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SCHOOL: SCIENCE AND TECHNLOGY

MODULE: APPLIED GIS AND REMOTE SENSING

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Notes on applied GIS and remote sensing

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April 2022

UNIT-1 PHOTOGRAMMETRY

Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points. Moreover, it may be used to recover the motion pathways of designated reference points located on any moving object, on its components and in the immediately adjacent environment. Photogrammetry may employ high-speed imaging and remote sensing in order to detect, measure and record complex 2-D and 3-D motion fields (see also sonar, radar, lidar etc.). Photogrammetry feeds the measurements from remote sensing and the results of imagery analysis into computational models in an attempt to successively estimate, with increasing accuracy, the actual, 3-D relative motions within the researched field.

Low altitude aerial photograph for use in Photogrammetry - Location Three Arch Bay, Laguna Beach CA.

Its applications include satellite tracking of the relative positioning alterations in all Earth environments (e.g. tectonic motions etc.), the research on the swimming of fish, of bird or insect flight, other relative motion processes (International Society for Photogrammetry and Remote Sensing). The quantitative results of photogrammetry are then used to guide and match the results of computational models of the natural systems, thus helping to invalidate or confirm new theories, to design novel vehicles or new methods for predicting or/and controlling the consequences of earthquakes, tsunamis, any other weather types, or used to understand the flow of fluids next to solid structures and many other processes.

Photogrammetry is as old as modern photography, can be dated to the mid-nineteenth century, and its detection component has been emerging from radiolocation, multilateration and radiometry while its 3-D positioning estimative component (based on modeling) employs methods related to triangulation, trilateration and multidimensional scaling.

In the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane can be determined by measuring their distance on the image, if the scale (s) of the image is known. This is done by multiplying the measured distance by $1/s$.

Algorithms for photogrammetry typically attempt to minimize the sum of the squares of errors over the coordinates and relative displacements of the reference points. This minimization is known as bundle adjustment and is often performed using the Levenberg– Marquardt algorithm.

BASIC CONCEPTS OF REMOTE SENSING

1. Introduction

Remote sensing is an art and science of obtaining information about an object or feature without physically coming in contact with that object or feature. Humans apply remote sensing in their day-to-day business, through vision, hearing and sense of smell. The data collected can be of many forms: variations in acoustic wave distributions (e.g., sonar), variations in force distributions (e.g., gravity meter), variations in electromagnetic energy distributions (e.g., eye) etc. These remotely collected data through various sensors may be analysed to obtain information about the objects or features under investigation. In this course we will deal with remote sensing through electromagnetic energy sensors only.

Thus, remote sensing is the process of inferring surface parameters from measurements of the electromagnetic radiation (EMR) from the Earth‘s surface. This EMR can either be reflected or emitted from the Earth‘s surface. In other words, remote sensing is detecting and measuring electromagnetic (EM) energy emanating or reflected from distant objects made of various materials, so that we can identify and categorize these objects by class or type, substance and spatial distribution [American Society of Photogrammetry, 1975].

Remote sensing provides a means of observing large areas at finer spatial and temporal frequencies. It finds extensive applications in civil engineering including watershed studies, hydrological states and fluxes simulation, hydrological modelling, disaster management services such as flood and drought warning and monitoring, damage assessment in case of natural calamities, environmental monitoring, urban planning etc.
Basic concepts of remote sensing are introduced below.

2. Electromagnetic Energy

Electromagnetic energy or electromagnetic radiation (EMR) is the energy propagated in the form of an advancing interaction between electric and magnetic fields (Sabbins, 1978). It travels with the velocity of light. Visible light, ultraviolet rays, infrared rays, heat, radio waves, X-rays all are different forms of electro-magnetic energy.

Electro-magnetic energy (E) can be expressed either in terms of frequency (f) or wave length (λ) of radiation as

$$E = h\,c\,f \text{ or } h\,c\,/\,\lambda$$

where h is Planck's constant (6.626×10^{-34} Joules-sec), c is a constant that expresses the celerity or speed of light (3×10^{8} m/sec), f is frequency expressed in Hertz and λ is the wavelength expressed in micro meters ($1\mu m = 10^{-6}$ m).

As can be observed from equation (1), shorter wavelengths have higher energy content and longer wavelengths have lower energy content.

Distribution of the continuum of energy can be plotted as a function of wavelength (or frequency) and is known as the EMR spectrum All matters reflect, emit or radiate a range of electromagnetic energy, depending upon the material characteristics. In remote sensing, it is the measurement of electromagnetic radiation reflected or emitted from an object, is the used to identify the target and to infer its properties.

3. Principles of Remote Sensing

Different objects reflect or emit different amounts of energy in different bands of the electromagnetic spectrum. The amount of energy reflected or emitted depends on the properties of both the material and the incident energy (angle of incidence, intensity and wavelength). Detection and discrimination of objects or surface features is done through the uniqueness of the reflected or emitted electromagnetic radiation from the object.

A device to detect this reflected or emitted electro-magnetic radiation from an object is called a ―sensor‖ (e.g., cameras and scanners). A vehicle used to carry the sensor is called a ―platform‖ (e.g., aircrafts and satellites).

Main stages in remote sensing are the following.

A. Emission of electromagnetic radiation

1. The Sun or an EMR source located on the platform

B. Transmission of energy from the source to the object

2. Absorption and scattering of the EMR while transmission

C. Interaction of EMR with the object and subsequent reflection and emission

3. D. Transmission of energy from the object to the sensor

E. Recording of energy by the sensor

4. Photographic or non-photographic sensors

F. Transmission of the recorded information to the ground station

G. Processing of the data into digital or hard copy image

H. Analysis of data

4. Passive/ Active Remote Sensing

Depending on the source of electromagnetic energy, remote sensing can be classified as passive or active remote sensing.

In the case of passive remote sensing, source of energy is that naturally available such as the Sun. Most of the remote sensing systems work in passive mode using solar energy as the source of EMR. Solar energy reflected by the targets at specific wavelength bands are recorded using sensors on board air-borne or space borne platforms. In order to ensure ample signal strength received at the sensor, wavelength / energy bands capable of traversing through the atmosphere, without significant loss through atmospheric interactions, are generally used in remote sensing Any object which is at a temperature above 0_o K (Kelvin) emits some radiation, which is approximately proportional to the fourth power of the temperature of the object. Thus the Earth also emits some radiation since its ambient temperature is about 300_o K. Passive sensors can also be used to measure the Earth‘s radiance but they are not very popular as the energy content is very low.

In the case of active remote sensing, energy is generated and sent from the remote sensing platform towards the targets. The energy reflected back from the targets are recorded using sensors on board the remote sensing platform. Most of the microwave remote sensing is done through active remote sensing.

As a simple analogy, passive remote sensing is similar to taking a picture with an ordinary camera whereas active remote sensing is analogous to taking a picture with camera having built-in flash

5. Remote Sensing Platforms

Remote sensing platforms can be classified as follows, based on the elevation from the Earth‘s surface at which these platforms are placed.

- Ground level remote sensing, Ground level remote sensors are very close to the ground. They are basically used to develop and calibrate sensors for different features on the Earth‘s surface. Aerial remote sensing - Low altitude aerial remote sensing - High altitude aerial remote sensing
- Space borne remote sensing - Space shuttles, Polar orbiting satellites, Geo-stationary satellites

From each of these platforms, remote sensing can be done either in passive or active mode.

6. Airborne and Space-borne Remote Sensing

In airborne remote sensing, downward or sideward looking sensors mounted on aircrafts are used to obtain images of the earth's surface. Very high spatial resolution images (20 cm or less) can be obtained through this. However, it is not suitable to map a large area. Less coverage area and high cost per unit area of ground coverage are the major disadvantages of airborne remote sensing. While airborne remote sensing missions are mainly one-time operations, space-borne missions offer continuous monitoring of the earth features. LiDAR, analog aerial photography, videography, thermal imagery and digital photography are commonly used in airborne remote sensing.

In space-borne remote sensing, sensors mounted on space shuttles or satellites orbiting the Earth are used. There are several remote sensing satellites (Geostationary and Polar orbiting) providing imagery for research and operational applications. Geosynchronous Satellites are used for communication and meteorological purposes, polar orbiting or sun-synchronous satellites are essentially used for remote sensing. The main advantages of space-borne remote sensing are large area coverage, less cost per unit area of coverage, continuous or frequent coverage of an area of interest, automatic/ semiautomatic computerized processing and analysis. However, when compared to aerial photography, satellite imagery has a lower resolution.

Landsat satellites, Indian remote sensing (IRS) satellites, IKONOS, SPOT satellites, AQUA and TERRA of NASA and INSAT satellite series are a few examples.

7. Ideal Remote Sensing System

The basic components of an ideal remote sensing system include:

i. A Uniform Energy Source which provides energy over all wavelengths, at a constant, known, high level of output ii. A Non-interfering Atmosphere which will not modify either the energy transmitted from the source or emitted (or reflected) from the object in any manner.

iii. A Series of Unique Energy/Matter Interactions at the Earth's Surface which generate reflected and/or emitted signals that are selective with respect to wavelength and also unique to each object or earth surface feature type.

iv. A Super Sensor which is highly sensitive to all wavelengths. A super sensor would be simple, reliable, accurate, economical, and requires no power or space. This sensor yields data on the absolute brightness (or radiance) from a scene as a function of wavelength.

v. A Real-Time Data Handling System which generates the instance radiance versus wavelength response and processes into an interpretable format in real time. The data derived is unique to a particular terrain and hence provide insight into its physical-chemical-biological state.

vi. Multiple Data Users having knowledge in their respective disciplines and also in remote sensing data acquisition and analysis techniques. The information collected will be available to them faster and at less expense. This information will aid the users in various decision making processes and also further in implementing these decisions

8. Characteristics of Real Remote Sensing Systems

Real remote sensing systems employed in general operation and utility have many shortcomings when compared with an ideal system explained above.

i. Energy Source: The energy sources for real systems are usually non-uniform over various wavelengths and also vary with time and space. This has major effect on the passive remote sensing systems. The spectral distribution of reflected sunlight varies both temporally and spatially. Earth surface materials also emit energy to varying degrees of efficiency. A real remote sensing system needs calibration for source characteristics.

ii. The Atmosphere: The atmosphere modifies the spectral distribution and strength of the energy received or emitted (Fig. 8). The effect of atmospheric interaction varies with the wavelength associated, sensor used and the sensing application. Calibration is required to eliminate or compensate these atmospheric effects.

iii. The Energy/Matter Interactions at the Earth's Surface: Remote sensing is based on the principle that each and every material reflects or emits energy in a unique, known way. However, spectral signatures may be similar for different material types. This makes differentiation difficult. Also, the knowledge of most of the energy/matter interactions for earth surface features is either at elementary level or even completely unknown.

iv. The Sensor: Real sensors have fixed limits of spectral sensitivity i.e., they are not sensitive to all wavelengths. Also, they have limited spatial resolution (efficiency in recording spatial details). Selection of a sensor requires a trade-off between spatial resolution and spectral sensitivity. For example, while photographic systems have very good spatial resolution and poor spectral sensitivity, non-photographic systems have poor spatial resolution.

v. The Data Handling System: Human intervention is necessary for processing sensor data; even though machines are also included in data handling. This makes the idea of real time data handling almost impossible. The amount of data generated by the sensors far exceeds the data handling capacity.

vi. The Multiple Data Users: The success of any remote sensing mission lies on the user who ultimately transforms the data into information. This is possible only if the user understands the problem thoroughly and has a wide knowledge in the data generation. The user should know how to interpret the data generated and should know how best to use them.

9. Advantages and Disadvantages of Remote Sensing

Advantages of remote sensing are: a)
Provides data of large areas

b) Provides data of very remote and inaccessible regions

c) Able to obtain imagery of any area over a continuous period of time through which the any anthropogenic or natural changes in the landscape can be analyzed

d) Relatively inexpensive when compared to employing a team of surveyors

e) Easy and rapid collection of data

f) Rapid production of maps for interpretation

Disadvantages of remote sensing are:

a) The interpretation of imagery requires a certain skill level
b) Needs cross verification with ground (field) survey data

c) Data from multiple sources may create confusion

d) Objects can be misclassified or confused

e) Distortions may occur in an image due to the relative motion of sensor and source

EMR SPECTRUM

1. Introduction

In remote sensing, some parameters of the target are measured without being in touch with it. To measure any parameters using remotely located sensors, some processes which convey those parameters to the sensor is required. A best example is the natural remote sensing by which we are able to see the objects around us and to identity their properties. We are able to see the objects around us when the solar light hits them and gets reflected and captured in our eyes. We are able to identify the properties of the objects when these signals captured in our eyes are transferred to the brain and are analyzed. The whole process is analogous to the manmade remote sensing techniques.

In remote sensing techniques, electromagnetic radiations emitted / reflected by the targets are recorded at remotely located sensors and these signals are analyzed to interpret the target characteristics. Characteristics of the signals recorded at the sensor depend on the characteristics of the source of radiation / energy, characteristics of the target and the atmospheric interactions.

This lecture gives details of the electromagnetic spectrum. Details of the energy sources and the radiation principles are also covered in this lecture.

2. Electromagnetic energy

Electromagnetic (EM) energy includes all energy moving in a harmonic sinusoidal wave pattern with a velocity equal to that of light. Harmonic pattern means waves occurring at frequent intervals of time.

Electromagnetic energy has both electric and magnetic components which oscillate perpendicular to each other and also perpendicular to the direction of energy propagation as shown in Fig..

It can be detected only through its interaction with matter.

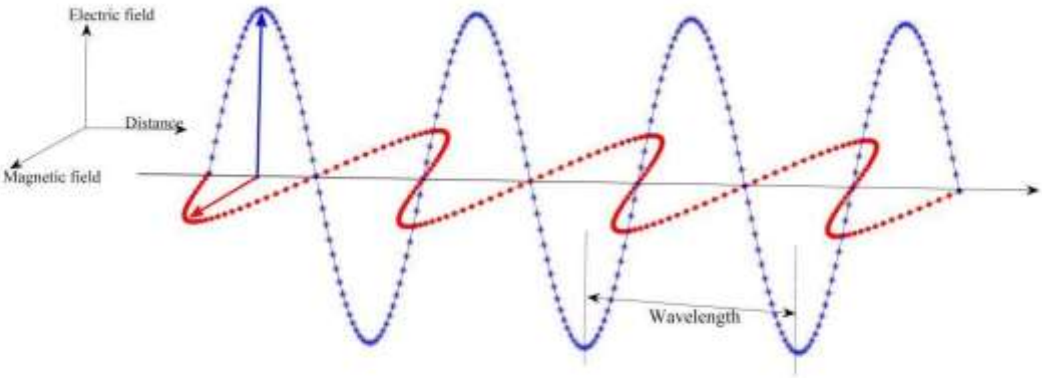


Fig.. Electromagnetic wave

Examples of different forms of electromagnetic energy: Light, heat etc.

EM energy can be described in terms of its velocity, wavelength and frequency.

All EM waves travel at the speed of light, *c*, which is approximately equal to 3×10^{8} m/s.

Wavelength λ of EM wave is the distance from any point on one wave to the same position on the next wave (e.g., distance between two successive peaks). The wavelengths commonly used in remote sensing are very small. It is normally expressed in micrometers (μm). 1 μm is equal to 1×10^{-6} m.

Frequency *f* is the number of waves passing a fixed point per unit time. It is expressed in Hertz (Hz).

Which implies that wavelength and frequency are inversely related since *c* is a constant. Longer wavelengths have smaller frequency compared to shorter wavelengths.

Engineers use frequency attribute to indicate radio and radar regions. However, in remote sensing EM waves are categorized in terms of their wavelength location in the EMR spectrum.

Another important theory about the electromagnetic radiation is the particle theory, which suggests that electromagnetic radiation is composed of discrete units called photons or quanta.

3. Electro-Magnetic Radiation (EMR) spectrum

Distribution of the continuum of radiant energy can be plotted as a function of wavelength (or frequency) and is known as the electromagnetic radiation (EMR) spectrum. EMR spectrum is divided into regions or intervals of different wavelengths and such regions are denoted by different names. However, there is no strict dividing line between one spectral region and its adjacent one. Different regions in EMR spectrum

The EM spectrum ranges from gamma rays with very short wavelengths to radio waves with very long wavelengths. The EM spectrum is shown in a logarithmic scale in order to portray shorter wavelengths.

The visible region (human eye is sensitive to this region) occupies a very small region in the range between 0.4 and 0.7 μm. The approximate range of color ―blue‖ is 0.4 – 0.5 μm,

―green‖ is 0.5-0.6 μm and ―red‖ is 0.6-0.7 μm. Ultraviolet (UV) region adjoins the blue end of the visible region and infrared (IR) region adjoins the red end.

The infrared (IR) region, spanning between 0.7 and 100 μm, has four subintervals of special interest for remote sensing. Film responsive subset, the photographic IR (0.7 - 0.9 μm) Thermal bands at (3 - 5 μm) and (8 - 14 μm).

Longer wavelength intervals beyond this region are referred in units ranging from 0.1 to 100 cm. The microwave region spreads across 0.1 to 100 cm, which includes all the intervals used by radar systems. The radar systems generate their own active radiation and direct it towards the targets of interest. The details of various regions and the corresponding wavelengths are given in Table 1

Energy in the gamma rays, X-rays and most of the UV rays are absorbed by the Earth‘s atmosphere and hence not used in remote sensing. Most of the remote sensing systems operate in visible, infrared (IR) and microwave regions of the spectrum. Some systems use the long wave portion of the UV spectrum also.

4. Energy sources and radiation principles

4.1 Solar radiation

Primary source of energy that illuminates different features on the earth surface is the Sun. Solar radiation (also called insolation) arrives at the Earth at wavelengths determined by the photosphere temperature of the sun (peaking near 5,600 °C).

Although the Sun produces electromagnetic radiation in a wide range of wavelengths, the amount of energy it produces is not uniform across all wavelengths. the solar irradiance (power of electromagnetic radiation per unit area incident on a surface) distribution of the Sun. Almost 99% of the solar energy is within the wavelength range of 0.28-4.96 μm. Within this range, 43% is radiated in the visible wavelength region between 0.4-0.7 μm. The maximum energy (*E*) is available at 0.48 μm wave length, which is in the visible green region.

$$Q = h\,f$$

Where *h* is the Plank's constant (6.626×10^{-34} J Sec) and *f* is the frequency.

