# Chapter – I

Aerial Photographs
Basic terms & Definitions
Scales
Relief Displacements
Flight Planning
Stereoscopy
Characteristics of Photographic Images
Aerial Photo Interpretation

**A photograph is usually looked at - seldom looked into.**
[Ansel Adams]

## Aerial Photographs

Aerial photography is the taking of photographs of the ground from an elevated position. The term usually refers to images in which the camera is not supported by a ground-based structure.

Platforms for aerial photography include fixed-wing aircraft, helicopters, balloons, blimps and dirigibles, rockets, kites, poles and parachutes. Aerial photography is different from Air-to-Air Photography, when aircraft serve both as a photo platform and subject.

Cameras for aerial photography are hand held or mounted, and photographs are taken by a photographer, triggered remotely or triggered automatically.

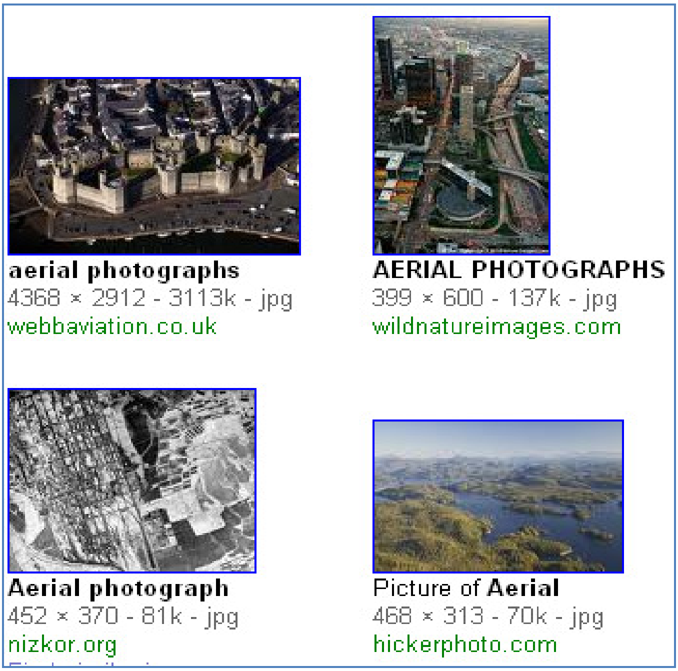



Figure 1: Google Image Results for 'Aerial Photographs'

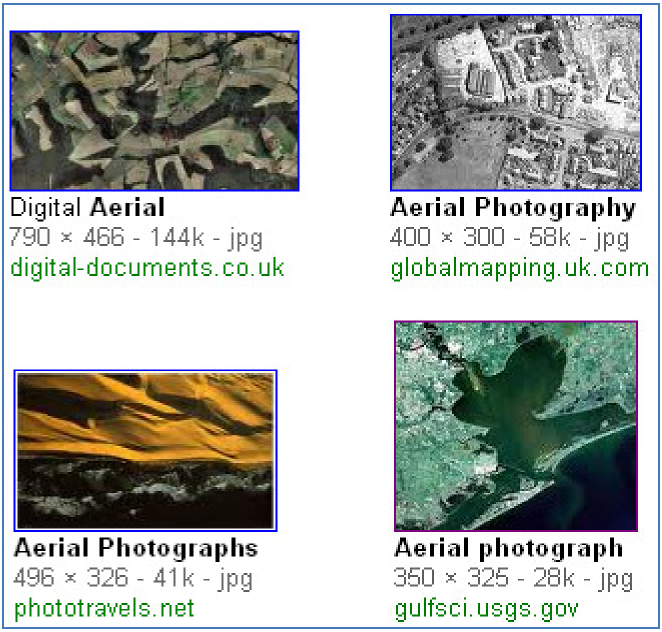



Figure 2: Google Image Results for 'Aerial Photographs'

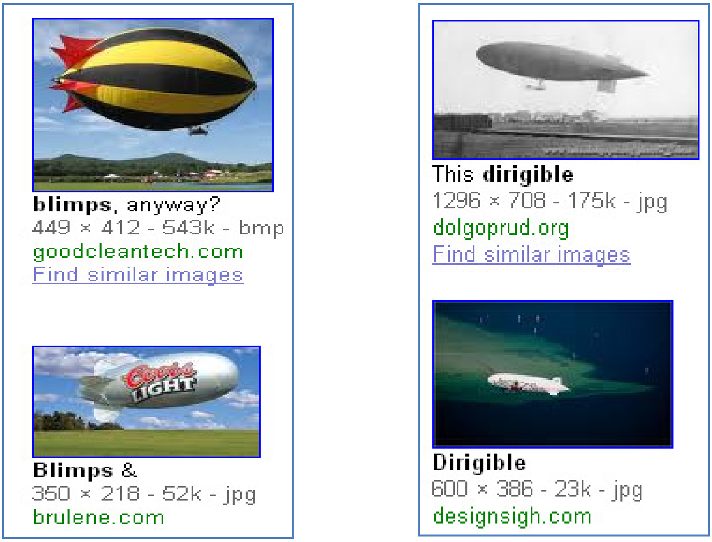



Figure 3: Google Image Results for 'Blimps' and 'Drigibles'

## Classification of Photographs

The photographs are usually classified as **terrestrial** and **aerial**. Aerial photos are further classified as **Vertical (True Vertical, Tilted)** and **Oblique (High Oblique and Low Oblique.)**

Vertical aerial photograph is a photo taken from an aerial platform (either moving or stationary) wherein the camera axis at the moment of exposure is truly vertical. Vertical airphotos with less than 3* tilt are considered vertical (for most photo interpretation purposes); while those with more than 3* tilt are considered oblique.

In a high angle oblique, the apparent horizon is shown; while in a low angle oblique the apparent horizon is not shown.

*Often because of atmosphere haze or other types of obscurations the true horizon of a photo is not seen. However one often can see a horizon in an oblique air photo. This is called the apparent horizon.*

## Advantages of Vertical Air Photos:

The basic advantages of vertical air photos are:

1. The scale is constant.
2. Measurements of directions are easier than on oblique photograph.
3. Directions can be measured more accurately.
4. Within limits a vertical aerial photograph can be used as a map.
5. Vertical aerial photographs are often easier to interpret than oblique and are better for stereo.

## Advantages of Oblique Aerial Photographs

The advantages of an oblique aerial photograph include:

1. Given a constant altitude and camera one can cover a much larger area on a single photo.
2. The view of some objects is more familiar to the interpreter.
3. Some objects not visible on vertical photos may be seen on oblique.

## Basic Terms and Definitions

### Film:

Most air photo missions are flown using black and white film, however colour, infrared, and false-colour infrared film are sometimes used for special projects.

### Focal Length:

This is the distance from the middle of the camera lens to the focal plane (i.e. the film).

As focal length increases, image distortion decreases. The focal length is specifically measured when the camera is calibrated.

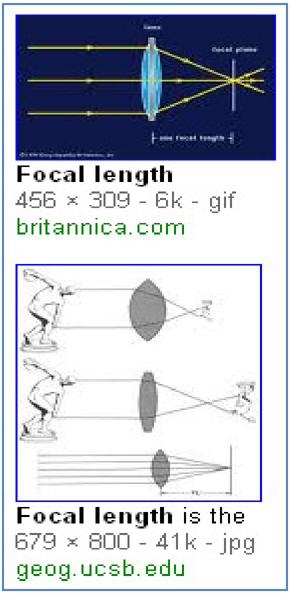



Figure 4: Google Image Results for 'Focal Length'

### Principal Point:

The principal point is the point where the perpendicular projected through the center of the lens intersects the photo image.

**Nadir:**
The Nadir is the point vertically beneath the camera center at the time of exposure.

**Isocenter:**
The point on the photo that falls on a line half- way between the principal point and the Nadir point.

**Fiducial marks:**
Small registration marks exposed on the edges of a photograph. The distances between fiducial marks are precisely measured when a camera is calibrated, and this information is used by cartographers when compiling a topographic map.

**Overlap:** This is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage. The photo survey is usually planned to acquire 60 per cent forward overlap (between photos along the same flight line) and 30 per cent lateral overlap (between photos on adjacent flight lines).

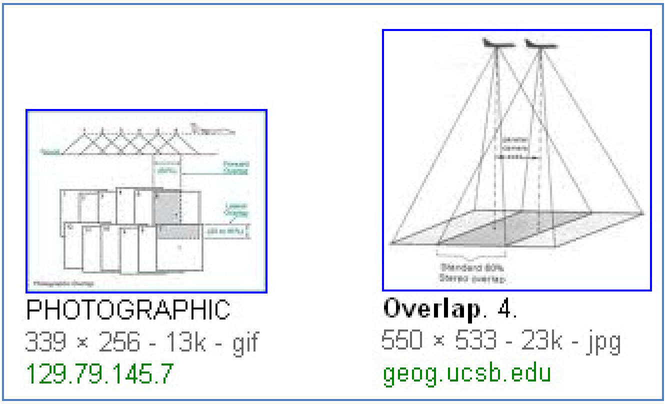



**Figure 5: Google Image Results for 'aerial overlap'**

## Geodetic Datum:

In surveying and geodesy, a geodetic datum (plural datums, not data) is a set of reference points on the Earth's surface against which position measurements are made. Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system. Vertical datums measure elevations or depths.

## Photogrametry:

Photogrametry is the art or science of making measurements from aerial imagery. The geometry of an air photo is fixed by the altitude, focal length and film format.

These three variables, along with measurements of the three dimensional position of the plane relative to the ground are used to remove spatial distortions caused by topography (ortho-rectification). By removing the geometric distortions and the topographic distortions aerial photographs can be used for very precise measurements.

## Stereoscopic Coverage:

The three-dimensional view which results when two overlapping photos (called a stereo pair), are viewed using a stereoscope. Each photograph of the stereo pair provides a slightly different view of the same area, which the brain combines and interprets as a 3-D view.

## Parallax:

This refers to the apparent change in relative positions of stationery objects caused by a change in viewing position.

### Roll and Photo Numbers:

Each aerial photo is assigned a unique index number according to the photo's roll and frame. For example, photo A23882-36 is the 36th annotated photo on roll A23882. This identifying number helps to find the photo in the archive, along with metadata information such as the date it was taken, the plane's altitude (above sea level), the focal length of the camera, and the weather conditions.

### Flight Lines and Index Maps:

At the end of a photo mission, the aerial survey contractor plots the location of the first, last, and every fifth photo centre, along with its roll and frame number, on a National Topographic System (NTS) map. Photo centers are represented by small circles, and straight lines are drawn connecting the circles to show photos on the same flight line.

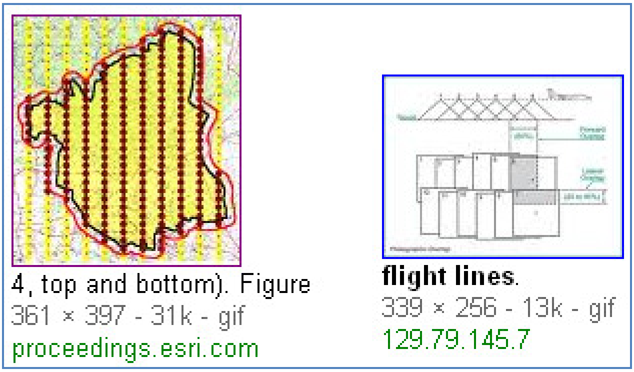



**Figure 6: Google Image Results for 'aerial flight lines'**

This graphical representation is called an air photo index map, and it allows you to relate the photos to their geographical location. Small-scale photographs are indexed on 1/250 000 scale NTS map sheets, and larger-scale photographs are indexed on 1/50 000 scale NTS maps.

## Orthophotos:

As opposed to a bird's-eye view, photographs may be directed vertically.
These are often used to create orthophotos – photographs which have been "corrected" so as to be usable as a map. In other words, an orthophoto is a simulation of a photograph taken from an infinite distance, looking straight down from nadir.
Perspective must obviously be removed, but variations in terrain should also be corrected for.
Multiple geometric transformations are applied to the image, depending on the perspective and terrain corrections are required on a particular part of the image.
Orthophotos are frequently used in geographic information systems, such as are used by mapping organizations (e.g. Ordnance Survey) to create maps.
Once the images have been associated, or 'registered', with known real-world coordinates, they can be extensively deployed.
Large sets of orthophotos, typically resulting from multiple sources and separated into "tiles" (each usually 256 x 256 pixels in size), are widely used in online map systems such as Google Maps.
OpenStreetMap offers the use of alike orthophotos for deriving fresh map data.
Google Earth superimposes orthophotos or satellite imagery onto a digital elevation model to simulate 3D landscapes.

**Relief:**
The difference in a raster object's values that shows variation between a surface's higher and lower parts in elevation and slope.

**Relief Map:**
This is the map that appears to be in 3-dimensions. A relief map is a topographic map that uses different colors or shades to show elevations.

## Scales

**(Definition):** the ratio of the distance between two points on a photo to the actual distance between the same two points on the ground (i.e. 1 unit on the photo equals "x" units on the ground).
Therefore, the Cartographic Scale is the relationship between a given distance on the ground and the corresponding distance on a photograph or image.
Scale is expressed in different ways. In the first, frequently used measuring systems are compared; for example 1" = 100' (one inch on the map equals 100 feet on the earth).
In the second, the map unit is not mentioned; for example, 1:100 means that one of anything (an inch, a foot, a centimeter, etc.) on the map equals 100 of that same unit on the earth. (1"=100' is the same scale as 1:1200).
Scale is presented in several ways: as a bar at the bottom of the map, as a ratio (1:100), or as an equation (1"=100').
The ratio is referred to as a representative fraction, and the equation as an equivalent scale.
**Large vs. small scale mapping:**
A small scale map covers a large area in less detail than a large scale map (1/1000000 is a smaller number than 1/100)

## Scale Calculation:

If a 1 km stretch of highway covers 4 cm on an air photo, the scale is calculated as follows:

$$\frac{\text{PHOTO DISTANCE}}{\text{GROUND DISTANCE}} = \frac{4\text{ cm}}{1\text{ km}} = \frac{4\text{ cm}}{100000\text{ cm}} = \frac{1}{25000} \quad \text{(SCALE: 1/25000)}$$

Another method used to determine the scale of a photo is to find the ratio between the camera's focal length and the plane's altitude above the ground being photographed. If a camera's focal length is 152 mm, and the plane's altitude Above Ground Level (AGL) is 7600 m, using the same equation as above, the scale would be:

$$\frac{\text{FOCAL LENGTH}}{\text{ALTITUDE ( AGL)}} = \frac{152\text{ mm}}{7600\text{ m}} = \frac{152\text{ mm}}{76\ 00000\text{ mm}} = \frac{1}{50000} \quad \text{(SCALE: 1/50000)}$$

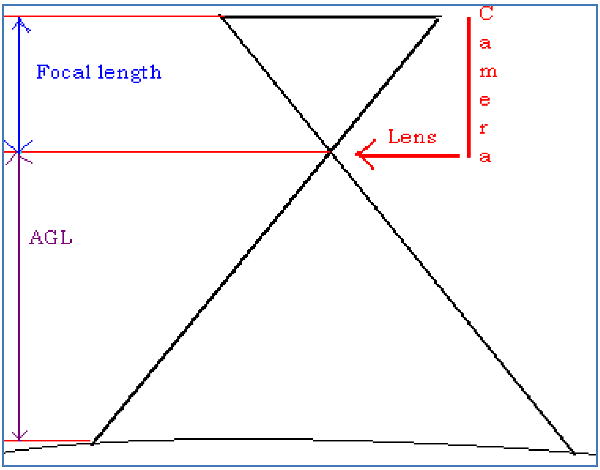



Figure 7: Focal length /AGL (Scale Calculations)

## Relief displacements

Relief displacement is a distortion that influences the spatial accuracy of the image.

Simply stated, points that are higher than the nadir are displaced outward from the center of the photograph and points that are lower in elevation are displace inward from their true positions.

