on these definitions, we can say that all photographs are images, but not all images are photographs. Therefore, unless we are talking specifically about an image recorded photographically, we use the term image.*



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

Fig. 1.20: Digital format

A photograph could also be represented and displayed in a ***digital*** *format by subdividing the image into small equal-sized and shaped areas, called picture elements or* ***pixels****, and representing the brightness of each area with a numeric value or* ***digital number****. Indeed, that is exactly what has been done to the photo to the left. In fact, using the definitions we have just discussed, this is actually a* ***digital image*** *of the original photograph! The photograph was scanned and subdivided into pixels with each pixel assigned a digital number representing its relative brightness. The computer displays each digital value as different brightness levels. Sensors that record electromagnetic energy, electronically record the energy as an array of numbers in digital format right from the start. These two different ways of representing and displaying remote sensing data, either pictorially or digitally, are interchangeable as they convey the same information (although some detail may be lost when converting back and forth).*

In previous sections we described the visible portion of the spectrum and the concept of colours. We see colour because our eyes detect the entire visible range of wavelengths and our brains process the information into separate colours. Can you imagine what the world would look like if we could only see very narrow ranges of wavelengths or colours? That is how many sensors work. The information from a narrow wavelength range is gathered and stored in *a **channel**, also sometimes referred to as a **band**. We can combine and display channels of information digitally using the three primary colours (blue, green, and red). The data from each channel is represented as one of the primary colours and, depending on the relative brightness (i.e. the digital value) of each pixel in each channel, the primary colours combine in different proportions to represent different colours.*

Fig. 1.21: Display

*When we use this method to display a single channel or range of wavelengths, we are actually displaying that channel through all three primary colours. Because the brightness level of each pixel is the same for each primary colour, they combine to form a **black and white image**, showing various shades of gray from black to white. When we display more than one channel each as a different primary colour, then the brightness levels may be different for*

1.3.2 Spectral Response

For any given material, the amount of solar radiation that it reflects, absorbs, transmits, or emits varies with wavelength.

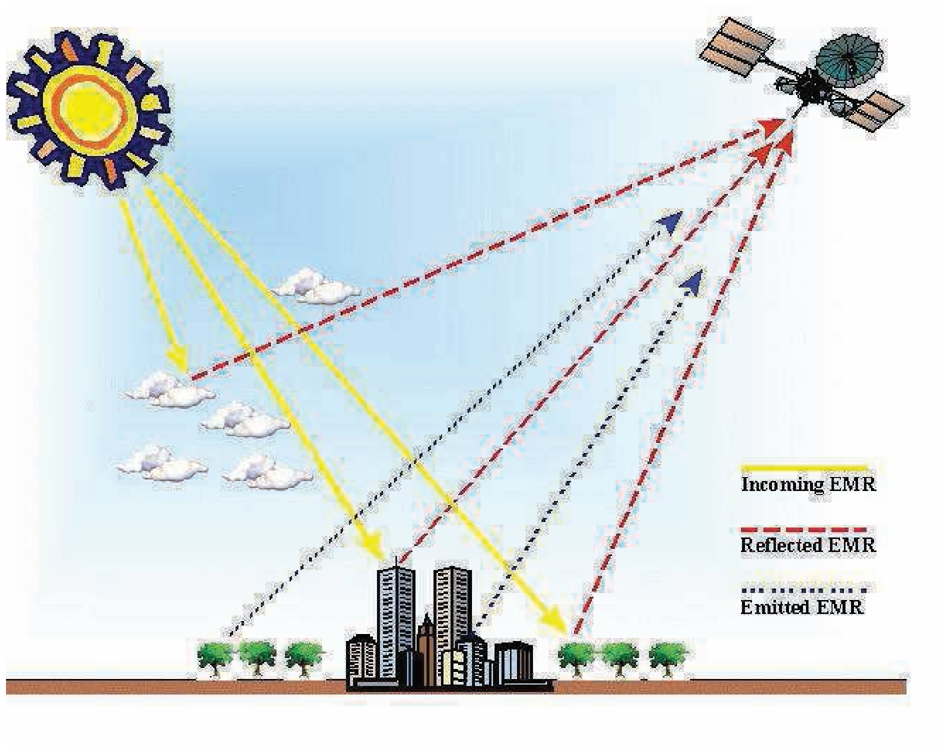


Fig. 1.22: EMR

When that amount (usually intensity, as a percent of maximum) coming from the material is plotted over a range of wavelengths, the connected points produce a curve called the material's ***spectral signature*** *(spectral response curve). Here is a general example of a reflectance plot for some (unspecified) vegetation type (bio-organic material), with the dominating factor influencing each interval of the curve so indicated; note the downturns of the curve that result from selective absorption:*

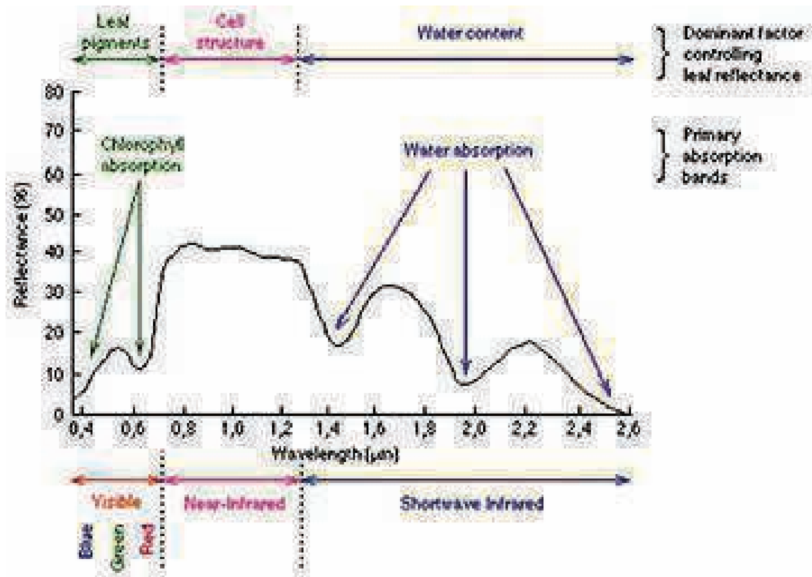
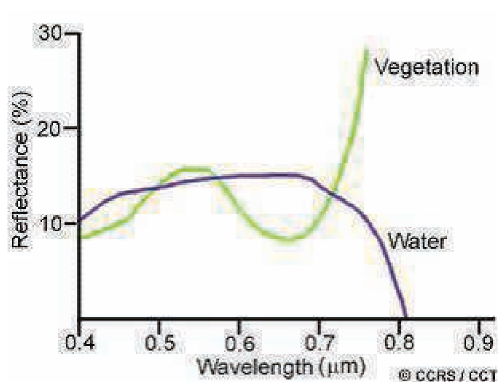
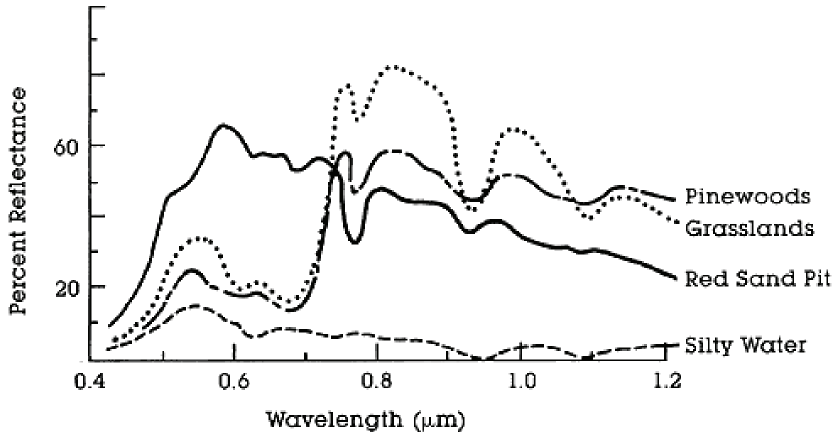


Fig. 1.23: Spectral response curve

This important property of matter makes it possible to identify different substances or classes and to separate them by their individual spectral signatures, as shown in the figure below.





For example, at some wavelengths, sand reflects more energy than green vegetation but at other wavelengths it absorbs more (reflects less) than does the vegetation. In principle, we can recognize various kinds of surface materials and distinguish them from each other by these differences in reflectance. Of course, there must be some suitable method for measuring these differences as a function of wavelength and intensity (as a fraction [normally in percent] of the amount of irradiating radiation). Using reflectance differences, we may be able to distinguish the four common surface materials in the above signatures (GL = grasslands; PW = pinewoods; RS = red sand; SW = silty water) simply by plotting the reflectances of each material at two wavelengths, commonly a few tens (or more) of micrometers apart.

1.3.3 Passive vs. Active Sensing

So far, throughout this chapter, we have made various references to the sun as a source of

energy or radiation. The sun provides a very convenient source of energy for remote sensing. The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then reemitted, as it is for thermal infrared wavelengths. Remote sensing systems which measure energy that is naturally available are called passive sensors. Passive sensors can only be used to detect *energy when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth. There is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded.*

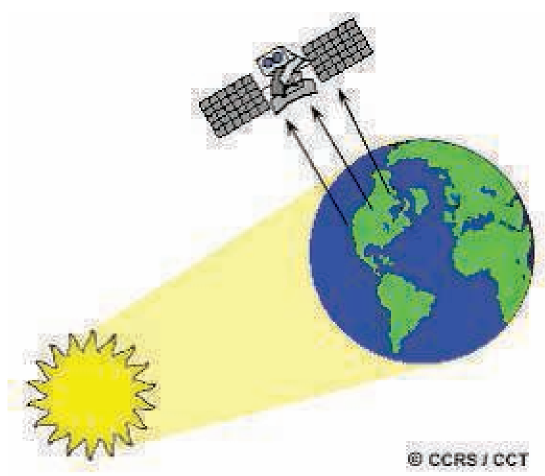


Fig. 1.24: Detecting EMR

These sensors are called radiometers and they can detect EMR within the ultraviolet to microwave wavelengths. Two important spatial characteristics of passive sensors are:

Their "instantaneous field of view" (IFOV) - this is the angle over which the detector is sensitive to radiation. This will control the picture element (pixel) size which gives the ground (spatial) resolution of the ultimate image i.e. the spatial resolution is a function of the detector angle and the height of the sensor above the ground. For more details on spatial, spectral, radiometric and temporal resolutions.

The Concept of IFOV and AFOV (after Avery and Berlin, 1985)

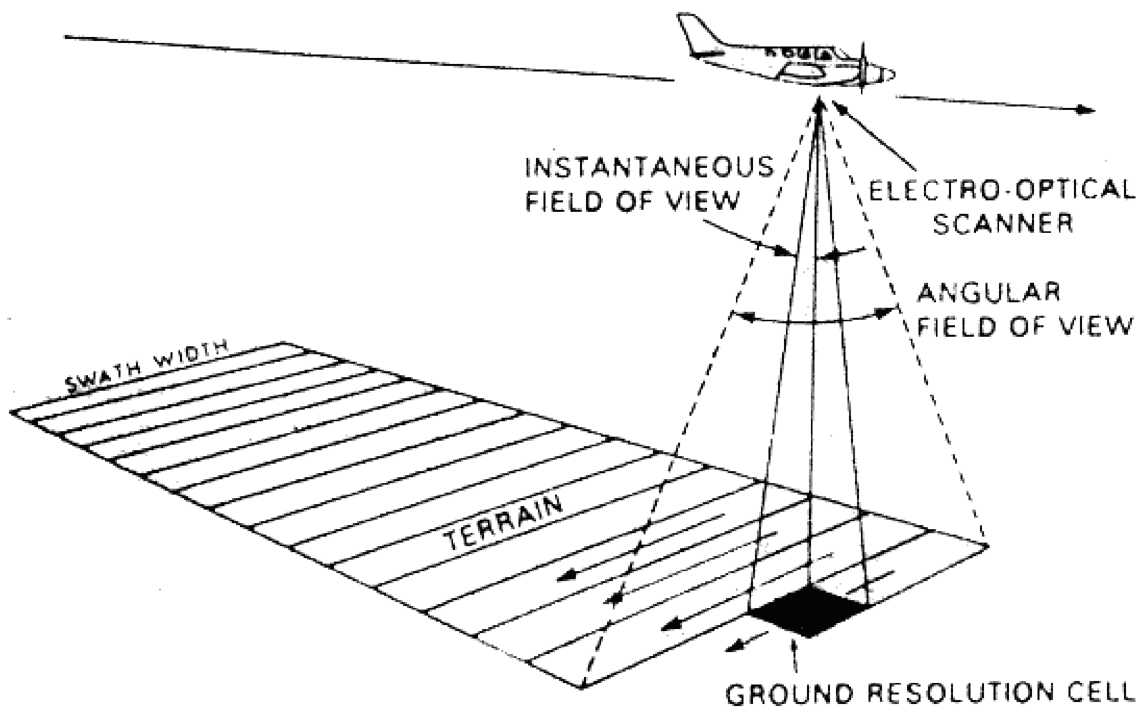


Fig. 1.25: AFOV

The "swath width" - this is the linear ground distance over which the scanner is tracking (at right angles to the line of flight). It is determined by the angular field of view (AFOV - or scanning angle) of the scanner. The greater the scanning angle, the greater the swath width.