Using the relationship between *c*, *λ* and *f* (Eq.1), the above equation can be written as follows

The energy per unit quantum is thus inversely proportional to the wavelength. Shorter wavelengths are associated with higher energy compared to the longer wavelengths. For example, longer wavelength electromagnetic radiations like microwave radiations are associated with lower energy compared to the IR regions and are difficult to sense in remote sensing. For operating with long wavelength radiations, the coverage area should be large enough to obtain a detectable signal.

4.2 Radiation from the Earth

Other than the solar radiation, the Earth and the terrestrial objects also are the sources of electromagnetic radiation. All matter at temperature above absolute zero (0 K or -273 ^{o}C) emits electromagnetic radiations continuously. The amount of radiation from such objects is a function of the temperature of the object

This is known as Stefan-Boltzmann law. *M* is the total radiant exitance from the source (Watts / m^2), *σ* is the Stefan-Boltzmann constant (5.6697×10^{-8} Watts m^{-2} k^{-4}) and *T* is the absolute temperature of the emitting material in Kelvin.

Since the Earth‘s ambient temperature is about 300 K, it emits electromagnetic radiations, which is maximum in the wavelength region of 9.7 μm, as shown in Fig.3. This is considered as thermal IR radiation. This thermal IR emission from the Earth can be sensed using scanners and radiometers.

According to the Stefan-Boltzmann law, the radiant exitance increases rapidly with the temperature. However, this law is applicable for objects that behave as a blackbody.

4.3 Blackbody Radiation

A blackbody is a hypothetical, ideal radiator. It absorbs and reemits the entire energy incident upon it.

Total energy emitted by a black body varies with temperature as given in Eq. 4. The total energy is distributed over different wavelengths, which is called the spectral distribution or spectral curve here. Area under the spectral curve gives the total radiant exitance *M*.

In addition to the total energy, the spectral distribution also varies with the temperature. Fig. 4 shows the spectral distribution of the energy radiated from black bodies at different temperatures. The figure represents the Stefan-Boltzmann‘s law graphically. As the temperature increases, area under the curve, and hence the total radiant exitance increases.

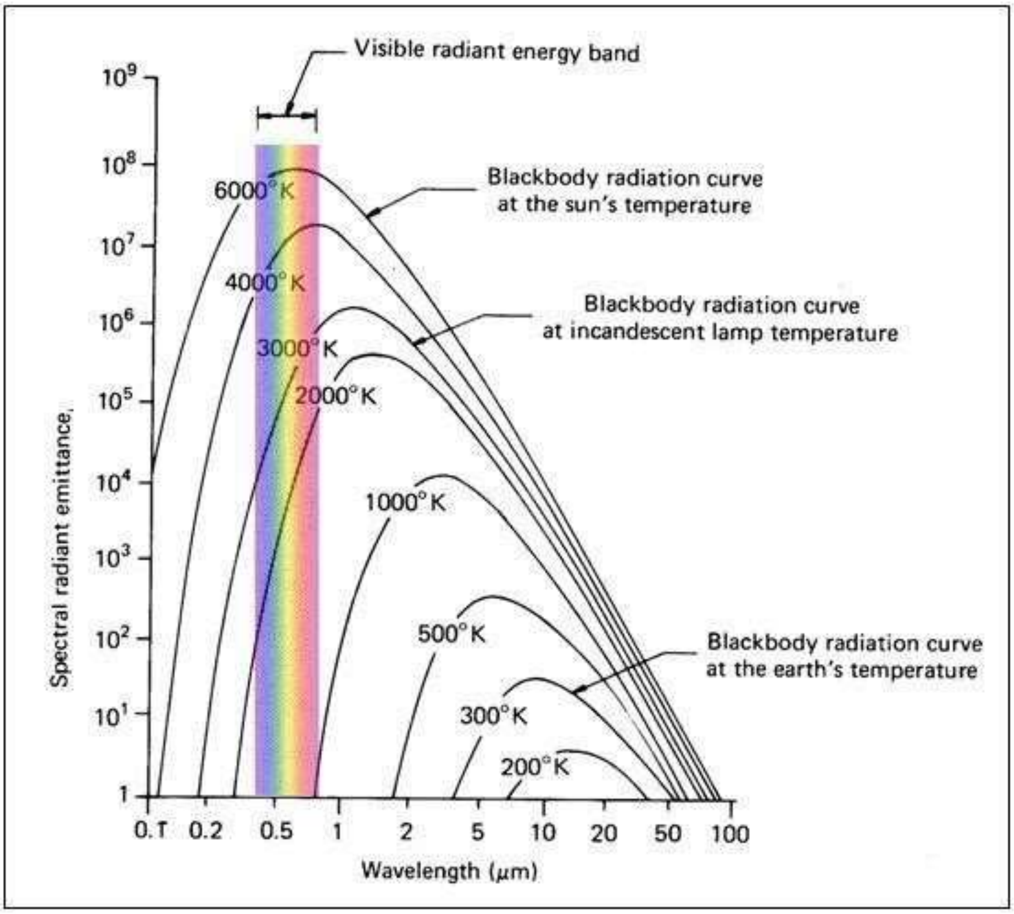


Figure 4. Spectral energy distribution of blackbody at various temperatures

From Fig. 4, it can be observed that the peak of the radiant exitance varies with wavelength. As the temperature increases, the peak shifts towards the left. This is explained by the Wien's displacement law. It states that the dominant wavelength at which a black body radiates λm is

Inversely proportional to the absolute temperature of the black body (in *K*) and is represented as given below.

Remote sensing using electromagnetic radiation

As solar energy travels through atmosphere to reach the Earth, the atmosphere absorbs or backscatters a fraction of it and transmits only the remainder. Wavelength regions, through which most of the energy is transmitted through atmosphere are referred as atmospheric windows. In Fig. 5 (Short, 1999), EMR spectrum is shown identifying different regions with specific names starting from visible region to microwave regions. In the microwave region, different radar bands are also shown such as κ, X, C, L and P. In Fig. 5, blue (or shaded) zones mark minimal passage of incoming and/or outgoing radiation, whereas white areas denote atmospheric windows. Various constituents of atmosphere at different wavelengths are mainly responsible for atmospheric absorption or back scatter at those wavelengths. Most remote sensing instruments on air or space platforms operate in one or more of these windows by making their measurements with detectors tuned to specific wavelengths that pass through the atmosphere.

Scattering

Atmospheric scattering is the process by which small particles in the atmosphere diffuse a portion of the incident radiation in all directions. There is no energy transformation while scattering. But the spatial distribution of the energy is altered during scattering.

There are three different types of scattering:

1. Rayleigh scattering
2. Mie scattering
3. Non-selective scattering

Rayleigh scattering

Rayleigh scattering mainly consists of scattering caused by atmospheric molecules and other tiny particles. This occurs when the particles causing the scattering are much smaller in diameter (less than one tenth) than the wavelengths of radiation interacting with them.

Smaller particles present in the atmosphere scatter the shorter wavelengths more compared to the longer wavelengths.

The scattering effect or the intensity of the scattered light is inversely proportional to the fourth power of wavelength for Rayleigh scattering. Hence, the shorter wavelengths are scattered more than longer wavelengths. Rayleigh scattering is also known as selective scattering or molecular scattering.

Molecules of Oxygen and Nitrogen (which are dominant in the atmosphere) cause this type of scattering of the visible part of the electromagnetic radiation. Within the visible range, smaller wavelength blue light is scattered more compared to the green or red. A "blue" sky is thus a manifestation of Rayleigh scatter. The blue light is scattered around 4 times and UV light is scattered about 16 times as much as red light. This consequently results in a blue sky. However, at sunrise and sunset, the sun's rays have to travel a longer path, causing complete scattering (and absorption) of shorter wavelength radiations. As a result, only the longer wavelength portions (orange and red) which are less scattered will be visible. The haze in imagery and the bluish-grey cast in a color image when taken from high altitude are mainly due to Rayleigh scatter.

Mie Scattering

Another type of scattering is Mie scattering, which occurs when the wavelengths of the energy is almost equal to the diameter of the atmospheric particles. In this type of scattering longer wavelengths also get scattered compared to Rayleigh scatter.

In Mie scattering, intensity of the scattered light varies approximately as the inverse of the wavelength. Mie scattering is usually caused by the aerosol particles such as dust, smoke and pollen. Gas molecules in the atmosphere are too small to cause Mie scattering of the radiation commonly used for remote sensing.

Non-selective scattering

A third type of scattering is nonselective scatter, which occurs when the diameters of the atmospheric particles are much larger (approximately 10 times) than the wavelengths being sensed. Particles such as pollen, cloud droplets, ice crystals and raindrops can cause non-selective scattering of the visible light. For visible light (of wavelength 0.4-0.7μm), non-selective scattering is generally caused by water droplets which is having diameter commonly in the range of 5 to 100 μm. This scattering is nonselective with respect to wavelength since all visible and IR wavelengths get scattered equally giving white or even grey colour to the clouds.

Absorption

Absorption is the process in which incident energy is retained by particles in the atmosphere at a given wavelength. Unlike scattering, atmospheric absorption causes an effective loss of energy to atmospheric constituents.

The absorbing medium will not only absorb a portion of the total energy, but will also reflect, refract or scatter the energy. The absorbed energy may also be transmitted back to the atmosphere.

The most efficient absorbers of solar radiation are water vapour, carbon dioxide, and ozone. Gaseous components of the atmosphere are selective absorbers of the electromagnetic radiation, i.e., these gases absorb electromagnetic energy in specific wavelength bands. Arrangement of the gaseous molecules and their energy levels determine the wavelengths that are absorbed.

Since the atmosphere contains many different gases and particles, it absorbs and transmits many different wavelengths of electromagnetic radiation. Even though all the wavelengths from the Sun reach the top of the atmosphere, due to the atmospheric absorption, only limited wavelengths can pass through the atmosphere. The ranges of wavelength that are partially or wholly transmitted through the atmosphere are known as "atmospheric windows." Remote sensing data acquisition is limited through these atmospheric windows. The atmospheric windows and the absorption characteristics

It can be observed that electromagnetic radiation at different wavelengths is completely absorbed, partially absorbed or totally transmitted through the atmosphere. Nitrogen and other gaseous components in the atmosphere cause absorption of wavelengths shorter than 0.1 µm. Wavelengths shorter than 0.3µm (X-rays, Gamma rays and part of ultraviolet rays) are mostly absorbed in the atmosphere. This is caused by the ozone (O3) present in the upper atmosphere. Oxygen in the atmosphere causes absorption centered at 6.3µm.In the visible part of the spectrum, little absorption occurs.

Infrared (IR) radiation is mainly absorbed due to the rotational and vibrational transitions of the molecules. The main atmospheric constituents responsible for infrared absorption are water vapour (H2O) and carbon dioxide (CO2) molecules. Most of the radiation in the far infrared region is also absorbed by the atmosphere. However, absorption is almost nil in the microwave region.

The most common sources of energy are the incident solar energy and the radiation from the Earth. The wavelength at which the Sun‘s energy reaches its maximum coincides with the visible band range. The energy radiated from the Earth is sensed through the windows at 3 to 5µm and 8 to 14µm using devices like thermal scanners.

Radar and Passive microwave systems operate through a window in the 1 mm to 1 m region Major atmospheric windows used for remote sensing are given n Table.

Table. Major atmospheric windows used in remote sensing and their characteristics Atmospheric window	Wavelength band μm	Characteristics
Upper ultraviolet, Visible and photographic IR	0.3-1 approx.	95% transmission
Reflected infrared	1.3, 1.6, 2.2	Three narrow bands
Thermal infrared	3.0-5.0 8.0-14.0	Two broad bands
Microwave	> 5000	Atmosphere is mostly transparent

ENERGY INTERACTIONS WITH EARTH SURFACE FEATURES

Energy incident on the Earth‘s surface is absorbed, transmitted or reflected depending on the wavelength and characteristics of the surface features (such as barren soil, vegetation, water body). Interaction of the electromagnetic radiation with the surface features is dependent on the characteristics of the incident radiation and the feature characteristics. After interaction with the surface features, energy that is reflected or re-emitted from the features is recorded at the sensors and are analysed to identify the target features, interpret the distance of the object, and /or its characteristics.

This lecture explains the interaction of the electromagnetic energy with the Earth‘s surface features.

Energy Interactions

The incident electromagnetic energy may interact with the earth surface features in three possible ways: Reflection, Absorption and Transmission. These three interactions are

Reflection

Absorption

Earth

Transmission

Incident radiation

Reflection occurs when radiation is redirected after hitting the target. According to the law of reflection, the angle of incidence is equal to the angle of reflection the EM energy which is absorbed by the Earth‘s surface is available for emission and as thermal radiation at longer wavelengths.

Transmission occurs when radiation is allowed to pass through the target. Depending upon the characteristics of the medium, during the transmission velocity and wavelength of the radiation changes, whereas the frequency remains same. The transmitted energy may further get scattered and / or absorbed in the medium.

These three processes are not mutually exclusive. Energy incident on a surface may be partially reflected, absorbed or transmitted. Which process takes place on a surface depends on the following factors:

1. Wavelength of the radiation
2. Angle at which the radiation intersects the surface
3. Composition and physical properties of the surface

The relationship between reflection, absorption and transmission can be expressed through the principle of conservation of energy. Let *EI* denotes the incident energy, *ER* denotes the reflected energy, *EA* denotes the absorbed energy and *ET* denotes the transmitted energy. Then the principle of conservation of energy (as a function of wavelength λ) can be expressed as

$$EI(\lambda) = ER(\lambda) + EA(\lambda) + ET(\lambda) \quad (1)$$

Since most remote sensing systems use reflected energy, the energy balance relationship can be better expressed in the form

$$ER(\lambda) = EI(\lambda) - EA(\lambda) - ET(\lambda) \quad (2)$$

The reflected energy is equal to the total energy incident on any given feature reduced by the energy absorbed or transmitted by that feature.

Reflection

Reflection is the process in which the incident energy is redirected in such a way that the angle of incidence is equal to the angle of reflection. The reflected radiation leaves the surface at the same angle as it approached.

Scattering is a special type of reflection wherein the incident energy is diffused in many directions and is sometimes called diffuse reflection.

When electromagnetic energy is incident on the surface, it may get reflected or scattered depending upon the roughness of the surface relative to the wavelength of the incident energy. If the roughness of the surface is less than the wavelength of the radiation or the ratio of roughness to wavelength is less than 1, the radiation is reflected. When the ratio is more than 1 or if the roughness is more than the wavelength, the radiation is scattered.

Fraction of energy that is reflected / scattered is unique for each material. This will aid in distinguishing different features on an image

A feature class denotes distinguishing primitive characteristic or attribute of an image that have been classified to represent a particular land cover type/spectral signature. Within one feature class, the proportion of energy reflected, emitted or absorbed depends on the wavelength. Hence, in spectral range two features may be indistinguishable; but their reflectance properties may be different in another spectral band. In multi-spectral remote sensing, multiple sensors are used to record the reflectance from the surface features at different wavelength bands and hence to differentiate the target features.

Variations in the spectral reflectance within the visible spectrum give the colour effect to the features.

For example, blue colour is the result of more reflection of blue light. An object appears as ―green‖ when it reflects highly in the green portion of the visible spectrum. Leaves appear green since its chlorophyll pigment absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Similarly, water looks blue-green or blue or green if viewed through visible band because it reflects the shorter wavelengths and absorbs the longer wavelengths in the visible band. Water also absorbs the near infrared wavelengths and hence appears darker when viewed through red or near infrared wavelengths. Human eye uses reflected energy variations in the visible spectrum to discriminate between various features.

For example, shows a part of the Krishna River Basin as seen in different bands of the Landsat ETM+ imagery. As the concepts of false colour composite (FCC) have been covered in module 4, readers are advised to refer to the material in module 4 for better understanding of the colour composite imageries as shown in Fig. 5. Reflectance of surface features such as water, vegetation and fallow lands are different in different wavelength bands. A combination of more than one spectral band helps to attain better differentiation of these features.

Diffuse and Specular Reflection

Energy reflection from a surface depends on the wavelength of the radiation, angle of incidence and the composition and physical properties of the surface.

Roughness of the target surface controls how the energy is reflected by the surface. Based on the roughness of the surface, reflection occurs in mainly two ways.

i. Specular reflection: It occurs when the surface is smooth and flat. A mirror-like or smooth reflection is obtained where complete or nearly complete incident energy is reflected in one direction. The angle of reflection is equal to the angle of incidence. Reflection from the surface is the maximum along the angle of reflection, whereas in any other direction it is negligible.

ii. Diffuse (Lambertian) reflection: It occurs when the surface is rough. The energy is reflected uniformly in all directions. Since all the wavelengths are reflected uniformly in all directions, diffuse reflection contains spectral information on the "color" of the reflecting surface. Hence, in remote sensing diffuse reflectance properties of terrain features are measured. Since the reflection is uniform in all direction, sensors located at any direction record the same reflectance and hence it is easy to differentiate the features.

Based on the nature of reflection, surface features can be classified as specular reflectors, Lambertian reflectors. An ideal specular reflector completely reflects the incident energy with angle of reflection equal to the angle incidence. An ideal Lambertian or diffuse reflector scatters all the incident energy equally in all the directions.

The specular or diffusive characteristic of any surface is determined by the roughness of the surface in comparison to the wavelength of the incoming radiation. If the wavelengths of the incident energy are much smaller than the surface variations or the particle sizes, diffuse reflection will dominate. For example, in the relatively long wavelength radio range, rocky terrain may appear smooth to incident energy. In the visible portion of the spectrum, even a material such as fine sand appears rough while it appears fairly smooth to long wavelength microwaves.

Most surface features of the earth are neither perfectly specular nor perfectly diffuse reflectors. In near specular reflection, though the reflection is the maximum along the angle of reflection, a fraction of the energy also gets reflected in some other angles as well. In near Lambertian reflector, the reflection is not perfectly uniform in all the directions. The characteristics of different types of reflectors are

Near diffusive

Near specular

Ideal diffusive

Ideal specular

Angle of reflection

Angle of incidence

Lambertian reflectors are considered ideal for remote sensing. The reflection from an ideal Lambertian surface will be the same irrespective of the location of the sensor. On the other hand, in case of an ideal specular reflector, maximum brightness will be obtained only at one location and for the other locations dark tones will be obtained from the same target. This variation in the spectral signature for the same feature affects the interpretation of the remote sensing data.