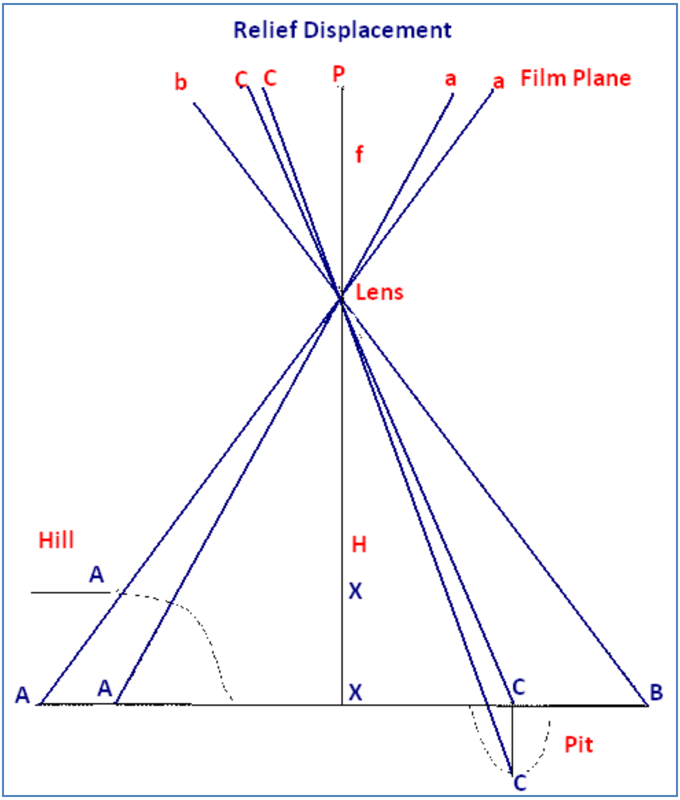



Figure 8: Relief Displacement

Refer to the given figure 8. The geometric displacement of both a hill and a pit in relation to the nadir are shown.

Relief displacement of the terrain is removed during the orthophoto development, thus the hills, and valleys will appear in their true location. Relief displacement of flagpoles, buildings, trees and other similar features will remain on the image since the top and bottom of the objects occupy the same X & Y coordinate on the ground. This artifact of relief displacement can be the foundation of some image distortions or illusions, mainly along the joint between orthophoto sheets. While sometimes disturbing, most are not considered as defects in the image product.

### Relief (Summary)

- Characteristic of aerial images over terrain.

- Objects that are risen above that the surface lean away from the principal point.

- Objects below the surface incline towards the principal point.

- Displacement increases with height of the object and/or distance from the principal point.

### Relief (for varied terrain)

- Terrain points in area of changing relief also display relief displacement.

- Point positions can move radically inwards or outwards throwing off length and orientation of measurement between points.

- Calculate and apply displacement value for each point to remove relief distortions.

- Displacement value can be positive or negative. (inward or outward)

## Requirements for Relief Calculations

- Truly vertical photograph is needed.
- Accurate value of flying height is required.
- There should be clearly visible objects on the photograph.
- Principal point is located accurately.
- Measurements for Relief displacements should be done carefully as small measurement errors may result in wrong height calculations.

## Calculations:

1. $D = R\,H / H'$
2. $H = D\,H' / R$

D is the length of the displaced object on the photo.

R is the radial distance from the principal point to the displaced image point.

H is the height above surface of the object point.

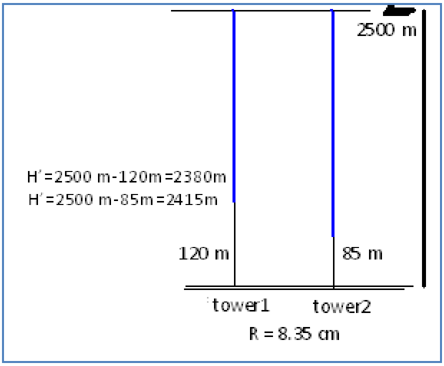
H' is the flying height above the surface.

**Example 1**

Two towers were identified on a perfectly vertical photograph taken from 2500 m above the datum. The distances from the base of the towers to the photo center are equal and are measured to be 8.35 cm. If the height of tower1 is 120 m and that of tower2 is 85 m above the datum, find the relief displacement of the summit of these towers on the photograph? Also give reasons.

**Solution:**

Given that the distances from the base of the towers to the photo center are equal and are measured to be 8.35 cm.




Therefore, R = 8.35 cm

Also given is the flying height above the surface=2500 m

**For tower 1:**

H = 120m

H'=2500 m-120m=2380m

**D = R H / H'**

D= 8.35cm*120m/2380m=4.42mm

**For tower 2:**
H = 85m
H’=2500 m-85m=2415m

**D = R H / H’**

D= 8.35cm*85m/2415m=2.94mm

Reason: Relief displacement varies directly as the height of the object. Because tower1 is higher than tower2, its image is displaced more.

**Example 2**
A tower was identified on a "perfectly" vertical photograph and the distance between its top and its bottom was measured to be 14.3 mm and that from the photo center to the top of the displaced tower was measured to be 85.6 mm. If the flying height of the aircraft is 1500 m above the mean sea level (MSL) and the base of the building is 400 m above MSL, how tall is the building?

**Solution:**
Given here, R=85.6 mm
H’=1500m-400m=1100m
D=14.3mm

H = D H’/ R
H= 14.3mm * 1100m/85.6mm=183.76m
Therefore the building is 183.76m tall.

## Flight Planning

Planning for aerial photography is important to the success of projects.

Many people use photographs obtained for some other purpose, simply to avoid costs of planning and acquisition. Federal agencies give 'general use' photographs that need to be evaluated with project purposes in hand. Objectives of the project determine procedures.

One of the most critical factors in aerial photography planning is the weather. Many areas of the world have but few cloud free days. For most photography, plan flight between 10am and 2pm local solar time. Long shadows should be avoided. Prime time is for puffy white clouds.

For flight planning the following are the **critical issues** that are necessary to consider:

- Where is the project area?
- How many photos are needed to cover the area at desired scale and resolution?
- When is the target in desirable condition?
- Is stereo viewing necessary?

Other **geometric factors** that are considered during flight planning include:

- Focal length of the camera lens
- Camera/film format size
- Photo scale
- Size of area to be photographed
- Average elevation of the ground
- Required Overlap
- Required Sidelap

- Ground speed of the aircraft
- Ground control requirements (such as considering the precise elevations for topography maps.)
- Camera calibration requirements where CFL (calibrated focal length is used for topography projects.

Mission timing is another critical specification for most photography. For example, one may consider the Crop calendars, Sun angle effects etc.

**Calculations:**

In a step-wise progression, the setup for a flight plan is usually done as follows:

1. State flight specifications: OL (overlap), SL (sidelap), OH (overhang), scale, film/filter
2. Square out the target area; i.e. minimum rectangle to cover desired area
3. Calculate the latitude/longitude of the target area corners
4. Calculate the number of lines and line lengths (images)
5. Plot the lines on a base map. In the absence of maps, small scale aerial imagery has sometimes been used.
6. Calculate the photo spacing and total number of photographs.
7. Calculate flying time; ferry time plus time-on-target
8. Develop flight constraints - tilt, crab, drift; acceptable scale variation; time of day (window); seasonal window, etc.
9. Specify the products needed; paper prints (contacts); positive transparencies, negatives, or all three.

## Flight Plan Example:

Given:
Photo Scale 1:15,840
Overlap 60%
Focal Length 6 inches
Sidelap 25%
Photo Format 9 x 9 inches
Overhang 30%
Plane Speed = 150 knots = 150(1.15) = 172.5 mph
Target Area = 5 x 10 miles = 26,400 x 52,800 ft.
1 nautical mile = 6076.11 ft
1 statute mile = 1.15 n.m.

Photo Scale 1 inch = 1320 feet

**PC = Photo Coverage = (photo width, inches) (photo scale, ft/ inch)**

PC = (9")*(1320) = 11,880 ft.

**SLC= SideLap Coverage = (1.0 - .SideLap%)(PC)= INTERIOR LINE SPACING= ILS**

SLC
ILS = SLC = (1-.25)*(11,880) = 8,910 ft.

**ELC= EndLap Coverage = (1 - .End%)(PC)= PHOTO SEPARATION**

ELC = (1-.60)*(11,880) = 4,752 ft.

**OHC = OverHang Coverage = (.OH%)(PC)**

OHC = (.30)*(11,880) = 3,564 ft.

$$\textbf{Total Flight Lines} = \frac{\text{(Target Area Width, ft.) + 2 (.OverHang\%)(PC)}}{\text{(SLC)}}$$

Total Flight Lines = [26,400 + 2(3,564)]/8,910
= 3.76 = 4 lines (round up/down at 0.5)

$$\textbf{Interior Flight Lines} = \frac{\text{(Width) - 2 (.5 - .OverHang \%)(PC)}}{\text{(SLC)}} - 1$$

Interior Lines = {[26,400-2(0.5-0.3)(11,880)]/8,910} - 1
= 2.42 - 1 = 1.42 = 2 interior (after round up)

| |
|---|
| **Line Space 1, N = (.5 - .OverHang%) (PC)** |

Line Space 1,N = (0.5-0.3)(11,880) = 2,376 ft.

$$\textbf{Interior Line Spacing} = \frac{\textbf{(Area Width) - 2 (.5 - .OverHang \%)(PC)}}{\textbf{(Interior Lines + 1)}}$$

Interior Line Spacing = [26,400-2(0.5-0.3)(11,880)]/(2 + 1)
= 21,648/3 = 7,216 ft.

$$\textbf{Actual Side\%} = \frac{\textbf{(PC)} - \left[\dfrac{\textbf{(Width) – 2 (.5 - .OverHang\%)(PC)}}{\textbf{Total Lines -1}}\right]}{\textbf{(PC)}}\ \textbf{100\%}$$

Or

$$\textbf{Actual Side\%} = \frac{\textbf{(PC- ILS)}}{\textbf{(PC)}} * \textbf{100\%}$$

Actual SideLap% = (11,880 - 7,216)/11,880 = 39.3%

| |
|---|
| **Photo Spacing, ft = ELC** |

Photo Spacing, ft. = ELC = 4,752 ft.

Number of Photos per Line = 52,800/4,752+4 = 11.11 = 16

Total Photos = 16/line * 4 lines = 64 total

| |
|---|
| **Photo Spacing, ft = ELC**<br><br>**1st Photo = 2.0 spaces beyond target area boundary** |

$$\text{Photo Spacing, sec} = \frac{\text{(Photo Spacing, ft)}}{\text{(speed, mph) * (5, 280) / (3600)}}$$

Photo Spacing, sec. = ELC/[(speed, mph* 5,280ft/mile)/(3600)]
= 4,752 /[(172.5 * 5,280)/(3600)]
= 18.78 seconds

$$\text{Time, hrs} = \frac{\text{(Line Length, miles) + (Lines - 1) * 5 + (Ferry Dist, miles)}}{\text{(Plane speed, mph)}}$$

Time, hrs = [(lines * length, miles)+(lines-1)*5]/(speed,mph)
= [(4 * 10)+(3 * 5)]/172.5 = .32 hrs

## Stereoscopy

Stereoscopy, stereoscopic imaging or 3-D (three-dimensional) imaging is any technique capable of recording three-dimensional visual information or creating the illusion of depth in an image.

Traditional stereoscopic photography consists of generating a 3-D illusion starting from a pair of 2-D images. The easiest way to develop depth perception in the brain is to provide the eyes of the viewer with two different images, representing two perspectives of the same thing, with a slight deviation exactly equal to the perspectives that both eyes naturally receive in binocular vision. If eyestrain and distortion are to be avoided, each of the two 2-D images preferably should be presented to each eye of the viewer so that any object at infinite distance seen by the viewer should be perceived by that eye while it is oriented straight ahead, the viewer's eyes being neither crossed nor diverging. When the picture contains no object at infinite distance, such as a horizon or a cloud, the pictures should be spaced correspondingly closer together.

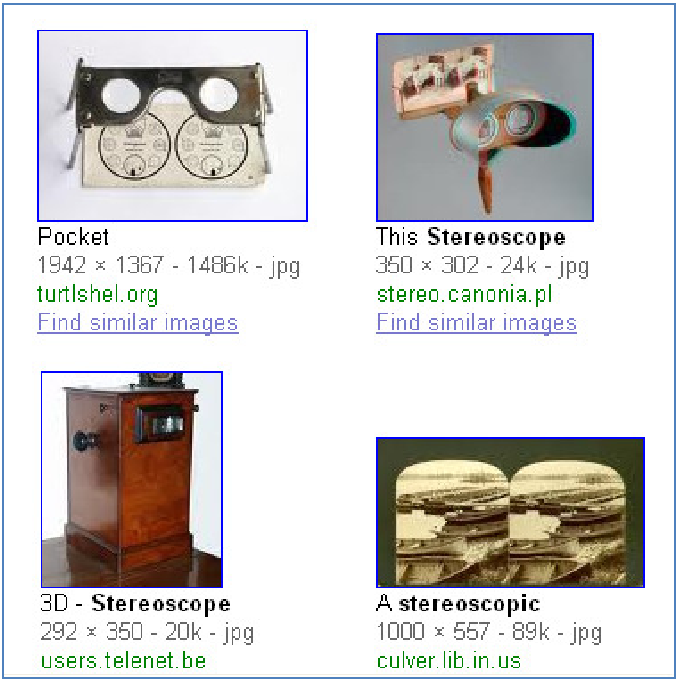



Figure 9: Google Image Results for ‘stereoscope’

## Characteristics of photographic images

The following are the basic characteristics of photographs:

**Tone** or hue refers to the comparative brightness or colour of objects on an image. It is the most important characteristics of the photo. It represents a record of the radiation that has been reflected from the Earth’s surface onto the film.

Light tone represents areas with a high reflectance/radiance and dark tone represents areas with low radiance. The nature of the materials on the Earth’s surface affects the amount of light reflected.

**Texture** is the frequency of tonal changes within an aerial photo that take place when a number of features are viewed together. Texture is produced by an aggregation of unit features that may be too small to determine individually on the image such as the tree leaves and leaf shadows. It determines the overall visual "softness" or "roughness" of image features.
Texture is dependent on the scale of aerial photograph. As the scale is reduced the texture progressively becomes finer and ultimately disappears.

**Pattern** is the spatial arrangement of objects. The repetition of certain general forms or relationships is characteristic of many objects, for examples road patterns or drainage pattern, crop disease pattern and litho logical pattern.

**Place/site** is a declaration of an object's position in relation to others in its surrounding area and usually aids in its identification (e.g. certain vegetations or tree species are likely to occur on well drained uplands or in certain countries).

**Shape** is a qualitative statement referring to the common form, design or outline of an object. (For example, O shaped objects in a photo may be the analytically viewed as tower tops).

**Shadows** of objects often aid in their identification. Shadows are important in two opposing respects: Sometimes the shape or outline of shadow helps in creating an impression of the profile view of objects (which aids in interpretation), however, shadows are usually avoided as objects with shadows are often difficult to discern on a photo.

**Sizeof** an object is a function of photo scale. The sizes of object scan are estimated by comparing them with objects whose sizes are known.
Sizes of objects must be measured while interpreting features and some features may be misinterpreted if sizes were not considered (e.g., a small storage shed might be misinterpreted as a barn if size was not measured).

**Association** refers to the occurrence of certain features in relation to others. For example, a merry-go-round wheel might be hard to recognize if positioned in a field near a barn, but would be easy to recognize if it is in an area known as amusement park.

## Characteristics of Aerial Photography

Aerial Photographs have the following characteristics:

**Synoptic viewpoint:** Aerial photographs give a bird eye view of large areas enabling us to see surface features in their spatial context. They facilitate the recognition of small scale features and spatial relationships that would not be seen on the ground.

**Time freezing ability**: They are virtually permanent records of the existing situations on the Earth at any one point in time, and are used as historical documents.

**Capability to stop action:** They provides a stop action view of dynamic conditions and are helpful in studying dynamic occurrences such as flooding, moving wildlife, traffic, oil spills, forest fires.