There are two main categories of passive sensor:

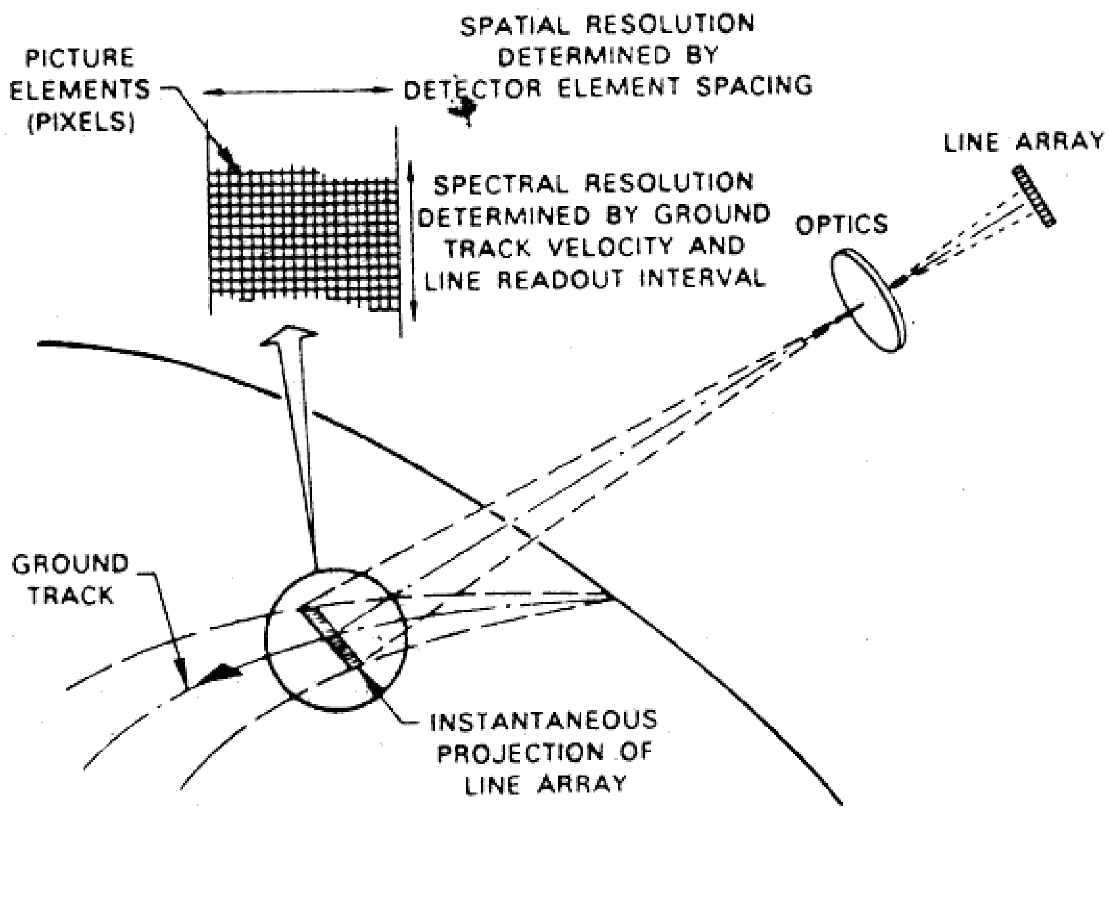
1.3.4 A mechanical scanning radiometer (Whisk Broom).

This is an electro-optical imaging system on which an oscillating or rotating mirror directs the incoming radiation onto a detector as a series of scan-lines perpendicular to the line of flight. The collected energy on the detector is converted into an electrical signal. This signal is then recorded in a suitably coded digital format, together with additional data for radiometric and geometric *calibration and correction, directly on magnetic tape on board the sensor platform.*

1.3.5 A push broom radiometer

This uses a wide angle optical system in which all the scenes across the AFOV are imaged on a detector array at one time, i.e. there is no mechanical movement. As the sensor moves along the flight line, successive lines are imaged by the sensor and sampled by a multiflexer for transmission. The push broom system is generally better than the mechanical scanner since there is less noise in the signal, there are no moving parts and it has a high geometrical accuracy.

Characteristics of a Push Broom Radiometer (after Avery and Berlin, 1985)



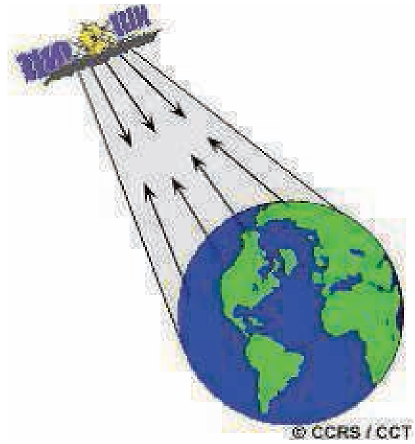


Fig. 1.26: Push Broom Radiometer

Active sensors, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets. Some examples of active sensors are a laser fluro-sensor and synthetic aperture radar (SAR).

We will review briefly airborne and satellite active systems, which are commonly called Radar, and which are generally classified either imaging or non-imaging:

Imaging Radars. These display the radar backscatter characteristics of the earth's surface in the form of a strip map or a picture of a selected area. A type used in aircraft is the SLAR whose sensor scans an area not directly below the aircraft, but at an angle to the vertical, i.e. it looks sideways to record the relative intensity of the reflections so as to produce an image of a narrow strip of terrain. Sequential strips are recorded as the aircraft moves forward allowing a complete image to be built up. The SLAR is unsuitable for satellites since, to achieve a useful spatial resolution, it would require a very large antenna. A variant used in *satellites is the SAR whose short antenna gives the effect of being several hundred times longer by recording and processing modified data.*

The Synthetic Aperture Radar System (after Avery and Berlin, 1985)

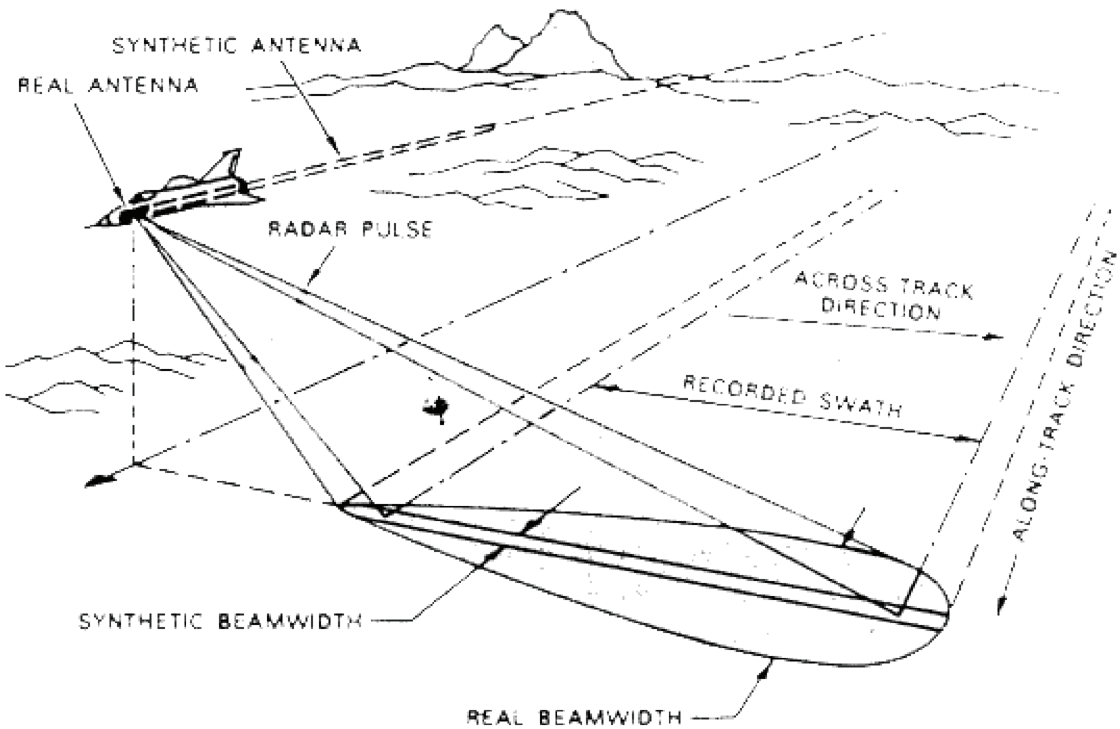


Fig. 1.27

1.4 Resolutions

1.4.1 Spatial Resolution, Pixel Size, and Scale

For some 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. Compare what an astronaut onboard the space shuttle sees of the Earth to what you can see from an airplane. The astronaut might see your whole province or country in one glance, but couldn't distinguish individual houses. Flying over a city or town, you would be able to see individual buildings *and cars, but you would be viewing a much smaller area than the astronaut. There is a similar difference between satellite images and airphotos. 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. 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 cone of visibility of the sensor (A) and determines the area on the Earth's surface which is "seen" from a given altitude at one particular moment in time (B). The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (C). This area on the ground is called the* ***resolution cell*** *and determines a sensor's maximum spatial resolution. For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If the feature is smaller than this, it may not be detectable as the average brightness of all features in that resolution cell will be recorded. However, smaller features may sometimes be detectable if their reflectance dominates within a articular resolution cell allowing sub-pixel or resolution cell detection.*

As we mentioned in earlier, 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.*

Images where only large features are visible are said to have ***coarse or low resolution.*** *In* ***fine or high resolution*** *images, small objects can be detected.*

Military sensors for example, are designed to view as much detail as possible, and therefore have very fine resolution. Commercial satellites provide imagery with resolutions varying from a few metres to several kilometres. Generally speaking, the finer the resolution, the less total ground area can be seen. The ratio of distance on an image or map, to actual ground distance is referred to as scale. If you had a map with a scale of 1:100,000, an object of 1cm length on the map would actually be an object 100,000cm (1km) long on the ground. Maps or images with small "map-to-ground ratios" are referred to as small scale (e.g. 1:100,000), and those with larger ratios (e.g. 1:5,000) are called large scale.

1.4.2 Spectral Resolution

*In Chapter 1, we learned about **spectral response** and **spectral emissivity curves** which characterize the reflectance and/or emittance of a feature or target over a variety of wavelengths. Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. Broad classes, such as water and vegetation, can usually be separated using very broad wavelength ranges - the visible and near infrared. Other more specific classes, such as **different rock types**, may not be easily distinguishable using either of these broad wavelength ranges and would require comparison at much finer wavelength ranges to separate them. Thus, we would require a sensor with higher **spectral resolution**. Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. Black and white film records wavelengths extending over much, or all of the visible portion of the electromagnetic spectrum. Its **spectral resolution** is fairly coarse, as the various wavelengths of the visible spectrum are not individually distinguished and the overall reflectance in the entire visible portion is recorded. Colour film is also sensitive to the reflected energy over the visible portion of the spectrum, but has higher spectral resolution, as it is individually sensitive to the reflected energy at the blue, green, and red wavelengths of the spectrum. Thus, it can represent features of various colours based on their reflectance in each of these distinct* *wavelength ranges. Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as **multi-spectral sensors** and will be described in some detail in following sections. Advanced multi-spectral 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.*

1.4.3 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 on film or 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 28=256 digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only 24=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). By **comparing a 2-bit image with an 8-bit image**, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions.*

1.4.4 Temporal Resolution

In addition to spatial, spectral, and radiometric resolution, the concept of ***temporal resolution*** *is also important to consider in a remote sensing system. We alluded to this idea in section 2.2 when we discussed the concept of revisit period, which refers to the length of time it takes for a satellite to complete one entire orbit cycle. The revisit period of a satellite sensor is usually several days. Therefore the absolute temporal resolution of a remote sensing system to image the exact same area at the same viewing angle a second time is equal to this period. However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of the Earth tend to be re-imaged more frequently. Also, some satellite systems are able to* ***point their sensors to image the same area*** *between different satellite passes separated by periods from one to five days. Thus, the actual temporal resolution of a sensor depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude. The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements for applying remote sensing data. Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing* ***multi-temporal*** *imagery. For example, during the growing season, most species of vegetation are in a continual state of change and our ability to monitor those subtle changes using remote sensing is dependent on when and how frequently we collect imagery. By imaging on a continuing basis at different times we are able to monitor the changes that take place on the Earth's surface, whether they are naturally occurring (such as changes in natural vegetation cover or flooding) or induced by humans (such as urban development or deforestation). The time factor in imaging is important when:*

persistent clouds offer limited clear views of the Earth's surface (often in the tropics) short-lived phenomena (floods, oil slicks, etc.) need to be imaged multi-temporal comparisons are required (e.g. the spread of a forest disease from one *year to the next) the changing appearance of a feature over time can be used to distinguish it from near similar features (wheat / maize)*

1.5 Summary

The unit begins with an introduction to remote sensing and its basic concepts. The electromagnetic spectrums being the key component have been elaborately discussed. We also learned about the various techniques of satellite remote sensing along with understanding the satellite remotely sensed data components. The resolution of a satellite remote sensing data and its various types has also been covered here.