Most natural surfaces observed using remote sensing are approximately Lambertian at visible and IR wavelengths. However, water provides specular reflection. Water generally gives a dark tone in the image. However due to the specular reflection, it gives a pale tone when the sensor is located in the direction of the reflected energy.

For the technique in archaeological surveying, see remote sensing (archaeology). For the claimed psychic ability, see remote viewing. For the electrical measurement technique, see four-terminal sensing. Synthetic aperture radar image of Death Valley colored using polarimetry.

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on site observation. Remote sensing is a sub-field of geography. In modern usage, the term generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of propagated signals (e.g. electromagnetic radiation). It may be split into active remote sensing (when a signal is first emitted from aircraft or satellites or passive (e.g. sunlight) when information is merely recorded.

Overview

Passive sensors gather radiation that is emitted or reflected by the object or surrounding areas. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, charge-coupled devices, and radiometers. Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR and LiDAR are examples of active remote sensing where the time delay between emission and return is measured, establishing the location, speed and direction of an object. Illustration of Remote Sensing Remote sensing makes it possible to collect data of dangerous or inaccessible areas. Remote sensing applications include monitoring deforestation in areas such as the Amazon Basin, glacial features in Arctic and Antarctic regions, and depth sounding of coastal and ocean depths. Military collection during the Cold War made use of stand-off collection of data about dangerous border areas. Remote sensing also replaces costly and slow data collection on the ground, ensuring in the process that areas or objects are not disturbed.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such as El Niño and other natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, agricultural fields such as land usage and conservation, and national security and overhead, ground-based and stand-off collection on border areas.

Data acquisition techniques

The basis for multispectral collection and analysis is that of examined areas or objects that reflect or emit radiation that stand out from surrounding areas. For a summary of major remote sensing satellite systems see the overview table.

Applications of remote sensing data

Conventional radar is mostly associated with aerial traffic control, early warning, and certain large scale meteorological data. Doppler radar is used by local law enforcements' monitoring of speed limits and in enhanced meteorological collection such as wind speed and direction within weather systems in addition to precipitation location and intensity. Other types of active collection includes plasmas in the ionosphere. Interferometry synthetic aperture radar is used to produce precise digital elevation models of large scale terrain (See RADARSAT, TerraSAR-X, Magellan).

Laser and radar altimeters on satellites have provided a wide range of data. By measuring the bulges of water caused by gravity, they map features on the seafloor to a resolution of a mile or so. By measuring the height and wavelength of ocean waves, the altimeters measure wind speeds and direction, and surface ocean currents and directions.

Ultrasound (acoustic) and radar tide gauges measure sea level, tides and wave direction in coastal and offshore tide gauges.

Light detection and ranging (LIDAR) is well known in examples of weapon ranging, laser illuminated homing of projectiles. LIDAR is used to detect and measure the concentration of various chemicals in the atmosphere, while airborne LIDAR can be used to measure heights of objects and features on the ground more accurately than with radar technology. Vegetation remote sensing is a principal application of LIDAR.

Radiometers and photometers are the most common instrument in use, collecting reflected and emitted radiation in a wide range of frequencies. The most common are visible and infrared sensors, followed by microwave, gamma ray and rarely, ultraviolet. They may also be used to detect the emission spectra of various chemicals, providing data on chemical concentrations in the atmosphere.

Stereographic pairs of aerial photographs have often been used to make topographic maps by imagery and terrain analysts in traffic ability and highway departments for potential routes, in addition to modelling terrestrial habitat features.

Simultaneous multi-spectral platforms such as Landsat have been in use since the 70's. These thematic mappers take images in multiple wavelengths of electro-magnetic radiation (multi-spectral) and are usually found on Earth observation satellites, including (for example) the Landsat program or the IKONOS satellite. Maps of land cover and land use from thematic mapping can be used to prospect for minerals, detect or monitor land usage, deforestation, and examine the health of indigenous plants and crops, including

Entire farming regions or forests. Landsat images are used by regulatory agencies such as KYDOW to indicate water quality parameters including Secchi depth, chlorophyll a density and total phosphorus content. Weather satellites are used in meteorology and climatology.

Hyper spectral imaging produces an image where each pixel has full spectral information with imaging narrow spectral bands over a contiguous spectral range. Hyper spectral imagers are used in various applications including mineralogy, biology, defense, and environmental measurements.

Within the scope of the combat against desertification, remote sensing allows to follow-up and monitor risk areas in the long term, to determine desertification factors, to support decision-makers in defining relevant measures of environmental management, and to assess their impacts.

Geodetic

Overhead geodetic collection was first used in aerial submarine detection and gravitational data used in military maps. This data revealed minute perturbations in the Earth's gravitational field (geodesy) that may be used to determine changes in the mass distribution of the Earth, which in turn may be used for geological studies.

Acoustic and near-acoustic

Sonar: *passive sonar*, listening for the sound made by another object (a vessel, a whale etc.); *active sonar*, emitting pulses of sounds and listening for echoes, used for detecting, ranging and measurements of underwater objects and terrain. Seismograms taken at different locations can locate and measure earthquakes (after they occur) by comparing the relative intensity and precise timings.

Ultrasound: Ultrasound sensors, that emit high frequency pulses and listening for echoes, used for detecting water waves and water level, as in tide gauges or for towing tanks.

To coordinate a series of large-scale observations, most sensing systems depend on the following: platform location and the orientation of the sensor. High-end instruments now often use positional information from satellite navigation systems. The rotation and orientation is often provided within a degree or two with electronic compasses. Compasses can measure not just azimuth (i. e. degrees to magnetic north), but also altitude (degrees above the horizon), since the magnetic field curves into the Earth at different angles at different latitudes. More exact orientations require gyroscopic-aided orientation, periodically realigned by different methods including navigation from stars or known benchmarks.

Data processing

Generally speaking, remote sensing works on the principle of the *inverse problem*. While the object or phenomenon of interest (the **state**) may not be directly measured, there exists some other variable that can be detected and measured (the **observation**) which may be related to the ject of interest through a calculation. The common analogy given to describe this is trying to determine the type of animal from its footprints. For example, while it is impossible to directly measure temperatures in the upper atmosphere, it is possible to measure the spectral emissions from a known chemical species (such as carbon dioxide) in that region. The frequency of the emissions may then be related via thermodynamics to the temperature in that region.

The quality of remote sensing data consists of its spatial, spectral, radiometric and temporal resolutions.

Spatial resolution

The size of a pixel that is recorded in a raster image – typically pixels may correspond to square areas ranging inside length from 1 to 1,000 meters (3.3 to 3,280.8 ft).

Spectral resolution

The wavelength width of the different frequency bands recorded – usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of seven bands, including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 μm. The Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 μm, with a spectral resolution of 0.10 to 0.11 μm per band.

Radiometric resolution

The number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of color, in each band. It also depends on the instrument noise.

Temporal resolution

The frequency of flyovers by the satellite or plane, and is only relevant in time-series studies or those requiring an averaged or mosaic image as in deforesting monitoring. This was first used by the intelligence community where repeated coverage revealed changes in infrastructure, the deployment of units or the modification/introduction of equipment. Cloud cover over a given area or object makes it necessary to repeat the collection of said location.

In order to create sensor-based maps, most remote sensing systems expect to extrapolate sensor data in relation to a reference point including distances between known points on the ground. This depends on the type of sensor used. For example, in conventional photographs, distances are accurate in the center of the image, with the distortion of measurements increasing the farther you get from the center. Another factor is that of the platen against which the film is pressed can cause severe errors when photographs are used to measure ground distances. The step in which this problem is resolved is called geo referencing, and involves computer-aided matching of points in the image (typically 30 or more points per image) which is extrapolated with the use of an established benchmark, "warping" the image to produce accurate spatial data. As of the early 1990s, most satellite images are sold fully geo referenced.

In addition, images may need to be radiometrically and atmospherically corrected. Radiometric correction

Allows to avoid radiometric errors and distortions. The illumination of objects on the Earth surface is uneven because of different properties of the relief. This factor is taken into account in the method of radiometric distortion correction. [10] Radiometric correction gives a scale to the pixel values, e. g. the monochromatic scale of 0 to 255 will be converted to actual radiance values.

Topographic correction (also called terrain correction)

In rugged mountains, as a result of terrain, the effective illumination of pixels varies considerably. In a remote sensing image, the pixel on the shady slope receives weak illumination and has a low radiance value, in contrast, the pixel on the sunny slope receives strong illumination and has a high radiance value. For the same object, the pixel radiance value on the shady slope will be different from that on the sunny slope. Additionally, different objects may have similar radiance values. These ambiguities seriously affected remote sensing image information extraction accuracy in mountainous areas. It became the main obstacle to further application of remote sensing images. The purpose of topographic correction is to eliminate this effect, recovering the true reflectivity or radiance of objects in horizontal conditions. It is the premise of quantitative remote sensing application.

Atmospheric correction

Elimination of atmospheric haze by rescaling each frequency band so that its minimum value (usually realized in water bodies) corresponds to a pixel value of 0. The digitizing of data also makes it possible to manipulate the data by changing gray-scale values.

Interpretation is the critical process of making sense of the data. The first application was that of aerial photographic collection which used the following process; spatial measurement through the use of a light table in both conventional single or stereographic coverage, added skills such as the use of photogrammetry, the use of photomosaic, repeat coverage, Making use of objects‘ known dimensions in order to detect modifications. Image Analysis is the recently developed automated computer-aided application which is in increasing use.

Object-Based Image Analysis (OBIA) is a sub-discipline of GIScience devoted to partitioning remote sensing (RS) imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale.

Old data from remote sensing is often valuable because it may provide the only long-term data for a large extent of geography. At the same time, the data is often complex to interpret, and bulky to store. Modern systems tend to store the data digitally, often with lossless compression. The difficulty with this approach is that the data is fragile, the format may be archaic, and the data may be easy to falsify. One of the best systems for archiving data series is as computer-generated machine-readable ultra fiche, usually in type fonts such as OCR-B, or as digitized half-tone images. Ultra fiches survive well in standard libraries, with lifetimes of several centuries. They can be created, copied, filed and retrieved by automated systems. They are about as compact as archival magnetic media, and yet can be read by human beings with minimal, standardized equipment.

Data processing levels

To facilitate the discussion of data processing in practice, several processing ―levels‖ were first defined in 1986 by NASA as part of its Earth Observing System and steadily adopted since then, both internally at NASA (e. g.,) and elsewhere (e. g.,; these definitions are:

Remote sensing software

Main article: Remote sensing application

Remote sensing data are processed and analyzed with computer software, known as a remote sensing application. A large number of proprietary and open source applications exist to process remote sensing data. Remote sensing software packages include:

PCI Geomatica made by PCI Geomatics, Tacit View from
2d3

Socet GXP from BAE Systems, TNTmips from
MicroImages, IDRISI from Clark Labs,

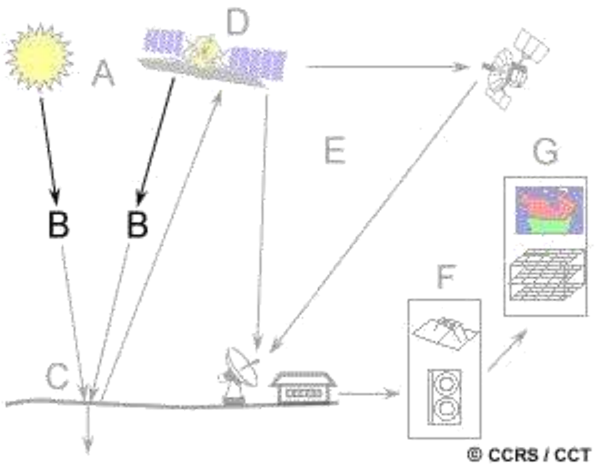
eCognition from Trimble, and Remote View made by Over watch Textron Systems.

Dragon/ips is one of the oldest remote sensing packages still available, and is in some cases free.

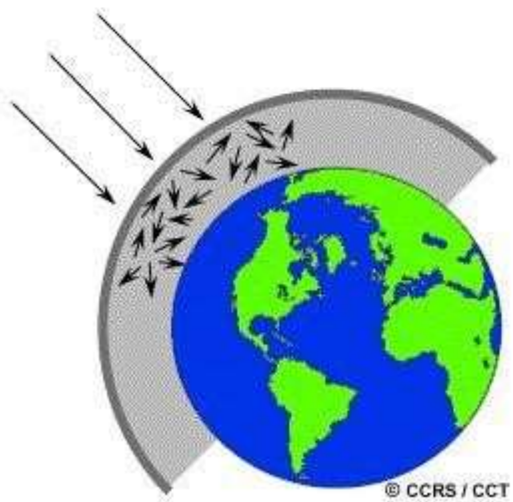
ERDAS IMAGINE from Hexagon Geospatial (Separated from Intergraph SG&I), ENVI/IDL from Exelis Visual Information Solutions,

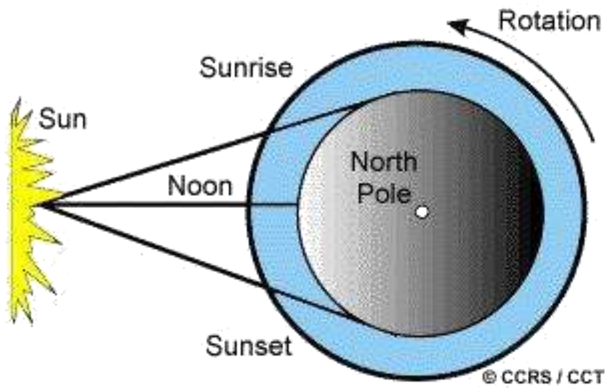
Interactions with the Atmosphere

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.



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.

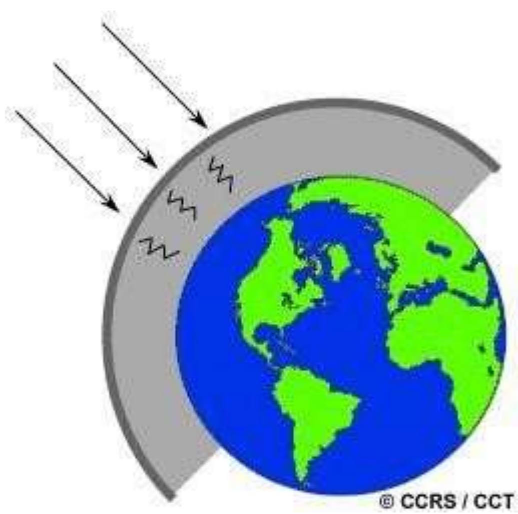




Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. These could be particles such as small specks of dust or nitrogen and oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh 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. 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.

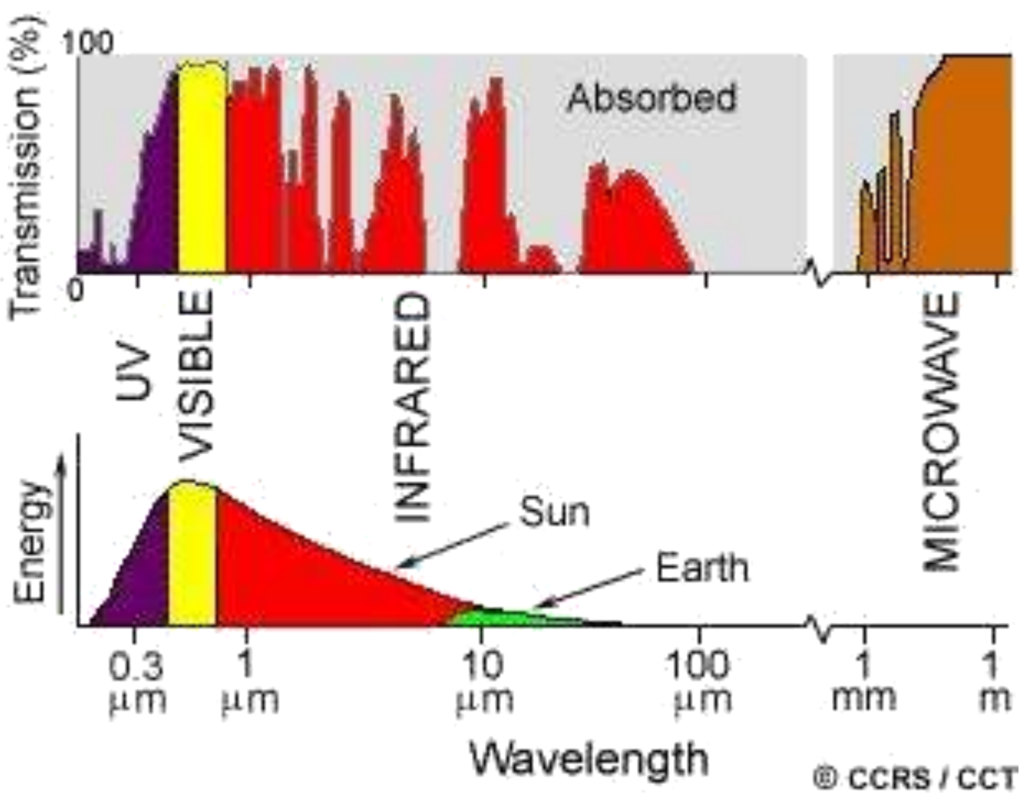
The final scattering mechanism of importance is called nonselective scattering. This occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all 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. 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 long wave 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. The visible portion of the spectrum, to which our eyes are most sensitive, corresponds to both an atmospheric window and the peak energy level of the sun. Note also that heat energy emitted by the Earth corresponds to a window around 10 µm in the thermal IR portion of the spectrum, while the large window at wavelengths beyond 1 mm is associated with the microwave region.

Now that we understand how electromagnetic energy makes its journey from its source to the surface (and it is a difficult journey, as you can see) we will next examine what happens to that radiation when it does arrive at the Earth's surface.

Did you know?

