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PRINCIPLES OF PHOTOGRAMMETRY AND REMOTE SENSING

M.A./M.Sc. 1st Semester

DEPARTMENT OF GEOGRAPHY AND NATURAL RESOURCE MANAGEMENT
SCHOOL OF EARTH AND ENVIRONMENTAL SCIENCE
UTTARAKHAND OPEN UNIVERSITY
(Teenpani Bypass, Behind Transport Nagar Haldwani (Nainital), Uttarakhand)

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BLOCK-I FUNDAMENTALS OF PHOTOGRAMMETRY

UNIT 1 - PHOTOGRAMMETRY

1.1OBJECTIVES

After reading this unit you will be able

- To understand the meaning of photogrammetry.
- To explain the classification and significance of photogrammetry.

1.2 INTRODUCTION

Photogrammetry, as its name implies, is a 3-dimensional coordinate measuring technique that uses photographs as the fundamental medium for metrology (or measurement). The fundamental principle used by Photogrammetry is triangulation or more specifically called Aerial Triangulation. By taking photographs from at least two different locations, so-called “lines of sight” can be developed from each camera to points on the object. These lines of sight (sometimes called rays owing to their optical nature) are mathematically intersected to produce the 3-dimensional coordinates of the points of interest.

The expression photogrammetry was first used by the Prussian architect Albrecht Meydenbauer in 1867 who fashioned some of the earliest topographic maps and elevation drawings. Photogrammetry service in topographic mapping is well established but in recent years the technique has been widely applied in the fields of architecture, industry, engineering, forensic, underwater, medicine, geology, and many others for the production of precise 3D data.

Photogrammetry can also be thought of as the sciences of geometry, mathematics, and physics that use the image of a 3D scene on a 2D piece of paper to reconstruct a reliable and accurate model of the original 3D scene. It is easier to understand the current expanded definition which includes the science of electronics by using video and other synthetic means of reproducing 2D images of 3D scenes. Furthermore, these images are also used to reconstruct reliable and accurate models of the captured scenes.

Raw aerial photographs and satellite imagery have large geometric distortions that are caused by various systematic and non-systematic factors. Photogrammetric processes eliminate these errors most efficiently and provide the most reliable solution for collecting geographic information from raw imagery. Photogrammetry is unique in terms of considering the image-forming geometry, utilizing information between overlapping images, and explicitly dealing with the third-dimension elevation.

The most important feature of photogrammetry is the fact that the objects are measured without being touched. Its applications are widespread. Principally, it is utilized for the interpretation and measurement of the object. Nowadays, photogrammetry is not just a way of making maps; rather it is another measurement tool available to the measurement scientist.

Photogrammetry and remote sensing are two related fields. This is also manifest in national and international organizations. The principal difference between photogrammetry and remote sensing is in the application; while photogrammetrists produce maps and precise three-dimensional positions of points, remote sensing specialists analyze and interpret images to derive information about the earth's land and water areas. As depicted in Fig. 1.1 both disciplines are also related to Geographic Information Systems (GIS) in that they provide GIS with essential information. Quite often, the core of topographic information is produced by photogrammetrists in the form of a digital map.

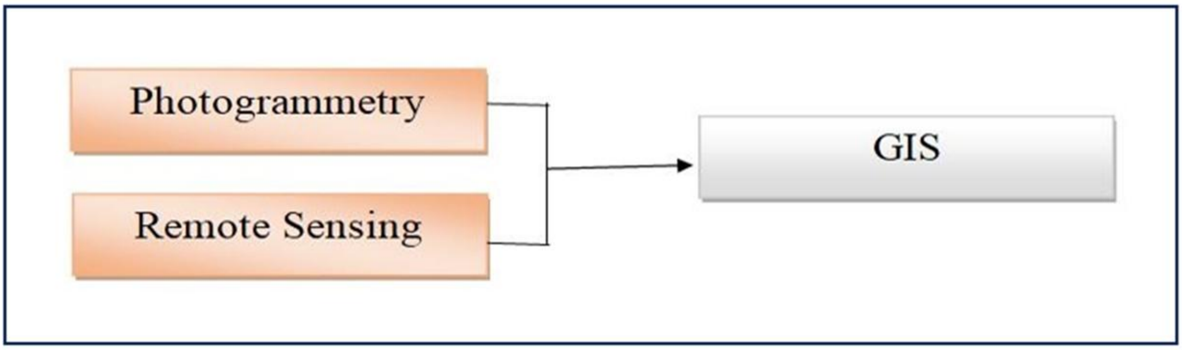

Fig. 1.1: Relationships between Photogrammetry, Remote Sensing and GIS.

1.3 PHOTOGRAMMETRY

Meaning and Definition

The word 'photogrammetry' is derived from three Greek words: *Photos*—light; *Gramma*—to draw; and *Metron*—to measure. Therefore, the root words originally signify measuring graphically using light. In simpler words, we may say that photogrammetry means photograph and its geometry, which means the geometry (metric) of the photograph.

Photogrammetry has been defined as "The science and art of determining the size and shape of objects because of analyzing images recorded on film or electronic media.

The American Society of Photogrammetry defined the term 'photogrammetry' in the year 1956 as the science or art of obtaining reliable measurements by means of photography, which was redefined later and stated as

There is no universally accepted definition of photogrammetry. The definition given below captures the most important notion of photogrammetry. **Photogrammetry** is the science of making measurements from photographs, especially for recovering the exact positions of surface points. Photogrammetry is as old as modern photography, dating to the mid-19th century and in the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane, can be determined by measuring their distance on the image, if the scale(s) of the image is known.

Development of Photogrammetry

The concept of photogrammetry goes back to the period of Leonardo da Vinci in 1492, when he began investigating perspective and central projections. Many other scientists continued da Vinci's work mathematically. One of the most important figures in photogrammetry is Aimé Laussedat, widely known as the 'Father of Photogrammetry.' In 1849, he was the first person to use terrestrial photographs for topographic mapping. In 1858, he started experimenting with aerial photography and by 1862 he had managed to get the use of photography for mappings accepted by the Science Academy of Madrid, and hence the science of photogrammetry was born, and has continued to develop. So far, photogrammetry is in its developing phase.

From around 1850, the development cycle in photogrammetry has followed four cycles. Each of these periods extended about 50 years. These cycles include

- Plane table photogrammetry (from about 1850 to 1900).
- Analog photogrammetry (from about 1900 to 1960).
- Analytical photogrammetry (from about 1960 to 1990).
- Digital photogrammetry (from 1990).

Before the invention of photography, photographs of the ground, taken by balloonists, were used to extract the relationship between objects using geometric principles. This was during the phase of plane table photogrammetry. "Plane table photogrammetry is an extension of the conventional plane table surveying." Each exposure station was determined by resection and plotted on the plane table. The exposed photos were oriented on the plane table and the directions to the different objects were transferred onto the map sheets.

In analog photogrammetry, optical or mechanical instruments (lens stereoscope/mirror stereoscope) were used to reconstruct 3D geometry from two overlapping photographs (stereo photographs). The main product during this phase was topographic maps. To develop photogrammetry to a phase analog one, two inventions were required; the stereo plotter and the Aeroplan, to provide a better platform for cameras. The first stereo-planigraph, stereo-plotting instrument was invented in 1896 by Edward Deville, Surveyor General of the Dominion; however, this instrument was extremely complicated and resulted in little use. It was not until 1907 that, in Germany, Ritter von Orel, helped to develop the first stereo-autograph with a small emerging company known as Zeiss. These were further incredibly complex devices even after 50 years of development.