1.6 Glossary

Bands- *A set of adjacent wavelengths or frequencies with a common characteristic. For example, visible light is one band of the electromagnetic spectrum, which also includes radio, gamma, radar and infrared waves.*

Electromagnetic- *The object / wavelength associated with electric and magnetic fields and their interactions with each other and with electric charges and currents.*

Radar- *Acronym for radio detection and ranging. A device or system that detects surface features on the earth by bouncing radio waves off them and measuring the energy reflected back.*

Radiometric- The sensitivity of a sensor to incoming reflectance

Radiation- *The emission and propagation of energy through space in the form of waves. Electromagnetic energy and sound are examples of radiation.*

Resolution- *The detail with which a map depicts the location and shape of geographic features. The larger the map scale, the higher the possible resolution. As scale decreases, resolution diminishes and feature boundaries must be smoothed, simplified, or not shown at all; for example, small areas may have to be represented as points.*

Sensors- *An electronic device for detecting energy, whether emitted or radiated, and converting it into a signal that can be recorded and displayed as numbers or as an image.Spatial- Related to or existing within space*

Spectral- *of, pertaining to, or produced by a spectrum, or the visible light*

Spectrum- *an array of entities, as light waves or particles, ordered in accordance with the magnitudes of a common physical property, as wavelength or mass: often the band of colors produced when sunlight is passed through a prism, comprising red, orange, yellow, green, blue, indigo, and violet.*

Temporal- *pertaining to or concerned with the objects/phenomenon of the present time in comparison with the same of the past time.*

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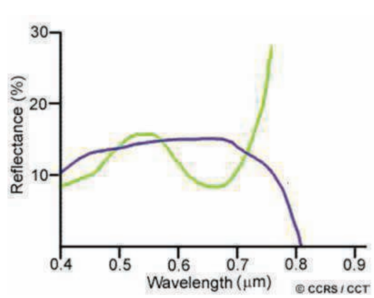
1.9 Terminal Questions

1. *Give a diagrammatic illustration of what is remote sensing.*

2. *What is EMS? Approximately what is the visible range in EMS?*

3. *What is atmospheric window? Why is it important in remote sensing?*

4. *What is a spectral signature?*



5. *Which are the two objects whose reflectance is shown in the picture. Explain why they are so different.*

6. *What are the three different types of resolutions? What do you understand by high resolution & low resolution?*

7. *Which type of resolution is characterized by the wavelength? Explain briefly.*

***

UNIT 2: SATELLITES AND SENSORS

2.1 Introduction

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*** *removed 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.*

2.2 Platforms

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 characterize the target which is being imaged by these other sensors, making it possible to better understand the information in the imagery.*

Fig. 1.1: Ground-based sensors

Sensors may be placed on a ladder, scaffolding, tall building, cherry-picker, crane, etc. Aerial platforms are primarily stable wing ***aircraft****, although helicopters are occasionally 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.*

Fig. 1.2: Space shuttle

In space, remote sensing is sometimes conducted from the ***space shuttle*** *or, more commonly, from satellites.* ***Satellites*** *are objects which 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.*

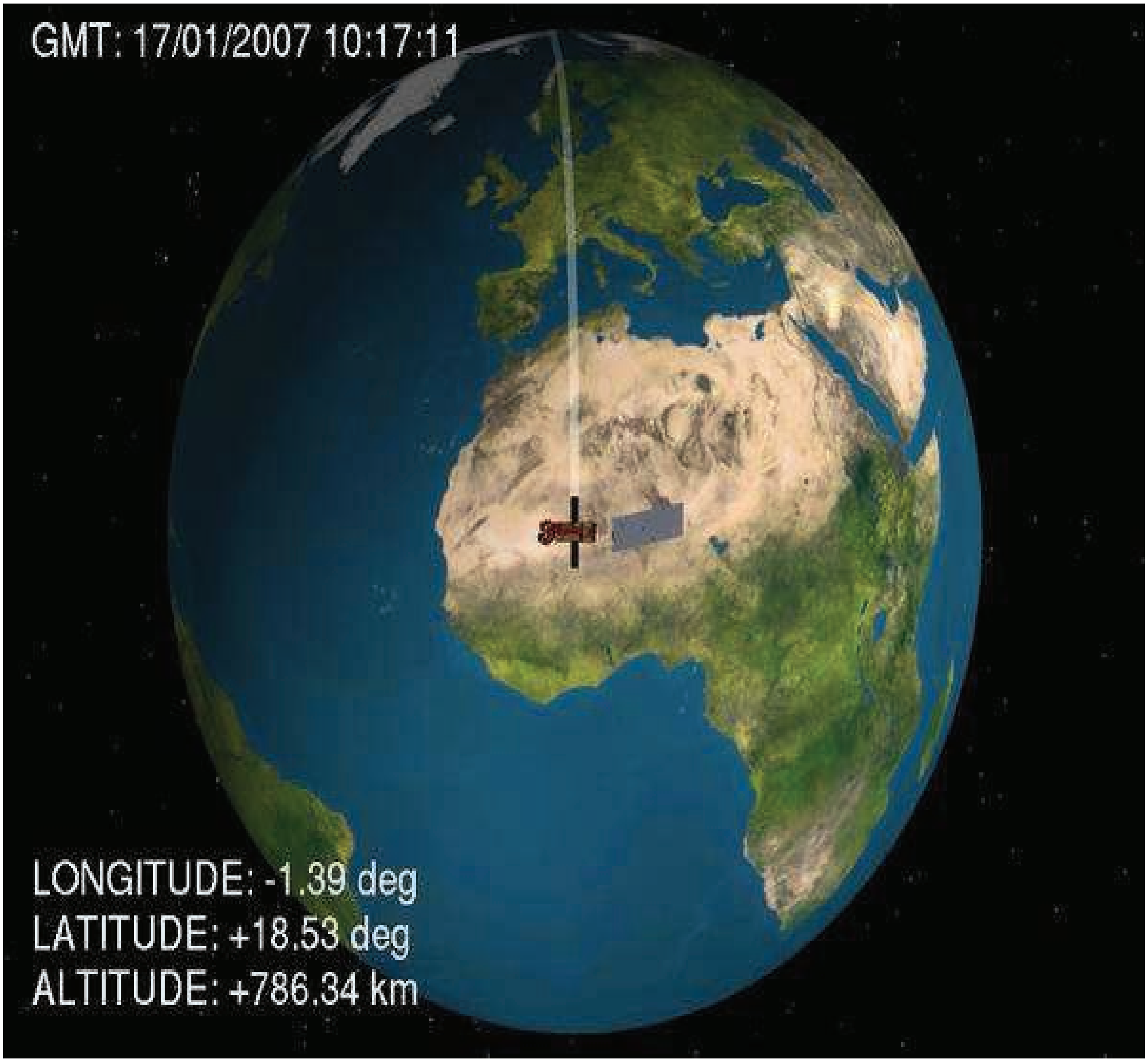


Fig. 1.3(a): Coverage of the Earth's surface

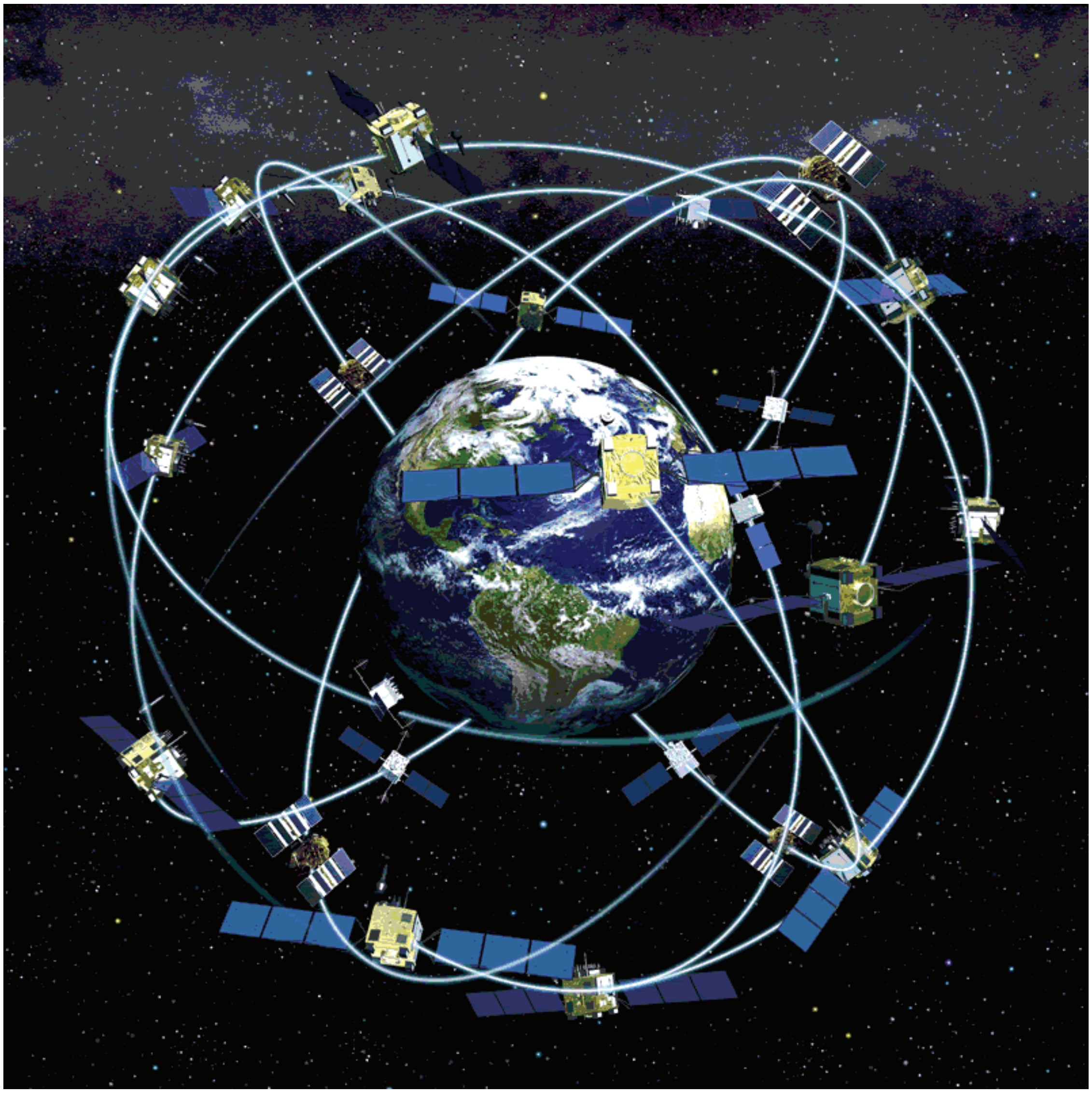


Fig. 1.3(b): Coverage of the Earth's surface

2.3 Satellite Remote Sensing

In the 1960s, a revolution in remote sensing technology began with the deployment of space satellites. From their high vantage-point, satellites have a greatly extended view of the Earth's surface. The first meteorological satellite, TIROS-1, was launched by the United States using an Atlas rocket on April 1, 1960. This early weather satellite used vidicon cameras to scan wide areas of the Earth's surface. Early satellite remote sensors did not use conventional film to produce their images. Instead, the sensors digitally capture the images using a device similar to a television camera. Once captured, this data is then transmitted electronically to receiving stations found on the Earth's surface. The image below is from TIROS-7 of a mid-latitude cyclone off the coast of New Zealand.