**Three dimensional perceptions:** It provides a stereoscopic view of the Earth's surface and make it possible to take measurements horizontally and vertically - a feature that is deficient for the mass of remotely sensed data.

**Spectral and spatial resolution:** Aerial photographs are sensitive to radiation in wavelengths that are outside of the spectral sensitivity of the human eye (0.3 μm to 0.9 μm versus 0.4 μm to 0.7 μm).
They are sensitive to objects outside the spatial resolving power of human eye.

**Accessibility:** Aerial photographs are readily available at a range of scales for much of the world.

**Cost-effective:** They are much cheaper than field surveys and are often cheaper and more accurate than maps.

## Aerial photo-interpretation

Aerial photographic interpretation is defined as the act of examining photographic images for the purpose of identifying objects and judging their significance (Curran, 1988).
Novice photo interpreters often encounter difficulties when presented with their first aerial photograph because objects are depicted from an unfamiliar perspective.
After experience one gets familiar with interpreting aerial photography. One becomes better at identifying features and recognizing diagnostic patterns. It's

simple, the more photos are look at the better a photo interpreter becomes.

When one looks at a photo the various objects of different sizes and shapes are seen. Some of these objects may be readily identifying while others may not, depending on individual perceptions and experience.
In the image interpretation, one can identify certain objects or areas and communicates the information identified to others.
During the process of interpretation, the aerial photo interpreters usually make use of seven tasks; detection, recognition and identification, analysis, deduction, classification, idealization and accuracy determination.

**Detection:** It involves carefully selection of objects that are directly visible (e.g. water bodies, rivers etc.) and areas that are indirectly visible (e.g. areas of wet soils) on the photographs.

**Recognition and identification:** These involve naming objects or areas.

**Analysis:** It involves trying to distinguish the spatial arrangement of the objects or areas.

**Deduction:** This is complex and involves the principle of convergence of evidence to calculate the occurrence of definite relationships on the photo.

**Classification:** It helps to put together the objects and elements acknowledged into an orderly system before the interpretation is done using guidelines.

**Accuracy determination:** During accuracy determination arbitrary points are visited in the field to confirm or disprove the interpretation.

A photo interpreter uses the characteristics of the photographs such as tone, texture, pattern, place, shape, shadow and size. Success in interpretation varies with the training and experience of the interpreter, the nature of the objects/phenomena being interpreted, and the quality of the image/photo being utilized.

## Chapter - II

Physics of remote sensing
Ideal remote sensing system
Remote sensing satellites
Data
Sensors
Orbital characteristics
Spectral reflectance curves
Resolution
Multi-concept
FCC

**Knowing where things are, and why, is essential to rational decision making**

[Jack Dangermond,
Environmental Systems Research Institute (ESRI)]

## Remote Sensing

Remote Sensing is the science of obtaining information (spectral, spatial, temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under examination. For this, without direct contact, some means of transferring information through space must be used. It provides an exceptional perspective from which to observe large regions. Global monitoring is possible from nearly any site on earth.

Remote sensing is an interesting and exploratory science, as it provides images of areas under study in a fast and cost-efficient manner, and attempts to demonstrate all that was happening in a particular study area at a given time. While airphotos and fieldwork remain critical as sources of information, the cost and time to carry out these methods sometimes may not be feasible for the study.

In remote sensing, information transfer is achieved by the use of electromagnetic radiation (EMR).

### Basic components

Remote Sensing Systems offer four basic components to measure and record data about an area from a distance.

These components include the energy source, the transmission path, the target and the satellite sensor.

The energy source, electromagnetic energy, is very important. It is the crucial medium required to transmit information from the target to the sensor. Sensors can determine energy at wavelengths which are even beyond the range of human vision (ultra-violet, infrared, microwave).

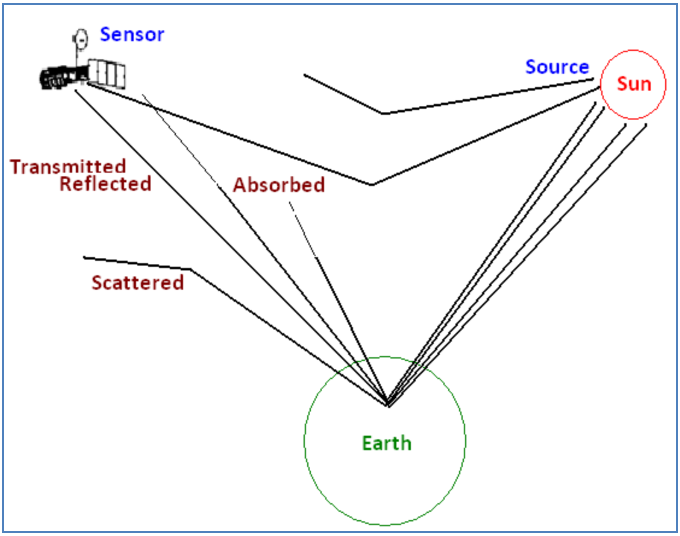


Figure 10: Remote Sensing Components

## Remote Sensing Types

With reference to the Wavelength Regions, Remote Sensing is classified into three types:

- Visible and Reflective Infrared Remote Sensing.
- Thermal Infrared Remote Sensing.
- Microwave Remote Sensing.

Other types include-

**Passive Remote Sensing:** It makes use of sensors that detect the reflected or emitted electro-magnetic radiation from natural sources.

**Active remote Sensing:** It makes use of sensors that detect reflected responses from objects that are irradiated from artificially-generated energy sources, such as radar.

## Physics of remote sensing

The physics of remote sensing is about knowing EMR. EMR is a form of energy that shows its existence by the observable effects it creates when it strikes the matter. It is reflected or emitted from an object and is the usual source of Remote Sensing data. However, any medium, such as gravity or magnetic fields, can be used in remote sensing. Remote Sensing Technology makes use of the wide range Electro-Magnetic Spectrum (EMS) from a very short wave "Gamma Ray" to a very long 'Radio Wave'.

The emission of EMR from gases is due to atoms and molecules in the gas. Atoms consist of a positively charged nucleus surrounded by orbiting electrons, which have discrete energy states. Transition of electrons from one energy state to the other leads to emission of radiation at discrete wavelengths. The resulting spectrum is called line spectrum. The molecules possess rotational and vibration energy states. Transition between these leads to emission of radiation in a band spectrum. The wavelengths, which are emitted by atoms/molecules, are also the ones, which are absorbed by them. Emission from solids and liquids occurs when they are heated and result in a continuous spectrum. This is called thermal emission and it is also an important source of EMR from the viewpoint of remote sensing.

### Electromagnetic spectrum:

In Remote Sensing, electromagnetic energy is the energy required to transmit information from the target to the sensor. It is an essential medium that is described as an electromagnetic spectrum.

On this many forms exist that describe energy in a specific region of the electromagnetic spectrum.

These are visible lights, radio waves, microwaves, UV rays, X-rays and gamma rays.
This spectrum is an overview of the range of electromagnetic energy from extremely short wavelengths (cosmic gamma rays) to extremely long wavelengths (radio and television waves).
These divisions are not absolute and definite; overlapping may occur.

**Units:**
Visible wavelengths (including U.V., visible, and near infrared) are referred to in units, rather than micrometer. The unit angstrom is used as (1 micrometer = 10000 angstroms). Other measurements include 1 micron = 1micrometer. Also see Table2, given below:

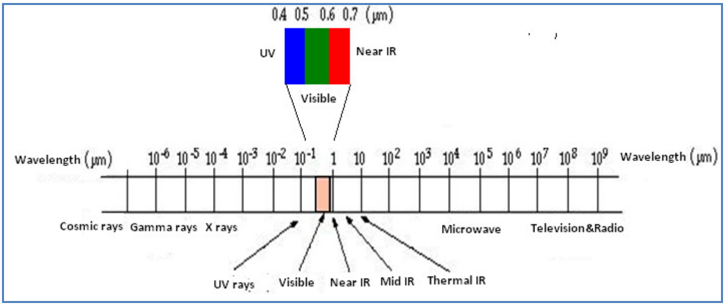



**Figure 11: Electromagnetic Spectrum**

| | |
|---|---|
| Gamma Ray | <0.03 nanometers |
| X- Ray | 0.03 – 3.0 nanometers |
| Ultraviolet | 3.0 nanometers – 0.4 micrometers |
| Visible | 0.4-0.7 micrometers |
| Near Infrared | 0.7-1.3 micrometers |
| Mid Infrared | 1.3-3.0 micrometers |
| Thermal Infrared | 3.0-5.0 mm +8.0 – 14.0mm |
| Microwave | 0.3 – 300.0 cm |

**Table1: Electro Magnetic Radiations**

| Unit of Measurement | Radiometer(m) |
|---|---|
| Nanometer(nm) | 10(-9)m, 10(-3)um |
| Micrometer(um) | 10(-6)m |
| Millimeter(mm) | .001m |
| Angstrom (A) | 10(-10)m |

Table2: Units of Measurements

## Ideal remote sensing system

The basic components of an ideal remote-sensing system include the following:

**A uniform energy source:** This source will provide energy over all wavelengths, at a constant, known, high level of output, irrespective of time and place.

**A non-interfering atmosphere:** This will be an atmosphere that will not modify the energy from the source in any manner, whether that energy is on its way to earth's surface or coming from it. Again, ideally this will hold irrespective of wavelength, time, place, and sensing altitude involved.

**A series of unique energy/matter interaction at the earth's surface:** These interactions will generate reflected and/or emitted signals that are not only selective in respect to wavelengths, but also are identified, invariant, and exclusive to each and every earth surface feature type and subtype of interest.

**A super sensor:**

This will be a sensor, highly responsive to all wavelengths, yielding spatially comprehensive data on the absolute brightness (or radiance) from a scene (a function of wavelength), throughout the spectrum. This super sensor will be uncomplicated and unfailing, require, virtually no power or space, and be accurate and economical to operate.

### A real-time data handling system:

In this system, the instant the radiance versus wavelength response over a terrain element is generated, it will be processed into an interpretable format and recognized as being unique to the particular terrain element from which it comes. This processing will be performed nearly instantaneously (real time), providing timely information. Because of the consistent nature of the energy/matter interactions, there will be no need for reference data in the analytical procedure. The derived data will provide insight into the physical-chemical-biological state of each feature of interest.

### Multiple data users:

These people will have comprehensive knowledge of both their respective disciplines and of remote-sensing data acquisition and analysis techniques. The same set of data will become various forms of information for different users, because of their vast knowledge about the particular earth resources being used.

Unfortunately, an ideal remote-sensing system, as described above, does not exist. Real remote-sensing systems fall short of the ideal at virtually every point in the sequence outlined.

## Remote Sensing Satellites

A satellite with remote sensors to observe the earth is called a remote-sensing satellite, or earth observation satellite.

Remote-Sensing Satellites are characterized by their altitude, orbit and sensor.

TRIOS Series (1960-1965):
(The Television and Infrared Observation Satelites):

**NOAA** It is the first generation of National Oceanic and Atmospheric Administration satellites and was as the first operation operational remote sensing satellite system.

The third generation NOAA satellites are also successfully used for vegetation monitoring, apart from meteorological monitoring. It is equipped with Advanced Very High Resolution Radiometer (AVHRR) sensors, and is established at an altitude of 850 km. in polar orbit.

**GMS** Geo-synchronous meteorological satellite: It is established at an altitude of 36,000 km, and its main purpose is meteorological observations.

**Landsat** is established at an altitude of 700 Kms is a polar orbit and is used mainly for land area observation.

Other remote sensing satellite series in operations are: **SPOT, MOS, JERS, ESR, RADARSAT, IRS** etc.

## Data Products

It is important to remember that a satellite image is not just a picture of the target similar to what a simple camera would take. Instead it is a collection of numeric data that is capable of being displayed as an image. The underlying dataset can be manipulated using algorithms (mathematical equations) that correct for errors (like atmospheric interference), re-map the data to a geographical reference point, or extract information that is not readily apparent in the data. The data for two or more images of the same location can even be combined mathematically, creating imagery that is a composite of multiple datasets. These data products, known as derived products, can be generated by performing calculations on the raw numerical (digital numbers) data.

Broadly, for satellite images here are two types of data, raster and vector.

**The raster (or pixel-based) data** includes all of the satellite imagery as well as the derived products, including composites, vegetation index, and unsupervised classification.

**The vector (or point-line-polygon)** data includes several datasets that provide the user with a context in which to view the raster data. For example, roads (vector) can be displayed over a satellite image to help the viewer more easily locate known features. Streams and watersheds (also vector) can also be drawn over these data sets to provide further reference.

**File formats**

Raster data is often provided in GeoTIF format (.TIF) and can be read by most software packages that display images (image processing, GIS, and standard photo/image editing packages).

Vector data example is shapefile format (.SHP). Since there is no easily usable standard for this type of data, the shapefile format, which was designed by Environmental Systems Research Institute (ESRI), is

often chosen because of its widespread use within the GIS community. Many software packages can import this file type, and free viewers such as ArcExplorer are available and easy to use.
A single "shapefile" consists of three separate files (.SHP, .SHX, .DBF). All three files should be present in the same folder when data is imported, for the data to be usable.
Both raster and vector files are often compressed to a .ZIP file. After the data has been downloaded, it is uncompressed using WinZip or a similar package before it can be used.

## Sensors

Radiometers are instruments that are sensitive to varying amounts of electromagnetic radiation.
Radiometers are designed to measure energy levels in well-defined ranges of wavelengths known as channels. A channel is a relatively narrow band of wavelengths within a portion of the electromagnetic spectrum. Radiometers are engineered to use specific channels based on the information about the target provided by the channel.
Multi-spectral remote sensing makes use of a radiometer that is comprised of an array of sensors, each tuned to a particular channel or band of wavelengths, in order to provide spectral data about a target across a range of energy levels.
Radiometers on aircraft or satellites scan the Earth and measure the levels of radiation that is reflected off or emitted from the materials on the surface or in the atmosphere. This information is transmitted back to Earth and usually converted into an image. Since each type of surface material on earth and each type of particle in the atmosphere has its own unique spectral characteristics (or spectral signature) these

data can be used to discern a great deal of information about the nature of the target.

**Passive sensors:** Passive sensors are those which are designed to detect naturally occurring energy. Many forms of remote sensing use passive detection, in which sensors measure levels of energy that are naturally emitted, reflected, or transmitted by the target object. Most often, the source of radiated energy is the sun. The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then red-emitted, as it is for thermal infrared wavelengths.
Passive detection can only work when the naturally occurring energy is available. Detection of reflected solar energy, for example, can only proceed when the target is illuminated by the sun, thus limiting visible light sensors on satellites from being used during a nighttime pass. The amount of solar radiation present at polar latitudes is often insufficient for visible light sensors, limiting the use of passive detectors to lower latitudes. Clouds, dust, smoke, and other particles in the atmosphere can block reflected energy from reaching a sensor.
The problems associated with passive sensing can be overcome when designing a remote sensing system. One common method is to use a sensor that is capable of detecting radiation in several different portions of the electromagnetic spectrum. For example, by using a combination of visible and thermal infrared channels, weather satellites can provide imagery of the Earth's cloud patterns during both day and night hours. A combination of visible channels and reflected infrared channels can also be used to mathematically correct an image for atmospheric interference, which is caused by energy

interacting with and being absorbed by particles in the atmosphere before it reaches a sensor.
The Thematic Mapper, the primary sensor on the Landsat satellites, is a good example of a passive sensor. This sensor has seven bands, or channels, each being sensitive to a different range of electromagnetic radiation. The sensors on the Thematic Mapper are sensitive to narrow portions of the visible and near infrared portion of the spectrum, with one band sensitive to thermal infrared. The selected range of wavelengths are specifically designed to detect differences in plant production, soil moisture, and mineral content in soils, providing a useful tool in assessing and monitoring land use practices. The sensors depend on available reflected solar energy, so the Landsat satellite is placed into an orbit that ensures that the satellite will pass overhead at the time when the amount of solar radiation is optimal for the sensor.