Only after the invention of the computer in 1941, by Zure in Germany, did significant advances in photogrammetry become possible, the primary scientist responsible for taking this phase of development on was Dr. Hellmut Schmid, who in 1953 developed the principles of multi-station analytical photogrammetry using matrix notation, and the least squares solution, However, Uuno (Uki) Vilho Helava is the one responsible for the invention of the analytical plotter. While working at the National Research Council in Canada, he developed the analytical plotter in 1957. This instrument was the first to be servo-controlled as opposed to optically or mechanically constructed. A computer drove the instrument around the stereo model, also digitally transforming image-map coordinates. In analytical photogrammetry, the computer replaces some expensive optical and mechanical components. The resulting devices were analog/digital hybrids. Analytical aero-triangulation, analytical plotters, and orthophoto projectors were the main developments during this phase. Outputs of analytical photogrammetry can be topographic maps, but can also be digital products, such as digital maps and digital elevation models (DEMs).

The digital or soft-copy photogrammetry systems are much simpler in design than the analytical systems. They consist of a computer with a stereo-capable graphics system, 3D glasses with electronic shutters, and a 3D mouse as a user interface. The 3D mouse is a reconfigured optical mouse with x, y, and z motion control and several user-configurable buttons. All other hardware of an analytical system has been replaced with software programming, alleviating the problems with mechanical devices wearing out or needing adjustments to stay within close tolerances.

Digital photogrammetry is applied to digital images that are stored and processed in a computer. Digital images can be obtained by scanning analog photographs or can be directly captured by digital cameras. Many photogrammetric tasks can be highly automated in digital photogrammetry (e.g., automatic DEM extraction, topographic contour generation, and digital orthophoto generation). The output products are in digital form, such as digital maps, DBMs, and digital Orthophotos saved in computer storage media. Therefore, they can be easily stored, managed, and used. It is important to remember that most digital image analysis and information extraction techniques use the spectral Information of the remotely sensed digital image; however, in the case of photogrammetry, it uses spatial information for analysis and information extraction.

The following quantitative measurements may be made using multiple (overlapping) stereoscopic aerial photographs and analog or digital measurements of stereoscopic parallax (to be defined):

- Precise planimetric (x, y) object location in a standard map projection.
- Precise object height (z).

In addition, the digital photogrammetric technique can provide

- Planimetrically accurate (x, y) orthophotographs
- Digital terrain models (DTM).
- Topographic contours.
- Bathymetric models (a map portraying the shape using isobaths or depth contours)
- Slope and aspect information derived from the digital elevation or bathymetric models.

Though analog/analytical photogrammetry is still taught in some colleges and universities, the new trend is digital photogrammetry. The present-day world is shifting from the analog to the digital era. It should be borne in mind that analog/analytical photogrammetry has been replaced by digital photogrammetry and there is no such significance of learning analog/analytical photogrammetry. The topics covered in the chapter mainly focus on digital photogrammetric techniques.

Classification of Photogrammetry

Principally, photogrammetry may be divided into

1. Depending on the lens-setting

- Far-range photogrammetry (with camera distance setting to infinite).
- Close-range photogrammetry (with camera distance settings to finite values).

2. Another grouping may be

- Aerial (or satellite) photogrammetry (which is mostly far-range photogrammetry).
- Terrestrial photogrammetry (mostly close-range photogrammetry).

The traditional and largest application of photogrammetry is to extract topographic and planimetric information (e.g., topographic maps) from aerial images. However, photogrammetry techniques have also been applied to process satellite images and close-range images to acquire topographic or on-topographic information of photographed elevation data. Planimetric information includes the geographic location of buildings, roads, rivers, etc. Aerial/satellite photogrammetry is mainly used to produce topographical maps, DTM, orthoimages, and 3D GIS vector data. Close-range photogrammetry is used by architects and civil engineers (to supervise buildings, document their current state, deformations, or damages), archaeologists, surgeons (plastic surgery), or police departments (documentation of traffic accidents and crime scenes), just to mention a few. Close-range photogrammetry also assists in setting up the design and modeling for the film industry.

Photogrammetry Process

In general, a photogrammetric process involves two stages: (1) acquisition of imagery and its support data (e.g., ground-control information) and (2) processing the imagery to derive information. The first stage involves several assurance operations such as project design, mission planning, and image acquisition, ground photogrammetric workstation (DPW) for processing. The figure shows the workflow of the digital photogrammetric process in brief.

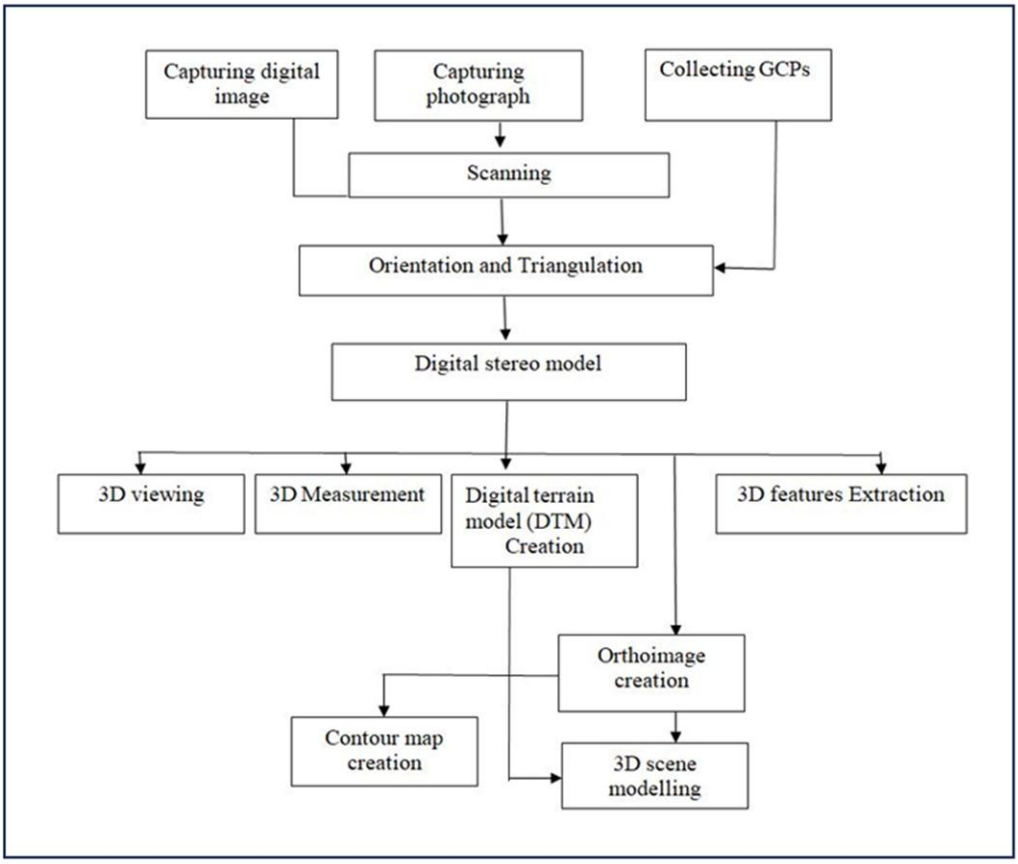

Fig. 1.2: Workflow diagram of digital photogrammetric process.