Fig. 1.4: TIROS-1 satellite (NASA)

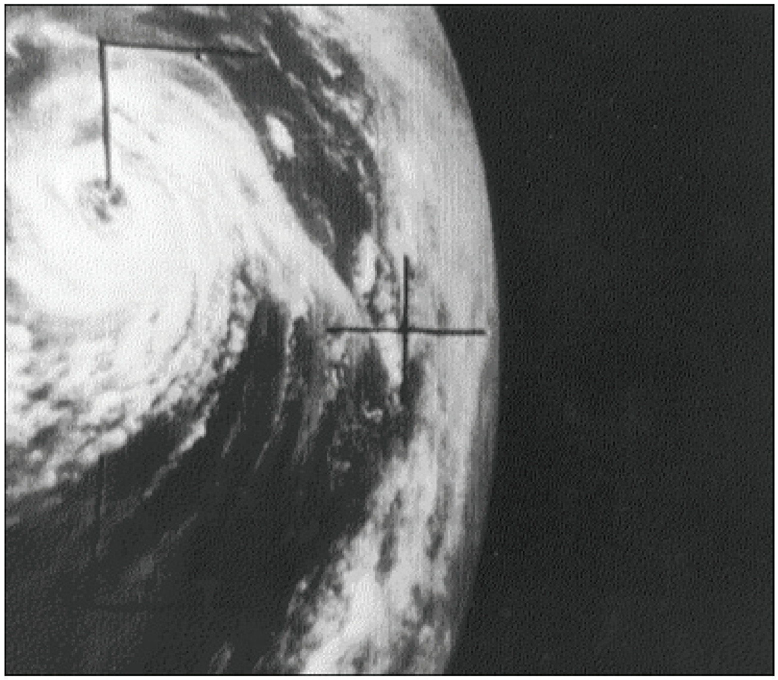


Fig. 1.5: TIROS-7 image of a mid-latitude cyclone off the coast of New Zealand, August 24, 1964

2.3.1 GOES

Today, the GOES (Geostationary Operational Environmental Satellite) system of satellites provides most of the remotely sensed weather information for North America. To cover the complete continent and adjacent oceans two satellites are employed in a geostationary orbit. The western half of North America and the eastern Pacific Ocean is monitored by GOES-10, which is directly above the equator and 135° West longitude. The eastern half of North America and the western Atlantic are cover by GOES-8. The GOES-8 satellite is located overhead of the equator and 75° West longitude. Advanced sensors aboard the GOES satellite produce a continuous data stream so images can be viewed at any instance. The imaging sensor produces visible and infrared images of the

Earth's terrestrial surface and oceans. Infrared images can depict weather conditions even during the night. Another sensor aboard the satellite can determine vertical temperature profiles, vertical moisture profiles, total perceptible water, and atmospheric stability.

Fig. 1.6: Color image from GOES-8 of hurricanes Madeline and Lester off the coast of Mexico, October 17, 1998. (Source: NASA - Looking at Earth From Space).

2.3.2 Landsat Missions

In the 1970s, the second revolution in remote sensing technology began with the deployment of the Landsat satellites. Since this 1972, several generations of Landsat satellites with their Multispectral_Scanners (MSS) have been providing continuous coverage of the Earth for almost 30 years. Current, Landsat satellites orbit the Earth's *surface at an altitude of approximately 700 kilometers. Spatial resolution of objects on the ground surface is 79 x 56 meters. Complete coverage of the globe requires 233 orbits and occurs every 16 days. The Multispectral Scanner records a zone of the Earth's surface that is 185 kilometers wide in four wavelength bands: band 4 at 0.5 to 0.6 micrometers, band 5 at 0.6 to 0.7 micrometers, band 6 at 0.7 to 0.8 micrometers, and band 7 at 0.8 to 1.1 micrometers. Bands 4 and 5 receive the green and red wavelengths in the visible light range of the electromagnetic spectrum. The last two bands image near-infrared wavelengths. A second sensing system was added to Landsat satellites launched after 1982. This imaging system, known as the Thematic_Mapper, records seven wavelength bands from the visible to far-infrared portions of the electromagnetic spectrum. In addition, the ground resolution of this sensor was enhanced to 30 x 20 meters. This modification allows for greatly improved clarity of imaged objects.*

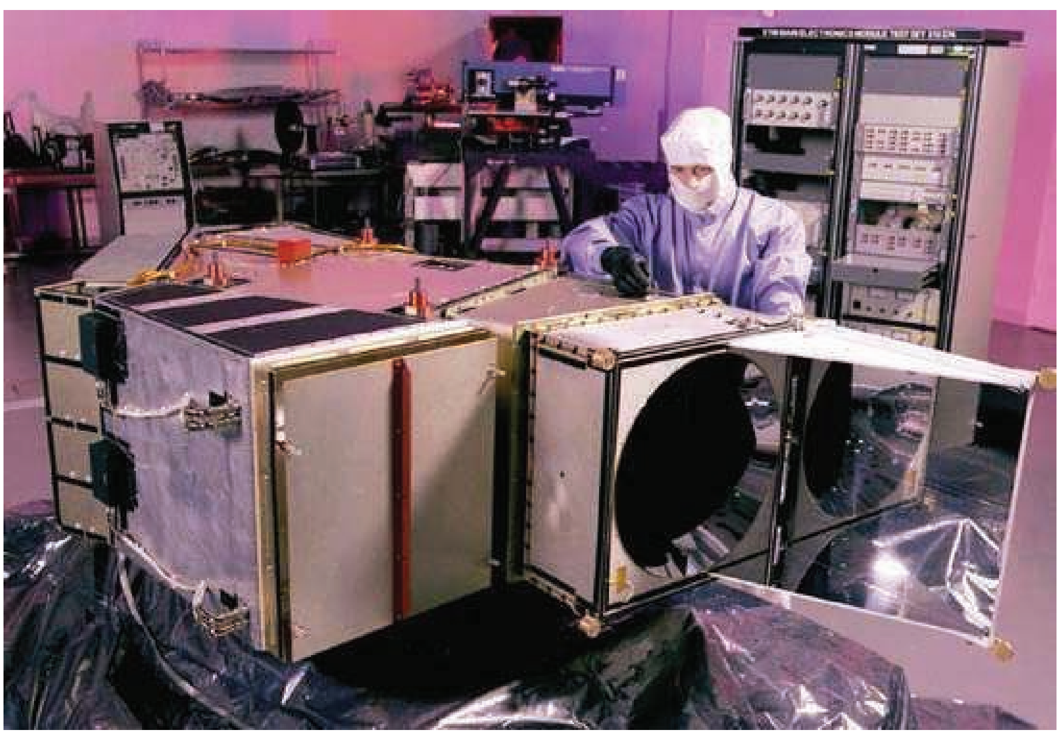


Fig. 1.7: The Landsat 7 enhanced Thematic Mapper instrument

2.3.3 SPOT

The usefulness of satellites for remote sensing has resulted in several other organizations launching their own devices. In France, the SPOT (Satellite Pour l'Observation de la Terre) satellite program has launched five satellites since 1986. Since 1986, SPOT satellites have produced more than 10 million images. SPOT satellites use two different sensing systems to image the planet. One sensing system produces black and white panchromatic images from the visible band (0.51 to 0.73 micrometers) with a ground resolution of 10 x 10 meters. The other sensing device is multispectral capturing green, red, and reflected infrared bands at 20 x 20 meters. SPOT-5, which was launched in 2002, is much improved from the first four versions of SPOT satellites. SPOT-5 has a maximum ground resolution of 2.5 x 2.5 meters in both panchromatic mode and multispectral operation.

Fig. 1.8: SPOT false-color image of the southern portion of Manhatten Island and part of Long Island, New York. The bridges on the image are (left to right): Brooklyn Bridge, Manhattan Bridge, and the Williamsburg Bridge. (Source: SPOT Image).

2.3.4 Radarsat

Radarsat-1 was launched by the Canadian Space Agency in November, 1995. As a remote sensing device, Radarsat is quite different from the Landsat and SPOT satellites. Radarsat is an active remote sensing system that transmits and receives microwave radiation. Landsat and SPOT sensors passively measure reflected radiation at wavelengths roughly equivalent to those detected by our eyes. Radarsat's microwave energy penetrates clouds, rain, dust, or haze and produces images regardless of the Sun's illumination allowing it to image in darkness. Radarsat images have a resolution between 8 to 100 meters. This sensor has found important applications in crop monitoring, *defence surveillance, disaster monitoring, geologic resource mapping, sea-ice mapping and monitoring, oil slick detection, and digital elevation modeling.*

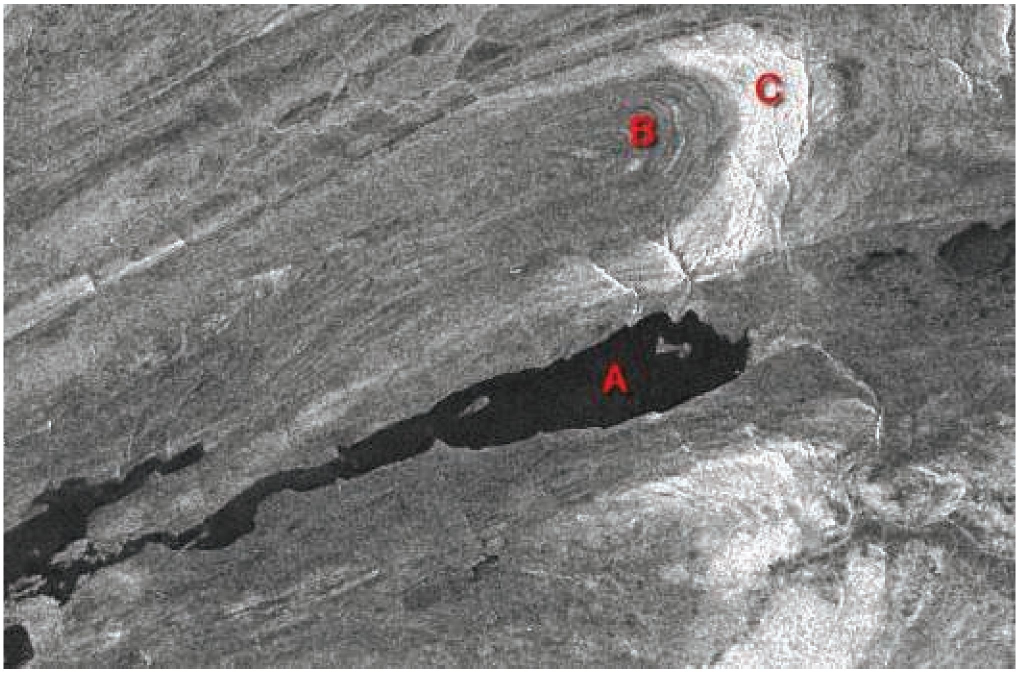


Fig. 1.9: Radarsat image acquired on March 21, 1996, over Bathurst Island in Nunavut, Canada.

This image shows Radarsat's ability to distinguish different types of bedrock. The light shades on this image (C) represent areas of limestone, while the darker regions (B) are composed of sedimentary siltstone. The very dark area marked A is Bracebridge Inlet which joins the Arctic ocean. (Source:Canadian Centre for Remote Sensing - Geological Mapping Bathurst Island, Nunavut, Canada March 21, 1996).

2.3.5 Sensors Used In Indian Satellites

A list of the sensors that have been used in Indian Remote Sensing satellites:

Satellite Microwave Radiometer (SAMIR) *SAMIR was the payload for BHASKAR I and II satellites launched in 1979 and 1981. They sucessfully provided data on the sea surface temperature, ocean winds, moisture content over the land and sea. It was a dicke type radiometer with a temperature resolution better than 1 degree kelvin.*

Two Band T.V. Payload

The Bhaskara satellites I and II *had a two band TV payload for land applications. It gave images of earth from a height of 525 Km. The data were used in meterology, hydrology, and forestry.*

Smart Sensor Rohini Rs-D2*, (the sucessor to the failed Rs-D1) was launched on Apr. 1983. It carried a Smart sensor, which was a 2-Band solid-state device. It had the first CCD camera developed in house.*

LISS-I, II and III

LISS-I (Linear Imaging self Scanner) was a payload for the IRS-1A satellite. This camera operated in four spectral bands. It operated in a push-broom scanning mode using a CCD array. It was again used in IRS-1B. It used 7 bit quantization, and had a swath of 148 Kms. Images of LISS-I were extensively used in forestry, crop acreage, yield estimation, drought monitoring, flood monitoring etc.

LISS-II was similar to LISS-I, but with higher spatial resolution and smaller swath. it was on payload in three satellites : IRS-1A, IRS-1B, IRS-P2.

LISS-III is onboard two satellites IRS-1C and IRS-1D. This is a multi-spectral camera which operates in four bands. It provides color images. Its images were used widely in the area of agriculture, mapping, crop acreage etc.