**Active Sensors:** Other forms of remote sensing provide their own energy source for illumination of the target. These devices, known as active sensors, direct a burst of radiation at the target and use sensors to measure how the target interacts with the energy. Most often the sensor detects the reflection of the energy, measuring the angle of reflection or the amount of time it took for the energy to return. Active sensors provide the capability to obtain measurements anytime, regardless of the time of day or season. They can be used for examining energy types that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets.

Doppler radar is an example of an active remote sensing technology. A Doppler radar device is a ground based system that emits radio energy in a radial pattern as the transmitter rotates. A sensor measures the reflection, or echoes, of this energy off such atmospheric particles as dust, raindrops, and even birds!

These echoes, when plotted on a regional map, assist a meteorologist in determining the exact location of storm centers, measuring the speeds in the wind field of a storm, and notifying the public of areas of potentially severe weather.

## Orbital Characteristics

A satellite's orbit around the Earth is in the shape of an ellipse, and the Earth's center of mass is at one of the focal points of the ellipse.

### Shape

**An ellipse** can be thought of as a circle that is somewhat "out of round," although the technical definition of an ellipse is "a closed plane curve generated by a point moving in such a way that the sum of the distances from two fixed points is a constant." The characteristics of an ellipse are probably best understood when compared to a circle.

A perfect circle has a single point in its center. Each point on the circle is an equal distance from this point, known as the focus of the circle. Any line that connects two sides of the circle and passes through the focus are equal in length.

An ellipse is a circle that is slightly stretched in one dimension. An ellipse has two focal points. The sum of the distances from any point to each focal point will always remain constant.

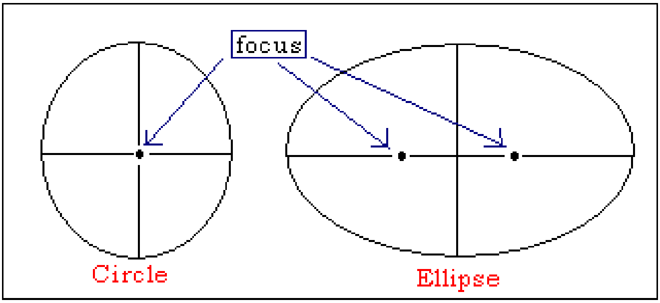


Figure 12: Circle and Ellipse

## Major Axis

A line that connects two sides of the ellipse and passes through both focal points is called the major axis of the ellipse.

## Minor Axis

A line perpendicular to the major axis that passes through the point directly between the focal points is the minor axis of the ellipse.

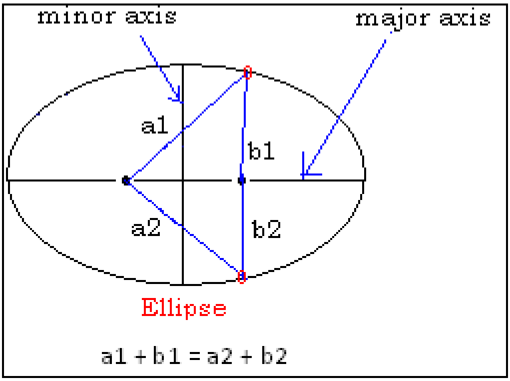


Figure 13: Minor Axis and Major Axis

## Eccentricity

The degree to which an ellipse is stretched is described as the eccentricity of the ellipse. The eccentricity can be described as the ratio between the length of the major axis and the distance between the foci of the ellipse. The foci in highly eccentric ellipse are spread farther apart than those of an ellipse with a lower eccentricity. The value of eccentricity ranges from 0 (a perfect circle) and approaches a value of 1 as the ellipse becomes more eccentric.

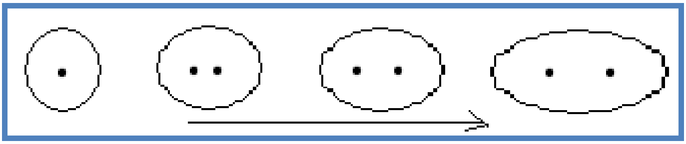


Figure 14: Eccentricity

A satellite orbit can be described by the eccentricity of the orbit. Satellite orbits range from nearly circular orbits (with a low eccentricity) to very highly elliptical orbits (with a high eccentricity). A satellite with a nearly circular orbit maintains a relatively constant altitude above the Earth's surface, while the altitude of a satellite with a very highly elliptical orbit is constantly changing.

### Size

Another of the orbital elements used to describe a satellite's orbits is the semi-major axis, which is defined as half the distance of the major axis. In general, the larger the semi-major axis the larger is the orbit. The larger the orbit, the greater the amount of energy required to place the satellite into the orbit. Thus, satellites with larger orbits and with higher altitudes above earth are much more expensive to launch and maintain.

## Velocity

As a satellite orbits the Earth in an elliptical orbit its distance from the Earth's surface changes. The point in its orbit at which the satellite is closest to the Earth is called perigee. The point opposite to perigee, when the satellite is at its furthest point from Earth, is called apogee. As a satellite approaches perigee, its orbital velocity increases. At perigee, the satellites velocity is at its maximum. As it approaches apogee, its orbital velocity decreases. At apogee, the satellites velocity is at its minimum. Thus, satellites with a nearly circular orbit maintain a nearly constant orbital velocity, while satellites with highly elliptical orbits have a wider range of orbital velocities, speeding up as they get closer to Earth and slowing down as they move further away.

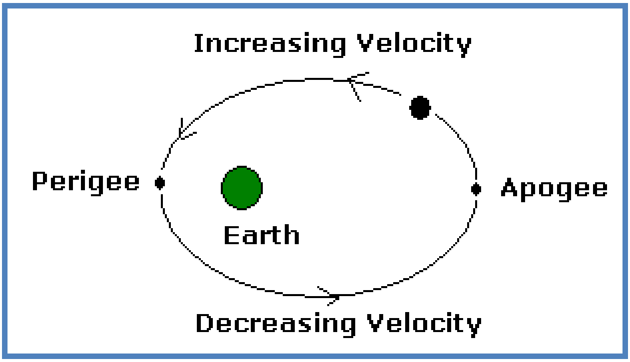



Figure 15: Perigee and Apogee

## Period

The period of an orbit is the amount of time it takes for a satellite to complete one full orbit around its primary body. A general rule of orbital mechanics states that the closer an orbiting object is to its primary body, the higher its velocity.

In addition, the closer a satellite is to the Earth, the less distance it must travel to complete a single orbit. The result is a general relationship between a satellite's altitude and its period; the lower the altitude, the shorter its period.
The lowest satellites orbit the earth with a period of approximately 87 minutes per orbit (if a satellite were placed any lower in the orbit the atmosphere would interfere so much that it will not maintain its orbit).
Other satellites at higher altitudes have orbital periods that are longer than a full 24 hour day.

### Inclination

Inclination of a satellite orbit describes the tilt of the orbit plane with respect to the equatorial plane. An orbit with inclination angle of 0º would orbit the Earth in the same plane as the Equator. This is known as an equatorial orbit, and a satellite in this type of orbit follows the Earth's equator. An orbit with an inclination angle of 90º would orbit the Earth crossing the North and South Poles in a plane that is perpendicular to the equatorial plane. This type of orbit is known as a polar orbit. Other satellites are in orbits with inclinations between 0 and 90º.

### Polar orbiting satellites

While a true polar orbit has an inclination of 90º, many satellites orbit the earth with inclinations that are close to 90º. These form a class of satellites known as polar orbiting satellites. These satellites orbit the Earth in an orbital plane that goes nearly from pole to pole. They are considered Low Earth Orbiters (LEO), which orbit the Earth at an altitude of approximately 300 km. Polar orbits are usually nearly circular and the satellites have a constant height above the planet. They generally have a period around 90 minutes and maintain a constant orbital velocity.

As a polar orbiter circles the planet, and as the Earth rotates underneath, the satellite crosses a different strip of the Earth with each orbit. The effect is that a polar orbiting satellite can scan the Earth in strips, and over the course of several orbits, it can collect data over a significant portion of the planet. The lower altitude of the polar orbits can allow the sensors to study the Earth in greater detail than a higher altitude craft, and it is far less expensive to build, launch, and maintain than a higher altitude satellite.

This type of orbit is primarily used for surveillance, environmental monitoring, and space related research.

Few examples of polar orbiting satellites are the Landsat satellites, the TIROS-class meteorological satellites, the space shuttle, and the Mir space station.

## Geostationary Satellites

A geostationary satellite orbits the Earth in an equatorial orbit at an altitude where its period is equal to that of the Earth's rotation (24 hours). The result is that the geostationary satellite turns with the Earth and remains over the same fixed point of the planet at all times. A geostationary orbit is usually circular with an inclination of 0º.

The fixed nature of a geostationary satellite with respect to a given point on the Earth makes them very useful for surveillance, communications and broadcasting, and environmental monitoring. Satellite television broadcasts make use of geostationary satellites, as do many of the telecommunications companies around the world. The GOES meteorological satellites operated by the U.S. provide

constant satellite coverage of the entire hemisphere from a geostationary orbit.
One limitation of a geostationary satellite is that the platform is only useful from the equator up to altitude of about 70 degrees north and south of the equator. Therefore, to provide communications or other satellite support to higher latitudes, either polar orbiter or highly elliptical orbiters must be used.

## HEO Satellites

Highly Elliptical Orbits (HEO) satellites orbit the Earth in an orbital plane with an inclination between 50 and 70°. The period of a HEO satellite is approximately 12 hours and the shape of the orbit is highly elliptical. During the HEO satellite's orbit, it comes very close the planet for part of its orbit, causing its velocity to increase. Then it travels very far away from the Earth and its orbital velocity decreases. As a result it spends much of its time in the portion of the orbit that is at a very high altitude. A HEO satellite is placed in an orbit in such a way that it will spend the greatest amount of time over a specific area of the planet. Thus, if a HEO communications satellite is launched to provide communications in the arctic region, its orbit would be configured so that is spends the bulk of its time in orbit above these latitudes. This is especially useful in providing communications and navigation services from a satellite. One example of HEO satellites is the Global Positioning System, which uses a fleet of HEO satellites to provide constant coverage of the entire planet and which are capable of providing precise location data to any point on the surface of the Earth.

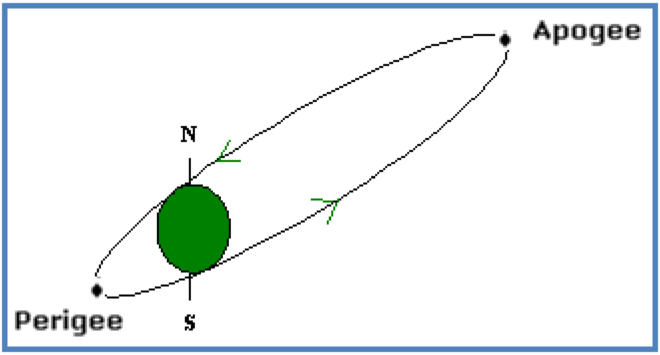


Figure 16: Orbital Positions

## Spectral Reflectance

Radiometers on aircraft or satellites scan the Earth and measure the levels of radiation that is reflected off or emitted from the materials on the surface or in the atmosphere. This information is transmitted back to Earth and usually converted into an image. Since each type of surface material on earth and each type of particle in the atmosphere has its own unique spectral characteristics (or spectral signature) these data can be used to discern a great deal of information about the nature of the target.

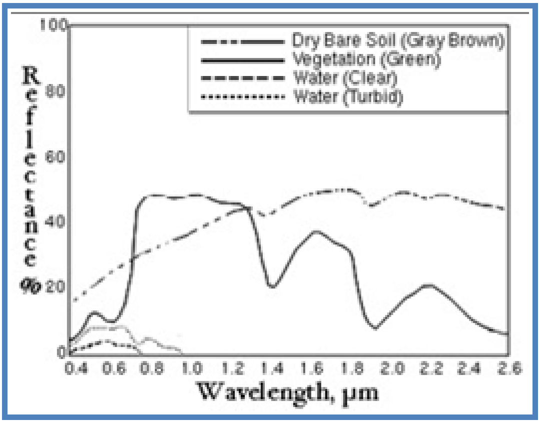


Figure 17: Reflectance

For an illustration, refer to the graph above. This compares the spectral signature of four surface types in the visible light spectrum. The curves on the graph illustrate the percent of energy reflected by each surface at each wavelength. Thus, a sensor can be designed to detect energy in specific wavelengths to provide known information about the surface type being scanned.

For example, weather satellite sensors are designed to detect energy in the visible, near infrared, and thermal infrared portions of the electromagnetic spectrum. The visible and near infrared channels measure the intensity of reflected solar radiation. The thermal channels measure the amounts of heat energy emitted from the various surface materials and atmospheric components. Together, the combination of data from each channel offers a deep set of information about the state of the atmosphere at any given time.

The radiometers on land use satellites such as Landsat and Spot are engineered to provide multispectral data that aids in measuring the spectral differences between varying surface materials. Different land surface types such as concrete, asphalt, crops, meadow, forest, water, and desert all exhibit unique spectral signatures. Even within one category of land use, differences exist. For example, corn, soybean, and wheat can be classified as crop land, but each will exhibit a unique spectral pattern when imaged with a multispectral radiometer. These differences can be extended even further. For example, a healthy crop of soybeans will exhibit a different spectral signature than one that is suffering from drought or a pest infestation.

All of the varying materials on the Earth's surface and in its atmosphere interact differently and uniquely with electromagnetic radiation. Through the use of satellite remote sensing technologies, these differences can be detected and measured from space, providing us with a very rich set of tools with which we can better monitor and understand our environment.

## Resolution

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

In general resolution is defined as the ability of an entire remote-sensing system, including lens antennae, display, exposure, processing, and other factors, to render a sharply defined image. Resolution of a remote-sensing is of different types.

**Spectral Resolution:** of a remote sensing instrument (sensor) is determined by the band-widths of the Electro-magnetic radiation of the channels used. High spectral resolution, thus, is achieved by narrow bandwidths width, collectively, are likely to provide a more accurate spectral signature for discrete objects than broad bandwidth.

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**: is determined by the number of discrete levels into which signals may be divided or 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 colour, in each band. It also depends on the instrument noise.

**Spatial Resolution:** in terms of the geometric properties of the imaging system, is usually described as the instantaneous field of view (IFOV).

The IFOV is defined as the maximum angle of view in which a sensor can effectively detect electro-magnetic energy.

**Temporal Resolution**: is related to the repetitive coverage of the ground by the remote-sensing system. It is 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. The temporal resolution of Landsat 4/5 is sixteen days.

**Resolution of an image:** It describes the level of detail that can be discerned from it. Since the smallest element in a satellite image is a single pixel, resolution describes the area on the Earth's surface represented by a single pixel. For example, in a weather satellite image that has a resolution of 1 km, each pixel represents the average brightness value over an area that is 1 km by 1 km. Features smaller than 1 km will be difficult to discern clearly in an image with 1 km resolution. In higher resolution imagery, each pixel represents a much smaller portion of the Earth. For example, Landsat 7 typically produces imagery with 30 meter resolution. Thus, each pixel in a Landsat image represents the average brightness of an area that is 30 meters by 30 meters. Thus, much greater detail can be seen in a Landsat image when compared to a 1 km weather satellite image since it has a higher resolution.

## Multi Concept

Ground truth activities are an integral part of the "multi" ("more than one") approach. Thus, one should procure data whenever possible from different platforms (multiplatform), at various altitudes (multistage; multilevel). (A "platform" is a synonym for any orbiting spacecraft, be it a satellite or a manned station, from which observations are made.) This gives rise to multi-scaled images or classification maps. Ideally, one should aim to employ multi-sensor systems simultaneously to provide data, commonly at multi-resolution, over various regions of the spectrum (multispectral). Often, data is obtained at different times (multi-temporal), whenever seasonal effects or illumination differences are factors or change detection is the objective. Supporting ground observations should come from many relevant, but not necessarily interrelated, sources (multisource). Some types of surface data may correlate with one another and with other types of remote sensing data (multiphase).