Acquisition of imagery and its Support Data

Any successful photogrammetry project begins with the acquisition of a suitable aerial photographic coverage of the project area. With the advent of efficient sensors capable to capture images with high spatial resolution, nowadays satellite imageries are also being used widely. Digital photogrammetric systems use digitized (scanned) photographs or digital images as the primary source of input. Digital imagery can be obtained from various sources. These include the following:

- Using the aerial platform.
    1. Digitizing/scanning hard-copy photographs or films.
    2. Using digital cameras to record imagery.
- Using sensors onboard satellites.

Stereo photogrammetry was developed to accurately reproduce the 3D surface of the earth from 2D photographs. This can be achieved by pairs of overlapping images, called stereo pairs. Typical image overlap (also called forward overlap or end-lap) between photographs is 60%. During photography or image collection, overlapping images are exposed along the direction of flight. Most photogrammetric applications involve the use of overlapping images. By using more than one image the geometry associated with the camera/sensor, image, and ground can be defined with greater accuracy.

A control survey (ground control points (GCPs) collection) is also required in photogrammetry to establish the relationship between the image and the ground.

Acquisition of Imagery Using Aerial Platform

Aerial photographs are a major data source in photogrammetric applications. With the introduction of computer-based photogrammetric mapping that operates in desktop computing environments that can manipulate the vector and raster data, the demand for images in raster (digital) format has increased sharply. The intent of this section is to provide guidelines related to the geometry of photographs, involved acquisition technology, etc.

As stated earlier, aerial image data may be collected in photographic film (analog) or in a CCD (digital). It must be stated that aerial photographs in film format may prove to be a more economical solution for many mapping and GIS database construction lion tasks. There are several topics involved in data acquisition for photogrammetry from aerial platforms. These topics are discussed in the following sections.

i. Flight Line

The first step in the production of digital orthophotograph and terrain models is capturing aerial photographs of the land surface. To acquire the images, an Aeroplan travels over a study area in a straight flight line, and photographs are taken such that every ground point appears in at least two successive photographs. The resulting photos are called a stereo pair, and the area of common coverage is called overlap (Figure 1.3). Standard overlap is 60%, Sometimes aerial photographs are acquired with 80% overlap in the mountainous terrain. If the area of interest requires more than one flight line for complete coverage, additional flight lines are flown parallel to the initial line.

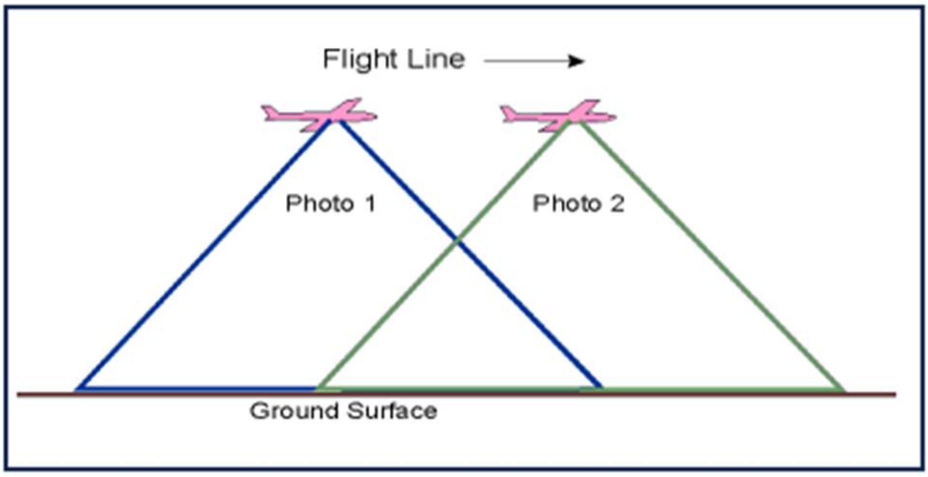

Figure 1.3: Flight Line of Aerial Photography.

ii. Exposure Station

During the collection of imagery, each point in the flight path at which the camera exposes the film, or the sensor captures the imagery, is called an exposure station. The time between individual exposures along a flight line is determined by setting the camera intervalometer. The aerial photographer considers the speed of the aircraft and the scale of the desired photography and sets the intervalometer so that each vertical aerial photograph overlaps the next photograph in the flight line by approximately 60% (referred to as stereoscopic overlap). All photos in the strip are assumed to be taken at approximately the same flying height and with a constant distance between stations.

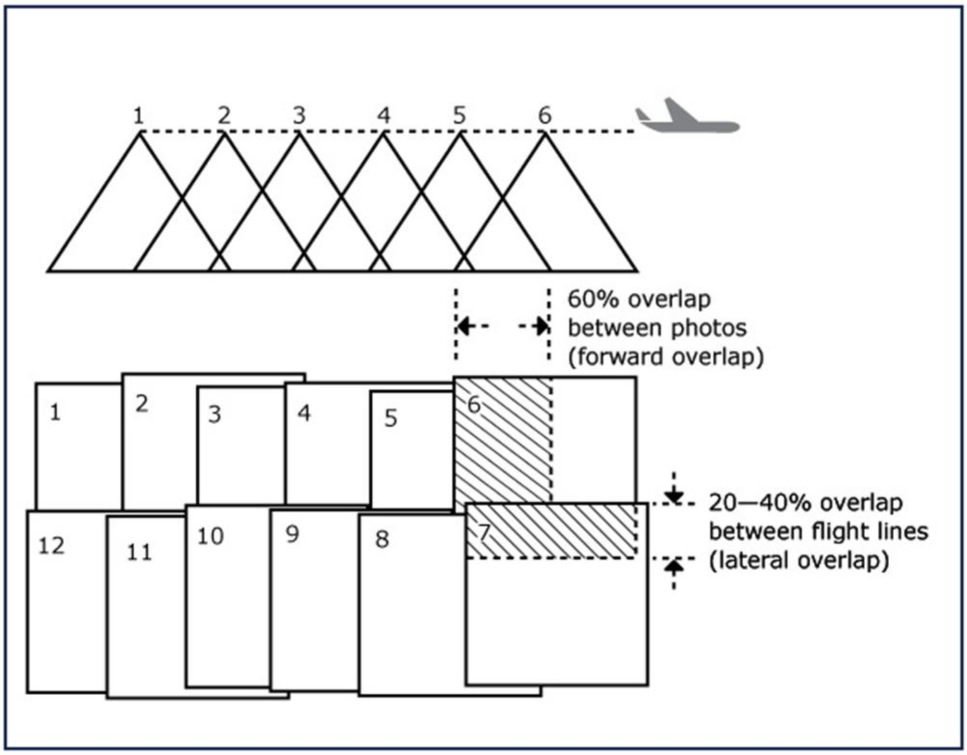

Fig. 1.4: Aerial Photography Line and Planning.

iii. Block of Photographs

Most aerial photography projects, such as mapping a watershed, county, or entire city, require multiple flight lines of photography to cover the geographic area of interest. When this occurs, the flight lines are normally overlapped by 20-30%. Overlap between adjacent flight lines is called side lap, and is used to prevent gaps in Coverage. To acquire multiple flight lines, a pilot must make a 180° turn at the end of a flight line and then fly in the opposite direction. Multiple flight lines with 20-30% side lap are commonly referred to as a block of aerial photography.