The Panchromatic Camera

This was carried by IRS-1c and IRS-1D satellites. Pan camera enables the acquisition of images at the resolution of 5.8m, which was the highest resolution offered by a civilian satellite until recently, when American satellite Ikonos with a resolution of 1m surpassed it. The Pan camera uses CCD's to capture images.

Wide Field Sensor

IRS-1C, IRS-1D, IRS-P3, which are all second generation Indian remote sensing satellites, carried the WIFS sensor. The WIFS camera uses an 8 element refractive optics like in LISS-III. Two such cameras are mounted with overlapping pixels of imaging. WIFS data was used in assesment of rabi cropped area, crop inventory, observation of crop phenology etc.

Ocean Color Monitor

IRS-P4, also called Oceansat, carried the ocean color monitor, launched on board PSLV-C1. This payload is meant for oceanographic applications. The OCM is a solid state camera operating in the push-broom scanning mode, using linear array CCD'S as detectors for generating ocean biological parameters.

Very High Resolution RadioMeter

All the INSAT-1 and the INSAT-2, INSAT-3 series communications satellites carry the VHRR to provide various remote sensing applications. Since INSAT satellites are geostationary, VHRR provides round the clock meteorological earth observations, disaster warning signals.

2.4 Summary

This unit begins with an introduction the various platforms available for remote sensing. The most widely used satellites and sensors have been covered here. The Indian satellites and the type of data it provides have also been illustrated.

2.5 Glossary

Aerial- *operating on a track or cable elevated above the ground*

Band- *A set of adjacent wavelengths or frequencies with a common characteristic. For example, visible light is one band of the electromagnetic spectrum, which also includes radio, gamma, radar and infrared waves.*

Satellite- *a device designed to be launched into orbit around the earth, another planet, the sun,*

using an earth-orbiting satellite to transmit communications signals

Sensor- *An electronic device for detecting energy, whether emitted or radiated, and converting it into a signal that can be recorded and displayed as numbers or as an image.*

Geostationary- *Positioned in an orbit above the earth's equator with an angular velocity the same as that of the earth and an inclination and eccentricity approaching zero. A geostationary satellite will orbit as fast as the earth rotates on its axis, so that it remains effectively stationary above a point on the equator. A geostationary satellite is geosynchronous, but geosynchronous satellites are not necessarily geostationary.*

Mulitspectral- *Related to two or more frequencies or wavelengths in the electromagnetic spectrum.*

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2.8 Terminal Questions

1. *What is the difference between a satellite, sensor and platform?*

2. *Name 5 satellites with sensors.*

3. *Name one active remote sensing satellite. What kind of information can be derived from this satellite data?*

4. *LISS III is the sensor of which satellite? How many bands are there in LISS III? Name a few uses of this multispectral data.*

5. *What is the full form of WIFS? Name two use of WIFS data.*

***

UNIT 3: GPS: GLOBAL POSITIONING SYSTEM

3.1 Introduction

Global Positioning System (GPS) technology is a great boon to anyone who has the need to navigate either great or small distances. This wonderful navigation technology was actually first available for government use back in the late 1970s. In the past ten or so years, It has been made available to the general public in the form of handheld receivers that use this satellite technology provided by the U.S. government.

GPS formally known as the NAVSTAR (Navigation Satellite Timing and Ranging) Global Positioning System, originally was developed for the military. Because of its popular navigation capabilities and because you can access GPS technology using small inexpensive equipment, the government mad the system available for civilian use. The USA owns GPS technology and the Department of Defense maintains it. The first satellite was placed in orbit on 22nd February 1978, and there are currently 28 operational satellites orbiting the Earth at a height of 20,180 km on 6 different orbital planes. Their orbits are inclined at 55° to the equator, ensuring that at least 4 satellites are in radio communication with any point on the planet. Each satellite orbits the Earth in approximately 12 hours and has four atomic clocks on board. During the development of the GPS system, particular emphasis was placed on the following three aspects:

1. *It had to provide users with the capability of determining position, speed and time, whether in motion or at rest.*
2. *It had to have a continuous, global, 3-dimensional positioning capability with a high degree of accuracy, irrespective of the weather.*
3. *It had to offer potential for civilian use.*

GPS has also demonstrated a significant benefit to the civilian community who are applying GPS to a rapidly expanding number of applications. What attracts us to GPS is:

1. *The relatively high positioning accuracies, from tens of meters down to the millimeter level.*

2. *The capability of determining velocity and time, to an accuracy commensurate with position.*

3. *The signals are available to users anywhere on the globe: in the air, on the ground, or at sea.*

4. *Its is a positioning system with no user charges, that simply requires the use of relatively low cost hardware.*

5. *It is an all-weather system, available 24 hours a day.*

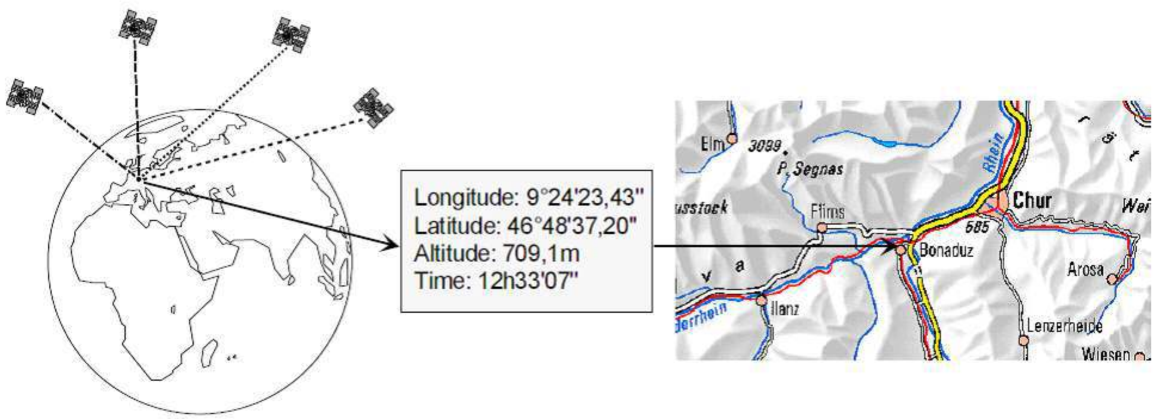
6. *The position information is in three dimensions, that is, vertical as well as horizontal information is provided*

Using the Global Positioning System (GPS, a process used to establish a position at any point on the globe) the following two values can be determined anywhere on Earth:

1. *One's exact location (longitude, latitude and height co-ordinates) accurate to within a range of 20 m to approx. 1 mm.*

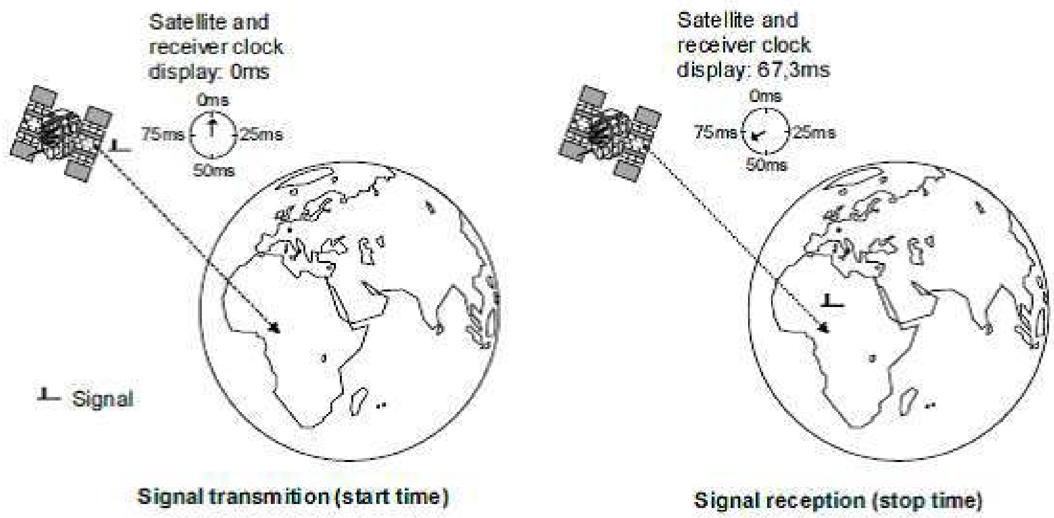
2. *The precise time (Universal Time Coordinated, UTC) accurate to within a range of 60ns to approx. 5ns.*

Speed and direction of travel (course) can be derived from these co-ordinates as well as the time. The coordinates and time values are determined by 28 satellites orbiting the Earth.



3.2 Concepts of GPS

Generating GPS signal transit time 28 satellites inclined at 55° to the equator orbit the Earth every 11 hours and 58 minutes at a height of 20,180 km on 6 different orbital planes (Figure 3). Each one of these satellites has up to four atomic clocks on board. Atomic clocks are currently the most precise instruments known, losing a maximum of one second every 30,000 to 1,000,000 years. In order to make them even more accurate, they are regularly adjusted or synchronised from various control points on Earth. Each satellite transmits its exact position and its precise on board clock time to Earth at a frequency of 1575.42 MHz. These signals are transmitted at the speed of light (300,000 km/s) and therefore require approx. 67.3 ms to reach a position on the Earth's surface located directly below the satellite. The signals require a further 3.33 us for each excess kilometer of travel. If you wish to establish your position on land (or at sea or in the air), all you require is an accurate clock. By comparing the arrival time of the satellite signal with the on board clock time the moment the signal was emitted, it is possible to determine the transit time of that signal (Figure 4).



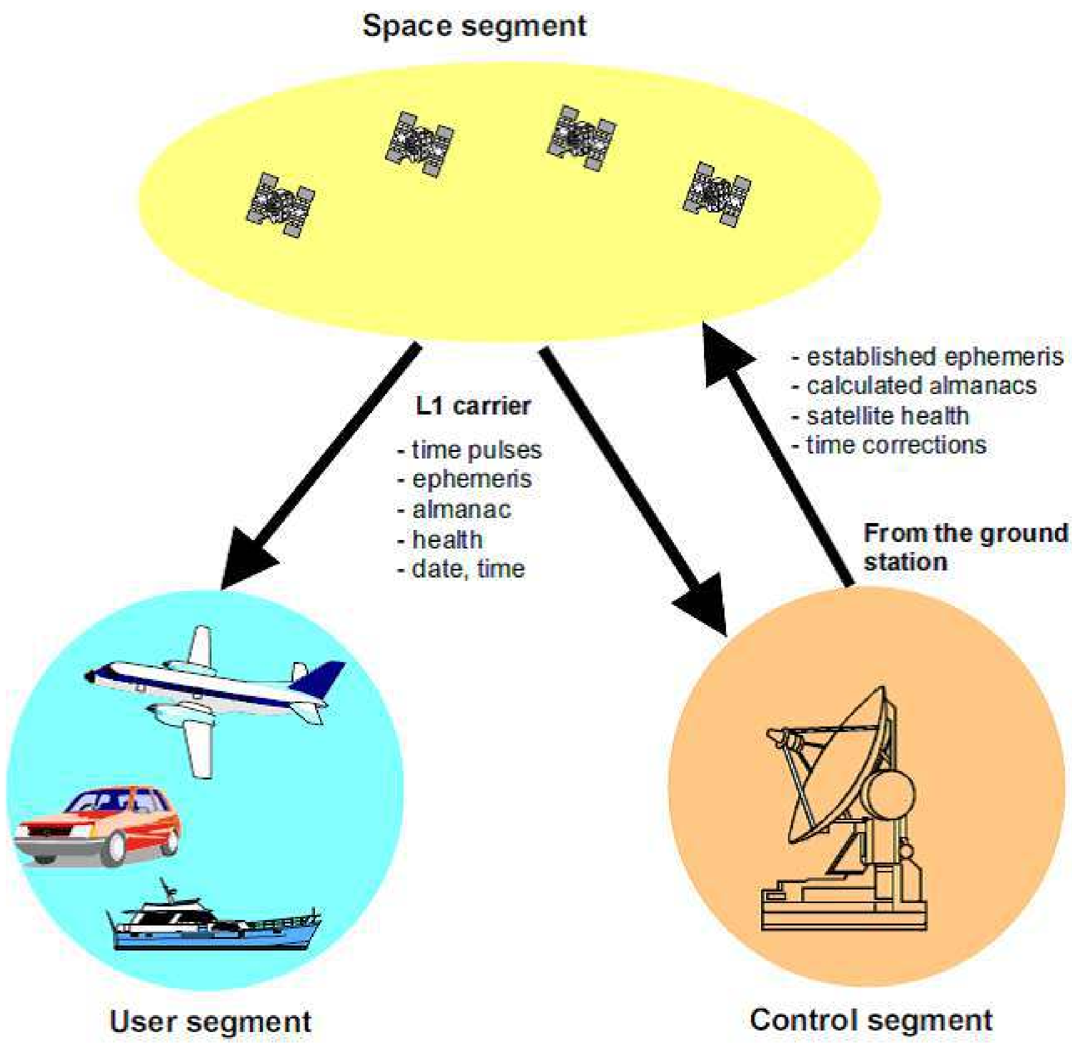
The distance S to the satellite can be determined by using the known transit time τ:

distance travel time x the speed of light

$S = \tau \times c$

Measuring signal transit time and knowing the distance to a satellite is still not enough to calculate one's own position in 3-D space. To achieve this, four independent transit time measurements are required. It is for this reason that signal communication with four different satellites is needed to calculate one's exact position. Why this should be so, can best be explained by initially determining one's position on a plane.