## Applications of remote sensing

Remote Sensing has the widespread use in different area. Few example areas are given below:

Forestry & Ecosystem

- Biomass estimation
- Deforestation mapping

- Forest cover & density mapping
- Forest fire mapping
- Species inventory
- Wetland mapping and monitoring

Agriculture

- Crop type classification
- Crop condition assessment
- Crop yield estimation
- Mapping of soil characteristic
- Soil moisture estimation

Geology

- Environmental geology
- Geo-hazard mapping
- Glacier mapping
- Lithological mapping
- Mineral exploration
- Sedimentation mapping and monitoring

Hydrology

- Encroachment

- Flood delineation and mapping
- Ground water targeting
- Land Use/Land Cover mapping
- Natural resource management
- Wildlife protection
- Watershed mapping & management

Urban Planning

- Future urban expansion planning
- Infrastructure mapping
- Land parcel mapping
- Land use change detection

Ocean applications

- Aquaculture inventory and monitoring
- Coastal vegetation mapping
- Navigation routing
- Oil spills
- Storm forecasting
- Water quality monitoring

# Chapter - III

Satellite Image
Characteristics and formats
Image histogram
Introduction to Image rectification
Image Enhancement
Land use and land cover classification system
Supervised Classification
Applications of remote sensing

> Good imaging beats good image processing
> [Dr. Michael Vannier]

## Satellite Image

After data is collected and transmitted to the ground station, it must be processed and converted into a format that is usable by the researcher who will interpret the data. Often satellite-derived data is converted into imagery that provides a visualization of the data collected by the sensor. However, the format of these data in their original form is usually not such that an interpreter can learn much about the target. The data must be processed, enhanced, and manipulated to provide a useful set of information. This technique, which is the fraction of science and art, is called image processing.

When remote sensing data are obtainable in digital format, digital processing and analysis may be performed using a computer. Digital processing may be used to enhance data as a lead up to visual interpretation. Digital processing and analysis may also be carried out to automatically identify targets and extract information completely without manual involvement of a human interpreter.

Analog Images: Remote sensing products such as aerial photos are the result of photographic imaging systems (i.e. Camera). Once the film is developed, then no more processing is required. In this case, the image data is referred to as being in an analog format.

Digital Images: Remote sensed images can also be represented in a computer as arrays of pixels (picture elements), with each pixel corresponding to a digital number, representing the brightness level of that pixel in the image. In this case, the data is in a digital format. These types of digital images are referred to as raster images in which the pixels are arranged in rows and columns.

Satellite image data is sent from the satellite to the ground station in a raw digital format, which is essentially a stream of numerical data. The smallest unit of digital data is a bit. A bit is represented by a binary number, which has only two feasible values, 0 or 1. A bit can be used to represent any piece of data that has two states, such as on/off, true/false, or open/closed. With only two potential values, a bit does not offer much flexibility in representing data that is more complex than a binary number. Therefore, data is often stored as a collection of eight bits, resulting in a unit of data called a byte.
A byte is a unit of data that is comprised of 8 bits, thus providing a data element with up to 256 potential values ($2^8$). Radiometers that measure the intensity of electromagnetic radiation will generally convert the detected energy levels into a value that ranges from 0 to 255 and represent each of these measured energy levels with a single byte. These bytes will be taken together in a pre-determined manner, converted into a signal, and transmitted to the collections facility. Here, the signal will be converted back into a digital stream of bytes where it can be read in and interpreted by processing software. Images generated in this manner are thus referred to as "8-bit digital images."

## Characteristics and formats

Though remotely-sensed images are collected from a wide variety of sensors and transmitted to a ground station through many different paths, all image data have certain characteristics in common.

## Pixels and Digital Number

When a stream of bytes is received from a satellite sensor, the value of each byte is applied to a single dot, or pixel (short for "picture element"). The numerical value of the pixel, known as its Digital Number (DN), is translated into a shade of gray that ranges somewhere between white and black. These pixels, when arranged together in the correct order, form an image of the target in which the varying shades of gray represent the varying energy levels detected on the target.

When a selected portion of the image is magnified several times, it becomes apparent that the image is really just comprised of rows of pixels, each with its own color.

## Gray scale

Most raw unprocessed satellite imagery is stored in a gray scale format. A gray scale is a color scale that ranges from black to white, with varying intermediate shades of gray. A commonly used gray scale for remote sensing image processing is a 256 shade gray scale, where a value of 0 represents a pure black color, the value of 255 represents pure white, and each value in between represents a progressively darker shade of gray.

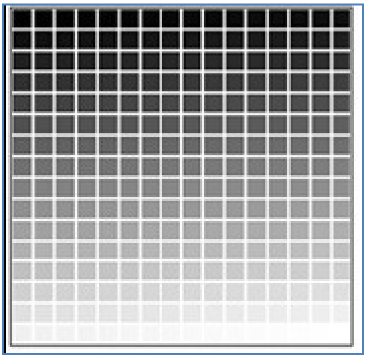


Figure 18: Gray Shades

Objects in a gray tone display have a brightness value (or digital number), which represents the measured energy level of the item.
Contrast refers to the difference in relative brightness between an item and its surroundings as seen in the image. A particular feature is easily detected in an image when contrast between an item and its background are high. However, when the contrast is low, an item might go undetected in an image.
Images of raw, unprocessed data streams are often not particularly useful to a human interpreter, since the contrast is often very low and the human eye can only distinguish between a few dozen shades of gray. Image processing techniques can be used to enhance the contrast between the most important shades of gray that make up an unprocessed image.

## Pixel Values

The magnitude of the electromagnetic energy captured in a digital image is represented by positive digital numbers. The digital numbers are in the form of binary digits (or 'bits') which vary from 0 to a selected power of 2.
Each bit records an exponent of power 2 (e.g. 1 bit = $2^1 = 2$). The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be 28 = 256 digital values available, ranging from 0 to 255; 8-bit is the most common bit value.

| Image Type | Pixel Value | Color Levels |
|---|---|---|
| 8-bit image | $2^8$=256 | 0-255 |
| 16-bit image | $2^{16}$=65536 | 0-65535 |
| 24-bit image | $2^{24}$=16777216 | 0-16777215 |

**Table 3: n bit Images and Color Levels**

## Image Resolution

The resolution of a digital image is dependent on the range in magnitude (i.e. range in brightness) of the pixel value. With a 2-bit image the maximum range in brightness is $2^2$ = 4 values ranging from 0 to 3, resulting in a low resolution image. In an 8-bit image the maximum range in brightness is $2^8$ = 256 values ranging from 0 to 255, which is a higher resolution image.

2-bit Image gives (4 grey levels)
8-bit Image gives (256 grey levels)

## Satellite Data (Vector Format)

- It is represented by point, line and polygon.
- File sizes are relatively small (small data volume)
- Excellent representation of networks.
- A large no. of attributes can be attached; hence more information intensive and a number of thematic maps can be prepared from a single layer.
- Features are more detailed & accurate.
- Creating, cleaning and updating data is more time and labour consuming.
- Topology-based analysis & operations are easier to perform (like network analysis etc.).
- Can not represent continuous values like land use, elevation etc very well.
- Assigning projection and transformations are less time taking and consumes less memory of the computer system.
- Topology makes data structure complex.

### Satellite Data (Raster Format)

- In raster format the Points, line & polygons everything in the form of Pixels.
- These usually have large file size.
- Networks are not so well represented.
- Pixel values represents grid cell.
- Generalization of features (like boundaries) hence accuracy may decrease.
- Simulations and modeling is easier (spatial analysis, terrain modeling etc.).
- Maintaining of raster drawing is easier.
- Excellent for representing data containing continuous values (like land use, elevation etc.)
- Coordinate-system transformations take more time and consume a lot of memory.
- Grid cells or pixel makes simpler data structure.

## Image histogram

A histogram is one of the simplest methods of analyzing an image. An image histogram maintains a count of the frequency for a given colour level. When graphed, a histogram can provide a good representation of the colour spread of the image.

For every digital image the pixel value represents the magnitude of an observed characteristic such as brightness level. An image histogram is a graphical representation of the brightness values that comprise an image. The brightness values (i.e. 0-255) are displayed along the X axis of the graph. The frequency of occurrence of each of these values in the image is shown on the Y axis. Here is an example of a histogram shown below with its image (For Red Color Values Only *within a selected image portion*):

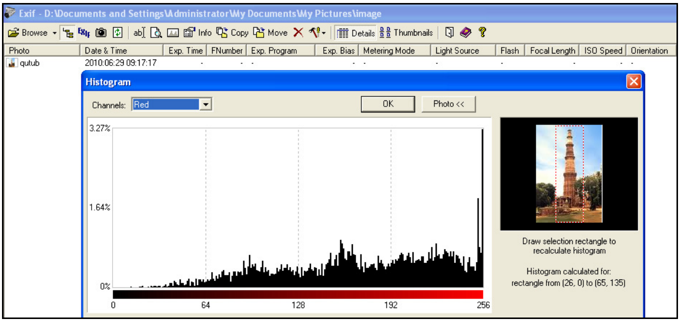


Figure 19: Image Histogram

Here is another example of a histogram shown below with its image (For RGB):

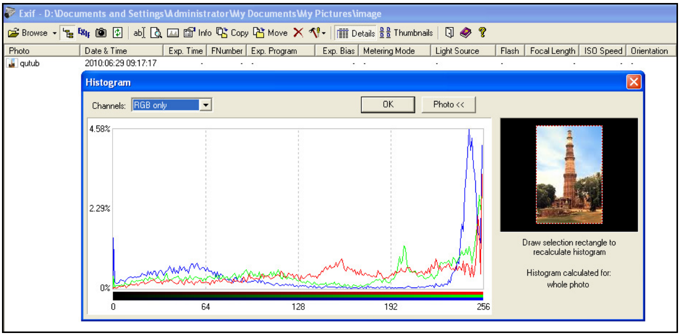


Figure 20: Image Histogram Example

Histograms can also be used to equalize the image, as well as providing a large number of statistics about it.

## Image Rectification

The raw satellite images may contain variety of errors in their geometry and radiometry (cosmetic appearance). Hence it is important to rectify these images before starting their interpretation. This typically involves the initial processing of raw satellite image for correcting geometric distortions, radiometric corrections and calibrations and noise removal from the data. This process is referred as Image Rectification or Image Preprocessing. Image preprocessing is done before enhancement, manipulation, interpretation and classification of satellite images hence it is called so.

## Image Restoration

Most recorded images are subject to distortion due to noise which degrades the image. Two of the more common errors that occur in multi-spectral imagery are striping (or banding) and line dropouts.

Stripping or banding, are errors that occur in the sensor response or data recording and transmission and results in a systematic error or shift of pixels between rows.

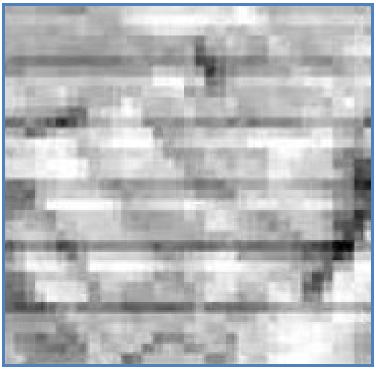


**Figure 21: Stripping**

Dropped Lines are errors that occur in the sensor response or data recording and transmission which loses a row of pixels in the image.

**Figure 22: Example of a Dropped Line**

## Mean filtering

It is a procedure for decreasing noise. The procedure takes an area surrounding a central pixel, calculates the average of the area and uses it as the new value for the pixel. This has the effect of spreading any noise across a neighborhood. Below is an example of mean filtering, taking a small 3x3 around each pixel and averaging it.

Figure 23: Effects of Mean Filtering

To blur the noise further, we could increase the window size for filtering. The figure 24 shows the effect of 3x3 and 9x9 filters. By this method, although the noise is much less visible, it also happens with other parts of the image. Obviously, we need a better way to process this noise.

## Median filtering

As the name suggests, median filtering works similarly to the mean filter, except the neighbourhood median is used as the new pixel value. For example, given this 3x3 neighbourhood of pixels:

223 210 198
210  000 188
198 188 175
223 210 198 210 000 188 198 188 175

We sort the pixels:
000 175 188 188 *198* 198 210 210 223

And select the middle element, 198, as our median value.
This has excellent results at removing the impulse noise from the image. This is because impulse noise often generates localized discrepancies, which the median filter can happily ignore. For consistency, let us look at what a 9x9 median filter will do to our input image:

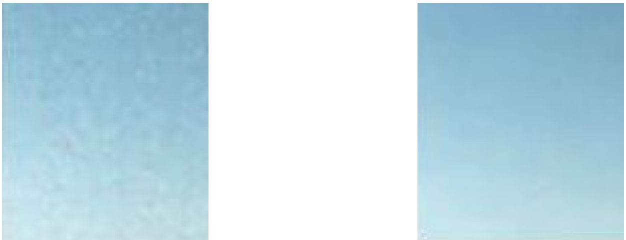


Figure 24: Effect of Median Filtering

## Image Enhancement

Raw satellite data often contain a vast amount of information that is not readily apparent to the analyst. Therefore, image enhancement techniques are used to highlight features of interest and expose subtle differences in the spectral signature of the components of the target.
One of the strengths of image processing is that it gives us the ability to enhance the view of an area by manipulating the pixel values, thus making it easier for visual interpretation. There are several techniques which we can use to enhance an image, such as Contrast Stretching and Spatial Filtering.
Some of these techniques involve modifying an image in order to improve contrast between features in a

well defined spectral range or to improve resolution and detail, while other techniques use complex mathematical calculations to derive an entirely new image from a set of raw image data.

## Contrast Stretching

Quite often the useful data in a digital image populates only a small portion of the available range of digital values (commonly 8 bits or 256 levels). Contrast enhancement involves changing the original values so that more of the available range is used; this then increases the contrast between features and their backgrounds. There are several types of contrast enhancements which can be subdivided into Linear and Non-Linear procedures.

## Linear Contrast Stretch

This involves identifying lower and upper bounds from the histogram (usually the minimum and maximum brightness values in the image) and applying a transformation to stretch this range to fill the full range. The linear contrast stretch enhances the contrast in the image with light toned areas appearing lighter and dark areas appearing darker, making visual interpretation much easier.

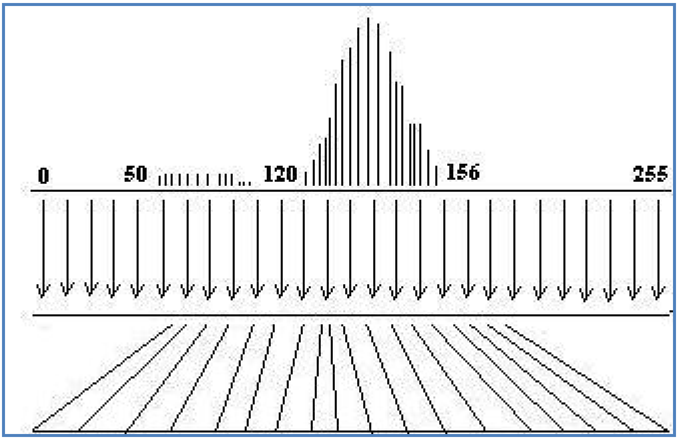


Figure 25: Effect of Linear Contrast Stretch

In the above figure, the DN values range from 50 to 156 (out of the limit available of 0 to 255). But below 120 there are few pixels, so the effective range is 120-156. When displayed without any expansion (stretch), the resulting image is of low contrast.

The linear stretch involves moving the 50 value to 0 and the 156 DN to 255; all intermediate values are moved (stretched) proportionately. This is the standard linear stretch.

**Other Contrast Stretch Schemes**

Other stretching functions are available, such as Histogram-equalization stretch where pixel frequency is considered in assigning stretch values.

Other Contrast Stretch Schemes are also available for special purposes. These are mostly nonlinear functions that affect the precise distribution of gray levels (in image) in different ways.