A regular block of photos is commonly a rectangular block in which the number of photos in each strip is the same. Figure 1.4 shows a block of 6 x 2 photographs. In cases where a nonlinear feature is being mapped (e.g., a river), photographic blocks are frequently irregular.

i. Central Perspective Geometry

A photographic image is a central perspective. This implies that every light ray, that reached the film surface during exposure, passed through the camera lens (which is mathematically considered as a single point, the so-called perspective center). This implies that the position of all the points is controlled by one single point (principal point) of the image, which controls the geometry of the entire photograph, Hence, displacement is radial outwards, away from the photograph. However, satellite imageries lack this attribute and hence they are called imageries but not photographs.

Traditionally, people use photographs for photogrammetry, but nowadays, people also extensively use imagery stored electronically on tape or disk taken by video or CCD cameras or radiation sensors such as scanners. To take measurements of objects from photographs, the ray bundle must be reconstructed. Therefore, the internal geometry of the used camera (which is defined by the focal length, the position of the principal point, and the lens distortion, referred to as interior orientation) and external geometry (which is defined by the position and angular orientation of the camera that captured an image, referred to as exterior orientation) has to be precisely known. The internal and external geometry of the sensor are collectively called the sensor model.

Photogrammetry is about photographs and then it is about the 'metric' (geometry) of the photographs. This immediately implies that we have to know something about the cameras, it is not necessary to learn how to build them, but we should understand the basics of the optics involved, or at least, know that cameras do not make geometrically perfect images. Often they are imperfect enough such that if we measure the distance between the two points of interest by a ruler, we do not get a reliable number. Once we know that our images are not perfect, we need to dwell on a little geometry and mathematics to know what is wrong with them and how it can be corrected.

Photogrammetric Imaging Devices

Depending on the availability of knowledge capturing system the photogrammetrist divides the imaging devices into four categories:

I. **Metric cameras:** They have stable and precisely known internal geometries and very low lens distortions. Therefore, they are very expensive devices. The principal distance (focal length) is constant, which means that the lens cannot be sharpened while taking photographs. As a result, metric cameras are only usable within a limited range of distances towards the object. Aerial metric cameras are built into Aeroplan's mostly looking straight downwards. At present, all of them have an image format of 23 cm x 23 cm.

II. **Stereometric camera:** If an object is photographed from two different positions, the line between the two perspective centers is called the base. If both photographs have viewing directions, which are parallel to each other and in a right angle to the base (the so-called 'normal ease'), then they have similar properties as the two images of our retinas. Therefore, the overlapping area of these two photographs (which are called a stereo pair) can be seen in 3D, simulating man's stereoscopic vision. In practice, a stereo pair can be produced with a single camera from two positions or using a stereometric camera. A stereometric camera in principle consists of two metric cameras mounted at both ends of a bar, which has a precisely measured length (mostly 40 or 120 cm). This bar functions as the base. Both cameras have the same geometric properties. Since they are adjusted to the normal case, stereo pairs are created easily.

III. **Digital Metric Cameras:** The aerial digital metric camera (DMC) is designed to replace film-based aerial cameras, enabling small, medium, or large-scale mapping. The transition from analytical to digital photogrammetry is well advanced and the dividing lines between photogrammetry and remote sensing grow increasingly blurred. One of the advantages of direct digital data capture in the air is the possibility of capturing multi-spectral data as well as panchromatic data. Between modem film-based aerial mapping cameras with their extremely high resolution and, at the other end of the spectrum, the forthcoming high-resolution satellite sensors, the market for new airborne devices is large and incontestable. A vertical panchromatic image is obtained using linear array CCDs or area array CCDs in a digital camera. The camera achieves stereo capability by means of two linear array CCDs taking panchromatic images, one looking forward and the other looking backward.

IV. **Amateur cameras**: The photogrammetrist speaks of an amateur camera, when the internal geometry is not stable and unknown, as is the case with any normal commercially available camera. However, these can be very expensive and technically highly developed professional photographic devices. Photographing a test field with many control points and at a fixed distance setting (for instance, at infinity), a calibration of the camera can be calculated. In this case, the four corners of the camera frame function as fiducials (to be defined). However, the precision will never reach that of the metric cameras. Therefore, they can only be used for such purposes where high accuracy is not required. But in many practical cases, such photography is better than nothing, and very useful in cases of emergency.

Conversion of Aerial Photographs to Digital Format

Once aerial (film-based) photographs have been acquired, they must be scanned into a digital format to allow manipulation, information extraction, and orthorectification in digital photogrammetry. Photogrammetric scanners are special devices capable of acquiring high-quality images with excellent positional accuracy. This type of scanner gives geometric accuracies like traditional analog and analytical photogrammetric instruments. These units usually scan only films because film is superior to paper, both in terms of image detail and geometry. These units usually have a root-mean-square error positional accuracy of 4 microns or less and are capable of scanning at a high resolution. The required pixel resolution varies depending on the application. Scanning at higher resolutions provides data with higher accuracy and detail.

Typically, photographs are scanned as raster images at pixel resolutions ranging from about 250 μm (100 dots per inch (DPI)) to about 10 μm (2500 DPI). Each pixel or dot has a grey value ranging from white to black encoded as an 8-bit with zero representing black and 255 representing white.

Acquisition of Imagery Using Satellite Platform

Satellite images are used in the photogrammetric process in the same way as aerial photographs. As the cost of satellite imagery comes down and spatial resolution increases, it is used to a larger extent and has several distinct advantages over aerial imagery.

Satellite photogrammetry has been a major step forward in mapping as it facilitates to mapping of large areas with very few images taken by satellites and is cost-effective compared with aerial photography. Aerial photogrammetry can be used to scan a particular extent of area and the image specifications like scale, camera, time of photograph, etc. can be manipulated. But in satellite remote sensing, the satellite orbits are very stable once the satellite has been launched. Aerial photographs always prevail over satellite imageries for better resolution, as the 1:5,000 scale of an aerial photo is compared with the 1:20,000 scale of a satellite image. However, the repetition of satellite imaging and the reliability of obtaining the image in any Weather conditions form a major advantage of satellite photogrammetry.

While acquiring aerial imagery, it is necessary to schedule specially equipped airplanes to be in the area. The Pilots may then have to wait for clear weather, as photos of clouds are not very useful. Satellites are constantly in the air so the scheduling dilemma is removed. Satellites can revisit a scene more frequently, taking pictures as often as 3 days (or less) apart. Satellites provide multi-spectral images, which allow for a very detailed analysis of the images produced.

Satellite systems are becoming more common in digital photogrammetry and are expected to grow rapidly in the next few years. Digital satellite imagery offers many advantages over film-based cameras. There is a great saving in time because the data can be moved directly to a computer for processing, as there is no need for film processing and scanning. Orthorectified imagery is available in hours instead of days which allows for rapid response.

Globally, many satellite systems provide high-resolution data to meet the requirements for photogrammetric and Cartographic applications. The CARTOSAT-1 satellite has several advantages over these systems in that it provides high-resolution near instantaneous stereo data with a spatial resolution of 2.5 m and 10-bit radiometric resolution. The CARTOSAT-1 satellite has two panchromatic cameras with 2.5 m spatial resolution, to acquire two images: simultaneously, one forward-looking (FORE) at +26º and one backward-looking (AFT) at -5° for near-instantaneous stereo data along the track. The time difference between the acquisitions of the same scene by the two cameras is about 52s. The spacecraft body is steerable to compensate the earth rotation effect and to force both fore and aft cameras to look at the same ground strip when operated in stereo mode. Simultaneous stereo pair acquisitions are of great advantage since the radiometric parameters of the images are identical. The stereo pairs have a swath of 26 km. This initiative of ISRO is a threshold in satellite photogrammetry.