"...sorry, no pot of gold at the end of this rainbow..."
...water droplets act as tiny, individual prisms. When sunlight passes through them, the constituent wavelengths are bent in varying amounts according to wavelength. Individual colors in the sunlight are made visible and a rainbow is the result, with shorter wavelengths (violet, blue) in the inner part of the arc, and longer wavelengths (orange, red) along the outer arc. ...if scattering of radiation in the atmosphere did not take place, then shadows would appear as jet black instead of being various degrees of darkness. Scattering causes the atmosphere to have its own brightness (from the light scattered by particles in the path of sunlight) which helps to illuminate the objects in the shadows.

Whiz quiz

Most remote sensing systems avoid detecting and recording wavelengths in the ultraviolet and blue portions of the spectrum. Explain why this would be the case.

2. What do you think would be some of the best atmospheric conditions for remote sensing in the Visible portion of the spectrum?

Whiz quiz - Answer

1. Detecting and recording the ultraviolet and blue wavelengths of radiation is difficult because of scattering and absorption in the atmosphere. Ozone gas in the upper atmosphere absorbs most of the ultraviolet radiation of wavelengths shorter than about 0.25 µm. This is actually a positive thing for us and most other living things, because of the harmful nature of ultraviolet radiation below these wavelengths. Rayleigh scattering, which affects the shorter wavelengths more severely than longer wavelengths, causes the remaining UV radiation and the shorter visible wavelengths (i.e. blue) to be scattered much more than longer wavelengths, so that very little of this energy is able to reach and interact with the Earth's surface. In fact, blue light is scattered about 4 times as much as red light, while UV light is scattered 16 times as much as red light!

2. Around noon on a sunny, dry day with no clouds and no pollution would be very good for remote sensing in the visible wavelengths. At noon the sun would be at its most directly overhead point, which would reduce the distance the radiation h. to travel and therefore the effects of scattering, to a minimum. Cloud-free conditions would ensure that there will be uniform illumination and that there will be no shadows from clouds. Dry, pollutant-free conditions would minimize the scattering and absorption that would take place due to water droplets and other particles in the atmosphere.

ATMOSPHERIC CORRECTIONS

1. Introduction

The energy registered by the sensor will not be exactly equal to that emitted or reflected from the terrain surface due to radiometric and geometric errors. They represent the commonly encountered error that alters the original data by including errors. Of these, geometric error types and their methods of correction have been discussed in the previous lecture. Radiometric errors can be sensor driven or due to atmospheric attenuation. Before analysis of remote sensing images, it is essential that these error types are identified and removed to avoid error propagation.

2. Sensor driven errors

Such errors occur due to the improper functioning of the sensor system. Some of the commonly encountered error due to sensor malfunctioning are discussed below:

a. **Line drop out**: This error results in transverse scanning systems when out of the multiple detectors used, 1 or 2 fails to function properly. Satellites like Landsat MSS has 6 detectors of which sometimes even if one detector fails to function properly, this results in zero DN recorded for every pixel during corresponding scan lines. Such images will be smeared with black lines. There is no exact methodology to restore the DN values of such images. However, to improve the interpretability of such images, sometimes average of preceding and succeeding lines of DN are used as corrected DN values. The justification of this procedure stems from the geographical continuity of terrain.

b. **Line banding**: Some detectors generate noise which is a function of the relative gain/offset differences of the detectors within a band which results in banding. Such errors can be corrected using a histogram based approach. For example, a histogram for each detector in each band can be produced. Assuming that each detector has sensed a representative sample of all the surface classes within the scene, each of the histograms will be similar (i.e., have the same mean and standard deviation) if the detectors are matched and calibrated. However, even if one detector is no longer producing data readings consistent with the other detectors, its histogram will be different. An average histogram can be generated by using the DN values from all the detectors except the faulty detector. The DN produced by all the detectors get altered so that their histograms are then made to match the average one. When this procedure is completed, the imbalance between the detectors is eliminated and the image is said to have been de-striped. This procedure changes the DN for all the lines, though the relative change for the properly functioning detectors is less when compared to systems having more detectors. A defective detector on the Landsat MSS forms one-sixth of the input to the average histogram whereas a defective detector for a reflected TM band contributed only one –sixteenth of the input to the average histogram. Fig. 2 show the histograms of each detector that tries to visually depict the line banding effect in detector 4. Fig. 3 shows the corrected histogram for the faulty detector 4.

3. Atmospheric Corrections

The DN measured or registered by a sensor is composed of two components. One is the actual radiance of the pixel which we wish to record, another is the atmospheric component. The magnitude of radiance leaving ground is attenuated by atmospheric absorption and the directional properties are altered due to scattering. Other sources of errors are due to the varying illumination geometry dependent on sun‘s azimuth and elevation angles, ground terrain. As the atmosphere properties vary from time to time, it becomes highly essential to correct the radiance values for atmospheric effects. But due to the highly dynamic and complex atmospheric system, it is practically not possible to understand fully the interactions between atmospheric system and electromagnetic radiation. Fig. 4 shows schematically the DN measured by a remote sensing sensor. However, the relationship between received sensor radiance and radiance leaving ground can be summarized in the form of the following relation:

The means of correcting for atmospheric attenuation are discussed below:

a. Based on images

Some of the simple techniques used are based on the histogram minimum method and regression. The extent to which the atmosphere alters the true DN is best seen by examining the DN histograms for various bands. Many scenes contain very dark pixels (such as those in deep shadow) and it might be assumed that they should have a DN of zero. A first order atmospheric correction may be applied to remotely sensed datasets by assuming that the offsets are due solely to the atmospheric effects and by subtracting the offset from each DN Regression method is applied by plotting pixel values of say near infrared (NIR) band with respect to values of other bands. Then a best fit line is fitted to represent the relationship, wherein the offset/intercept represents an estimate of the atmospheric path radiance

b. Radiative transfer model

There are several numerical radiative transfer models available such as LOWTRAN, ATREM 5S/6S etc which make use of different assumptions to model the complex and dynamic atmosphere system. The use of these models requires huge amounts of data collection. Sometimes, due to the associated high costs for data collection, the use of standard atmospheres such as mid latitude summer is relied upon.

c. Empirical method

This method relies on apriori knowledge about the reflectance of two targets-one of which is light and the other is dark. Now, the radiances recorded by the sensor can be calculated from the DN of images. The line joining the two target points can be defined to determine the intercept representing atmospheric radiance.

Though the above methods are available to rectify errors due to atmospheric attenuation of radiance energy flux, several studies have relied on avoiding this step suggesting that when the training data and the data to be classified are both measured on the same relative scale, the atmospheric attenuation from both sources tend to cancel out.

4. Solar Illumination Corrections

Satellite sensor recorded radiance is dependent on several factors such as the reflectance properties of the target, view angle of sensor, solar elevation angle, terrain surface characteristics like slope aspect etc, and on atmospheric attenuations. As shown in Fig. 5, corrections need to be applied to DN in order to take an account of different illumination angles. The reflectance of any target varies with change in illumination angle and angle of view of sensor. A function called as bi-directional reflectance distribution function (BRDF) is the name given to the function relating magnitude of upwelling radiance of target with respect to these two angles. Images obtained at different times of the year are acquired under different illumination conditions. Solar illumination angle, as measure from the horizontal, is greater in the summer than in the winter.

As the earth‘s surface is not flat, terrain slope and aspect properties introduce radiometric distortion. Among the different means of correcting terrain effects, one of them namely the cosine correction is discussed. Assuming a lamebrain surface, a constant distance between Earth and sun and a constant amount of solar energy illuminating earth, the magnitude of irradiance that reaches a pizel on a slope is going to be directly proportional to the cosine of the incidence angle

UNIT-3 GEOGRAPHIC INFORMATION SYSTEM

Geographic information system

"GIS" redirects here. For other uses, see

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. The acronym GIS is sometimes used for geographic information science (GIS) to refer to the academic discipline that studies geographic information systems and is a large domain within the broader academic discipline of Geoinformatics. What goes beyond a GIS is a spatial data infrastructure, a concept that has no such restrictive boundaries.

In a general sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations Geographic information science is the science underlying geographic concepts, applications, and systems.

GIS is a broad term that can refer to a number of different technologies, processes, and methods. It is attached to many operations and has many applications related to engineering, planning, management, transport/logistics, insurance, telecommunications, and business. [3] For that reason, GIS and location intelligence applications can be the foundation for many locationenabled services that rely on analysis and visualization.

GIS can relate unrelated information by using location as the key index variable. Locations or extents in the Earth space–time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. All Earth-based spatial–temporal location and extent references should, ideally, be relatable to one another and ultimately

to a "real" physical location or extent. This key characteristic of GIS has begun to open new avenues of scientific inquiry.

GIS techniques and technology

Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a CAD program, and geo-referencing capabilities. With the wide availability of ortho-rectified imagery (from satellites, aircraft, Helikites and UAVs), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of by the traditional method of tracing the geographic form on a separate digitizing tablet (heads-down digitizing).

Relating information from different sources

GIS uses spatio-temporal (space-time) location as the key index variable for all other information. Just as a relational database containing text or numbers can relate many different tables using common key index variables, GIS can relate otherwise unrelated information by using location as the key index variable. The key is the location and/or extent in space-time.

Any variable that can be located spatially, and increasingly also temporally, can be referenced using a GIS. Locations or extents in Earth space–time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. These GIS coordinates may represent other quantified systems of temporal-spatial reference (for example, film frame number, stream gage station, highway mile-marker, surveyor benchmark, building address, street intersection, entrance gate, water depth sounding, POS or CAD drawing origin/units). Units applied to recorded temporal-spatial data can vary widely (even when using exactly the same data, see map projections), but all Earth-based spatial–temporal location and extent references should, ideally, be relatable to one another and ultimately to a "real" physical location or extent in space–time.

Related by accurate spatial information, an incredible variety of real-world and projected past or future data can be analyzed, interpreted and represented. This key characteristic of GIS has begun to open new avenues of scientific inquiry into behaviors and patterns of real-world information that previously had not been systematically correlated.

GIS uncertainties

GIS accuracy depends upon source data, and how it is encoded to be data referenced. Land surveyors have been able to provide a high level of positional accuracy utilizing the GPSderived positions. High-resolution digital terrain and aerial imagery, powerful computers and Web technology are changing the quality, utility, and expectations of GIS to serve society on a grand scale, but nevertheless there are other source data that have an impact on overall GIS accuracy like paper maps, though these may be of limited use in achieving the desired accuracy since the aging of maps affects their dimensional stability.

In developing a digital topographic database for a GIS, topographical maps are the main source, and aerial photography and satellite imagery are extra sources for collecting data and identifying attributes which can be mapped in layers over a location facsimile of scale. The scale of a map and geographical rendering area representation type are very important aspects since the information content depends mainly on the scale set and resulting locatability of the map's representations. In order to digitize a map, the map has to be checked within theoretical dimensions, then scanned into a raster format, and resulting raster data has to be given a theoretical dimension by a rubber sheeting/warping technology process.

A quantitative analysis of maps brings accuracy issues into focus. The electronic and other equipment used to make measurements for GIS is far more precise than the machines of conventional map analysis. All geographical data are inherently inaccurate, and these inaccuracies will propagate through GIS operations in ways that are difficult to predict.

Data representation

Main article: GIS file formats

GIS data represents real objects (such as roads, land use, elevation, trees, waterways, etc.) with digital data determining the mix. Real objects can be divided into two abstractions: discrete objects (e.g., a house) and continuous fields (such as rainfall amount, or elevations). Traditionally, there are two broad methods used to store data in a GIS for both kinds of abstractions mapping references: raster images and vector. Points, lines, and polygons are the stuff of mapped location attribute references. A new hybrid method of storing data is that of identifying point clouds, which combine three-dimensional points with RGB information at each point, returning a " 3D color image". GIS thematic maps then are becoming more and more realistically visually descriptive of what they set out to show or determine.

Data capture

Example of hardware for mapping (GPS and laser rangefinder) and data collection (rugged computer). The current trend for geographical information system (GIS) is that accurate mapping and data analysis are completed while in the field. Depicted hardware (field-map technology) is used mainly for forest inventories, monitoring and mapping.

Data capture—entering information into the system—consumes much of the time of GIS practitioners. There are a variety of methods used to enter data into a GIS where it is stored in a digital format.

Existing data printed on paper or PET film maps can be digitized or scanned to produce digital data. A digitizer produces vector data as an operator traces points, lines, and polygon boundaries from a map. Scanning a map results in raster data that could be further processed to produce vector data.

Survey data can be directly entered into a GIS from digital data collection systems on survey instruments using a technique called coordinate geometry (COGO). Positions from a global navigation satellite system (GNSS) like Global Positioning System can also be collected and then imported into a GIS. A current trend in data collection gives users the ability to utilize field Computers with the ability to edit live data using wireless connections or disconnected editing sessions. This has been enhanced by the availability of low-cost mapping-grade GPS units with decimeter accuracy in real time. This eliminates the need to post process, import, and update the data in the office after fieldwork has been collected. This includes the ability to incorporate positions collected using a laser rangefinder. New technologies also allow users to create maps as well as analysis directly in the field, making projects more efficient and mapping more accurate.

Remotely sensed data also plays an important role in data collection and consist of sensors attached to a platform. Sensors include cameras, digital scanners and lidar, while platforms usually consist of aircraft and satellites. In England in the mid-1990s, hybrid kite/balloons called Helikites first pioneered the use of compact airborne digital cameras as airborne GeoInformation Systems. Aircraft measurement software, accurate to 0.4 mm was used to link the photographs and measure the ground. Helikites are inexpensive and gather more accurate data than aircraft. Helikites can be used over roads, railways and towns where UAVs are banned.

Recently with the development of miniature UAVs, aerial data collection is becoming possible with them. For example, the Aeryon Scout was used to map a 50-acre area with a Ground sample distance of 1 inch (2.54 cm) in only 12 minutes. [18]

The majority of digital data currently comes from photo interpretation of aerial photographs. Soft-copy workstations are used to digitize features directly from stereo pairs of digital photographs. These systems allow data to be captured in two and three dimensions, with elevations measured directly from a stereo pair using principles of photogrammetry. Analog aerial photos must be scanned before being entered into a soft-copy system, for high-quality digital cameras this step is skipped.

Satellite remote sensing provides another important source of spatial data. Here satellites use different sensor packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed using different bands to identify objects and classes of interest, such as land cover.

When data is captured, the user should consider if the data should be captured with either a relative accuracy or absolute accuracy, since this could not only influence how information will be interpreted but also the cost of data capture.

After entering data into a GIS, the data usually requires editing, to remove errors, or further processing. For vector data it must be made "topologically correct" before it can be used for some advanced analysis. For example, in a road network, lines must connect with nodes at an intersection. Errors such as undershoots and overshoots must also be removed. For scanned maps, blemishes on the source map may need to be removed from the resulting raster. For example, a fleck of dirt might connect two lines that should not be connected.

REMOTE SENSING APPLICATIONS IN WATERSHED MANAGEMENT

Introduction

Scientific planning and management is essential for the conservation of land and water resources for optimum productivity. Watersheds being the natural hydrologic units, such studies are generally carried out at watershed scale and are broadly referred under the term watershed management. It involves assessment of current resources status, complex modeling to assess the relationship between various hydrologic components, planning and implementation of land and water conservation measures etc.

Remote sensing via aerial and space-borne platforms acts as a potential tool to supply the essential inputs to the land and water resources analysis at different stages in watershed planning and management. Water resource mapping, land cover classification, estimation of water yield and soil erosion, estimation of physiographic parameters for land prioritization and water harvesting are a few areas where remote sensing techniques have been used.

This lecture covers the remote sensing applications in water resources management under the following five classes:

1. Water resources mapping
2. Estimation of watershed physiographic parameters
3. Estimation of hydrological and meteorological variables
4. Watershed prioritization
5. Water conservation

Water resources mapping

Identification and mapping of the surface water boundaries has been one of the simplest and direct applications of remote sensing in water resources studies. Water resources mapping using remote sensing data require fine spatial resolution so as to achieve accurate delineation of the boundaries of the water bodies.

Optical remote sensing techniques, with their capability to provide very fine spatial resolution have been widely used for water resources mapping. Water absorbs most of the energy in Remote Sensing- R and MIR wavelengths giving darker tones in the bands, and can be easily differentiated from the land and vegetation.

Fig. shows images of a part of the Krishna river basin in different bands of the Land sat ETM+. In the VIS bands (bands 1, 2 and 3) the contrast between water and other features are not very significant. On the other hand, the IR bands (bands 4 and 5) show a sharp contrast between them due to the poor reflectance of water in the IR region of the EMR spectrum.

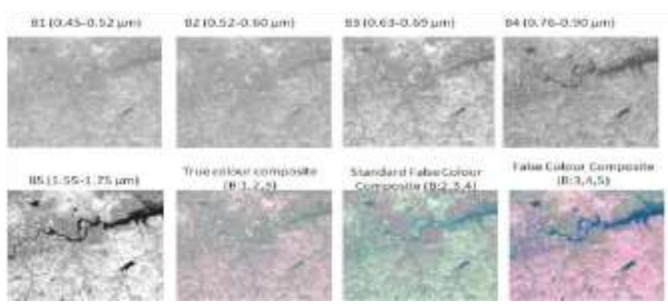


Fig. Land sat ETM+ images of a part of the Krishna river basin in different spectral bands.

Poor cloud penetration capacity and poor capability to map water resources under thick vegetation cover are the major drawbacks of the optical remote sensing techniques. Use of active microwave sensor helps to overcome these limitations as the radar waves can penetrate the clouds and the vegetation cover to some extent. In microwave remote sensing, water surface provides specular reflection of the microwave radiation, and hence very little energy is scattered back compared to the other land features. The difference in the energy received back at the radar sensor is used for differentiating, and to mark the boundaries of the water bodies.

Estimation of watershed physiographic parameters

This section covers the remote sensing applications in estimating watershed physiographic parameters and the land use / land cover information.

Watershed physiographic parameters

Various watershed physiographic parameters that can be obtained from remotely sensed data include watershed area, size and shape, topography, drainage pattern and landforms.