3.2.1 GPS system elements



The GPS system consists of three segments. (Good general references on the GPS system are) :

*• The **Space Segment**: comprising the satellites and the transmitted signals.*

*• The **Control Segment**: the ground facilities carrying out the task of satellite tracking, orbit computations, telemetry and supervision necessary for the daily control of the space segment.*

• *The* ***User Segment****: the entire spectrum of applications equipment and computational techniques that are available to the users.*

The Space Segment consists of the constellation of spacecraft and the signals broadcast by them

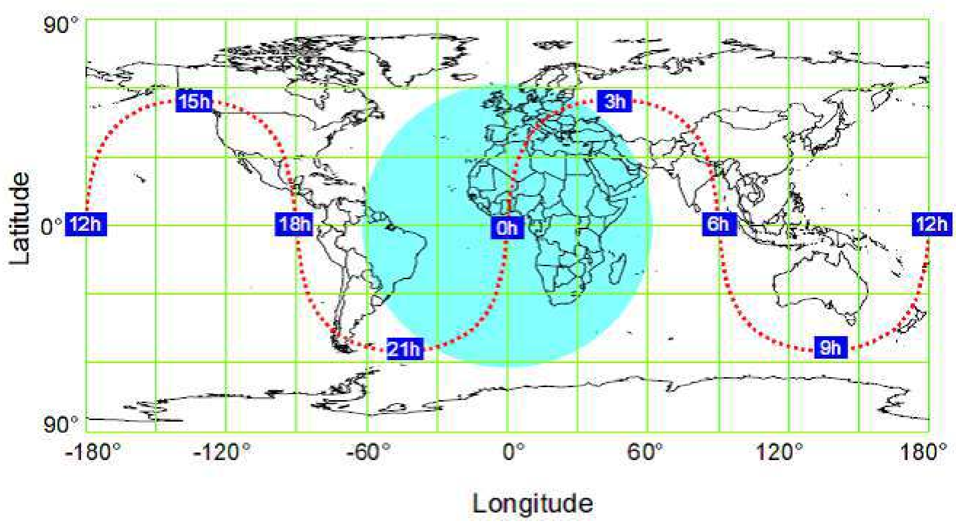
which allow users to determine position, velocity and time. The basic functions of the satellites are to:

• *Receive and store data transmitted by the Control Segment stations.*

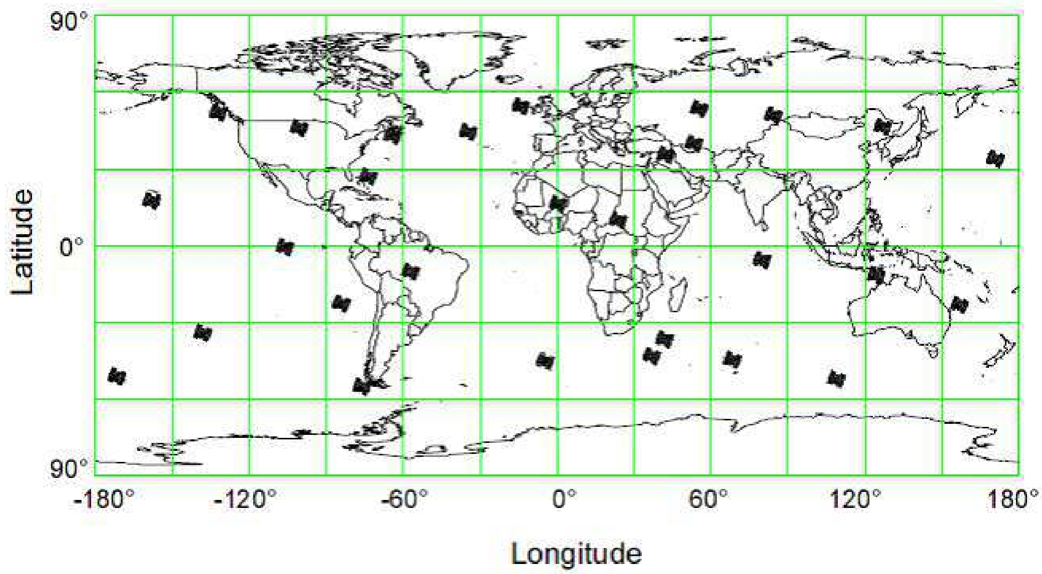
• *Maintain accurate time by means of several onboard atomic clocks.*

• *Transmit information and signals to users on two L-band frequencies.*

• *Provide a stable platform and orbit for the L-band transmitters.*



Satellite signals can be received anywhere within a satellite's effective range. The effective range (shaded area) of a satellite located directly above the equator/zero meridian intersection. The distribution of the 28 satellites at any given time can be seen. It is due to this ingenious pattern of distribution and to the great height at which they orbit that communication with at least 4 satellites is ensured at all times anywhere in the world.



ure 10: Position of the 28 GPS satellites at 12.00 hrs UTC on 14th April 2001

3.2.2 Control segment

The control segment (Operational Control System OCS) consists of a Master Control Station located in the state of Colorado, five monitor stations equipped with atomic clocks that are spread around the globe in the vicinity of the equator, and three ground control stations that transmit information to the satellites.

The most important tasks of the control segment are:

- *Observing the movement of the satellites and computing orbital data (ephemeris)*
- *Monitoring the satellite clocks and predicting their behaviour*
- *Synchronising on board satellite time*
- *Relaying precise orbital data received from satellites in communication*
- *Relaying the approximate orbital data of all satellites (almanac)*
- *Relaying further information, including satellite health, clock errors etc.*

The control segment also oversees the artificial distortion of signals (SA, Selective Availability), in order to degrade the system's positional accuracy for civil use. System accuracy had been intentionally degraded up until May 2000 for political and tactical reasons by the U.S. Department of Defense (DoD), the satellite operators. It was shut down in May 2000, but it can be started up again, if necessary, either on a global or regional basis.

3.2.3 User segment

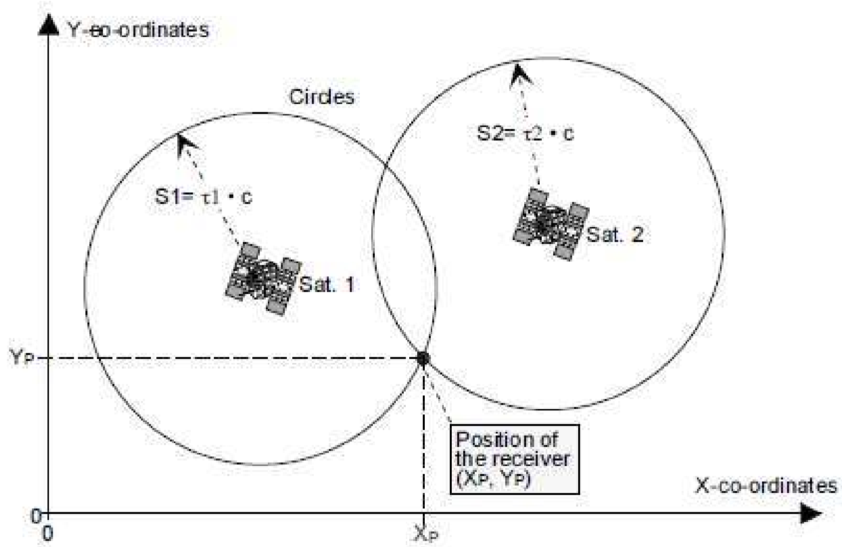
The signals transmitted by the satellites take approx. 67 milliseconds to reach a receiver. As the signals travel at the speed of light, their transit time depends on the distance between the satellites and the user.

Four different signals are generated in the receiver having the same structure as those received from the 4 satellites. By synchronising the signals generated in the receiver with those from the satellites, the four satellite signal time shifts Δt *are measured as a timing mark.*

3.2.4 Determining a position on a plane

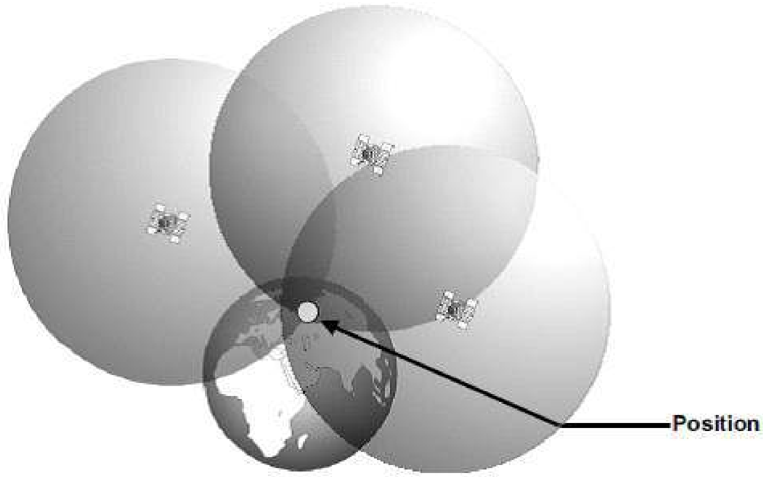
Imagine that you are wandering across a vast plateau and would like to know where you are. Two satellites are orbiting far above you transmitting their own on board clock times and positions. By using the signal transit time to both satellites you can draw two circles with the radii S1 and S2 around the satellites. Each radius corresponds to the distance calculated to the satellite. All possible distances to the satellite are located on the circumference of the circle. If the position above the satellites is excluded, the location of the receiver is at the exact point where the two circles intersect beneath the satellites.

Two satellites are sufficient to determine a position on the X/Y plane.



In reality, a position has to be determined in three-dimensional space, rather than on a plane. As the difference between a plane and three-dimensional space consists of an extra dimension (height Z), an additional third satellite must be available to determine the true position. If the distance to the three satellites is known, all possible positions are located on the surface of three spheres whose radii correspond to the distance calculated.

The position sought is at the point where all three surfaces of the spheres intersect.



All statements made so far will only be valid, if the terrestrial clock and the atomic clocks on board the satellites are synchronised, i.e. signal transit time can be correctly determined.

3.3 Types of GPS

Google Earth and Google Maps are made to work with GPS data

Many services allow you to upload your GPS tracks and waypoints to Google Earth. Others also let you upload your photos and even geo-reference them for you, so they are projected exactly on the spots where they have been taken.

Hybrid GeoTools *make custom and standard software to extend the functionality of popular geographic tools such as Google Earth.*

Hybrid GeoTools' **Active GPX Route Player** *for Google Earth. The "Media Player" of GPS playback. Simple to use yet endlessly customizable, up to 50 routes can be played back at the same time. Adjust time, speed scale, viewing behavior, track and icon appearance and watch progress against an altitude profile. Every turn, acceleration and stop is faithfully recreated.*

New in Version 1.1 - Virtual Cyclist - Set the power, weight, aerodynamics and see how you'd perform on the climbs of the Tour de France.

Hybrid GeoTools' ***3D Route Builder*** *is a GPS Editor for Google Earth. It offers fine grain control of routes directly in Google Earth not only in terms of positioning and altitude but also in time. Easily shift and scale time, correct barometric drift, synch to video files and build accurate GPS (GPX), KML/KMZ and Garmin TCX files from scratch or from existing files. Playback routes in real-time and optionally with absolute altitude - that means tunnels, bridges, cable car rides and flights take on new levels of realism.*

3dtracking *Ltd has just launched a new range of completely free GPS services through their website http://www.3dtracking.net. Simply put, through using your mobile phone or PDA, along with your GPS receiver, you can record and view your movements in detail on Google Earth or Google Maps. You can even use the free service for live tracking using Google Earth or Google Maps. Download of the required 3dtracking GPS software application, as well as use of the website, is completely free (and there are no future* *plans to charge for this either. Ever). The web server also retains all the data you've ever recorded and submitted, so you can always go back and view your older recorded data at any time.*

Adam Schneider has added Google Maps as an output format in ***GPS Visualizer****. You can upload your GPS data file (in a supported format) and instantly view it in Google Maps. It is also available as an output choice in the other input forms, including the address form.*

Phone2GEarth *is an easy Nokia Series 80 GPS software application that allows to log tracks which are directly saved as Google Earth KML files. New and useful features like: - English, Spanish, German and French languages. - Place marks supported with timestamps in the track. - bluetooth autostart, for easy use. - Complete Series 80: 9300, 9500 - Color and phone name configurable. It allows deferent phones, tracks etc. Requirements: * Series 80 (Symbian) Smartphone (9500, 9300). * GPS Bluetooth (NMEA protocol). * Google Earth (Windows).*

Earth Bridge *is designed to bridge the gap between Google Earth and your GPS receiver. See your location on Google Earth in real-time and easily control your view. Record your track as you move. Earth Bridge GPS software requires an NMEA 0183 compatible GPS device connected via a serial interface.*

GEtrax *is a Windows GPS software application that can.*

Plot various format track files in Google Earth.