Another method of having along-track stereoscopy is to have the sensor itself tilted in the along-track direction. In this case, off-nadir along-track scanning can provide stereo images by a single camera. This is being used by IKONOS panchromatic and CARTOSAT-2 PAN. But this technology may be adopted for scene-specific areas, and not for a very large area. The geometry and scale of two overlapping images also vary.

Control Surveys

Control surveys are the survey methods that establish the exact, location of points on the ground. The purpose of control surveys for aerial photography and photogrammetry is to determine the exact position of the aerial camera at the instant of exposure and to establish the known reference points. As an airplane flies over the terrain, it snaps many exposures at specified intervals. Without control surveys there is no way of determining exactly where the aircraft was at the instant of exposure. Control surveys are used to determine the precise geometric relationship between the physical position of the aircraft camera (its altitude and attitude) and the internal spatial geometry of the camera itself.

To accomplish this task, targets are physically placed on the ground at specified locations within the project area. These targets are then surveyed to establish the locations. For proper visibility, targets must be sized according to the photo scale. The number of targeted control points and their overall positions within the project area is relative to the flight altitude. Lower aerial photography requires more control points than higher aerial photography.

Another approach to establish control for aerial photography is to use the technique of airborne global positioning system (GPS). Airborne GPS involves the use of GPS receivers mounted on board aircraft. The GPS receiver records the position of the aerial camera at the time of the photo exposure, enabling the photography to be controlled from the air instead of on the ground. As a result, fewer ground control stations are required.

Significance of Photogrammetry

Aerial photogrammetry is often used for the following: 1. Highway reconnaissance 2. Environmental 3. Preliminary design 4. Geographic Information System (GIS). The information produced from aerial photographs of the existing terrain allows both designers and environmental personnel to explore alternate routes without having to collect additional field information.

The photographs can be used to layout possible alignments for a more detailed study. Photogrammetry has evolved into a limited substitution for topographic ground surveying. It can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. However, ground surveys will always remain an indispensable part of aerial surveys as a basis for accuracy refinement, quality control and a source of supplemental information unavailable to aerial data acquisition.

Photogrammetry is used in fields such as topographic mapping, architecture, engineering, manufacturing, quality control, police investigation, and geology. Photogrammetry is also used for 1. Highly detailed DTM 2. Drainage analysis 3. Preliminary design and design scale mapping 4.3D vegetation mapping 5. Flood plain mapping 6. Planimetric feature extraction 7. In combination with photogrammetry for large-scale mapping, LiDAR has quickly evolved over the last several years to become a valuable tool for 3D mapping. Like photogrammetry, it can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. It can provide detailed terrain data and additional information that would be too time-consuming using photogrammetry or field surveys.

Advantages: 1. Photos provide a permanent record of the existing terrain conditions at the time the photograph was taken. 2. Photos can be used to convey information to the general public, and other federal, state, or local agencies. 3. Photos can be used for multiple purposes within CDOT such as reconnaissance, preliminary design, environmental, and Right of Way. 4. Topographic mapping and DTMs of large areas can be accomplished relatively quickly and at a lower cost when compared to ground survey methods. 5. Photogrammetry can be used in locations that are difficult or impossible to access from the ground.

Disadvantages: 1. Seasonal conditions, including weather, vegetation, and shadows can affect both the taking of photographs and the resulting measurement quality. If the ground is not visible in the photograph it cannot be mapped. 2. Overall accuracy is relative to camera quality and flying height. Elevations derived from photogrammetry are less accurate than ground surveys (when compared to conventional or GPS ground survey methods using appropriate elevation procedures). 3. Identification of planimetric features can be difficult or impossible (e.g., type of curb and gutter, size of culverts, type of fences, and information on signs). 4. Underground utilities cannot be located, measured, or identified. 5. Right of Way and property boundary monuments cannot be located, measured, or identified. 6. Since photogrammetric features are compiled from a plan view, buildings are measured around overhangs and eaves rather than at building footprints, resulting in some areas of DTM occlusion under overhangs, eaves, and overhead walkways. Areas under bridges are similarly affected.

1.4 SUMMARY

It can be summarized that photogrammetry is a very important science and technology for obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting images. This technique is developing day by day, as it has much significance in a variety of resource management applications.

1.5 GLOSSARY

Aerial Photography: Photography from airborne platform.

Air Base: Ground distance between optical centers of successive overlapping aerial photographs.

Aerial Photo: Photograph taken from an aerial platform, either vertically or obliquely.

Analog Image: Analog photography is photography that uses a progressively changing recording medium, which may be either chemical process based or electronic.

Analog Recorder: Analog recording (Greek, ana is "according to" and logos "relationship") is a technique used for their cording of analog signals which, among many possibilities, allows analog audio and analog video for later playback.

DEM: A digital elevation model (DEM) is a 3D CG representation of a terrain's surface – commonly of a planet (e.g., Earth), moon, or asteroid – created from a terrain's elevation data.

DTM: Digital terrain modeling (DTM), also known as digital elevation modeling, is the practice of creating a digital representation of ground topography and terrain.

GIS: A geographic information system is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data. Orthophoto/Orthoimage:

Plane Table: A plane table (plain table prior to 1830) is a device used in surveying and related disciplines to provide a solid and level surface on which to make field drawings, charts, and maps. The early use of the name plain table reflected its simplicity and plainness rather than its flatness.

3D: A three-dimensional stereoscopic film is a motion picture that enhances the illusion of depth perception, hence adding a third dimension. The most common approach to the production of 3D films is derived from stereoscopic photography.

2D: 2D computer graphics is the computer-based generation of digital images—mostly from two-dimensional models (such as 2D geometric models, text, and digital images) and by techniques specific to them.

Remote Sensing: Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on-site observation.

1.6 ANSWER TO CHECK YOUR PROGRESS

1. Do you know CARTOSAT-1 is an Indian Earth observation satellite that was launched on May 5, 2005?
2. Aerial imagery data can be gathered using either traditional photographic film (analog) or through the use of digital CCD (Charge-Coupled Device) technology.
3. Do you know ISRO, which stands for the Indian Space Research Organisation, is the space agency of the Government of India?
4. Vector data represents geographic features using points, lines, and polygons with associated attribute information, used in GIS for precise spatial representation and analysis.

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1.8 TERMINAL QUESTIONS

LONG QUESTIONS

1. What do you understand by photogrammetry? What are the quantitative measurements that may be made by analog and digital photogrammetry?
2. Define photogrammetry and its development.
3. Explain the types and significance of photogrammetry.
4. What do you understand by the advantages and limitations of photogrammetry?

SHORT QUESTIONS

1. Write a short note on Flight Line.
2. Write a short note on the Exposure process
3. Write a short note on the Photogrammetry process.
4. Write down 4 applications of photogrammetry.
5. What do you mean by metric cameras?