Commonly used special stretches include

Exponential

Linear with Saturation

Logarithmic,

Piecewise Linear,
Probability Distribution Function, and
Ramp Cumulative Distribution Function,
Sinusoidal Linear with Saturation.

### Spatial Filtering

Spatial filters are designed to highlight or suppress features in an image based on their spatial frequency. The spatial frequency is related to the textural characteristics of an image. Rapid variations in brightness levels ('roughness') reflect a high spatial frequency; 'smooth' areas with little variation in brightness level or tone are characterized by a low spatial frequency. Spatial filters are used to suppress 'noise' in an image, or to highlight specific image characteristics.

### Low-pass Filters

These are used to emphasize large homogenous areas of similar tone and reduce the smaller detail. Low frequency areas are retained in the image resulting in a smoother appearance to the image.

### High-pass Filters

These allow high frequency areas to pass with the resulting image having greater detail resulting in a sharpened image.

### Directional Filters

They are designed to enhance linear features such as roads, streams, faults, etc. The filters can be designed to enhance features which are oriented in specific directions, making these useful for radar imagery and for geological applications. Directional filters are also known as edge detection filters.

### Density Slicing
This is a form of enhancement where the grey tones in an image are divided into a number of intervals reflecting a range of digital numbers. This transforms the image from a continuum of gray tones into a limited number of gray or color tones reflecting the specified ranges in digital numbers. This is useful in displaying weather satellite information.

### Mosaicing of Multiple Images
Images taken at different times and lighting conditions can be manipulated in order to produce a seamless mosaic from several images. In areas which are frequently cloud covered, it is possible to collect a number of images over time and selectively use only the portions which are nearly cloud-free in order to produce a cloud-free image mosaic of an area.

## Land Use and Land Cover
One of the most important uses of image interpretation in remote sensing is the production of Land Use and Land Cover maps.

### Land Use
It refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture, urban development, and mostly areas impacted by human activity. Knowledge of land use helps us to develop strategies to balance conservation, conflicting uses, and developmental pressures.

Some of the issues which are of concern include the removal or disturbance of productive land, urban encroachment, and depletion of forests.

### Land Cover
It refers to the surface cover whether vegetation, bare soil, water, urban development or other. Identifying,

delineating and mapping land cover is important for global monitoring studies, resource management, and planning activities.

## USGS LU/LC Classification

The United States Geological Survey (USGS) is a scientific agency of the United States government.
Land use and land cover classification was combined into a single hierarchical system by the USGS and referred to as the USGS Land Use Land Cover Classification System.
The classification system consists of four Levels:

**USGS Level I** is the most general and allows for land classification at a small scale (>1:250,000) and is used for satellite imagery (Landsat).

| | Level I Categories |
|---|---|
| 1 | Urban Land |
| 2 | Agricultural Land |
| 3 | Range Land |
| 4 | Forest Land |
| 5 | Water |
| 6 | Wet Land |
| 7 | Barren Land |
| 8 | Tundra |

**Table 4: USGS Level I Land Classification**

**USGS Level II** is a subdivision of Level I categories into related classes. This level of generalization is useful for air photos at scales of about 1:80,000.
Level II Categories: (Michigan Land/Use Cover Classification System)

I URBAN & BUILT UP

11 Residential
12 Commercial, Services, & Institutional
13 Industrial
14 Transportation, Communication & Utilities
[15] Map Industrial Parks under appropriate category in Commercial
Services & Institutional (12) or Industrial (13)
16 Mixed
17 Extractive
19 Open & Other

2 AGRICULTURAL LAND

21 Cropland, Rotation & Permanent Pasture
22 Orchards, Bush-Fruits, Vineyards & Ornamental Horticulture Areas
23 Confined Feeding Operations
[28] Inactive Land (These plant communities will be mapped under
herbaceous, rangelands (31).
29 Other Agricultural Land

3 RANGELAND

31 Herbaceous Rangeland
32 Shrub Rangeland

4 FOREST LAND

41 Broadleaved Forest (generally deciduous)
42 Coniferous Forest
43 Mixed Conifer-Broadleaved Forest

5 WATER

51 Streams & Waterways
52 Lakes
53 Reservoirs
54 Great Lakes

6 WETLANDS

61 Forested (wooded) Wetlands
62 Non-Forested (non-wooded) Wetlands

7 BARREN

71 Salt Flats (not applicable to Michigan)
72 Beaches & Riverbanks
73 Sand Other than Beaches
74 Bare Exposed Rock
75 Transitional Areas
79 Other

8 TUNDRA

9 PERMANENT SNOW & ICE

Level III is suitable for classifying images at scales ranging from 1:20,000 to 1:80,000. The categories are designed to be adaptable to the local needs of public agencies.

Level IV is most useful for air photos at scales larger than 1:20,000. The categories are designed to be adaptable to the local needs of public agencies.

USGS Level I, II, III and IV Classification Example

4 Forest Land (Level I)
42 Coniferous Forest (Level II)

421 Upland Conifers (Level III)
4211 White Pine Predominates (Level 1V)
4212 Red Pine Predominates (Level 1V)
4213 Jack Pine Predominates (Level 1V)
4214 Scotch Pine Predominates (Level 1V)
4215 White Spruce Predominates (Level 1V)
4219 Others (Level 1V)
422 Lowland Conifers (Level III)
4221 Cedar Predominates (Level 1V)
4222 Black Spruce Predominates (Level 1V)
4223 Tamarack Predominates (Level 1V)
4224 Balsam Fir – white Spruce Predominates (Level 1V)
4225 Balsam Fir Predominates (Level 1V)
4229 Others (Level 1V)

## Classification

Classification is a process by which a set of items is grouped into classes based on common characteristics. Classification of satellite image data is based on placing pixels with similar values into groups and identifying the common characteristics of the items represented by these pixels.

Classification is another tool that is very useful when multispectral imagery of the same geographical region is compared. Algorithms can be used that derive a value for each pixel in the image from its brightness values in each image. Plotting the resulting data on a 2 or 3 dimensional graph can identify clusters of pixels that share common spectral characteristics across multiple bands.

In classifying features in an image we use the elements of visual interpretation to identify homogeneous groups of pixels which represent various features or land cover classes of interest. In digital images it is possible to model this process, to some extent, by using two methods: Unsupervised Classifications and Supervised Classifications.

### Unsupervised Classifications

This is a computerized method without direction from the analyst in which pixels with similar digital numbers are grouped together into spectral classes using statistical procedures such as nearest neighbor and cluster analysis. The resulting image may then be interpreted by comparing the clusters produced with maps, airphotos, and other materials related to the image site.

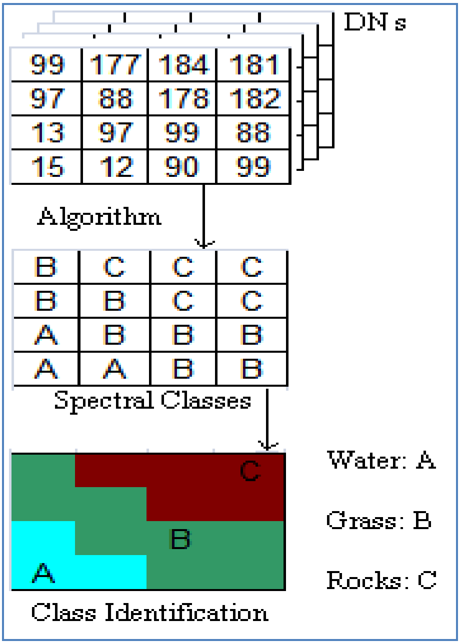


Figure 26: Example of Unsupervised Classification

### Supervised Classification

In a supervised classification the analyst identifies several areas in an image which represent known features or land cover. These known areas are referred to as 'training sites' where groups of pixels are a good representation of the land cover or surface phenomenon. Using the pixel information the computer program (algorithm) then looks for other areas which have a similar grouping and pixel value. The analyst decides on the training sites and thus supervises the classification process.

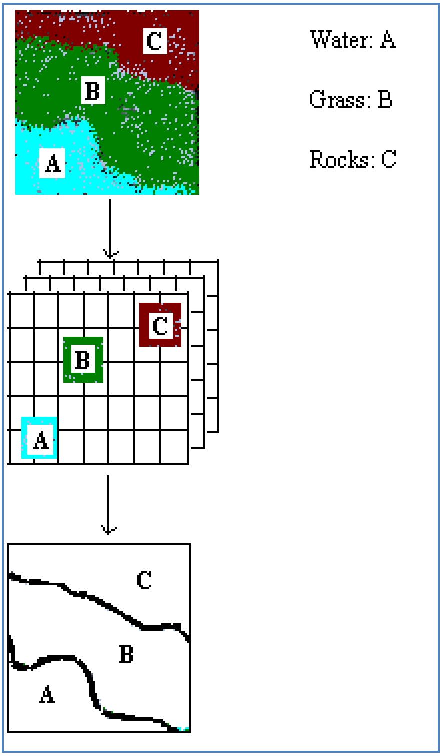


Figure 27: Example of Supervised Classification

## False-colour composite (FCC):

False colour image, also called a false-colour composite (FCC) is a colour image where parts of the non-visible EM spectrum are expressed as one or more of the red, green, and blue components; such that the colours produced by the Earth's surface do not correspond to normal visual experience. The most commonly seen false-colour images display the very-near infrared as red, red as green, and green as blue.

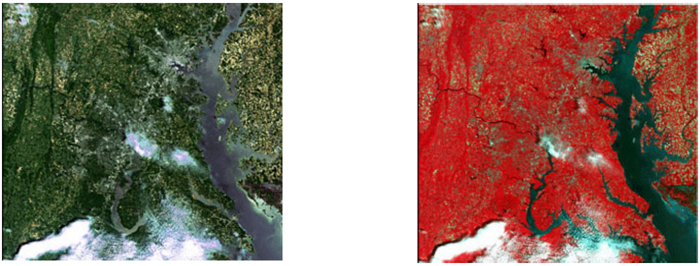


Figure 28: An Image and its FCC

Colour is widely used in remote sensing work. In many instances, the use of colour conveys additional information both visually and scientifically. Remote sensing satellites view the earth in different spectral bands, viz. near infrared (NIR), red, green, and blue bands, in a conventional multispectral imaging system. In the absence of a blue channel, colour images can be generated using near infrared, red, and green bands in what is known as a false colour composite (FCC) and does not look natural, like the image we see with the naked eye. For a trained interpreter, this does not pose any problems, however for the non-remote sensing professional, this may become a handicap. To overcome this, there is a requirement to generate natural colour composites (NCC) from the given false colour composite, which demands the simulation of a blue band to be combined with green and red bands.

# Chapter - IV

Basic Concepts of Geographic Data
GIS and its Components
Data Acquisition
Raster and Vector formats
Topology and Data models
Spatial modeling
Data output
GIS Applications

**A map is the greatest of all epic poems. Its lines and colors show the realization of great dreams.**

[Gilbert H. Grosvenor,
Editor of National Geographic (1903- 1954)]

## Basic Concepts of Geographic Data

A Geographic Information System (GIS) is an information system designed to work with data referenced by spatial / geographical coordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. It may also be considered as a higher order map. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. (ESRI)

A Geographic Information System is a computer based system which is used to digitally reproduce and analyze the feature present on earth surface and the events that take place on it. In the light of the fact that almost 70% of the data has geographical reference as its denominator, it becomes imperative to underline the importance of a system which can represent the given data geographically.

A typical GIS can be understood by the help of various definitions given below:-

A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on Earth

Burrough in 1986 defined GIS as, "Set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes"

Arnoff in 1989 defines GIS as, "a computer based system that provides four sets of capabilities to handle geo-referenced data:

- data input
- data management (data storage and retrieval)
- manipulation and analysis
- data output. "

Hence GIS is looked upon as a tool to assist in decision-making and management of attributes that needs to be analyzed spatially.

A GIS stores information about the world as a collection of thematic layers that can be linked together by geography. This simple but exceptionally powerful and versatile concept has proven invaluable for solving many real-world problems such as tracking delivery vehicles, recording details of planning applications and modeling global atmospheric circulation.

Geographic information contains either an explicit geographic reference, such as a latitude and longitude or national grid coordinate; or an implicit reference such as an address, postal code, census tract name, forest identifier, or road name. The automated process called geo-coding is used to create explicit geographic references (multiple locations) from implicit references (descriptions such as addresses). These geographic references allow one to locate features, such as a business or forest stand, and events, such as an earthquake, on the earth's surface for analysis.

Geographic information systems work with two fundamentally different types of geographic models - the "vector" model and the "raster" model. In the vector model, information about points, lines, and polygons is encoded and stored as a collection of x,y coordinates. The location of a point feature, such as a bore hole, can be described by a single x,y coordinate. Linear features, such as roads and rivers, can be stored as a collection of point coordinates. Polygonal features, such as sales territories and river catchments, can be stored as a closed loop of coordinates.

The vector model is extremely useful for describing discrete features, but less useful for describing continuously varying features such as soil type or accessibility costs for hospitals. The raster model has evolved to model such continuous features. A raster image comprises a collection of grid cells rather like a scanned map or picture. Both the vector and raster models for storing geographic data have unique advantages and disadvantages. Modern GISs are able to handle both models.

### What can GIS Do?

- GIS is used to perform Geographic Queries and Analysis. The ability of GIS to search databases and perform geographic queries has saved many companies millions of dollars. GISs have helped reduce costs by :
    - Streamlining customer service.
    - Reducing land acquisition costs through better analysis.
    - Reducing fleet maintenance costs through better logistics.
    - Analyzing data quickly, for example - a realtor could use a GIS to find all houses within a certain area that have tiled roofs and five bedrooms, and then list their characteristics.
- Improve Organizational Integration

  Many organizations that have implemented a GIS have found that one of its main benefits is improved management of their own organization and resources. Because GISs have the ability to link data sets together by geography, they facilitate interdepartmental information sharing and communication. By creating a shared database, one department can benefit from the work of another - data can be collected once and used many times.

- Make Better Decisions
  A GIS is not an automated decision making system but a tool to query, analyze, and map data in support of the decision making process. GIS technology has been used to assist in tasks such as presenting information at planning inquiries, helping resolve territorial disputes, and setting pylons in such a way as to minimize visual intrusion.
- GIS can be used to take decisions about the location of new housing developments that have minimal environmental impact or are located in a low-risk area or are close to a population hub. The information can be presented briefly and clearly in the form of a map and associated report, allowing decision makers to focus on the real issues rather than trying to understand the data. Because GIS products can be created quickly, multiple scenarios can be evaluated efficiently and effectively.
- Making Maps
  Maps have a special place in GIS. The process of making maps with GIS is much more flexible than are traditional manual or other automated cartography approaches. It begins with database creation. Existing paper maps can be digitized and computer-compatible information is translated into the GIS. The GIS-based cartographic database can

be both continuous and scale free. This allows the creation of map products which are centered on any location, at any scale, and showing selected information symbolized effectively to highlight specific characteristics. The characteristics of atlases and map series can be encoded in computer programs and compared with the database at final production time. Digital products for use in other GISs can also be derived by simply copying data from one database to other. In a large organization, topographic databases can be used as reference frameworks by other departments.

## Principal Functions of GIS

Given below are the principal functions of GIS:

### Data Capture

Data used in GIS often come from many types, and are stored in different ways. A GIS provides tools and a method for the combination of different data into a format to be compared and analyzed. Data sources are mainly obtained from manual digitization and scanning of aerial photographs, paper maps, and existing digital data sets. Remote-sensing satellite imagery and GPS are promising data input sources for GIS.

### Database Management and Update

After data are collected and integrated, the GIS must provide facilities, which can store and maintain data. Effective data management has many definitions; however, it should include all of the following aspects - data security, data integrity, and data storage / retrieval, and data maintenance abilities.