GPX

XML

OziExplorer

Raw NMEA data (text)

CSV data (text - one type only)

Plot GPX or OziExplorer format waypoint files in Google Earth (as placemarks).

Read live (NMEA) data from any gps (COM port) and plot location and track in Google Earth.

Read a track file directly from a Garmin gps and plot it in Google Earth.

Put tracks (including live data) on a server and email a recipient for remote viewing.

Save tracks in GoogleMap and OziExplorer format.

Save track and waypoint files as GPX format for archiving.

Read track data from existing KML files.

Read Ham radio tracking data from Findu.com or from a receiver and plot the location and track in Google Earth.

***GPS Radar** GPS software from JGUI allows you to use your Windows Mobile*) device for the following reasons:*

- *monitor your localization by GPS receiver.*
- *save the track and points of moving.*
- *generate various XML reports.*
- *upload points to dedicated Internet server.*
- *review your moving on designed web pages with Google Maps streets or satellites images.*
- *generate GoogleEarth current location.*
- *generate GoogleEarth track files.*
- *review your moving directly on GoogleEarth interface screen with all its features.*

This GPS software version works well with any Windows Mobile device with GSM network connection built-in. So called: Phone Edition devices. Any GPS receiver is required.

GPS Track *GPS software connects to a GPS and records the path that you travel. Tracks can be uploaded to a web site, sent by email, transferred via Bluetooth, or written to a flash memory card. Google Maps and Google Earth are used to view the tracks. File formats such as GPX and CSV are also supported. Compatibility: This GPS software requires a cell phone or other mobile device with:*

J2ME (Java 2 mobile edition).

Java API for Bluetooth (JSR-82).

A GPS with Bluetooth is also required.

EveryTrail *is an online platform that enables you to visualize your travel and outdoor activities and share these with like minded people from all over the world. With EveryTrail you can easily upload GPS data you recorded while out on the trail and add your photos and notes, to create a visual record of your outdoor activity. EveryTrail was created by a small group of passionate travel and outdoor enthusiasts, out of dissatisfaction with current solutions to share trips with friends and like minded people.*

3.3.1 Components of a GPS Instrumentation

The following components of a generic GPS receiver can be identified (figure 1.9):

Antenna and Preamplifier: Antennas used for GPS receivers have broadbeam characteristics, thus they do not have to be pointed to the signal source like satellite TV receiving dishes. The antennas are compact and a variety of designs are possible. There is a trend to integrating the antenna assembly with the receiver electronics.

Radio Frequency Section and Computer Processor: The RF section contains the signal processing electronics. Different receiver types use somewhat different techniques to process the signal. There is a powerful processor onboard not only to carry out computations such as extracting the ephemerides and determining the elevation/azimuth of the satellites, etc., but also to control the tracking and measurement function within modern digital circuits, and in some cases to carry out digital signal processing.

Control Unit Interface: The control unit enables the operator to interact with the microprocessor. Its size and type varies greatly for different receivers, ranging from a handheld unit to soft keys surrounding an LCD screen fixed to the receiver "box".

Recording Device: in the case of GPS receivers intended for specialised uses such as the surveying the measured data must be stored in some way for later data processing. In the case of ITS applications such as the logging of vehicle movement, only the GPS-derived coordinates and velocity may be recorded. A variety of storage devices were utilised in the past, including cassette and tape recorders, floppy disks and computer tapes, etc., but these days almost all receivers utilise solid state (RAM) memory or removable memory "cards".

Power Supply: Transportable GPS receivers these days need low voltage DC power. The trend towards more energy efficient instrumentation is a strong one and most GPS receivers operate from a number of power sources, including internal NiCad or Lithium batteries, external batteries such as wet cell car batteries, or from mains power.

3.3.2 Primary GPS terms

TRACK: *This indicates the direction in which you move. Sometimes this is called HEADING. For navigation on land this is OK, but a boat or a plane can travel in another direction, than the direction in which it is headed, due to wind or current.*

TRACKLOG: *This is the electronic equivalent of the famous bread crumb trail. If you turned (automatic) tracklog on, your receiver will, at fixed intervals or at special occasions, save the position, together with the time, to its memory. This can be invaluable if at any moment during your trip you (have to) decide to go back exactly along the route that brought you to your actual position.*

TRACBACK: *Among the best known GPS terms, it is the navigation method that will bring you back to your point of departure along the same trail that you traveled to your actual position. In order to be able to use this method, you may need to copy the tracklog to one of the free track channels. (This is where you need your manual for). Often a saved track can only contain 250 points, but be assured that your GPS receiver will do a wonderful job in choosing the points which best represent your traveled track.*

WAYPOINT: *Probably one of the most used general GPS terms. A waypoint is nothing more or less than a saved set of co-ordinates. It does not have to represent a physical point on land. Even at sea or in the air, one can mark a waypoint. Once saved in your GPS receiver, you can turn back to exactly that set of co-ordinates. You can give waypoints meaningful names. They can be created 'on the fly', which means that you can register them at 130 km/h on the road or even at 800 km/h in a plane. Your GPS will attribute it a number, which you can change to any name you want, once you have the time. You can also manually enter a set of co-ordinates, that you found on a map. This way you can plan ahead a trip or a walk with as much detail as you like.*

Waypoints are very powerful navigation aids and for really critical operations it should be considered to not only store their co-ordinates in your GPS receiver, but also in your paper notebook. After all a highly sophisticated device as a GPS receiver could stop functioning correctly for a lot of reasons.

ROUTE: *A route is a series of two or more waypoints. To create a route, you have to tell your GPS to reserve some place in its memory for a new route and then you indicate which waypoints will form the route. You enter them in the* *order in which you want to travel them, but you can easily navigate them in reverse order. You can add waypoints and delete others, but once saved, the order in which your GPS will guide you along the waypoints is fixed.*

This is a great way to plan ahead a walk. You can even create waypoints and routes on your desktop PC and transfer them to your GPS receiver. All you need for this is a cable which links your GPS to a RS232-port(COM) on your computer and a piece of software, that enables you to mark points on a map at your screen. We will treat this in more detail elsewhere on the site. You will see that this is absolutely not rocket-science.

ROUTE LEG *is the straight line between two adjacent waypoints in a route.*

GOTO *is also among the best known GPS terms and probably the most used navigation method with a GPS receiver, because it is easily understood and executed. If you tell your companion that you will GOTO waypoint X, it will calculate the direction and distance from your actual location to the set of co-ordinates, represented by the indicated waypoint. Your GPS receiver is unable to know what obstacles, hazards or whatever, if any, there are between you and waypoint X, so it will guide you in a straight line to the indicated point. This is great on open water or in the air, but on land it is often not the best method.*

BEARING: *Once you told to which point you want to travel, your GPS will continuously calculate in which direction that point is situated, seen from your actual position. That direction is the bearing. If you navigate along a route, the bearing will be the direction to the NEXT waypoint in the route. If you do or can not travel in a straight line to the waypoint, the bearing will fluctuate all the time.*

TURN: *This GPS term indicates the difference between the direction you should travel in (BEARING) and the direction in which you are actually traveling (TRACK). An indication of '28L' means that you should modify your actual direction of travel with 28° to the Left, if you wish to ever reach your point. In principle, when you have the reading of TURN on your navigation page, you* *don't need the readings of those other two GPS terms BEARING and TRACK, but most people prefer reading these two.*

3.4 GPS Errors and Correction

3.4.1 The effect and correction of time error

We have been assuming up until now that it has been possible to measure signal transit time precisely. However, this is not the case. For the receiver to measure time precisely a highly accurate, synchronised clock is needed. If the transit time is out by just 1 μs this produces a positional error of 300m. As the clocks on board all three satellites are synchronised, the transit time in the case of all three measurements is inaccurate by the same amount. Mathematics is the only thing that can help us now. We are reminded when producing calculations that if N variables are unknown, we need N independent equations.

If the time measurement is accompanied by a constant unknown error, we will have four unknown variables in

3-D space:

- *longitude (X)*
- *latitude (Y)*
- *height (Z)*
- *time error (Δt)*

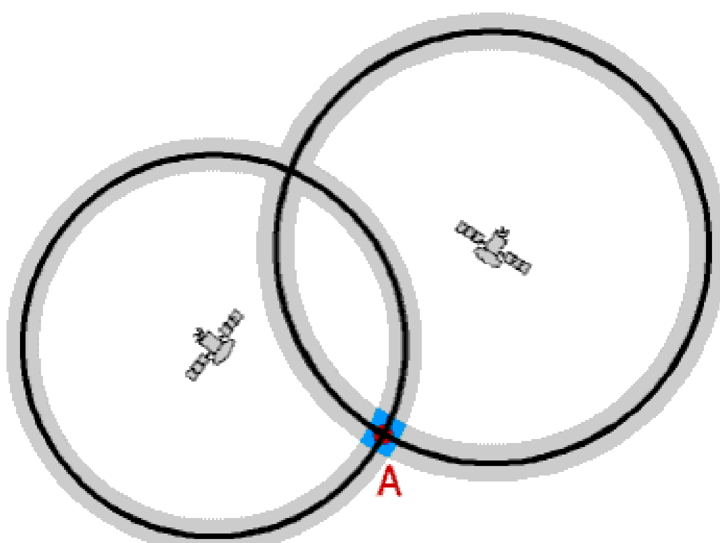
It therefore follows that in three-dimensional space four satellites are needed to determine a position.

3.4.2 Satellite geometry

Another factor influencing the accuracy of the position determination is the "satellite geometry". Simplified, satellite geometry describes the position of the satellites to each other from the view of the receiver.

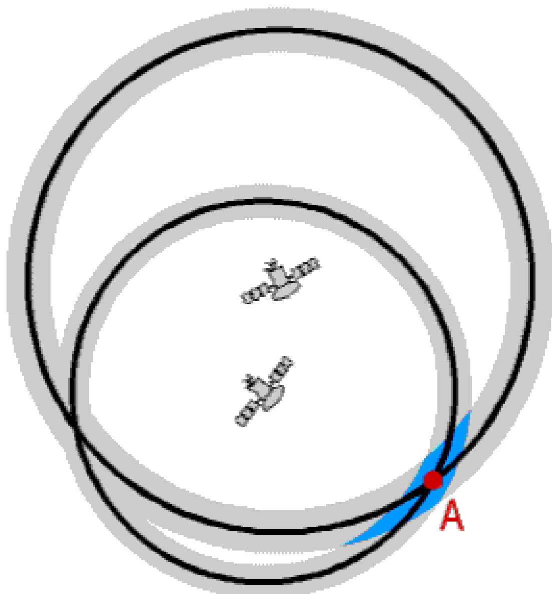
If a receiver sees 4 satellites and all are arranged for example in the north-west, this leads to a "bad" geometry. In the worst case, no position determination is possible at all, when all distance determinations point to the same direction. Even if a position is determined, the error of the positions may be up to 100 – 150 m. If, on the other hand, the 4 satellites are well distributed over the whole firmament the determined position will be much more accurate. Let's assume the satellites are positioned in the north, east, south and west in 90° steps. Distances can then be measured in four different directions, reflecting a „good" satellite geometry.

The following graph shows this for the two-dimensional case.



Good geometrical alignment of two satellites

If the two satellites are in an advantageous position, from the view of the receiver they can be seen in an angle of approximately 90° to each other. The signal runtime can not be determined absolutely precise as explained earlier. The *possible positions are therefore marked by the grey circles. The point of intersection A of the two circles is a rather small, more or less quadratic field (blue), the determined position will be rather accurate.*



Bad geometrical alignment of two satellites

If the satellites are more or less positioned in one line from the view of the receiver, the plane of intersection of possible positions is considerably larger and elongated- The determination of the position is less accurate.