Stereoscopic attribute of aerial photographs or satellite images permit quantitative assessment of landforms and evaluation of basin topography, which can be used to develop or update the topographic maps. With the help of satellite remote sensing, global scale digital elevation models (DEMs) are available today at fine spatial resolution and reasonable vertical accuracy. DEM from the Shuttle Radar Topographic Mission (SRTM) and ASTER GDEM are examples. SRTM DEM provides near-global DEM at 90m spatial resolution and 16m vertical accuracy. Airborne laser altimeters also provide quick and accurate measurements for evaluating changes in land surface features and are effective tools to ascertain watershed properties.

Fine resolution DEMs have been used to extract the drainage network/ pattern using the flow tracing algorithms. The drainage information can also be extracted from the optical images using digital image processing techniques.

The drainage information may be further used to generate secondary information such as structure of the basin, basin boundary, stream orders, stream length, stream frequency, bifurcation ratio, stream sinuosity, drainage density and linear aspects of channel systems etc. Fig. shows the ASTER GDEM for a small region in the Krishna Basin in North Karnataka and the drainage network delineated from it using the flow tracing algorithm included in the _spatial analyst‘ tool box of ArcGIS. Fig. (b) Also shows the stream orders assigned to each of the delineated streams.

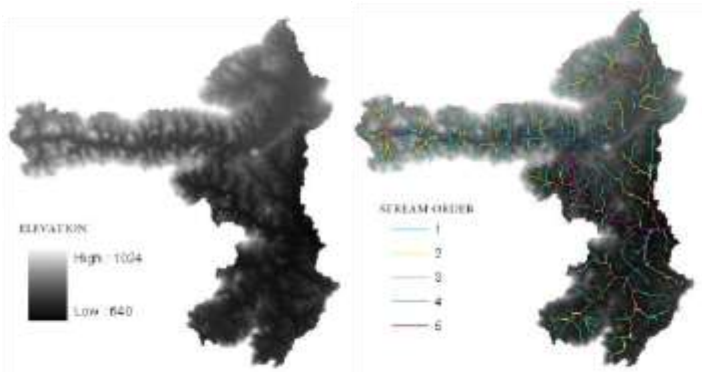


Fig. (a) ASTER GDEM of a small region in the Krishna Basin (b) and the stream network delineated from the DEM

Land use / land cover classification

Detailed land use / land cover map is another important input that remote sensing can yield for hydrologic analysis.

Land cover classification using multispectral remote sensing data is one of the earliest, and well established remote sensing applications in water resources studies. With the capability of the remote sensing systems to provide frequent temporal sampling and the fine spatial resolution, it is possible to analyze the dynamics of land use / land cover pattern, and also its impact on the hydrologic processes.

Use of hyper-spectral imageries helps to achieve further improvement in the land use / land cover classification, wherein the spectral reflectance values recorded in the narrow contiguous bands are used to differentiate different land use classes which show close resemblance with each other. Identification of crop types using hyper-spectral data is an example.

With the help of satellite remote sensing, land use land cover maps at near global scale are available today for hydrological applications. European Space Agency (ESA) has released a global land cover map of 300 m resolution, with 22 land cover classes at 73% accuracy (Fig. 3).

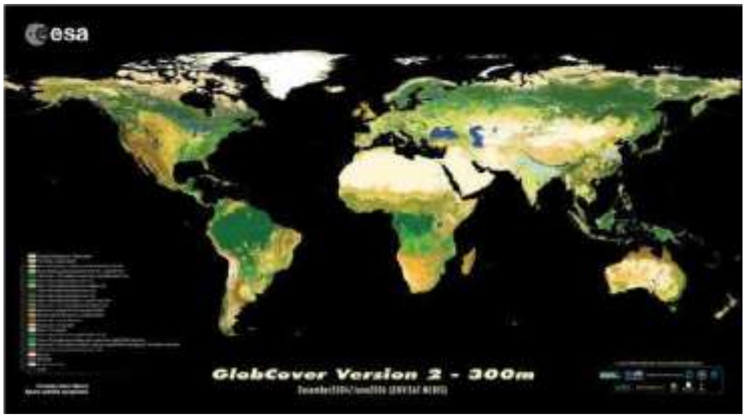


Fig. Global 300 m lands cover classification from the European Space Agency

Estimation of hydrological and meteorological variables

Hydrological processes such as precipitation and evapotranspiration are generally used as inputs to the hydrological models to simulate other processes such as runoff (surface and sub-surface), storage change in the unsaturated zone, and ground water flow. This section covers the remote sensing applications in estimating precipitation, evapotranspiration and soil moisture.

Precipitation

Remote sensing techniques have been used to provide information about the occurrence of rainfall and its intensity. Basic concept behind the satellite rainfall estimation is the differentiation of precipitating clouds from the non-precipitating clouds (Gibson and Power, 2000) by relating the brightness of the cloud observed in the imagery to the rainfall intensities. Satellite remote sensing uses both optical and microwave remote sensing (both passive and active) techniques.

Evapotranspiration

Evapotranspiration (ET) represents the water and energy flux between the land surface and the lower atmosphere. ET fluxes are controlled by the feedback mechanism between the atmosphere and the land surface, soil and vegetation characteristics, and the hydro-meteorological conditions. There are no direct methods available to estimate the actual ET by means of remote sensing techniques. Remote sensing application in the ET estimation is limited to the estimation of the surface conditions like albedo, soil moisture, surface temperature, and vegetation characteristics like normalized differential vegetation index (NDVI) and leaf area index (LAI). The data obtained from remote sensing are used in different models to simulate the actual ET.

Courault et al. (2005) grouped the remote sensing data-based ET models into four different classes:

1. Empirical direct methods: Use the empirical equations to relate the difference in the surface air temperature to the ET.

2. Residual methods of the energy budget: Use both empirical and physical parameterization. Example: SEBAL (Bastiaanssen et al., 1998), FAO-56 method (Allen at al., 1998)

3. Deterministic models: Simulate the physical process between the soil, vegetation and atmosphere making use of remote sensing data such as Leaf Area Index (LAI) and soil moisture. SVAT (Soil-Vegetation-Atmosphere-Transfer) model is an example (Olioso et al., 1999).

4. Vegetation index methods: Use the ground observation of the potential or reference ET. Actual ET is estimated from the reference ET by using the crop coefficients obtained from the remote sensing data (Allen et al., 2005; Neale et al., 2005).

Optical remote sensing using the VIS and NIR bands have been commonly used to estimate the input data required for the ET estimation algorithms.

As a part of the NASA / EOS project to estimate global terrestrial ET from earth‘s land surface by using satellite remote sensing data, MODIS Global Terrestrial Evapotranspiration Project (MOD16) provides global ET data sets at regular grids of 1 sq.km for the land surface at 8-day, monthly and annual intervals for the period 2000-2010.

Soil moisture estimation

Remote sensing techniques of soil moisture estimation are advantageous over the conventional *in-situ* measurement approaches owing to the capability of the sensors to capture spatial variation over a large aerial extent. Moreover, depending upon the revisit time of the satellites, frequent sampling of an area and hence more frequent soil moisture measurements are feasible.

Fig. shows the global average monthly soil moisture in May extracted from the integrated soil moisture database of the European Space Agency- Climate Change Initiative (ESA-CCI).

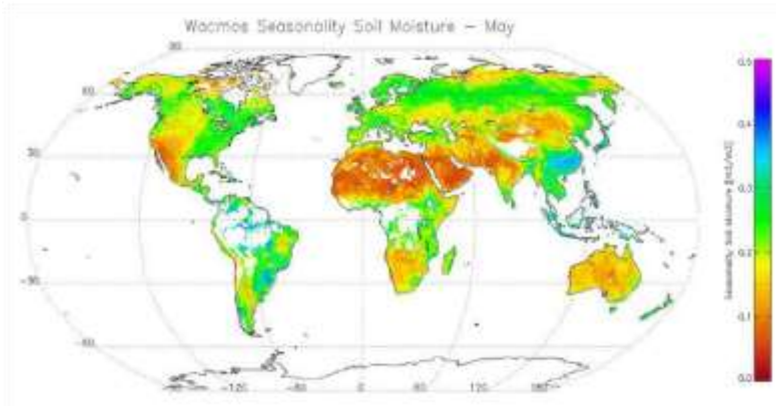


Fig. Global monthly average soil moisture in May from the CCI data

Remote sensing of the soil moisture requires information below the ground surface and therefore mostly confined to the use of thermal and microwave bands of the EMR spectrum.

Remote sensing of the soil moisture is based on the variation in the soil properties caused due to the presence of water. Soil properties generally monitored for soil moisture estimation include soil dielectric constant, brightness temperature, and thermal inertia.

Though the remote sensing techniques are giving reasonably good estimation of the soil moisture, due to the poor surface penetration capacity of the microwave signals, it is considered to be effective in retrieving the moisture content of the surface soil layer of maximum 10 cm thickness. In the recent years, attempts have been made to extract the soil moisture of the entire root zone with the help of remote sensing data. Such methods assimilate the remote sensing derived surface soil moisture data with physically based distributed models to simulate the root zone soil moisture. For example, Das et al. (2008) used the Soil-Water-Atmosphere-Plant (SWAP) model for simulating the root zone soil moisture by assimilating the aircraft-based remotely sensed soil moisture into the model.

Some of the satellite based sensors that have been used for retrieving the soil moisture information are the following.

1. Passive microwave sensors: SMMR, AMSR-E and SSM/I

2. Active microwave sensors (radar): Advanced Scatter meter (ASCAT) aboard the EUMETSAT MetOp satellite

3. Thermal sensors: Data from the thermal bands of the MODIS sensor onboard Terra satellite have also been used for retrieving soil moisture data.

Use of hyper-spectral remote sensing technique has been recently employed to improve the soil moisture simulation. Hyper-spectral monitoring of the soil moisture uses reflectivity in the VIS and the NIR bands to identify the changes in the spectral reflectance curves due to the presence of soil moisture (Yanmin et al., 2010). Spectral reflectance measured in multiple narrow bands in the hyper spectral image helps to extract most appropriate bands for the soil moisture estimation, and to identify the changes in the spectral reflectance curves due to the presence of soil moisture.

Watershed characterization and prioritization

Watershed characterization involves the measurement and analysis of various hydro-geological and geo-morphological parameters, soil and land use characteristics etc. (Rao and Raju, 2010). Watershed prioritization is the ranking of different watersheds or sub-watersheds within a watershed for any specific application based on the watershed characteristics

Examples:

1. Watershed prioritization considering the erosion risk, using parameters such as relief ratio, drainage density, drainage texture and bifurcation ratio (Chaudhary and Sharma, 1984).
2. Watershed prioritization based on the sediment yield index (Khan et al., 2001)

3. Watershed characterization and land suitability evaluation using land use/ land cover, soil data, slope, and soil degradation status (Saxena et al., 2000)

4. Prioritization of micro-catchments based on morphological parameters (Raju and Nagesh Kumar, 2012)

Fig. shows a sample watershed characterization map of the Northern United States for water quality risks

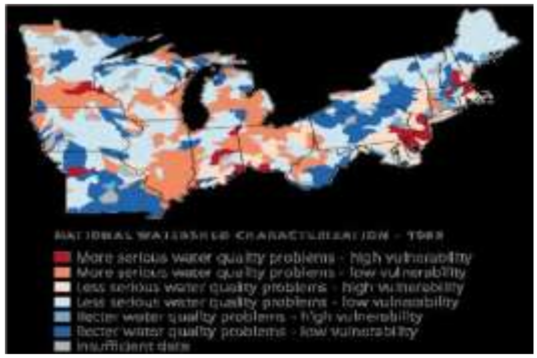


Fig. Watershed characterization of the Northern United States for water quality risk Remote sensing techniques have been effectively used for watershed characterization and prioritization to identify the water potential, erosion risk, management requirements etc. Remote sensing helps in obtaining the database essential for such analyses. Input data that have been generated using remote sensing techniques for such studies includes physiographic and morph metric parameters, land use / land cover information and hydrological parameters as mentioned in the previous section

Case study: Prioritization of micro-catchments in the Kherthal catchment in Rajasthan based on morphology (Source: Raju and Nagesh Kumar, 2012)

Kherthal catchment in Rajasthan lies between latitudes 24o51‘ and 25o58‘ N and longitudes 73o8‘ and 73o19‘ E. The catchment consists of 25 micro-catchments and spreads over approximately 159 km^2 Area.

Fig. Location map of the Kherthal catchment

Raju and Nagesh Kumar (2012) considered a set of seven geomorphologic parameters to prioritize the micro-catchments in the Kherthal catchment for the watershed conservation and management practices.

Morphologic parameters considered are the following.

1. Drainage density (Dd)
2. Bifurcation ratio (Rb)
3. Stream frequency (Fu)
4. Texture ratio (T)
5. Form factor (Rf)
6. Elongation ratio (Re)
7. Circulatory ratio (Rc)

Water conservation and rainwater harvesting

Rainwater harvesting, wherein water from the rainfall is stored for future usage, is an effective water conservation measure particularly in the arid and semi-arid regions.

Rainwater harvesting techniques are highly location specific. Selection of appropriate water harvesting technique requires extensive field analysis to identify the rainwater harvesting potential of the area, and the physiographic and terrain characteristics of the locations. It depends on the amount of rainfall and its distribution, land topography, soil type and depth, and local socio-economic factors (Rao and Raju, 2010).

Rao and Raju (2010) had listed a set of parameters which need to be analyzed to fix appropriate locations for the water harvesting structures. These are

- Rainfall
- Land use or vegetation cover
- Topography and terrain profile
- Soil type & soil depth
- Hydrology and water resources
- Socio-economic and infrastructure conditions

• Environmental and ecological impacts

Remote sensing techniques had been identified as potential tools to generate the basic information required for arriving at the most appropriate methods for each area.

In remote sensing aided analysis, various data layers were prepared and brought into a common GIS framework. Further, multi-criteria evaluation algorithms were used to aggregate the information from the basic data layers. Various decision rules were evaluated to arrive at the most appropriate solution as shown in Fig.

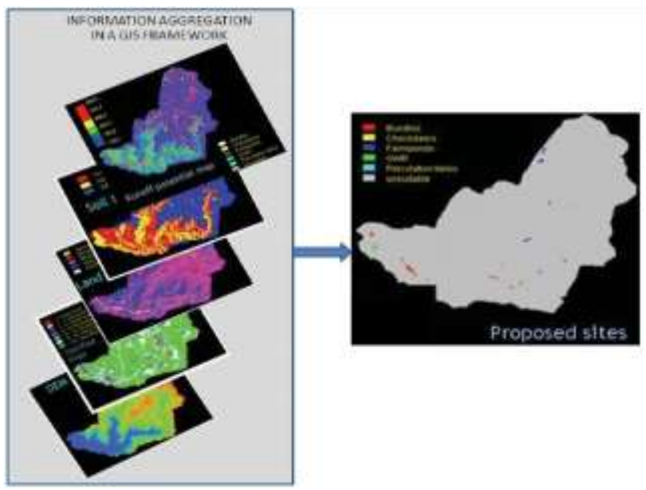


Fig. Schematic representation showing the remote sensing data aggregation in evaluating the suitability of various water harvesting techniques

The capability to provide large areal coverage at a fine spatial resolution makes remote sensing techniques highly advantageous over the conventional field-based surveys.

REMOTE SENSING APPLICATIONS IN RAINFALL-RUNOFF MODELLING

Introduction

The most common application of the remote sensing techniques in the rainfall-runoff studies is the estimation of the spatially distributed hydro-meteorological state variables that are required for the modeling, e.g., rainfall, temperature, ET, soil moisture, surface characteristics and land use land cover classes. Ability to achieve high spatial resolution and aerial coverage is the major advantage of the remote sensing techniques over the conventional methods.

Hydrologic models that incorporate the remote sensing information include regression models, conceptual models, and distributed models. While selecting the hydrologic model for integration with the remote sensing data, spatial resolution of the hydrologic model structure and the input data must be comparable. Fine resolution data is relevant only if the hydrologic model uses spatially distributed information of all the relevant input parameters sufficient to capture the spatial heterogeneity, and also when the highly dynamic processes are monitored.

This lecture gives the details of the remote sensing-aided rainfall-runoff modeling using the ArcGIS integrated Soil and Water Assessment Tool (ArcSWAT). Most of the figures and the results shown in this lecture are from Reshmidevi and Nagesh Kumar (2013)

SWAT and ArcSWAT

Reshmidevi and Nagesh Kumar (2013) used the Soil and Water Assessment Toll (SWAT) for rainfall-runoff simulation. SWAT is a river basin scale hydrological model developed for the United States Department of Agriculture (USDA), Agricultural Research Service (Neitsch et al. 2005). Being a semi-distributed, continuous time model, it requires numerous spatial and attribute inputs that represent weather, hydrology, soil properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management.

Integration of SWAT with a user interface in a Geographic Information System (GIS) environment provides the facility to input spatially referenced data and thereby enhances its capability to represent spatial heterogeneity (e.g., AVSWAT, ArcSWAT). The schematic flow of the SWAT integrated with a GIS framework (ArcView) is provided in Figure

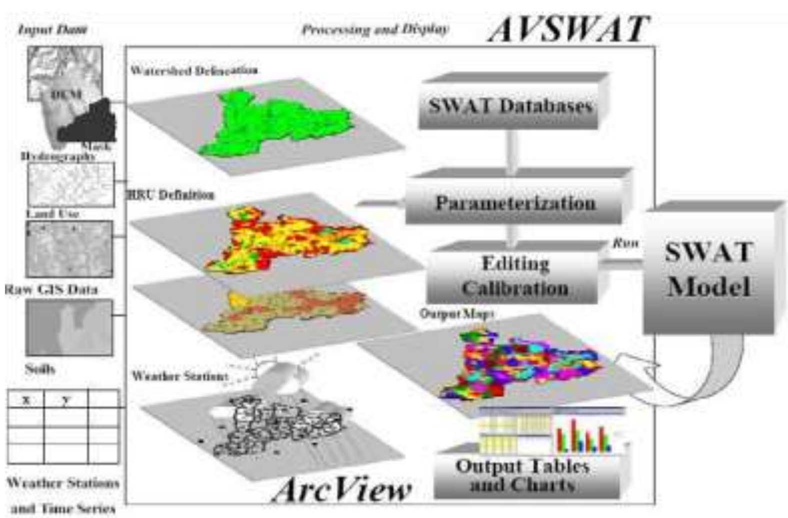


Fig. Schematic of GIS integrated SWAT (Di Luzio et al., 2002)

In the study by Reshmidevi and Nagesh Kumar (2013), ArcSWAT (Winchell et al., 2007), a recent version of the GIS integrated SWAT was selected. ArcSWAT is the ArcGIS interface of SWAT. ArcSWAT uses various spatial and attribute data as input to the model and produces the output of hydrologic simulations in the form of tables showing various water budget components.