MULTIPLE CHOICE QUESTIONS

1) The word 'photogrammetry' is derived from which Greek words:

a) Latin
b) Greek
c) Indian
d) Chinese

2) Who is often referred to as the 'Father of Photogrammetry'?

a) Aimé Laussedat
b) Ansel Adams
c) Thomas Edison
d) Marie Curie

3) In what year did Aimé Laussedat become the first person to use terrestrial photographs for topographic mapping?

a) 1849
b) 1899
c) 1949
d) 1999

4) During which period did Plane table photogrammetry dominate the field of photogrammetry?

a) 1850 to 1900
b) 1900 to 1960
c) 1960 to 1990

d) From 1990 onwards

5) **Which era is characterized as the period of Analog photogrammetry?**
   a) 1850 to 1900
   b) 1900 to 1960
   c) 1960 to 1990
   d) From 1990 onwards
6) **In determining latitude and longitude with the prismatic astrolabe an error of one second in time measurement is made. How great an error in longitude results?**
   a) 5 sec.
   b) 10 sec.
   c) 15 sec.
   d) 25 sec.
7) **These are determined by measurements made in two or more photographic images taken from different positions (see ________).**
   a) Holography
   b) Stereoscopy
   c) Auto stereoscopy
   d) 3d display
8) **Photogrammetry, Geographic coordinate system and map projection are all…….**
   a) Computer Vision
   b) Photogrammetry
   c) Cartography
   d) Measurement
9) **Photogrammetry is …….**
   a) A way to obtain information from objects without touching them
   b) Transmission of data from one place to another
   c) The way your microwave works
   d) Taking pictures from different viewpoints

Answers: 1.b 2. a 3.b 4. a 5.b 6. c 7.b 8. c and 9. d.

UNIT 2 - PRINCIPLES OF STEREOPHOTOGRAMMETRY

2.1 OBJECTIVES

2.2 INTRODUCTION

2.3 PRINCIPALS OF STEREOPHOTOGRAMMETRY

2.4 SUMMARY

2.5 GLOSSARY

2.6 ANSWER TO CHECK YOUR PROGRESS

2.7 REFERENCES

2.8 TERMINAL QUESTIONS

2.1OBJECTIVES

After reading this unit you should be able to

- Understand the stereoscope and its orientation
- Know about Stereo modeling (3D Viewing)
- Gaining knowledge about stereoscopic parallax
- Know about relief displacement

2.2 INTRODUCTION

A stereoscope is a device for viewing a stereoscopic pair of separate images, depicting left-eye and right-eye views of the same scene, as a single three-dimensional image. The function of a stereoscope is to deflect normally converging lines of sight so that each eye views a different image. Instruments in use today for the three-dimensional study of aerial photographs are of two types i.e., Lens Stereoscope and reflecting or mirror stereoscope. Stereoscopic vision also called space vision or plastic vision, is a characteristic, possessed by most persons of normal vision and is important for the ability to conceive objects in three-dimensional effects and to judge distances. Stereoscopic vision is the basic prerequisite for photogrammetry and photo interpretation. Stereoscopy is defined as the science or art which deals with stereoscopic or other three-dimensional effects and methods by which these effects are produced. Human beings can distinguish depth instinctively. However, there are many aids to depth perception, for instance, closer objects partly cover distant objects or distant objects appear smaller than similar objects nearby.

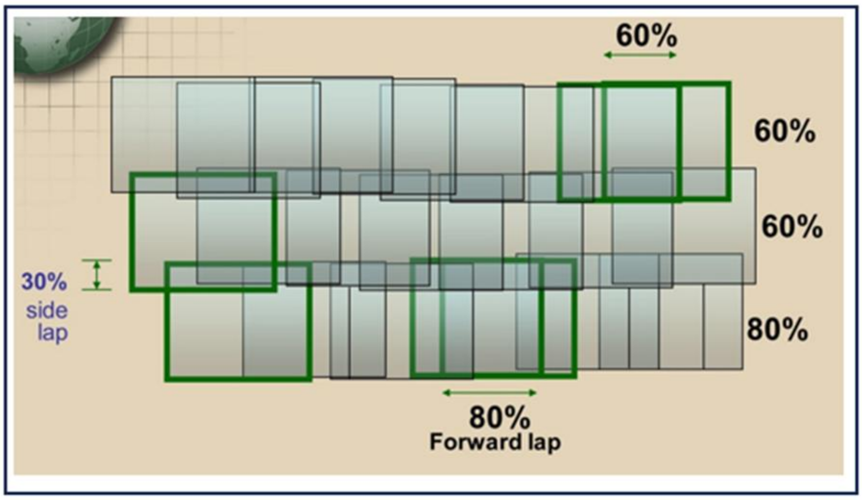

Fig. 2.1: Overlapping of Aerial Photo.

Generally, the images overlap by approximately 60% along flight lines (overlap) and 20% to 30% between flight lines (side lap). Overlap between images is essential to allow three-dimensional, viewing (depth perception) of photographs. The exposure station is the position of the front nodal point of the lens at the instant of exposure. The distance between the exposure stations of two successive images is called the air base and is equal to the ground distance between the principal points of the two images (Figure 2.1).

It is expected that the flight line will coincide with the X-axis of the image but it rarely happens because of the prevailing wind velocity and direction. It causes a slight change in the flight direction. It is known as crabbing which ultimately affects the area of overlap.

Geometry of Stereoscopy

One of the limitations of the vertical aerial photograph is the lack of apparent relief. Stereoscopic vision (or as it is more commonly known, stereovision or depth perception) is the ability to see three-dimensionally or to see length, width, and depth (distance) at the same time. This requires two views of a single object from two slightly different positions. Most people can see three-dimensionally. Whenever an object is it is seen twice-once with the left eye and once with the right eye. The fusion or blending of these two images in the brain permits the judgment of depth or distance.

a) In taking aerial photographs, it is rare for only a single picture to be taken. Generally, the aircraft flies over the area to be photographed taking a series of pictures, each of which overlaps the photograph preceding it and the photograph following it on that an unbroken coverage of the area is obtained. The amount of overlap is usually 60 percent, which means that 60 percent of the ground detail appearing on one photo also appeals on the next photograph, when a single flight does not give the necessary coverage of an area, additional flights must be made. These additional flights are parallel to the first and must have an overlap between them. This overlap between flights is known as side lap and usually is between 15 and 30 percent.

b) The requirement for stereovision can be satisfied by overlapping photographs if one eye sees the object on one photograph and the other eye sees the same object on another photograph. While this can be done after practice with the eyes alone, it is much easier if an optical aid is used. These optical aids are known as stereoscopes. There are many types of stereoscopes, but only the two most used are discussed in this manual.

Pocket Stereoscope: The pocket stereoscope, sometimes known as a lens stereoscope, consists of two magnifying lenses mounted in a metal frame. Because of its simplicity and case of carrying, it is the type used most frequently by military personnel.

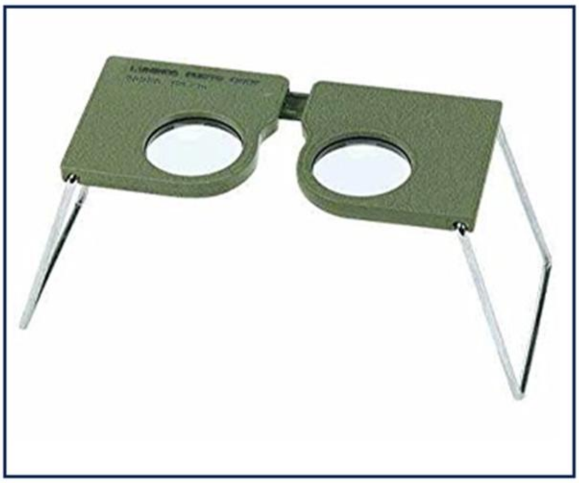

Fig. 2.2: Pocket Stereoscope.