### Geographic Analysis

Data integration and conversion are only a part of the input phase of GIS. What is required next is the ability to interpret and to analyze the collected information quantitatively and qualitatively. For example, satellite image can assist an agricultural scientist to project crop yield per hectare for a particular region. For the same region, the scientist also has the rainfall data for the past six months collected through weather station observations. The scientists also have a map of the soils for the region which shows fertility and suitability for agriculture. These point data can be interpolated and what you get is a thematic map showing isohyets (*A line drawn on a map connecting points that receive equal amounts of rainfall*) or contour lines of rainfall.

### Presenting Results

One of the most exciting aspects of GIS technology is the variety of ways in which the information can be presented once it has been processed by GIS. Traditional methods of tabulating and graphing data can be supplemented by maps and three dimensional images. Visual communication is one of the most fascinating aspects of GIS technology and is available in a diverse range of output options.

## GIS and its Components

A working GIS integrates **five key components**: hardware, software, data, people, and methods.

**Hardware** is the computer on which a GIS operates. Today, GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations.

**Software**

GIS software provides the functions and tools needed to store, analyze, and display geographic information.

Key software components are:

- Tools for the input and manipulation of geographic information.
- A database management system (DBMS).
- Tools that support geographic query, analysis, and visualization.
- A graphical user interface (GUI) for easy access to tools.

**Data**

Possibly the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organizations to organize and maintain their data, to manage spatial data.

**People**

GIS technology is of limited value without the people who manage the system and develop plans for applying it to real-world problems. GIS users range from technical specialists who design and maintain the system, to those who use it to help them perform their day to day work.

**Methods**

A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization.

## Data Acquisition

The functionality of GIS relies on the quality of data available, which, in most developing countries, is either redundant or inaccurate. Although GIS are being used widely, effective and efficient means of data collection have yet to be systematically established. The true value of GIS can only be realized if the proper tools to collect spatial data and integrate them with attribute data are available.

### Manual Digitization

Manual Digitizing still is the most common method for entering maps into GIS. The map to be digitized is affixed to a digitizing table, and a pointing device (called the digitizing cursor or mouse) is used to trace the features of the map. These features can be boundary lines between mapping units, other linear features (rivers, roads, etc.) or point features (sampling points, rainfall stations, etc.) The digitizing table electronically encodes the location of the cursor with the precision of a fraction of a millimeter. The most common digitizing table uses a fine grid of wires, embedded in the table. The vertical wires will record the Y-coordinates, and the horizontal ones, the X-coordinates. The range of digitized coordinates depends upon the density of the wires (called digitizing resolution) and the settings of the digitizing software. A digitizing table is in general a rectangular area in the middle, separated from the outer boundary of the table by a small border. Outside of this so-called active area of the digitizing table, no coordinates are recorded. The lower left corner of the active area will have the coordinates $x = 0$ and $y = 0$. Therefore, the (part of the) map that is to be digitized should always be fixed within the active area.

### Scanning System

The second method of obtaining vector data is with the use of scanners. Scanning (or scan digitizing) provides a quicker means of data entry than manual digitizing. In scanning, a digital image of the map is produced by moving an electronic detector across the map surface. The output of a scanner is a digital raster image, consisting of a large number of individual cells ordered in rows and columns.

Scanning works best with maps that are very clean, simple, relate to one feature only, and do not contain extraneous information, such as text or graphic symbols. For example, a contour map should only contain the contour line, without height indication, drainage network, or infrastructure. In most cases, such maps will not be available, and should be drawn especially for the purpose of scanning.

### Conversion

Usually the conversion is from vector to raster, because the biggest part of the analysis is done in the raster domain. Vector data are transformed to raster data by overlaying a grid with a user-defined cell size. Sometimes the data in the raster format are converted into vector format. This is the case especially if one wants to achieve data reduction because the data storage needed for raster data is much larger than for vector data. A digital data file with spatial and attribute data might already exist in some way or another. There might be a national database or specific databases from ministries, projects, or companies. In some cases a conversion is necessary before these data can be downloaded into the desired database. The commonly used attribute databases were dBase and Oracle. Sometimes spreadsheet programmes like Lotus, Quattro, or Excel were used, although these cannot be regarded as real database softwares. Remote-sensing images are digital datasets recorded by satellite operating agencies and stored in their own image database. They usually have to be converted into the format of the spatial (raster) database before they can be downloaded.

For the Conversion to vector format, two types of raster image can be used.

- In the case of Chloropleth maps or thematic maps, such as geological maps, the individual mapping units can be separated by the scanner according to their different colours or grey tones. The resulting images will be in colours or grey tone images.
- In the case of scanned line maps, such as topographic maps, the result is a black-and-white image. Black lines are converted to a value of 1, and the white areas in between lines will obtain a value of 0 in the scanned image. These images, with only two possibilities (1 or 0) are also called **binary images**.

The raster image is processed by a computer to improve the image quality and is then edited and checked by an operator. It is then converted into vector format by special computer programmes, which are different for colour/grey tone images and binary images.

Scanning and conversion to vector is therefore, only beneficial in large organizations, where a large number of complex maps are entered. In most cases, however, manual digitizing will be the only useful method for entering spatial data in vector format.

## Raster and Vector Formats

The term file format refers to the logical structure used to store information in a GIS file. File formats are important in part because not every GIS software package supports all formats. If a data set is to be used but it isn't available in a format that your GIS supports, you will have to find a way to transform it, find another data set, or find another GIS.

Almost every GIS has its own internal file format. These formats are designed for optimal use inside the software and are often proprietary. They are not designed for use outside their native systems. Most systems also support transfer file formats. Transfer formats are designed to bring data in and out of the GIS software, so they are usually standardized and well documented. If your data needs are simple, your main concern will be with the internal format that your GIS software supports. If you have complex data needs, you will want to learn about a wider range of transfer formats, especially if you want to mix data from different sources. Transfer formats will be required to import some data sets into your software.

### Vector Formats

Many GIS applications are based on vector technology, so vector formats are common. They are also complex because there are many ways to store coordinates, attributes, attribute linkages, database structures, and display information. Some of the most common formats are briefly described below:

**Geography Markup Language (GML)** – GML is XML based open standard (by OpenGIS) for GIS data exchange.

**AutoCAD DXF** - Contour elevation plots in AutoCAD DXF format

**Shapefile** - ESRI's open, hybrid vector data format using SHP, SHX and DBF files.

**MapInfo TAB format** - MapInfo's vector data format using TAB, DAT, ID and MAP files.

**National Transfer Format (NTF)** - National Transfer Format (mostly used by the UK Ordnance Survey)

**TIGER** - Topologically Integrated Geographic Encoding and Referencing

**Cartesian coordinate system (XYZ)** - Simple point cloud

**Vector Product Format** - National Geospatial-Intelligence Agency's (NGA) format of vectored data for large geographic databases.

**GeoMedia** - Intergraph's Microsoft Access based format for spatial vector storage.

**ISFC** - Intergraph's MicroStation based CAD solution attaching vector elements to a relational Microsoft Access database

**Personal Geodatabase** - ESRI's closed, integrated vector data storage strategy using Microsoft's Access MDB format

**File Geodatabase** - ESRI's file-based geodatabase format, stored as folders in a file system. ESRI also has an enterprise Geodatabase format for use in an RDBMS.

**Coverage** - ESRI's closed, hybrid vector data storage strategy. Legacy ArcGIS Workstation / ArcInfo format with reduced support in ArcGIS Desktop lineup

**Spatial Data File** - Autodesk's high-performance geodatabase format, native to MapGuide

**GeoJSON** - a lightweight format based on JSON, used by many open source GIS packages

**SOSI_Standard** - a spatial data format used for all public exchange of spatial data in Norway

## Raster Formats

Raster files generally are used to store image information, such as scanned paper maps or aerial photographs. They are also used for data captured by satellite and other airborne imaging systems. Images from these systems are often referred to as remote-sensing data. Unlike other raster files, which express resolution in terms of cell size and dots per inch (dpi), resolution in remotely sensed images is expressed in meters, which indicates the size of the ground area covered by each cell.

## Raster Formats for Geographic Images

**GeoTIFF** - A standard image file format for GIS applications

The GeoTIFF specification defines a set of TIFF tags provided to describe all "Cartographic" information associated with TIFF imagery that originates from satellite imaging systems, scanned aerial photography, scanned maps, digital elevation models, or as a result of geographic analysis. Its aim is to allow means for tying a raster image to a known model space or map projection.

The Aldus-Adobe's public domain Tagged Image File Format (TIFF) is one of the widely used raster file formats, which is platform independent and has provision for extension. The basic idea was to exploit the extensibility feature of TIFF, which allows to officially register new TIFF Tags in order to create a well established structured format for a variety of geographic information. GeoTIFF format fully complies with the TIFF 6.0 specifications, and its extensions do not in any way go against the TIFF recommendations, nor it limits the scope of raster data supported by TIFF. It uses a "MetaTag" (GeoKey) approach to encode dozens of information elements into just six tags, taking advantage of TIFF platform-independent data format representation to avoid cross-platform interchange difficulties.

## ARC Digitized Raster Graphics (ADRG)

ADRG is a standard National Imagery and Mapping Agency (NIMA)'s digital product designed to support applications that require a raster map background display.

- ADRG data is divided into geographic data sets as Distribution Rectangles (DRs).
- ADRG directories contain a general information file (.GEN extension) and one or more ADRG zone distribution rectangle (ZDR) image files (.IMG extension).

- The GEN file provides image parameters and support data for the ZDR image files associated with a DR.
- For each dataset, image data within a ZDR image file is returned as a single feature, since this feature will contain the entire image data of one ZDR image file.

## BIL - Band Interleaved by Line

ESRI raster image is provided as four main files, with the extension of each file defining the file type.

| Extension | File type |
|---|---|
| .bil | Raster data file |
| .hdr | Header file |
| .blw | World file |
| .stx | Statistics file |

Raster data file (.bil)

The raster data for each layer are provided as unsigned integer data in a simple binary raster format (either 8-bit, 16-bit, or 32-bit). There are no header or trailer bytes embedded in the image. The data are stored in row major order (all the data for row 1, followed by all the data for row 2, etc.).

Header file (.hdr)

The raster data header file is an ASCII text file containing size and coordinate information for the layer. Many standard software packages require the header file to provide important geo-referencing information for the image. It includes the information such as the number of rows in the image, number of columns in the image, number of spectral bands in the, number of bits per pixel (8, 16 or 32) etc.

World file (.blw)
The world file is an ASCII text file containing coordinate information. It is used by some packages for geo-referencing of image data. It includes XDIM( x-dimension of a pixel in geographic units (decimal degrees)), Negative YDIM (negative y-dimension of a pixel in geographic units (decimal degrees)) etc.

Statistics file (.stx)
The statistics file is an ASCII text file which lists the band number, minimum value, maximum value, mean value, and standard deviation of the values in the raster data file.

## Digital Raster Graphic (DRG)

A digital raster graphic (DRG) is a digital image resulting from scanning a United States Geological Survey (USGS) paper topographic map for use on a computer. DRGs created by USGS are typically scanned at 250 dpi and saved as a TIFF. The raster image typically includes the original border information, referred to as the "map collar". The map file is projected using Universal Transverse Mercator (UTM) coordinate system and geo-referenced to the surface of the earth. DRG's are regularly used in GIS applications.

## ECW (Enhanced Compression Wavelet)

ECW is a proprietary wavelet compression image format optimized for aerial and satellite imagery. It was developed by Earth Resource Mapping, and is now owned by ERDAS Inc. The lossy compression format efficiently compresses very large images with fine alternating contrast. ECW enables Discrete Wavelet Transformations (DWT) and inverse-DWT operations to be performed on very large images very quickly, while only using a tiny amount of RAM.

## Topology and Data models

The greatness of GIS is in the analytical capabilities of the system. What distinguish the GIS system from other information system are its spatial analysis functions. Although the data input is, in general, the most time consuming part, it is for data analysis that GIS is used. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis assists the study of real-world processes by developing and applying models. Such models shed light on the underlying trends in geographic data and thus make new information obtainable. Results of geographic analysis can be communicated with the help of viewers and maps.

When viewing a map, the map-reader must interpret a variety of points, lines, and other symbols to identify spatial relationships among the represented geographic entities. For example, one can use a map to find a route from one city to another, or to identify which county contains a feature of interest. The information required to perform these analyses is not explicit in the map; however, the map-reader can interpret the required spatial relationships from mapped objects.

In a GIS database, the method by which spatial relationships are explicitly represented is termed as topology.

Topology is used to describe how linear objects connect, to define areas, and to identify the areas lying to either side of a linear object. Information about these spatial relationships is stored in a topological data structure and is essential to carry out most GIS functions.

Topology gives the spatial relationship between connecting and adjacent coverage features (e.g., arc, nodes, polygons, and points). For instance, the topology of an arc includes from and to nodes (beginning of the arc and ending of the arc representing direction) and its left and right polygon. Topological relationships are built from simple elements into complex elements: points (simplest elements), arcs (sets of connected points), and areas (sets of connected arcs). Topological data structure, in fact, adds intelligence to the GIS database.

## Spatial modeling

Geographic data are organized in a geographic database. This database can be considered as a collection of spatially referenced data that acts as a model of reality. There are two important components of this geographic database: its geographic position and its attributes or properties. In other words, spatial data (Where is it?) and attribute data (What is it?)

The attributes refer to the properties of spatial entities. They are often referred to as non-spatial data since they do not in themselves represent location information.

### Spatial data

Geographic position refers to the fact that each feature has a location that must be specified in a unique way. To specify the position in an absolute way a coordinate system is used. For small areas, the simplest coordinate system is the regular square grid. For larger areas, certain approved cartographic projections are commonly used. Internationally there are many different coordinate systems in use.

Geographic object can be shown by FOUR types of representation viz., points, lines, areas, and continuous surfaces.

### Point Data

Points are the simplest type of spatial data. They are-zero dimensional objects with only a position in space but no length.

### Line Data

Lines (also termed segments or arcs) are one-dimensional spatial objects. Besides having a position in space, they also have a length.

### Area Data

Areas (also termed polygons) are two-dimensional spatial objects with not only a position in space and a length but also a width (in other words they have an area).

### Spatial Analysis

It helps to:

- Identify trends on the data.
- Create new relationships from the data.
- View complex relationships between data sets.
- Make better decisions.

Before beginning geographic analysis, one needs to review the problem and create an objective. The analysis requires step-by-step procedures to arrive at the conclusions.

The variety of geographical analysis procedures can be subdivided into the following categories.

- Database Query.
- Overlay.
- Network analysis.
- Digital Terrain Model.
- Statistical and Tabular Analysis.

## Database Query

The selective display and retrieval of information from a database are among the essential requirements of GIS. The capacity to selectively retrieve information from GIS is an important facility. Database query simply asks to see already stored information. Chiefly there are two types of queries that most common GIS permit:

- Query by attribute,
- Query by geometry.

Map features can be retrieved on the basis of attributes. For example, the query may be to show all the urban areas having the population density greater than 1,500 per square kilometer. Many GIS include a sophisticated function of RDBMS known as Standard Query Language (SQL), to search a GIS database. The attribute database, in general, is stored in a table (relational database mode.) with a unique code linked to the geometric data. This database can be searched with specific characteristics. However, more complex queries can be made with the help of SQL.
GIS can carry out a number of geometric queries. The simplest application, for example, is to show the attributes of displayed objects by identifying them with a graphical cursor. There are five forms of primitive geometric query: viz.,

- Query by point,
- Query by rectangle,
- Query by circle,
- Query by line,
- Query by polygon

### Overlay Operations

The characteristic of GIS is the overlay operations. Using these operations, new spatial elements are created by the overlaying of maps.

There are two different types of overlay operations depending upon data structures:

### Raster overlay

It is a relatively straightforward operation and often many data sets can be combined and displayed at once.

### Vector overlay

The vector overlay, however is far more difficult and complex and involves more processing.

### Logical Operators

The concept of map logic can be applied during overlay. The logical operators are Boolean functions. There are mainly four types of Boolean Operators: OR, AND, NOT, and XOR.

With the use of logical, or Boolean, operators spatial elements / or attributes are selected that fulfill certain condition, depending on two or more spatial elements or attributes.