Study region and inputs to the ArcSWAT

As a case study, the catchment of Malaprabha reservoir in the Karnataka state of India was taken up. It has an area of 2,564 km_2. Fig. shows the location map of the study area.

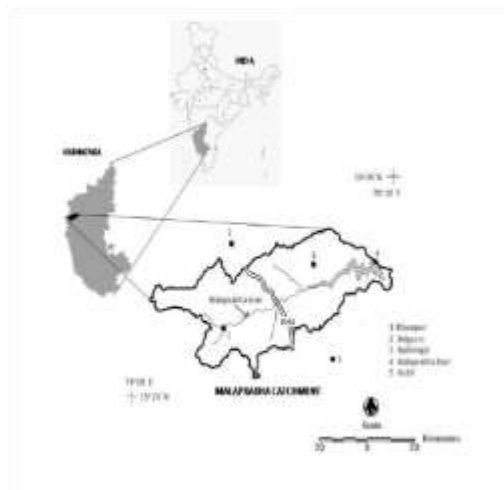


Fig. Location map of the Malaprabha catchment

Spatial data inputs

Spatially referenced data used in the ArcSWAT include DEM, land use / land cover map and soil map. DEM used in the study was the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global DEM (GDEM) released by the Japan‘s Ministry of Economy, Trade and Industry (METI) and NASA, at a spatial resolution of 30m, generated using the satellite remote sensing techniques. Fig. 3 shows the DEM of the study area.

In ArcSWAT, DEM was used to delineate the catchment boundary and to extract the topographic characteristics related to hydrology.

Land use / land cover (LU/LC) map at 30m spatial resolution was generated from multi-season Landsat-7 ETM + imageries. Seven main LU/LC classes viz., water, agricultural land, barren / fallow land, rocky area, forest, settlement and grass land were extracted in the first step.

Based on the field information and the district statistical information about the crop production, the agricultural area was further classified into various crop classes. Each of the LU/LC classes was assigned to a corresponding SWAT class

Soil map of the area was procured from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur. Fig.6 shows the soil map of the study area.

Attribute data

Attribute data used as input to the model includes observed hydro-meteorological variables namely stream flow, precipitation, maximum and minimum temperatures, wind speed and relative humidity. Data at the stream flow gauging station recording the inflow to the Malaprabha reservoir on daily time scale was obtained from Water Resources Development Organization (WRDO), Karnataka, India, for the period 1978-2000.

Observed daily data of temperature, wind speed, relative humidity, and cloud cover at one gauging stations namely Santhebasthewadi were obtained from the Directorate of Economics and Statistics, Bangalore, for the period 1992-2003.

Spatial variation in the rainfall was accounted by using the rainfall observations at 9 stations in the catchment.

Fig. shows the locations of the rain gauges, and the meteorological observatory in the catchment.

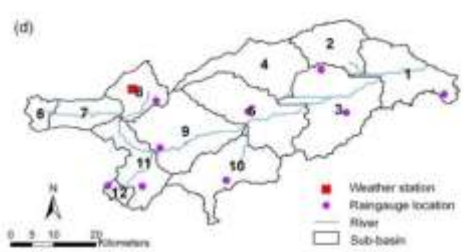


Fig. Locations of the hydro-meteorological stations in the Malaprabha catchment

Runoff simulation in ArcSWAT

The modified SCS curve number method (USDA-NRCS, 2004) included in the ArcSWAT interface was used for the runoff simulation.

Delineating the sub-watershed boundaries, defining the Hydrologic response units (HRUs), generating SWAT input files, creating agricultural management scenarios, executing SWAT simulations, and reading and charting of results were all carried out by various tools available in the interface. Data contained within HRU can include topographic characteristic, information about water flow, land cover, erosion, depressional storage areas etc.

In ArcSWAT, hydrologic processes are simulated in two phases: land phase and the channel phase. The land phase was divided into various sub-basins, which were further disaggregated into spatially homogeneous HRUs. Each HRU was vertically divided into the surface layer, root zone, shallow aquifer and the deep aquifer layers as shown in Fig. 8. Hydrologic processes considered at each layer

The SWAT model estimates the water yield from a HRU for a time step, using eqn. 1. The water leaving a HRU contributes to stream flow in the reach.

WYLD = SURQ + LATQ +GWQ - TLOSS - Pond abstractions (1)

Where SURQ, LATQ and GWQ represent contribution to stream flow in the reach from surface runoff, lateral flow and groundwater, respectively, during the time step. TLOSS refers to the amount of water lost from tributary channels during transmission. The groundwater is primarily contributed by shallow aquifers.

UNIT-4

RASTER DATA

Raster-to-vector translation

Data restructuring can be performed by a GIS to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion.

More advanced data processing can occur with image processing, a technique developed in the late 1960s by NASA and the private sector to provide contrast enhancement, false color rendering and a variety of other techniques including use of two dimensional Fourier transforms. Since digital data is collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert geographic data from one structure to another. In so doing, the implicit assumptions behind different ontologies and classifications require analysis. [19] Object ontologies have gained increasing prominence as a consequence of object-oriented programming and sustained work by Barry Smith and co-workers.

Projections, coordinate systems, and registration

Main article: Map Projection

The earth can be represented by various models, each of which may provide a different set of coordinates (e.g., latitude, longitude, elevation) for any given point on the Earth's surface. The simplest model is to assume the earth is a perfect sphere. As more measurements of the earth have accumulated, the models of the earth have become more sophisticated and more accurate. In fact, there are models called datum‘s that apply to different areas of the earth to provide increased accuracy, like NAD83 for U.S. measurements, and the World Geodetic System for worldwide measurements.

Spatial analysis with geographical information system (GIS)

GIS spatial analysis is a rapidly changing field, and GIS packages are increasingly including analytical tools as standard built-in facilities, as optional toolsets, as add-ins or 'analysts'. In many instances these are provided by the original software suppliers (commercial vendors or collaborative noncommercial development teams), whilst in other cases facilities have been developed and are provided by third parties. Furthermore, many products offer software development kits (SDKs), programming languages and language support, scripting facilities and/or special interfaces for developing one's own analytical tools or variants. The website "Geospatial Analysis" and associated book/ebook attempt to provide a reasonably comprehensive guide to the subject. The increased availability has created a new dimension to business intelligence termed " spatial intelligence" which, when openly delivered via intranet, democratizes access to geographic and social network data. Geospatial intelligence, based on GIS spatial analysis, has also become a key element for security. GIS as a whole can be described as conversion to a vectorial representation or to any other digitization process.

Slope and aspect

Slope can be defined as the steepness or gradient of a unit of terrain, usually measured as an angle in degrees or as a percentage. Aspect can be defined as the direction in which a unit of terrain faces. Aspect is usually expressed in degrees from north. Slope, aspect, and surface curvature in terrain analysis are all derived from neighborhood operations using elevation values of a cell's adjacent neighbours. Slope is a function of resolution, and the spatial resolution used to calculate slope and aspect should always be specified. Authors such as Skidmore, Jones and Zhou and Liu have compared techniques for calculating slope and aspect.

The following method can be used to derive slope and aspect:

The elevation at a point or unit of terrain will have perpendicular tangents (slope) passing through the point, in an east-west and north-south direction. These two tangents give two components,

∂z/∂x and ∂z/∂y, which then be used to determine the overall direction of slope, and the aspect of the slope. The gradient is defined as a vector quantity with components equal to the partial derivatives of the surface in the x and y directions.

The calculation of the overall 3x3 grid slope *S* and aspect *A* for methods that determine east-west and north-south component use the following formulas respectively:

$$\tan S = \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2}$$

$$\tan A = \left(\frac{\left(\frac{-\partial z}{\partial y}\right)}{\left(\frac{\partial z}{\partial x}\right)}\right)$$

Zhou and Liu describe another algorithm for calculating aspect, as follows:

$$A = 270^\circ - \arctan\left(\frac{\frac{\partial z}{\partial y}}{\frac{\partial z}{\partial x}}\right) + 90^\circ \frac{\frac{\partial z}{\partial x}}{\left|\frac{\partial z}{\partial x}\right|}$$

Data analysis

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and schools. A GIS, however, can be used to depict two- and threedimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with isopleth or contour lines that indicate differing amounts of rainfall. Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area. This GIS derived map can then provide additional information - such as the viability of water power potential as a renewable energy source. Similarly, GIS can be used compare other renewable energy resources to find the best geographic potential for a region.

Additionally, from a series of three-dimensional points, or digital elevation model, isopleth lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined for any given reach, by computing all of the areas contiguous and uphill from any given point of interest. Similarly, an expected of where surface water would want to travel in intermittent and permanent streams can be computed from elevation data in the GIS.

Topological modeling

A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modelling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

Geometric networks

Geometric networks are linear networks of objects that can be used to represent interconnected features, and to perform special spatial analysis on them. A geometric network is composed of edges, which are connected at junction points, similar to graphs in mathematics and computer science. Just like graphs, networks can have weight and flow assigned to its edges, which can be used to represent various interconnected features more accurately. Geometric networks are often used to model road networks and public utility networks, such as electric, gas, and water networks. Network modeling is also commonly employed in transportation planning, hydrology modeling, and infrastructure modeling.

Hydrological modeling

GIS hydrological models can provide a spatial element that other hydrological models lack, with the analysis of variables such as slope, aspect and watershed or catchment area. Terrain analysis is fundamental to hydrology, since water always flows down a slope. As basic terrain analysis of a digital elevation model (DEM) involves calculation of slope and aspect, DEMs are very useful for hydrological analysis. Slope and aspect can then be used to determine direction of surface runoff, and hence flow accumulation for the formation of streams, rivers and lakes. Areas of divergent flow can also give a clear indication of the boundaries of a catchment. Once a flow direction and accumulation matrix has been created, queries can be performed that show contributing or dispersal areas at a certain point. More detail can be added to the model, such as terrain roughness, vegetation types and soil types, which can influence infiltration and evapotranspiration rates, and hence influencing surface flow. One of the main uses of hydrological modeling is in environmental contamination research.

Cartographic modeling

An example of use of layers in a GIS application. In this example, the forest cover layer (light green) is at the bottom, with the topographic layer over it. Next up is the stream layer, then the boundary layer, then the road layer. The order is very important in order to properly display the final result. Note that the pond layer was located just below the stream layer, so that a stream line can be seen overlying one of the ponds.

The term "cartographic modeling" was probably coined by Dana Tomlin in his PhD dissertation and later in his book which has the term in the title. Cartographic modeling refers to a process where several thematic layers of the same area are produced, processed, and analyzed. Tomlin used raster layers, but the overlay method (see below) can be used more generally. Operations on map layers can be combined into algorithms, and eventually into simulation or optimization models.

Map overlay

The combination of several spatial datasets (points, lines, or polygons) creates a new output vector dataset, visually similar to stacking several maps of the same region. These overlays are similar to mathematical Venn diagram overlays. A union overlay combines the geographic features and attribute tables of both inputs into a single new output. An intersect overlay defines the area where both inputs overlap and retains a set of attribute fields for each. A symmetric difference overlay defines an output area that includes the total area of both inputs except for the overlapping area.

Data extraction is a GIS process similar to vector overlay, though it can be used in either vector or raster data analysis. Rather than combining the properties and features of both datasets, data extraction involves using a "clip" or "mask" to extract the features of one data set that fall within the spatial extent of another dataset.

In raster data analysis, the overlay of datasets is accomplished through a process known as "local operation on multiple rasters" or‖ map algebra," through a function that combines the values of each raster's matrix. This function may weigh some inputs more than others through use of an "index model" that reflects the influence of various factors upon a geographic phenomenon.

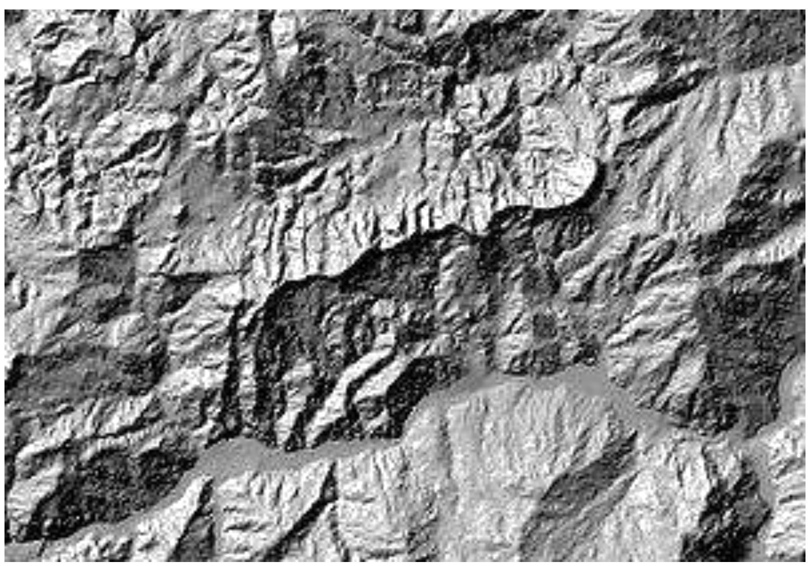
Geostatistics

Main article: Geostatistics

Geostatistics is a branch of statistics that deals with field data, spatial data with a continuous index. It provides methods to model spatial correlation, and predict values at arbitrary locations (interpolation).

When phenomena are measured, the observation methods dictate the accuracy of any subsequent analysis. Due to the nature of the data (e.g. traffic patterns in an urban environment; weather patterns over the Pacific Ocean), a constant or dynamic degree of precision is always lost in the measurement. This loss of precision is determined from the scale and distribution of the data collection.

To determine the statistical relevance of the analysis, an average is determined so that points (gradients) outside of any immediate measurement can be included to determine their predicted behavior. This is due to the limitations of the applied statistic and data collection methods, and interpolation is required to predict the behavior of particles, points, and locations that are not directly measurable.



Hillshade model derived from a Digital Elevation Model of the Valestra area in the northern Apennines (Italy)

Interpolation is the process by which a surface is created, usually a raster dataset, through the input of data collected at a number of sample points. There are several forms of interpolation, each which treats the data differently, depending on the properties of the data set. In comparing interpolation methods, the first consideration should be whether or not the source data will change (exact or approximate). Next is whether the method is subjective, a human interpretation, or objective. Then there is the nature of transitions between points: are they abrupt or gradual. Finally, there is whether a method is global (it uses the entire data set to form the model), or local where an algorithm is repeated for a small section of terrain.

Interpolation is a justified measurement because of a spatial autocorrelation principle that recognizes that data collected at any position will have a great similarity to, or influence of those locations within its immediate vicinity.

Digital elevation models, triangulated irregular networks, edge-finding algorithms, Thiessen polygons, Fourier analysis, (weighted) moving averages, inverse distance weighting, kriging, spline, and trend surface analysis are all mathematical methods to produce interpolative data.

Address geocoding

Main article: Geocoding

Geocoding is interpolating spatial locations (X, Y coordinates) from street addresses or any other spatially referenced data such as ZIP Codes, parcel lots and address locations. A reference theme is required to geocode individual addresses, such as a road centerline file with address ranges. The individual address locations have historically been interpolated, or estimated, by examining address ranges along a road segment. These are usually provided in the form of a table or database. The software will then place a dot approximately where that address belongs along the segment of centerline. For example, an address point of 500 will be at the midpoint of a line segment that starts with address 1 and ends with address 1,000. Geocoding can also be applied against actual parcel data, typically from municipal tax maps. In this case, the result of the geocoding will be an actually positioned space as opposed to an interpolated point. This approach is being increasingly used to provide more precise location information.

Reverse geocoding

Reverse geocoding is the process of returning an estimated street address number as it relates to a given coordinate. For example, a user can click on a road centerline theme (thus providing a coordinate) and have information returned that reflects the estimated house number. This house number is interpolated from a range assigned to that road segment. If the user clicks at the midpoint of a segment that starts with address 1 and ends with 100, the returned value will be

Somewhere near 50. Note that reverse geocoding does not return actual addresses, only estimates of what should be there based on the predetermined range.

Multi-criteria decision analysis

Coupled with GIS, multi-criteria decision analysis methods support decision-makers in analyzing a set of alternative spatial solutions, such as the most likely ecological habitat for restoration, against multiple criteria, such as vegetation cover or roads. MCDA uses decision rules to aggregate the criteria, which allows the alternative solutions to be ranked or prioritized.
GIS MCDA may reduce costs and time involved in identifying potential restoration sites.

Data output and cartography

Cartography is the design and production of maps, or visual representations of spatial data. The vast majority of modern cartography is done with the help of computers, usually using GIS but production of quality cartography is also achieved by importing layers into a design program to refine it. Most GIS software gives the user substantial control over the appearance of the data.
Cartographic work serves two major functions:

First, it produces graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces (AJAX, Java, Flash, etc.).

Second, other database information can be generated for further analysis or use. An example would be a list of all addresses within one mile (1.6 km) of a toxic spill.

Graphic display techniques

Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines or with shaded relief.

Today, graphic display techniques such as shading based on altitude in a GIS can make relationships among map elements visible, heightening one's ability to extract and analyze information. For example, two types of data were combined in a GIS to produce a perspective view of a portion of San Manto, California.

The digital elevation model, consisting of surface elevations recorded on a 30-meter horizontal grid, shows high elevations as white and low elevation as black.

The accompanying Landsat Thematic Mapper image shows a false-color infrared image looking down at the same area in 30-meter pixels, or picture elements, for the same coordinate points, pixel by pixel, as the elevation information.

A GIS was used to register and combine the two images to render the three-dimensional perspective view looking down the San Andreas Fault, using the Thematic Mapper image pixels, but shaded using the elevation of the landforms. The GIS display depends on the viewing point of the observer and time of day of the display, to properly render the shadows created by the sun's rays at that latitude, longitude, and time of day.
An archeochrome is a new way of displaying spatial data. It is a thematic on a 3D map that is applied to a specific building or a part of a building. It is suited to the visual display of heat-loss data.