Mirror Stereoscope: The mirror stereoscope is larger, heavier, and more subject to damage than the pocket stereoscope. It consists of four mirrors mounted in a metal frame.

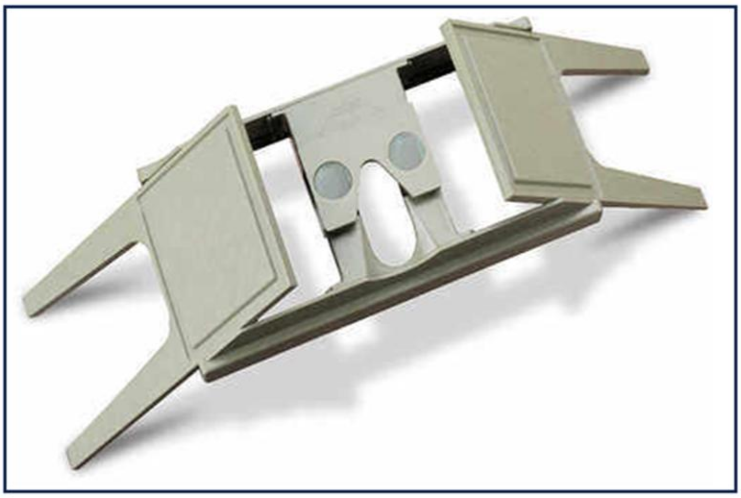

Fig. 2.3: Mirror Stereoscope.

Stereo Pairs of Aerial Photographs

A pair of successive overlapping photographs along a flight line constitutes a stereo pair which may be viewed with a stereoscope to produce a three-dimensional image called a stereo model. Figure 2.4 is a stereo pair of the Alkali anticline in the eastern part of the Bighorn Basin, Wyoming, that is suitable for viewing with a simple stereoscope (Figure 2.3). Before viewing the photographs in stereo, it is advisable to test one's ability to see in stereo.

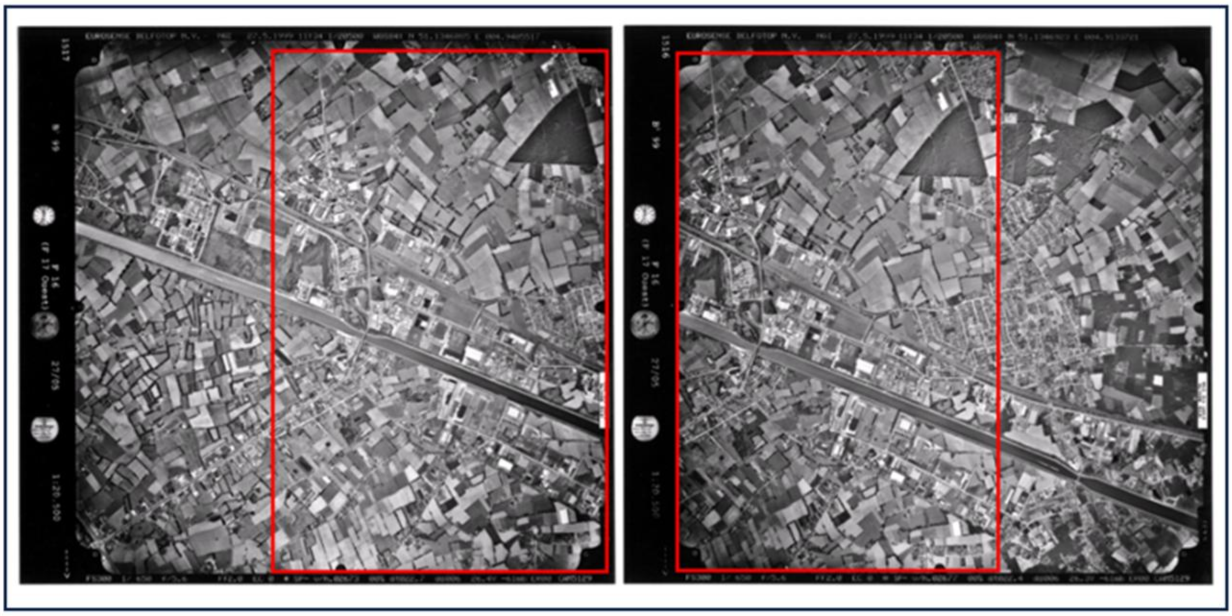

Fig. 2.4: Stereo pairs of Aerial Photograph.

Orientation

The orientation is the procedure where the transformation parameters from one coordinate system to a second coordinate system are determined. A 2D orientation includes the shift and rotation of an object along a plane, and a 3D orientation includes the determination of the position and attitude of an object in both coordinate systems. It uses a logic known as collinearity, which specifies that, for any image, the exposure station, the ground point, and its corresponding image point must lie along a straight line.

In photogrammetry, the orientation is described as interior or exterior orientations, or as relative and absolute orientations. Interior and exterior orientation relates to the digital photogrammetry, whereas the relative and absolute orientations were introduced aside from interior and exterior orientations to operate analog/analytical stereo plotters. The interior and exterior orientation parameters usually include six parameters: three rotations around the coordinate axes, and three shifts along them.

Interior Orientation

Interior orientation or inner orientation defines the internal geometry of a camera or sensor as it existed at the time of image capture. The variables associated with image space are obtained during the process of defining interior orientation. Interior orientation is primarily used to transform the image pixel coordinate system or other image coordinate measurement systems to the image space coordinate system.

In the case of photographic (film) images, the interior orientation is an image-related variable. As it regards the measuring d the interior orientation is a preceding operation before the actual object measurements. It includes the observation of fiducial marks in the coordinate system of the measuring instrument first, and then an adjustment for solving the parameter values for interior orientation. The same values are then used for transforming the actual object measurements to the image space coordinate. The transformation is different for all subsequent images arid therefore the procedure must be repeated separately.

In the case of digital cameras, the interior orientation is a camera-related variable. in the of imaging systems which is a combination of a video camera, a digitizer and cables in-between perhaps a feature projector, the interior orientation is a system-related variable. As it regards the measuring procedure, this simplifies the entire interior orientation largely as the transformation parameters have to be determined only once for each camera or system. The internal geometry of a digital camera is defined by specifying the following variables:

- Focal Length
- Pixel size of the CCD, and so on.

For satellite sensors, internal geometry is defined by specifying

- Pixel size
- Number of columns in the sensor, and so on.

Internal geometry of camera is defined by specifying the following variables:

- Fiducial marks
- Principal point
- Focal length
- Lens distortion

Fiducial marks: We may notice that in an aerial photograph, eight dark marks located at the four corners and at the centres of the four sides. Some metric cameras have only four marks. These marks are known as fiducial marks. These marks are transferred from the camera body to the film (figure 2.5). They are precisely measured positions hi the frame of camera. They are used to locate the position of the photograph. The fiducial measurements, along with the calibrated focal length of the lens are included in the camera calibration report. The main purpose of the fiducial marks is to define the position of the principal point. The design of fiducial marks may vary.