The satellite geometry is also relevant when the receiver is used in vehicles or close to high buildings. If some of the signals are blocked off, the remaining satellites determine the quality of the position determination and if a position fix is possible at all. This can be observed in buildings close to the windows. If a position determination is possible, mostly it is not very accurate. The larger the obscured part of the sky, the more difficult the position determination gets.

Most GPS receivers do not only indicate the number of received satellites, but also their position on the firmament. This enables the user to judge, if a relevant satellite is obscured by an obstacle and if changing the position for a couple of meters might improve the accuracy. Many instruments provide a statement of the *accuracy of the measured values, mostly based on a combination of different factors (which manufacturer do not willingly reveal).*

To indicate the quality of the satellite geometry, the DOP values (dilution of precision) are commonly used. Based on which factors are used for the calculation of the DOP values, different variants are distinguished:

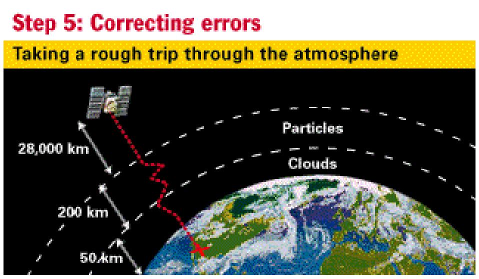
GDOP (Geometric Dilution Of Precision); Overall-accuracy; 3D-coordinates and time

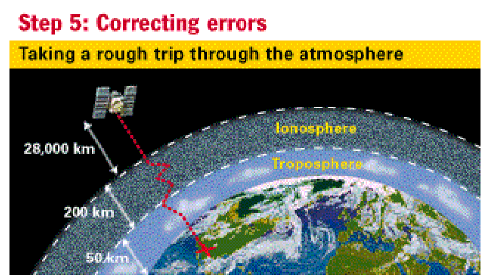
PDOP (Positional Dilution Of Precision) ; Position accuracy; 3D-coordinates

HDOP (Horizontal Dilution Of Precision); horizontal accuracy; 2D-coordinates

VDOP (Vertical Dilution Of Precision); vertical accuracy; height

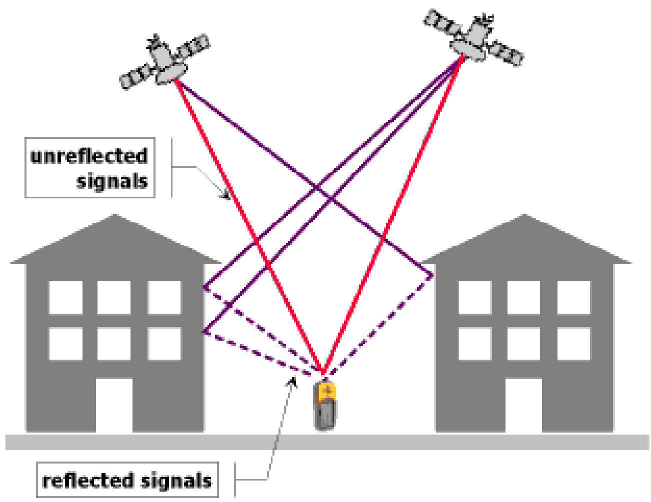
TDOP (Time Dilution Of Precision); time accuracy; time





Although the satellites are positioned in very precise orbits, slight shifts of the orbits are possible due to gravitation forces. Sun and moon have a weak influence on the orbits. The orbit data are controlled and corrected regularly and are sent to the receivers in the package of ephemeris data. Therefore the influence on the correctness of the position determination is rather low, the resulting error being not more than 2 m.

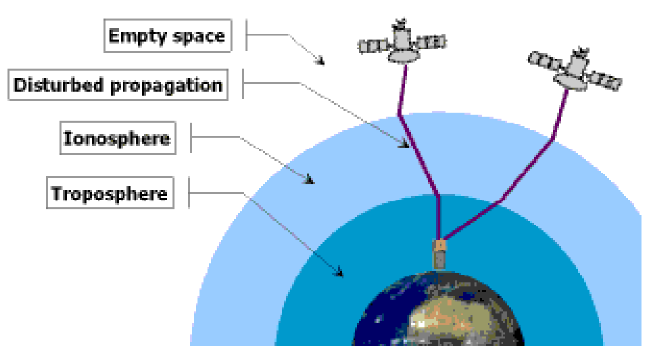
3.4.3 Multipath effect



The multipath effect is caused by reflection of satellite signals (radio waves) on objects. It was the same effect that caused ghost images on television when antennae on the roof were still more common instead of todays satellite dishes.

For GPS signals this effect mainly appears in the neighbourhood of large buildings or other elevations. The reflected signal takes more time to reach the receiver than the direct signal. The resulting error typically lies in the range of a few meters.

3.3.4 Atmospheric effects



Another source of inaccuracy is the reduced speed of propagation in the troposphere and ionosphere. While radio signals travel with the velocity of light in the outer space, their propagation in the ionosphere and troposphere is slower.

In the ionosphere in a height of 80 – 400 km a large number of electrons and positive charged ions are formed by the ionizing force of the sun. The electrons and ions are concentrated in four conductive layers in the ionosphere (D-, E-, F1-, and F2-layer). These layers refract the electromagnetic waves from the satellites, resulting in an elongated runtime of the signals.

These errors are mostly corrected by the receiver by calculations. The typical variations of the velocity while passing the ionosphere for low and high frequencies are well known for standard conditions. Theses variations are taken into account for all calculations of positions. However civil receivers are not capable of correcting unforeseen runtime changes, for example by strong solar winds.

3.3.5 Clock inaccuracies and rounding errors

Despite the synchronization of the receiver clock with the satellite time during the position determination, the remaining inaccuracy of the time still leads to an error of about 2 m in the position determination. Rounding and calculation errors of the receiver sum up approximately to 1 m.

3.3.6 Relativistic effects

The following section shall not provide a comprehensive explanation of the theory of relativity. In the normal life we are quite unaware of the omnipresence of the theory of relativity. However it has an influence on many processes, among them is the proper functioning of the GPS system. This influence will be explained shortly in the following.

As we already learned, the time is a relevant factor in GPS navigation and must be accurate to 20 - 30 nanoseconds to ensure the necessary accuracy. Therefore *the fast movement of the satellites themselves (nearly 12000 km/h) must be considered.*

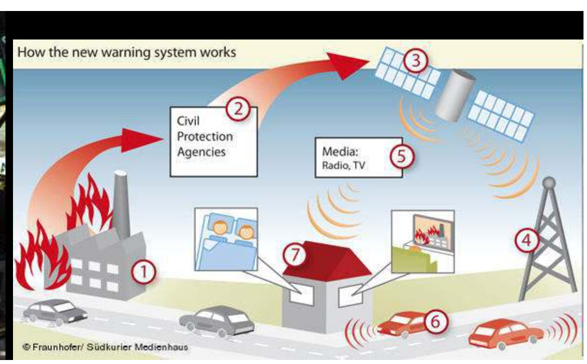
Whoever already dealt with the theory of relativity knows that time runs slower during very fast movements. For satellites moving with a speed of 3874 m/s, clocks run slower when viewed from earth. This relativistic time dilation leads to an inaccuracy of time of approximately 7,2 microseconds per day (1 microsecond = 10-6 seconds).

The theory of relativity also says that time moves the slower the stronger the field of gravitation is. For an observer on the earth surface the clock on board of a satellite is running faster (as the satellite in 20000 km height is exposed to a much weaker field of gravitation than the observer). And this second effect is six times stronger than the time dilation explained above.

3.5 Application of GPS

That's right - we are the 'Users'. All kinds of people use GPS for all kinds of purposes. While the GPS was designed for the Military, the number of civilian users is greater than Military users. Some of the more common uses of the GPS are:

Emergency Services - *Fire, ambulance or other 911 services to locate people in distress.*



Aviation *- pilots use it to guide their aircraft.*

Agriculture *- farmers use it manage their farms better*

Ground Transportation

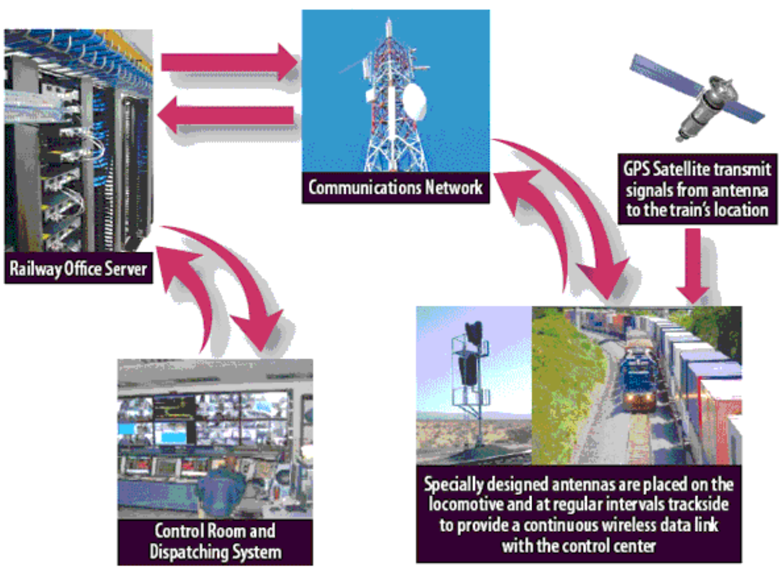
GPS technology helps with automatic vehicle location and in-vehicle navigation systems. Many navigation systems show the vehicle's location on an electronic street map, allowing drivers to keep track of where they are and to look up other destinations. Some systems atutomatically create a route and give turn-by-turn directions. GPS technology also helps monitor and plan routes for delivery vans and emergency vehicles.

GIS (Geographic Information System) Data Collection *- cities use it to locate their services such as power lines and water hydrants even streets*

Marine *- fishermen and vessels at sea use it as a guide to steer their boats or to identify a location on the sea*

Rail

Precise knowledge of train location is essential to prevent collisions, maintain smooth traffic flow, and minimize costly delays. Digital maps and onboard inertial units allow fully-automated train control.



Vehicle Navigation *- so you don't need maps to get to Grandma's house*

Recreation *- hikers and campers use it to keep from getting lost*

There will be many more users to follow in the future...

3.6 Summary

In this unit we have discussed the technology of global positioning system. The key components essential for a global positioning system to function has also been discussed. We also learned about the errors that can be present in a GPS data and therefore what are the most suitable methods of collecting data with a GPS. The types of GPS enables us to understand the various functionality of the GPS, and thus its applications have also been enclosed.

3.7 Glossary

Signal- *Information conveyed via an electric current or electromagnetic wave.*

Synchronization- *The process of automatically updating certain elements of a metadata file.*

Google Earth/Maps- *Software or an interphase where online maps and satellite data can be viewed. This was launched by the network chain Google.*

GPS position- *A satellite based device that records x,y,z coordinates and other data. Ground locations are calculated by signals from satellites orbiting the Earth.*

Navigation- *The combined mental and physical activities involved in traveling to a destination, often a distant or unfamiliar one. The activity of guiding a ship, plane, or other vehicle to a destination, along a planned or improvised route, according to reliable methods.*

Orbital Plane- *All of the planets, comets, and asteroids in the solar system are in orbit around the Sun. All of those orbits line up with each other making a semi-flat disk called the orbital plane. The orbital plane of an object orbiting another is the geometrical plane in which the orbit is embedded.*

3.8 References

1. *http://www.gmat.unsw.edu.au/snap/gps/gps_notes1.pdf*
2. *http://www8.garmin.com/manuals/GPSGuideforBeginners_Manual.pdf*
3. *http://www.inovatrack.com/gps/GPS_basics_u_blox_en.pdf*
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9. *http://www.geod.nrcan.gc.ca/edu/geod/gps/gps09_e.php*
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12. *http://www.vehicle-tracking-gps.com/buyhere-payhere.htm*

13. *http://www.vosizneias.com/60544/2010/07/21/goshen-ny-orange-county-emergency-services-to-receive-automatic-vehicle-locator-dispatching-system*

14. *http://www.dw-world.de/dw/article/0,,4543691,00.html*

3.9 Suggested Readings

1. *http://www.gmat.unsw.edu.au/snap/gps/gps_notes1.pdf*
2. *http://www.kowoma.de/en/gps/errors.htm*
3. *http://www.geod.nrcan.gc.ca/edu/geod/gps/gps09_e.php*
4. *Fundamentals of Remote Sensing .pdf*

3.10 Terminal Questions

1. *Why do we need a GPS?*
2. *How many satellites are needed by a GPS in a 3D space?*
3. *Name 3 different types of GPS and cite their uses.*
4. *Name any 4 errors in acquiring GPS data. Explain geometric error and its corrections.*
5. *Give 5 examples of application of GPS.*

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