Spatial ETL

Spatial ETL tools provide the data processing functionality of traditional Extract, Transform, Load (ETL) software, but with a primary focus on the ability to manage spatial data. They provide GIS users with the ability to translate data between different standards and proprietary formats, whilst geometrically transforming the data en route. These tools can come in the form of add-ins to existing wider-purpose software such as Microsoft Excel.

GIS data mining

GIS or spatial data mining is the application of data mining methods to spatial data. Data mining, which is the partially automated search for hidden patterns in large databases, offers great potential benefits for applied GIS-based decision making. Typical applications include environmental monitoring. A characteristic of such applications is that spatial correlation between data measurements require the use of specialized algorithms for more efficient data analysis.

Applications

The implementation of a GIS is often driven by jurisdictional (such as a city), purpose, or application requirements. Generally, a GIS implementation may be custom-designed for an organization. Hence, a GIS deployment developed for an application, jurisdiction, enterprise, or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, jurisdiction, enterprise, or purpose.

GIS provides, for every kind of location based organization, a platform to update geographical data without wasting time to visit the field and update a database manually. GIS when integrated with other powerful enterprise solutions like SAP helps creating powerful decision

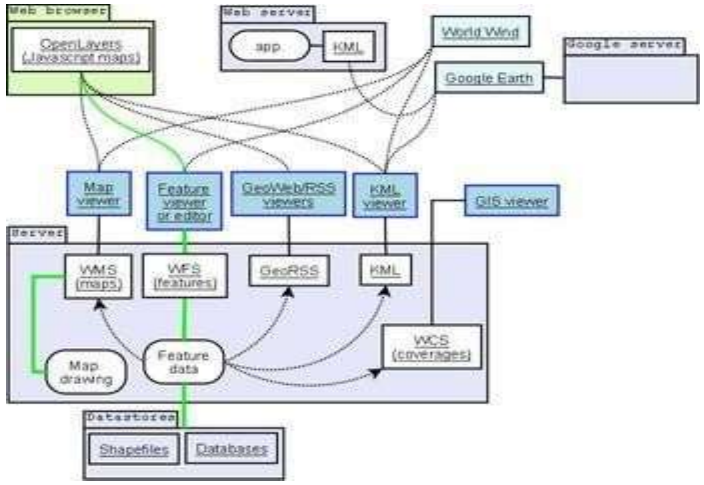
Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS, and usage in the fields of science, government, business, and industry, with applications including real estate, public health, crime mapping, national defense, sustainable development, natural resources, climatology landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services, which allows GPS-enabled mobile devices to display their location in relation to fixed objects (nearest restaurant, gas station, fire hydrant) or mobile objects (friends, children, police car), or to relay their position back to a central server for display or other processing.

Open Geospatial Consortium standards

Open Geospatial Consortium

The Open Geospatial Consortium (OGC) is an international industry consortium of 384 companies, government agencies, universities, and individuals participating in a consensus process to develop publicly available geo processing specifications. Open interfaces and protocols defined by Open GIS Specifications support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT, and empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications. Open Geospatial Consortium protocols include Web Map Service, and web Feature Service.

GIS products are broken down by the OGC into two categories, based on how completely and accurately the software follows the OGC specifications.



OGC standards help GIS tools communicate.

Compliant Products are software products that comply to OGC's Open GIS Specifications. When a product has been tested and certified as compliant through the OGC Testing Program, the product is automatically registered as "compliant" on this site.

Implementing Products are software products that implement Open GIS Specifications but have not yet passed a compliance test. Compliance tests are not available for all specifications. Developers can register their products as implementing draft or approved specifications, though OGC reserves the right to review and verify each entry.

Web mapping

In recent years there has been an explosion of mapping applications on the web such as Google Maps and Bing Maps. These websites give the public access to huge amounts of geographic data.

Some of them, like Google Maps and Open Layers, expose an API that enable users to create custom applications. These toolkits commonly offer street maps, aerial/satellite imagery, geocoding, searches, and routing functionality. Web mapping has also uncovered the potential of crowdsourcing geo data in projects like Open Street Map, which is a collaborative project to create a free editable map of the world.

Adding the dimension of time

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years. As an example, the changes in vegetation vigor through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic represents a rough measure of plant health. Working with two variables over time would then allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation.

GIS technology and the availability of digital data on regional and global scales enable such analyses. The satellite sensor output used to generate a vegetation graphic is produced for example by the Advanced Very High Resolution Radiometer (AVHRR). This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR and more recently the ModerateResolution Imaging Spectro radiometer (MODIS) are only two of many sensor systems used for Earth surface analysis. More sensors will follow, generating ever greater amounts of data.

In addition to the integration of time in environmental studies, GIS is also being explored for its ability to track and model the progress of humans throughout their daily routines. A concrete example of progress in this area is the recent release of time-specific population data by the U.S. Census. In this data set, the populations of cities are shown for daytime and evening hours highlighting the pattern of concentration and dispersion generated by North American Commuting patterns. The manipulation and generation of data required to produce this data would not have been possible without GIS.

Using models to project the data held by a GIS forward in time have enabled planners to test policy decisions using spatial decision support systems.

Semantics

Tools and technologies emerging from the Data Activity are proving useful for data integration problems in information systems. Correspondingly, such technologies have been proposed as a means to facilitate interoperability and data reuse among GIS applications and also to enable new analysis mechanisms.

Ontologies are a key component of this semantic approach as they allow a formal, machinereadable specification of the concepts and relationships in a given domain. This in turn allows a GIS to focus on the intended meaning of data rather than its syntax or structure. For example, reasoning that a land cover type classified as *deciduous needle leaf trees* in one dataset is a specialization or subset of land cover type *forest* in another more roughly classified dataset can help a GIS automatically merge the two datasets under the more general land cover classification. Tentative ontologies have been developed in areas related to GIS applications, for example the hydrology ontology developed by the Ordnance Survey in the United Kingdom and the SWEET ontologies developed by NASA's Jet Propulsion Laboratory. Also, simpler ontologies and semantic metadata standards are being proposed by the W3C Geo Incubator Group [39] to represent geospatial data on the web. Geo SPARQL is a standard developed by the Ordnance Survey, United States Geological Survey, Natural Resources Canada, Australia's Commonwealth Scientific and Industrial Research Organization and others to support ontology creation and reasoning using well-understood OGC literals (GML, WKT), topological relationships (Simple Features, RCC8, DE-9IM), RDF and the SPARQL database query protocols.

Recent research results in this area can be seen in the International Conference on Geospatial Semantics and the Terra Cognita – Directions to the Geospatial Semantic Web workshop at the International Semantic Web Conference.

Society

Main articles: Neogeography and Public Participation GIS

With the popularization of GIS in decision making, scholars have begun to scrutinize the social implications of GIS. It has been argued that the production, distribution, utilization, and representation of geographic information are largely related with the social context. Other related topics include discussion on copyright, privacy, and censorship. A more optimistic social approach to GIS adoption is to use it as a tool for public participation.

1. Introduction

Remote sensing is an art and science of obtaining information about an object or feature without physically coming in contact with that object or feature. Humans apply remote sensing in their dayto-day business, through vision, hearing and sense of smell. The data collected can be of many forms: variations in acoustic wave distributions (e.g., sonar), variations in force distributions (e.g., gravity meter), variations in electromagnetic energy distributions (e.g., eye) etc. These remotely collected data through various sensors may be analysed to obtain information about the objects or features under investigation. In this course we will deal with remote sensing through electromagnetic energy sensors only.

Thus, remote sensing is the process of inferring surface parameters from measurements of the electromagnetic radiation (EMR) from the Earth‘s surface. This EMR can either be reflected or emitted from the Earth‘s surface. In other words, remote sensing is detecting and measuring electromagnetic (EM) energy emanating or reflected from distant objects made of various materials, so that we can identify and categorize these objects by class or type, substance and spatial distribution [American Society of Photogrammetry, 1975].

Remote sensing provides a means of observing large areas at finer spatial and temporal frequencies. It finds extensive applications in civil engineering including watershed studies, hydrological states and fluxes simulation, hydrological modelling, disaster management services such as flood and drought warning and monitoring, damage assessment in case of natural calamities, environmental monitoring, urban planning etc.

Basic concepts of remote sensing are introduced below.

2. Electromagnetic Energy

Electromagnetic energy or electromagnetic radiation (EMR) is the energy propagated in the form of an advancing interaction between electric and magnetic fields (Sabbins, 1978). It travels with the velocity of light. Visible light, ultraviolet rays, infrared rays, heat, radio waves, X-rays all are different forms of electro-magnetic energy.

Electro-magnetic energy (E) can be expressed either in terms of frequency (f) or wave length (λ) of radiation as

$E = h\ c\ f$ or $h\ c\ /\ \lambda$ (1) where h is Planck's constant (6.626×10^{-34} Joules-sec), c is a constant that expresses the celerity or speed of light (3×10^{8} m/sec), f is frequency expressed in Hertz and λ is the wavelength expressed in micro meters ($1\mu m = 10^{-6}$ m).

As can be observed from equation (1), shorter wavelengths have higher energy content and longer wavelengths have lower energy content.

Distribution of the continuum of energy can be plotted as a function of wavelength (or frequency) and is known as the EMR spectrum All matters reflect, emit or radiate a range of electromagnetic energy, depending upon the material characteristics. In remote sensing, it is the measurement of electromagnetic radiation reflected or emitted from an object, is the used to identify the target and to infer its properties.

3. Principles of Remote Sensing

Different objects reflect or emit different amounts of energy in different bands of the electromagnetic spectrum. The amount of energy reflected or emitted depends on the properties of both the material and the incident energy (angle of incidence, intensity and wavelength). Detection and discrimination of objects or surface features is done through the uniqueness of the reflected or emitted electromagnetic radiation from the object.

A device to detect this reflected or emitted electro-magnetic radiation from an object is called a ―sensor‖ (e.g., cameras and scanners). A vehicle used to carry the sensor is called a ―platform‖ (e.g., aircrafts and satellites).

Main stages in remote sensing are the following.

A. Emission of electromagnetic radiation

 The Sun or an EMR source located on the platform

B. Transmission of energy from the source to the object

 Absorption and scattering of the EMR while transmission

C. Interaction of EMR with the object and subsequent reflection and emission

D. Transmission of energy from the object to the sensor

E. Recording of energy by the sensor

 Photographic or non-photographic sensors

F. Transmission of the recorded information to the ground station

G. Processing of the data into digital or hard copy image

H. Analysis of data

4. Passive/ Active Remote Sensing

Depending on the source of electromagnetic energy, remote sensing can be classified as passive or active remote sensing.

In the case of passive remote sensing, source of energy is that naturally available such as the Sun. Most of the remote sensing systems work in passive mode using solar energy as the source of EMR. Solar energy reflected by the targets at specific wavelength bands are recorded using sensors on board air-borne or space borne platforms. In order to ensure ample signal strength received at the sensor, wavelength / energy bands capable of traversing through the atmosphere, without significant loss through atmospheric interactions, are generally used in remote sensing

Any object which is at a temperature above 0_o K (Kelvin) emits some radiation, which is approximately proportional to the fourth power of the temperature of the object. Thus the Earth also emits some radiation since its ambient temperature is about 300_o K. Passive sensors can also be used to measure the Earth‘s radiance but they are not very popular as the energy content is very low. In the case of active remote sensing, energy is generated and sent from the remote sensing platform towards the targets. The energy reflected back from the targets are recorded using sensors on board the remote sensing platform. Most of the microwave remote sensing is done through active remote sensing.

As a simple analogy, passive remote sensing is similar to taking a picture with an ordinary camera whereas active remote sensing is analogous to taking a picture with camera having built-in flash

5. Remote Sensing Platforms

Remote sensing platforms can be classified as follows, based on the elevation from the Earth‘s surface at which these platforms are placed.

- Ground level remote sensing, Ground level remote sensors are very close to the ground. They are basically used to develop and calibrate sensors for different features on the Earth‘s surface. Aerial remote sensing - Low altitude aerial remote sensing - High altitude aerial remote sensing
- Space borne remote sensing - Space shuttles, Polar orbiting satellites, Geo-stationary satellites

From each of these platforms, remote sensing can be done either in passive or active mode.

6. Airborne and Space-borne Remote Sensing

In airborne remote sensing, downward or sideward looking sensors mounted on aircrafts are used to obtain images of the earth's surface. Very high spatial resolution images (20 cm or less) can be obtained through this. However, it is not suitable to map a large area. Less coverage area and high cost per unit area of ground coverage are the major disadvantages of airborne remote sensing. While airborne remote sensing missions are mainly one-time operations, space-borne missions offer continuous monitoring of the earth features. LiDAR, analog aerial photography, videography, thermal imagery and digital photography are commonly used in airborne remote sensing.

In space-borne remote sensing, sensors mounted on space shuttles or satellites orbiting the Earth are used. There are several remote sensing satellites (Geostationary and Polar orbiting) providing imagery for research and operational applications. Geosynchronous Satellites are used for communication and meteorological purposes, polar orbiting or sun-synchronous satellites are essentially used for remote sensing. The main advantages of space-borne remote sensing are large area coverage, less cost per unit area of coverage, continuous or frequent coverage of an area of interest, automatic/ semiautomatic computerized processing and analysis. However, when compared to aerial photography, satellite imagery has a lower resolution.

Landsat satellites, Indian remote sensing (IRS) satellites, IKONOS, SPOT satellites, AQUA and TERRA of NASA and INSAT satellite series are a few examples.

7. Ideal Remote Sensing System

The basic components of an ideal remote sensing system include:

i. A Uniform Energy Source which provides energy over all wavelengths, at a constant, known, high level of output ii. A Non-interfering Atmosphere which will not modify either the energy transmitted from the source or emitted (or reflected) from the object in any manner.

iii. A Series of Unique Energy/Matter Interactions at the Earth's Surface which generate reflected and/or emitted signals that are selective with respect to wavelength and also unique to each object or earth surface feature type.

iv. A Super Sensor which is highly sensitive to all wavelengths. A super sensor would be simple, reliable, accurate, economical, and requires no power or space. This sensor yields data on the absolute brightness (or radiance) from a scene as a function of wavelength.

v. A Real-Time Data Handling System which generates the instance radiance versus wavelength response and processes into an interpretable format in real time. The data derived is unique to a particular terrain and hence provide insight into its physical-chemical-biological state.

vi. Multiple Data Users having knowledge in their respective disciplines and also in remote sensing data acquisition and analysis techniques. The information collected will be available to them faster and at less expense. This information will aid the users in various decision making processes and also further in implementing these decisions

8. Characteristics of Real Remote Sensing Systems

Real remote sensing systems employed in general operation and utility have many shortcomings when compared with an ideal system explained above.

iii. Energy Source: The energy sources for real systems are usually non-uniform over various wavelengths and also vary with time and space. This has major effect on the passive remote sensing systems. The spectral distribution of reflected sunlight varies both temporally and spatially. Earth surface materials also emit energy to varying degrees of efficiency. A real remote sensing system needs calibration for source characteristics.

iv. The Atmosphere: The atmosphere modifies the spectral distribution and strength of the energy received or emitted (Fig. 8). The effect of atmospheric interaction varies with the wavelength associated, sensor used and the sensing application. Calibration is required to eliminate or compensate these atmospheric effects.

iii. The Energy/Matter Interactions at the Earth's Surface: Remote sensing is based on the principle that each and every material reflects or emits energy in a unique, known way. However, spectral signatures may be similar for different material types. This makes differentiation difficult. Also, the knowledge of most of the energy/matter interactions for earth surface features is either at elementary level or even completely unknown.

iv. The Sensor: Real sensors have fixed limits of spectral sensitivity i.e., they are not sensitive to all wavelengths. Also, they have limited spatial resolution (efficiency in recording spatial details). Selection of a sensor requires a trade-off between spatial resolution and spectral sensitivity. For example, while photographic systems have very good spatial resolution and poor spectral sensitivity, non-photographic systems have poor spatial resolution.

v. The Data Handling System: Human intervention is necessary for processing sensor data; even though machines are also included in data handling. This makes the idea of real time data handling almost impossible. The amount of data generated by the sensors far exceeds the data handling capacity.

vi. The Multiple Data Users: The success of any remote sensing mission lies on the user who ultimately transforms the data into information. This is possible only if the user understands the problem thoroughly and has a wide knowledge in the data generation. The user should know how to interpret the data generated and should know how best to use them.

9. Advantages and Disadvantages of Remote Sensing

Advantages of remote sensing are: a)
Provides data of large areas
b) Provides data of very remote and inaccessible regions

c) Able to obtain imagery of any area over a continuous period of time through which the any anthropogenic or natural changes in the landscape can be analyzed

d) Relatively inexpensive when compared to employing a team of surveyors

e) Easy and rapid collection of data

f) Rapid production of maps for interpretation

Disadvantages of remote sensing are:

a) The interpretation of imagery requires a certain skill level

b) Needs cross verification with ground (field) survey data

c) Data from multiple sources may create confusion

d) Objects can be misclassified or confused

e) Distortions may occur in an image due to the relative motion of sensor and source

UNIT-5 VECTOR DATA

Data acquisition techniques

The basis for multispectral collection and analysis is that of examined areas or objects that reflect or emit radiation that stand out from surrounding areas. For a summary of major remote sensing satellite systems see the overview table.

Applications of remote sensing data

Conventional radar is mostly associated with aerial traffic control, early warning, and certain large scale meteorological data. Doppler radar is used by local law enforcements‘ monitoring of speed limits and in enhanced meteorological collection such as wind speed and direction within weather systems in addition to precipitation location and intensity. Other types of active collection includes plasmas in the ionosphere. Interferometric synthetic aperture radar is used to produce precise digital elevation models of large scale terrain (See RADARSAT, TerraSAR-X, Magellan).

Laser and radar altimeters on satellites have provided a wide range of data. By measuring the bulges of water caused by gravity, they map features on the seafloor to a resolution of a mile or so. By measuring the height and wavelength of ocean waves, the altimeters measure wind speeds and direction, and surface ocean currents and directions.

Ultrasound (acoustic) and radar tide gauges measure sea level, tides and wave direction in coastal and offshore tide gauges.