### Network Analysis

Network models are based on interconnecting logical components, of which the most important are:

"Nodes" - These define start, end and intersections.

"Chains" – These are line features joining nodes.

"Links" – These join together the points making up the chains.

Simple and most apparent network analysis applications are:

Street network analysis,

Traffic flow modelling,

Telephone cable networking,

Pipelines etc.

The other obvious applications would be service centre locations based on travel distance. Basic forms of network analysis simply extract information from a network. More complex analysis process information in the network model to derive new information. One example of this is the classic shortest-path between two points. The vector mode is more suited to network analysis than the raster model.

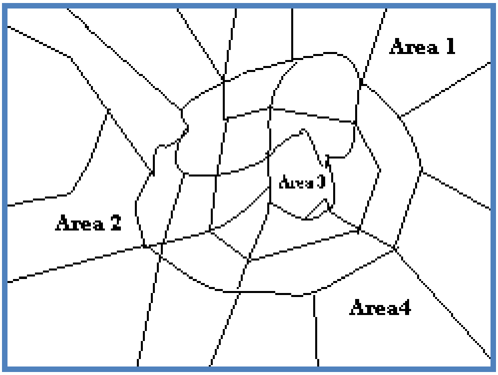


Figure 29: Area network

## Digital Terrain Model

The object of Digital Terrain analysis is to represent a surface and its properties accurately. This is normally achieved by creating a digital terrain model, often known as DTM, formed by sampling the surface. A digital terrain model can be viewed in two different ways:

- as an isoline map,
- as an isometric model.

Isolines join points of equal value on a surface. The shading defines bands, including all heights, between the isolines. Isometric models can be shown in three-dimensional models. These models show the terrain in perspective so that the apparent height is proportional to the value of the point. Visualization techniques are used to project the model from the given viewpoint.

### Tabular Statistical Analysis

If in a road network, the streets have been categorized then in such a case the statistical analysis may answer questions like

- What unique categories are there for streets?
- How many features can be identified for each unique category?
- Summarizing the analysis by using any attribute.

## Data output

Data output is in the form of Raster or Vector formats. Currently used data formats for raster image data like PNG, GIF, BMP, and TIFF have a common limitation in the data that they can store. In contrast, the Hierarchical Data Format (HDF) designed by the US National Centre for Supercomputing Applications (NCSA) is a general purpose scientific data format which can store any datatype.

HDF is a multi-object file format used for the transfer of graphical and numerical data between machines. It is versatile, flexible, extensible and portable. HDF files are self describing. The term self-description means that, for each HDF data structure in a file, its metadata (comprehensive information about the data and its location in the file) is also available as part of the format.

Many types of data can be included within an HDF file. For example, it is possible to store symbolic, numerical and graphical data by using appropriate HDF data structures.

## Viewers

There are various tools for viewing geographic data. Some of these viewers can be found on Internet.

Examples are:

**TatukGIS Viewer** - The free TatukGIS Viewer provides an easy way to quickly evaluate the TatukGIS technology and compatibility with various formats, as well as a great companion product for the TatukGIS Internet Server. It can read the following formats:

Raster - TIFF/GEOTIFF, ECW, MrSID, BMP, SPOT, JPEG, PNG, PixelStore

Vector: SHP, E00, MIF/MID, TAB, DXF, DGN, TIGER

**ArcGIS Explorer** - ESRI's free ArcGIS Explorer GIS viewers offers an easy way to view, present, and share your GIS data. It connects directly to a variety of ready-to-use ArcGIS Online basemaps and layers. It also enables one to connect to the map services or add local data such as geodatabases, shapefiles, KML files, and rasters. One can extend ArcGIS Explorer with other tools to deliver GIS analysis and other capabilities to people who do not necessarily know anything about GIS.

**GPS2CAD-08** – This GPS software gives design professionals major cost savings in data collection by using recreational-grade GPS units to collect field information and plot it in AutoCAD, or their favorite CAD program. Most recreational GPS units are well-suited for site layout and "topo-plotting" requirements that do not need great accuracy, and GPS2CAD bridges the gap between these GPS units and CAD.

**GeoMedia Viewer** - GeoMedia Viewer is an easy to use, FREE GIS software application for desktop viewing and distribution of geospatial data. It allows an organization to maximize the value of its geospatial data by extending availability to novice users who wouldn't otherwise have access because of the barriers of purchasing and learning how to use a full GIS software application.

## GIS Applications

GIS is about business. In fact, a whole new industry of business geographic is developing because GIS can affect the bottom line, improve product quality, and provide new opportunities. Here are a few examples of how different sectors of the business world are using GIS:

**Banking:** GIS activities in banking and financial institutions contain regulatory compliance (such as home mortgage disclosure act regulations), customer prospecting, and locating new branches and ATMs.

**Business locations and customer behavior:** One can more effectively figure out where to place a business if one knows the customers' base location. The closer or more accessible a business is to the people whose buying patterns match its products, the more chances are to be successful. Businesses can also compare market share with other surrounding businesses and adjust to changing demographic conditions.

**Insurance claims adjustment:** GIS can perform all the typical business and marketing tasks, including identifying potential clients, and determining risk factors.

**Journalism:** The media especially the television news media can use flythrough, zoom-ins, and visual overlays of maps on imagery, thus providing a media-rich and attractive product.

**Real estate:** Real estate agents, both residential and commercial, can use a GIS (the multiple listing service) to search for and select properties that match client needs. Some evaluators use GIS to perform mass appraisals of whole region at the same time.

**Trucking and delivery:** Moving products and material is getting more expensive all the time. Minimizing route lengths reduces cost; speeds delivery times, and enhances customer contentment. GIS has tools specifically designed to work with road and rail networks.

**Planning city operations and expansion:** City, county, and regional planning has long used GIS to track development, zone land parcels, assess available resources, and plan for future growth.
GIS allows planners to assess master plans, monitor expansion and traffic patterns, forecast change, examine population, and even decide the best place to put the latest government planning office.

**Providing protection and emergency services**
Police, human services, and emergency services are beginning to use GIS. Crime mappers can identify crime hot spots and move officers where needed, corrections officers can track their parolees, hospitals can be placed where they meet the most need, and dispatchers can route emergency services (such as

ambulance and fire) to their destinations — all with the power of GIS.

### Land management and conservation

GIS can be used to control land use and land inventory, choose set asides and easements, track and manage wildlife, plan for ecotourism, and much more.

### Military and defense-related tasks

The military and intelligence communities are taking advantage of the GIS toolkit, which includes tools purposely targeted to those users. By combining top-secret satellite data and visual evaluation from unmanned aerial vehicles (UAVs) with the power of GIS and existing datasets, defense departments can evaluate troop movements, target artillery fire, test scenarios, carry out supply and logistics operations, and monitor borders. The military and intelligence communities frequently rely on the same geospatial tools available to the general public — but they have exclusive access to certain data and data sources, as well as some additional and sophisticated software.

# Chapter - V

Satellite Navigation System
GPS
Space segment
Control segment
User segment
GPS satellite signals
Receivers
Survey Systems
Differential GPS
Static
Kinematic
Uses and Applications of GPS

**A map is the greatest of all epic poems. Its lines and colors show the realization of great dreams.**

[Gilbert H. Grosvenor,
Editor of National Geographic (1903- 1954)]

## Satellite Navigation Systems

Global Navigation Satellite Systems (GNSS) is the standard generic term for Satellite Navigation Systems (Sat Nav) that provide autonomous geo-spatial positioning with global coverage. GNSS allows small meters using time signals transmitted along a line-of-sight by radio from satellites. Receivers calculate the precise time as well as position, which can be used as a reference for scientific experiments.

As of 2010, the United States NAVSTAR Global Positioning System (GPS) is the only fully operational GNSS.

The Russian GLONASS is a GNSS in the process of being restored to full operation (21 of 24 satellites are operational).

The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be operational in 2014.

The People's Republic of China has specified that it will expand its regional Beidou navigation system into the global Compass navigation system by 2015-2017.

The global coverage for each system is generally achieved by a constellation of 20–30 Medium Earth Orbit (MEO) satellites spread between several orbital planes.

The actual systems vary, but use orbit inclinations of >50° and orbital periods of roughly twelve hours and at a height of 20,200 km.

## GPS

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS.

### How it works?

GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth. GPS receivers take this information and use triangulation to calculate the user's exact location. Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. Now, with distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map.

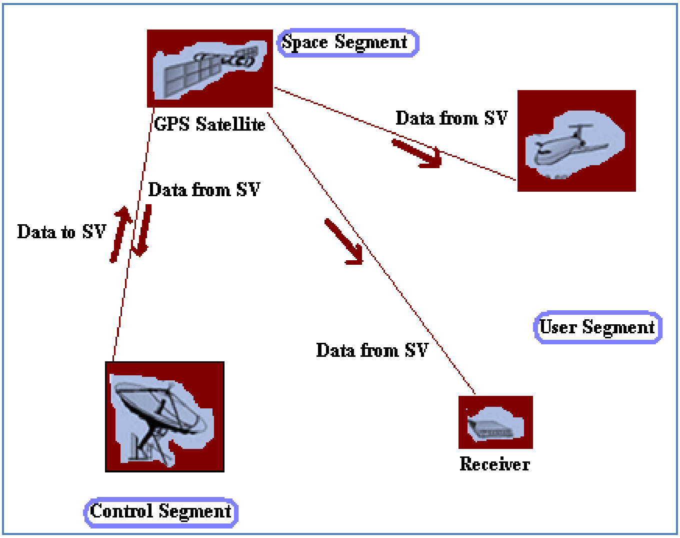


Figure 30: Control, Space and User Segments

## Space segment

Space segment consists of the all weather global system of 24 satellites, orbiting the earth every 12 hours, in six orbital planes, at an altitude of 20,200km inclined at 55 degree to the equator in a sun synchronous orbit. The following figure shows the nominal constellation of satellites. There are often more than 24 operational satellites as new ones are launched to replace older satellites. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day). The satellites are orientated in such a way that from any place on the earth, at any time, at least four SVs (Space Vehicles) are available for navigational purposes.

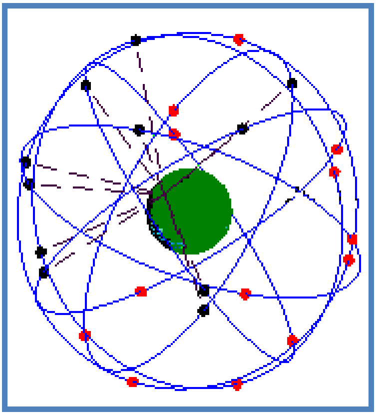


Figure 31: GPS Constellation

Four satellites are located in each of six orbits. The satellites orbit at an altitude of about 11,000 nautical miles.

## Control Segment

Control segment consists of a group of four ground based monitor stations, three upload stations and a master control station. The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in Colorado. Monitor station tracks the satellite continuously and provides data to the master control station. The monitor stations measure signals from the SVs, which are incorporated into orbital models for each satellite. The master control station calculates satellite ephemeris and clock correction coefficients and forwards them to an upload station. The upload stations transmit the data to each satellite at least once a day. The SVs then send subsets of the orbital ephemeris to GPS receivers over radio signals.

## User segment

GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity, and time estimates. A minimum of four satellites are required to compute the four dimensions of X, Y, Z (position) and Time.

## GPS satellite signals

GPS satellites transmit two low power radio signals, designated L1 and L2.

Civilian GPS uses the L1 frequency of 1575.42 MHz in the UHF band. The signals travel by line of sight, meaning they can pass through clouds, glass and plastic but will not go through most solid objects such as buildings and mountains.

A GPS signal contains three different bits of information - a pseudorandom code, ephemeris data and almanac data.

The **pseudorandom code** is simply an I.D. code that identifies which satellite is transmitting information.

Example:

One can view this number on the Garmin GPS unit's satellite page, as it identifies which satellites it's receiving.

**Ephemeris data**, which is constantly transmitted by each satellite, contains important information about the status of the satellite (healthy or unhealthy), current date and time. This part of the signal is essential for determining a position.

The **almanac data** tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite transmits almanac data showing the orbital information for that satellite and for every other satellite in the system.

**Sources of GPS signal errors**
GPS errors are often a combination of noise, bias and blunders. The sources can be SV clock errors or errors due to atmospheric effects. **Noise errors** are the combined effect of code noise (around 1 meter) and noise within the receiver (around 1 meter).

Factors that can degrade the GPS signal and thus affect accuracy include the following:

**Ionosphere and troposphere delays** - The satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct this type of error.

**Signal multipath** - This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.

**Receiver clock errors** - A receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites. Therefore, it may have slight timing errors.

**Orbital errors** - Also known as ephemeris errors, these are inaccuracies of the satellite's reported location.

**Bias errors** result from Selective Availability and other factors.
Selective Availability (SA): SA is the intentional degradation of the GPS signals by a time varying bias. SA was controlled by US Department of Defense to limit accuracy for non-US military and government

users. SA was intended to prevent military adversaries from using the highly accurate GPS signals. SA was turned off in May 2000, which significantly improved the accuracy of civilian GPS receivers.

**Blunders** can result in errors of hundreds of kilometers and can be the cause of control segment mistakes, human mistake or receiver errors from software or hardware failures.
Noise and bias errors may combine, resulting in typical ranging errors of around fifteen meters for each satellite used in the position solution.

**Number of visible satellites**
The more satellites a GPS receiver can see, the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, thereby, causing position errors or no position reading at all.
GPS units typically will not work indoors, underwater or underground.

**Satellite geometry/shading** - This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping.

## Receivers

A GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude and altitude). Once the user's position has been determined, the GPS unit can calculate other information, such as speed, bearing, track, trip distance, distance to destination, sunrise and sunset time and more.

## Survey Systems

GPS survey systems were one of the first uses of commercial GPS. These units are more accurate than the typical navigation units but rely on post-processing of the data collected by roving receivers
and a fixed reference receiver, and on averaging the data collected over a period of time, by using carrier phase tracking, (and other techniques) to get the increased accuracy.

## Differential GPS

In order to achieve on-line positioning with high accuracies, Differential GPS (DGPS) is used. In the differential positioning user point position derived from satellite signals and applies correction to that position. These corrections, difference of determined position and the known position, are generated by a reference receiver, whose position is known and is fed to the instrument, and are used by the second receiver to correct its internally generated position. This is known as Differential GPS. It is assumed that the two receivers suffer from approximately the same magnitude of geometry and timing errors and the most of the common errors cancel out using this correction technique. To remove Selective Availability (SA) and other bias errors, differential corrections are computed at the reference station and applied at the remote receiver at an update rate that is less than the correlation time of SA, which is usually less than twenty seconds. The differential positioning accuracy is of order of 1-5 m.

## Static

Two GPS receivers can be placed in separate locations for a period of time (for short distances 2mins upto 1hr) and the raw pseudo range data can be collected. This data can then be post-processed and a baseline established i.e. range and bearing. The position can be as good as 1mm but may be less good under poor satellite geometry or larger distances. This method can then be used to transfer the knowledge of one accurate point to a new point.

## Kinematic

In the same way as static surveys, raw pseudo range data is recorded at a fixed site and a mobile. One can then post process the data to see accurately where one has been. Again the distances between the static and mobile systems determine the accuracy but 0.1m is generally possible.

### Real Time Kinematic GPS

RTK systems work in similar ways to DGPS short range systems but mathematically like Kinematic post processed and can achieve accuracies of around 7cm in real time.

## Uses and Applications of GPS

GPS receivers are used for navigation, positioning, time dissemination, and other researches. Navigation in three dimensions is the primary function of GPS. Accurate positioning is possible using GPS receivers at reference locations providing corrections and relative positioning data for remote receivers. Surveying, geodetic control, and plate tectonic studies are examples. Time and frequency dissemination, based on the precise clocks is another use for GPS. Research projects have used GPS signals to calculate atmospheric factors. It is also used for Geo-referencing that is conveying correct latitude and longitude to the control points of satellite imageries and topographic maps.