Light detection and ranging (LIDAR) is well known in examples of weapon ranging, laser illuminated homing of projectiles. LIDAR is used to detect and measure the concentration of various chemicals in the atmosphere, while airborne LIDAR can be used to measure heights of objects and features on the ground more accurately than with radar technology. Vegetation remote sensing is a principal application of LIDAR.

Radiometers and photometers are the most common instrument in use, collecting reflected and emitted radiation in a wide range of frequencies. The most common are visible and infrared sensors, followed by microwave, gamma ray and rarely, ultraviolet. They may also be used to detect the emission spectra of various chemicals, providing data on chemical concentrations in the atmosphere.

Stereographic pairs of aerial photographs have often been used to make topographic maps by imagery and terrain analysts in traffic ability and highway departments for potential routes, in addition to modeling terrestrial habitat features.

Simultaneous multi-spectral platforms such as Land sat have been in use since the 70‘s. These thematic mappers take images in multiple wavelengths of electro-magnetic radiation (multispectral) and are usually found on Earth observation satellites, including (for example) the Land sat program or the IKONOS satellite. Maps of land cover and land use from thematic mapping can be used to prospect for minerals, detect or monitor land usage, deforestation, and examine the health of indigenous plants and crops, including entire farming regions or forests. Landsat images are used by regulatory agencies such as KYDOW to indicate water quality parameters including Secchi depth, chlorophyll a density and total phosphorus content. Weather satellites are used in meteorology and climatology.

Hyper spectral imaging produces an image where each pixel has full spectral information with imaging narrow spectral bands over a contiguous spectral range. Hyper spectral imagers are used in various applications including mineralogy, biology, defense, and environmental measurements.

Within the scope of the combat against desertification, remote sensing allows to followup and monitor risk areas in the long term, to determine desertification factors, to support decision-makers in defining relevant measures of environmental management, and to assess their impacts.

Geodetic

Overhead geodetic collection was first used in aerial submarine detection and gravitational data used in military maps. This data revealed minute perturbations in the Earth's gravitational field (geodesy) that may be used to determine changes in the mass distribution of the Earth, which in turn may be used for geological studies.

Acoustic and near-acoustic

Sonar: *passive sonar*, listening for the sound made by another object (a vessel, a whale etc.); *active sonar*, emitting pulses of sounds and listening for echoes, used for detecting, ranging and measurements of underwater objects and terrain.

Seismograms taken at different locations can locate and measure earthquakes (after they occur) by comparing the relative intensity and precise timings.

Ultrasound: Ultrasound sensors, that emit high frequency pulses and listening for echoes, used for detecting water waves and water level, as in tide gauges or for towing tanks.

To coordinate a series of large-scale observations, most sensing systems depend on the following: platform location and the orientation of the sensor. High-end instruments now often use positional information from satellite navigation systems. The rotation and orientation is often provided within a degree or two with electronic compasses. Compasses can measure not just azimuth (i. e. degrees to magnetic north), but also altitude (degrees above the horizon), since the magnetic field curves into the Earth at different angles at different latitudes. More exact orientations require gyroscopic-aided orientation, periodically realigned by different methods including navigation from stars or known benchmarks.

Data processing

Generally speaking, remote sensing works on the principle of the *inverse problem*. While the object or phenomenon of interest (the state) may not be directly measured, there exists some other variable that can be detected and measured (the observation) which may be related to the ject of interest through a calculation. The common analogy given to describe this is trying to determine the type of animal from its footprints. For example, while it is impossible to directly measure temperatures in the upper atmosphere, it is possible to measure the spectral emissions from a known chemical species (such as carbon dioxide) in that region. The frequency of the emissions may then be related via thermodynamics to the temperature in that region.
The quality of remote sensing data consists of its spatial, spectral, radiometric and temporal resolutions.

Spatial resolution

The size of a pixel that is recorded in a raster image – typically pixels may correspond to square areas ranging inside length from 1 to 1,000 meters (3.3 to 3,280.8 ft).

Spectral resolution

The wavelength width of the different frequency bands recorded – usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of seven bands, including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 µm. The Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 µm, with a spectral resolution of 0.10 to 0.11 µm per band.

Radiometric resolution

The number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of color, in each band. It also depends on the instrument noise.

Temporal resolution

The frequency of flyovers by the satellite or plane, and is only relevant in time-series studies or those requiring an averaged or mosaic image as in deforesting monitoring. This was first used by the intelligence community where repeated coverage revealed changes in infrastructure, the deployment of units or the modification/introduction of equipment. Cloud cover over a given area or object makes it necessary to repeat the collection of said location.

In order to create sensor-based maps, most remote sensing systems expect to extrapolate sensor data in relation to a reference point including distances between known points on the ground. This depends on the type of sensor used. For example, in conventional photographs, distances are accurate in the center of the image, with the distortion of measurements increasing the farther you get from the center. Another factor is that of the platen against which the film is pressed can cause severe errors when photographs are used to measure ground distances. The step in which this problem is resolved is called geo referencing, and involves computer-aided matching of points in the image (typically 30 or more points per image) which is extrapolated with the use of an established benchmark, "warping" the image to produce accurate spatial data. As of the early 1990s, most satellite images are sold fully geo referenced.

In addition, images may need to be radio metrically and atmospherically corrected.
Radiometric correction

Allows to avoid radiometric errors and distortions. The illumination of objects on the Earth surface is uneven because of different properties of the relief. This factor is taken into account in the method of radiometric distortion correction. Radiometric correction gives a scale to the pixel values, e. g. the monochromatic scale of 0 to 255 will be converted to actual radiance values.

Topographic correction (also called terrain correction)

In rugged mountains, as a result of terrain, the effective illumination of pixels varies considerably. In a remote sensing image, the pixel on the shady slope receives weak illumination and has a low radiance value, in contrast, the pixel on the sunny slope receives strong illumination and has a high radiance value. For the same object, the pixel radiance value on the shady slope will be different from that on the sunny slope. Additionally, different objects may have similar radiance values. These ambiguities seriously affected remote sensing image information extraction accuracy in mountainous areas. It became the main obstacle to further application of remote sensing images. The purpose of topographic correction is to eliminate this effect, recovering the true reflectivity or radiance of objects in horizontal conditions. It is the premise of quantitative remote sensing application.

Atmospheric correction

Elimination of atmospheric haze by rescaling each frequency band so that its minimum value (usually realized in water bodies) corresponds to a pixel value of 0. The digitizing of data also makes it possible to manipulate the data by changing gray-scale values.

Interpretation is the critical process of making sense of the data. The first application was that of aerial photographic collection which used the following process; spatial measurement through the use of a light table in both conventional single or stereographic coverage, added skills such as the use of photogrammetry, the use of photo mosaics, repeat coverage, Making use of objects‘ known dimensions in order to detect modifications. Image Analysis is the recently developed automated computer-aided application which is in increasing use.

Object-Based Image Analysis (OBIA) is a sub-discipline of GI Science devoted to partitioning remote sensing (RS) imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale.

Old data from remote sensing is often valuable because it may provide the only long-term data for a large extent of geography. At the same time, the data is often complex to interpret, and bulky to store. Modern systems tend to store the data digitally, often with lossless compression. The difficulty with this approach is that the data is fragile, the format may be archaic, and the data may be easy to falsify. One of the best systems for archiving data series is as computergenerated machine-readable ultra-fiche, usually in type fonts such as OCR-B, or as digitized half-tone images. Ultra fiches survive well in standard libraries, with lifetimes of several centuries. They can be created, copied, filed and retrieved by automated systems. They are about as compact as archival magnetic media, and yet can be read by human beings with minimal, standardized equipment.

Data processing levels

To facilitate the discussion of data processing in practice, several processing ―levels‖ were first defined in 1986 by NASA as part of its Earth Observing System and steadily adopted since then, both internally at NASA (e. g.,) and elsewhere (e. g.,; these definitions are:

Remote sensing software

Main article: Remote sensing application

Remote sensing data are processed and analyzed with computer software, known as a remote sensing application. A large number of proprietary and open source applications exist to process remote sensing data. Remote sensing software packages include:

Scattering

Atmospheric scattering is the process by which small particles in the atmosphere diffuse a portion of the incident radiation in all directions. There is no energy transformation while scattering. But the spatial distribution of the energy is altered during scattering.

There are three different types of scattering:

1. Rayleigh scattering
2. Mie scattering

3. Non-selective scattering

Rayleigh scattering

Rayleigh scattering mainly consists of scattering caused by atmospheric molecules and other tiny particles. This occurs when the particles causing the scattering are much smaller in diameter (less than one tenth) than the wavelengths of radiation interacting with them.
Smaller particles present in the atmosphere scatter the shorter wavelengths more compared to the longer wavelengths.
The scattering effect or the intensity of the scattered light is inversely proportional to the fourth power of wavelength for Rayleigh scattering. Hence, the shorter wavelengths are scattered more than longer wavelengths. Rayleigh scattering is also known as selective scattering or molecular scattering.
Molecules of Oxygen and Nitrogen (which are dominant in the atmosphere) cause this type of scattering of the visible part of the electromagnetic radiation. Within the visible range, smaller wavelength blue light is scattered more compared to the green or red. A "blue" sky is thus a manifestation of Rayleigh scatter. The blue light is scattered around 4 times and UV light is scattered about 16 times as much as red light. This consequently results in a blue sky. However, at sunrise and sunset, the sun's rays have to travel a longer path, causing complete scattering (and absorption) of shorter wavelength radiations. As a result, only the longer wavelength portions (orange and red) which are less scattered will be visible.
The haze in imagery and the bluish-grey cast in a color image when taken from high altitude are mainly due to Rayleigh scatter.

Mie Scattering

Another type of scattering is Mie scattering, which occurs when the wavelengths of the energy is almost equal to the diameter of the atmospheric particles. In this type of scattering longer wavelengths also get scattered compared to Rayleigh scatter.
In Mie scattering, intensity of the scattered light varies approximately as the inverse of the wavelength. Mie scattering is usually caused by the aerosol particles such as dust, smoke and

pollen. Gas molecules in the atmosphere are too small to cause Mie scattering of the radiation commonly used for remote sensing.

Non-selective scattering

A third type of scattering is nonselective scatter, which occurs when the diameters of the atmospheric particles are much larger (approximately 10 times) than the wavelengths being sensed. Particles such as pollen, cloud droplets, ice crystals and raindrops can cause nonselective scattering of the visible light.

For visible light (of wavelength 0.4-0.7µm), non-selective scattering is generally caused by water droplets which is having diameter commonly in the range of 5 to 100 µm. This scattering is nonselective with respect to wavelength since all visible and IR wavelengths get scattered equally giving white or even grey colour to the clouds.

Absorption

Absorption is the process in which incident energy is retained by particles in the atmosphere at a given wavelength. Unlike scattering, atmospheric absorption causes an effective loss of energy to atmospheric constituents.

The absorbing medium will not only absorb a portion of the total energy, but will also reflect, refract or scatter the energy. The absorbed energy may also be transmitted back to the atmosphere. The most efficient absorbers of solar radiation are water vapour, carbon dioxide, and ozone. Gaseous components of the atmosphere are selective absorbers of the electromagnetic radiation, i.e., these gases absorb electromagnetic energy in specific wavelength bands. Arrangement of the gaseous molecules and their energy levels determine the wavelengths that are absorbed. Since the atmosphere contains many different gases and particles, it absorbs and transmits many different wavelengths of electromagnetic radiation. Even though all the wavelengths from the Sun reach the top of the atmosphere, due to the atmospheric absorption, only limited wavelengths can pass through the atmosphere. The ranges of wavelength that are partially or wholly transmitted through the atmosphere are known as "atmospheric windows." Remote sensing data acquisition is limited through these atmospheric windows. The atmospheric windows and the absorption characteristics

It can be observed that electromagnetic radiation at different wavelengths is completely absorbed, partially absorbed or totally transmitted through the atmosphere. Nitrogen and other gaseous components in the atmosphere cause absorption of wavelengths shorter than 0.1 μm. Wavelengths shorter than 0.3μm (X-rays, Gamma rays and part of ultraviolet rays) are mostly absorbed in the atmosphere. This is caused by the ozone (O3) present in the upper atmosphere.
Oxygen in the atmosphere causes absorption centered at 6.3μm.In the visible part of the spectrum, little absorption occurs.

Infrared (IR) radiation is mainly absorbed due to the rotational and vibrational transitions of the molecules. The main atmospheric constituents responsible for infrared absorption are water vapour (H2O) and carbon dioxide (CO2) molecules. Most of the radiation in the far infrared region is also absorbed by the atmosphere. However, absorption is almost nil in the microwave region.
The most common sources of energy are the incident solar energy and the radiation from the Earth. The wavelength at which the Sun's energy reaches its maximum coincides with the visible band range. The energy radiated from the Earth is sensed through the windows at 3 to 5μm and 8 to 14μm using devices like thermal scanners.
Radar and Passive microwave systems operate through a window in the 1 mm to 1 m region.

BASIC CONCEPTS OF REMOTE SENSING

Introduction

Remote sensing is an art and science of obtaining information about an object or feature without physically coming in contact with that object or feature. Humans apply remote sensing in their dayto-day business, through vision, hearing and sense of smell. The data collected can be of many forms: variations in acoustic wave distributions (e.g., sonar), variations in force distributions (e.g., gravity meter), variations in electromagnetic energy distributions (e.g., eye) etc. These remotely collected data through various sensors may be analysed to obtain information about the objects or features under investigation. In this course we will deal with remote sensing through electromagnetic energy sensors only.

Thus, remote sensing is the process of inferring surface parameters from measurements of the electromagnetic radiation (EMR) from the Earth's surface. This EMR can either be reflected or emitted from the Earth's surface. In other words, remote sensing is detecting and measuring electromagnetic (EM) energy emanating or reflected from distant objects made of various materials, so that we can identify and categorize these objects by class or type, substance and spatial distribution [American Society of Photogrammetry, 1975].

Remote sensing provides a means of observing large areas at finer spatial and temporal frequencies. It finds extensive applications in civil engineering including watershed studies, hydrological states and fluxes simulation, hydrological modelling, disaster management services such as flood and drought warning and monitoring, damage assessment in case of natural calamities, environmental monitoring, urban planning etc.

Basic concepts of remote sensing are introduced below.

Electromagnetic Energy

Electromagnetic energy or electromagnetic radiation (EMR) is the energy propagated in the form of an advancing interaction between electric and magnetic fields (Sabbins, 1978). It travels with the velocity of light. Visible light, ultraviolet rays, infrared rays, heat, radio waves, X-rays all are different forms of electro-magnetic energy.

Electro-magnetic energy (E) can be expressed either in terms of frequency (f) or wave length (λ) of radiation as

$$E = h\,c\,f \text{ or } h\,c / \lambda$$

where h is Planck's constant (6.626×10^{-34} Joules-sec), c is a constant that expresses the celerity or speed of light (3×10^{8} m/sec), f is frequency expressed in Hertz and λ is the wavelength expressed in micro meters ($1\mu m = 10^{-6}$ m).

As can be observed from equation (1), shorter wavelengths have higher energy content and longer wavelengths have lower energy content.

Distribution of the continuum of energy can be plotted as a function of wavelength (or frequency) and is known as the EMR spectrum All matters reflect, emit or radiate a range of electromagnetic energy, depending upon the material characteristics. In remote sensing, it is the measurement of electromagnetic radiation reflected or emitted from an object, is the used to identify the target and to infer its properties.

Principles of Remote Sensing

Different objects reflect or emit different amounts of energy in different bands of the electromagnetic spectrum. The amount of energy reflected or emitted depends on the properties of both the material and the incident energy (angle of incidence, intensity and wavelength). Detection and discrimination of objects or surface features is done through the uniqueness of the reflected or emitted electromagnetic radiation from the object.

A device to detect this reflected or emitted electro-magnetic radiation from an object is called a ―sensor‖ (e.g., cameras and scanners). A vehicle used to carry the sensor is called a ―platform‖ (e.g., aircrafts and satellites).

Main stages in remote sensing are the following.

A. Emission of electromagnetic radiation

   1. The Sun or an EMR source located on the platform

B. Transmission of energy from the source to the object

   2. Absorption and scattering of the EMR while transmission

C. Interaction of EMR with the object and subsequent reflection and emission

   3. D. Transmission of energy from the object to the sensor

E. Recording of energy by the sensor

   4. Photographic or non-photographic sensors

F. Transmission of the recorded information to the ground station

G. Processing of the data into digital or hard copy image

H. Analysis of data

Passive/ Active Remote Sensing

Depending on the source of electromagnetic energy, remote sensing can be classified as passive or active remote sensing.

In the case of passive remote sensing, source of energy is that naturally available such as the Sun. Most of the remote sensing systems work in passive mode using solar energy as the source of EMR. Solar energy reflected by the targets at specific wavelength bands are recorded using sensors on board air-borne or space borne platforms. In order to ensure ample signal strength received at the sensor, wavelength / energy bands capable of traversing through the atmosphere, without significant loss through atmospheric interactions, are generally used in remote sensing

Any object which is at a temperature above 0_o K (Kelvin) emits some radiation, which is approximately proportional to the fourth power of the temperature of the object. Thus the Earth also emits some radiation since its ambient temperature is about 300_o K. Passive sensors can also be used to measure the Earth‘s radiance but they are not very popular as the energy content is very low.

In the case of active remote sensing, energy is generated and sent from the remote sensing platform towards the targets. The energy reflected back from the targets are recorded using sensors on board the remote sensing platform. Most of the microwave remote sensing is done through active remote sensing.

As a simple analogy, passive remote sensing is similar to taking a picture with an ordinary camera whereas active remote sensing is analogous to taking a picture with camera having built-in flash

Remote Sensing Platforms

Remote sensing platforms can be classified as follows, based on the elevation from the Earth‘s surface at which these platforms are placed.

1. Ground level remote sensing, Ground level remote sensors are very close to the ground. They are basically used to develop and calibrate sensors for different features on the Earth‘s surface.
2. Aerial remote sensing - Low altitude aerial remote sensing - High altitude aerial remote sensing.
3. Space borne remote sensing - Space shuttles, Polar orbiting satellites, Geo-stationary satellites

From each of these platforms, remote sensing can be done either in passive or active mode.