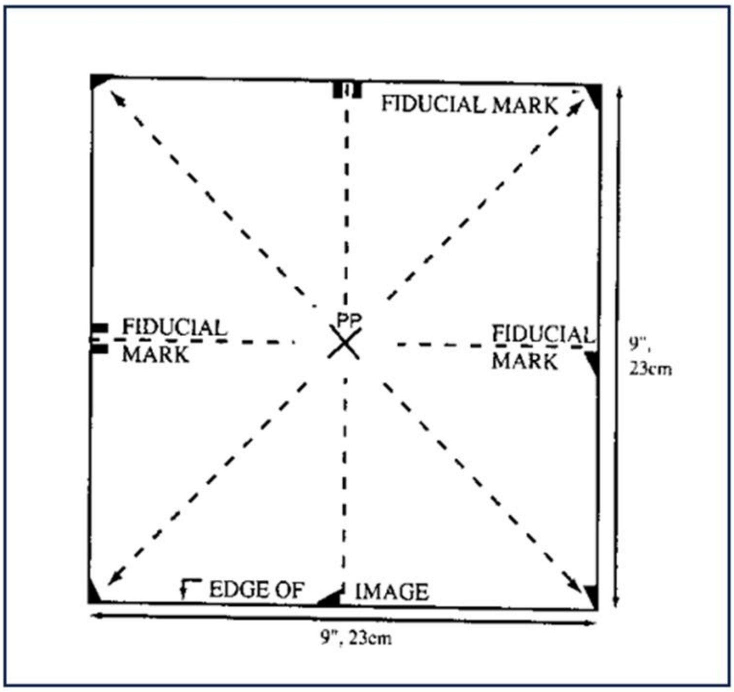

Fig. 2.5: Fiducial marks in Aerial Photograph.

Principal point: Drawing a line between the opposite fiducial marks locates the principal point (PP) of the photograph (Figure 2.6(a), which is the exact point on the earth where the optical axis of the camera was pointing during the instant of exposure. The principal is mathematically defined as the intersection of the perpendicular line through the perspective centre of the image plane (the plane where the positive or negative images created). The optical definition of principal point is the image position where the optic axis intersects the image plane.

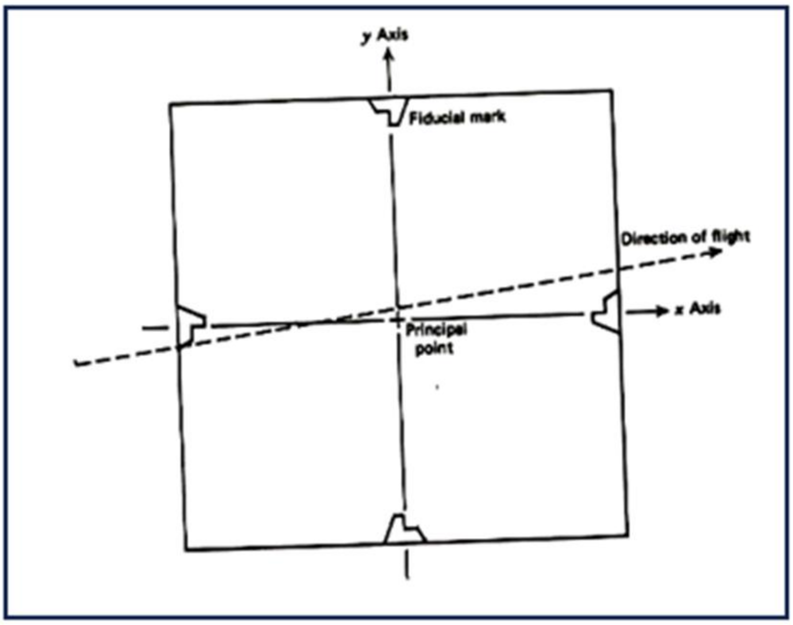

Fig. 2.6(a): Principal Point Location in Aerial Photo.

Fiducial mark is the center of each side of a photograph. Connecting the fiducial mark of either side, the principal point which is the geometric center of the photograph is obtained. In a stereopair the principal point of a photograph can be found on the either photograph, which is known as conjugate principal point on that photograph (marked as pink in Fig. 2.4 (C)). On each photograph a principal point and conjugate principal point are connected by a straight line. These two photographs are adjusted in the stereoscope so that that these two straight lines are coincident. To achieve good stereoscopic vision the distance of the two straight lines should be equal to the intraocular distance y.

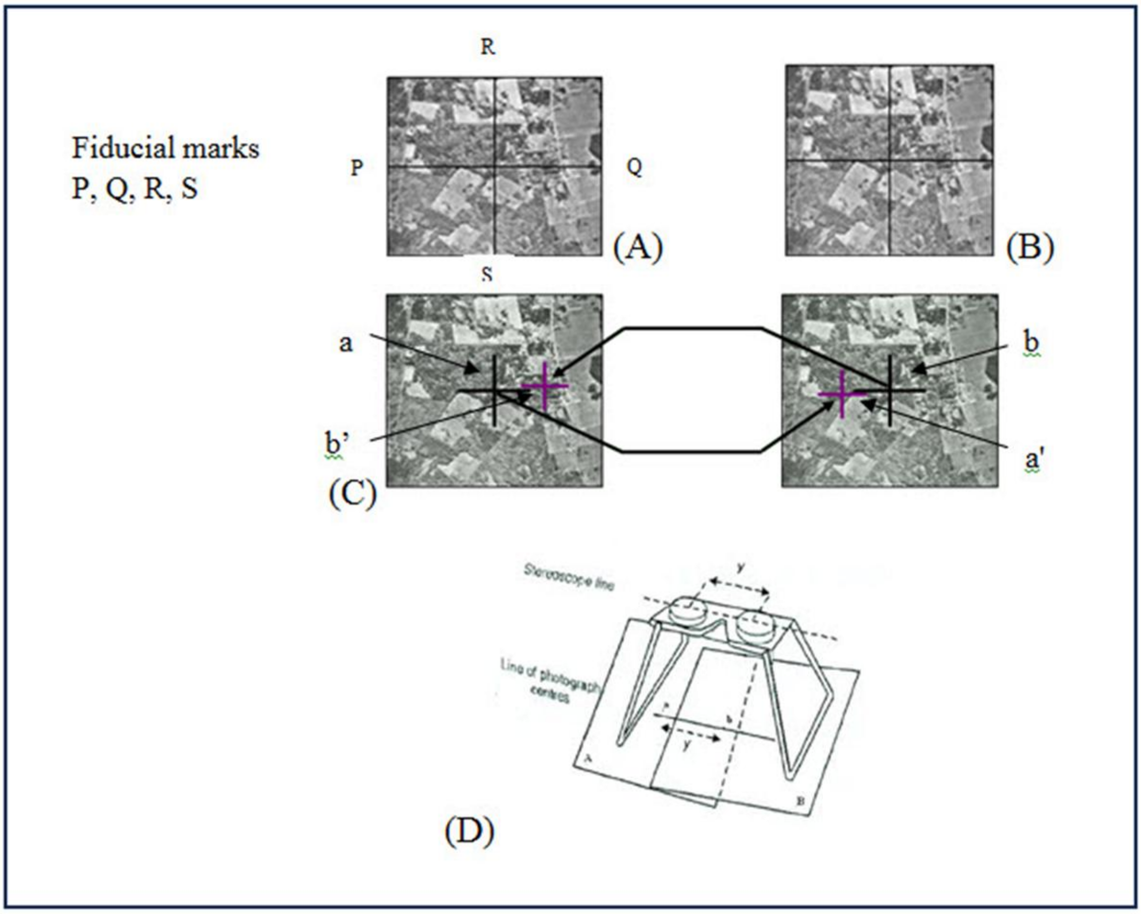

Fig. 2.6(b): (A), (B) are photographs makes a stereo pair, (C) principal points (a, b) are marked as black and conjugate principal points (a', b') are marked as pink. (D) Stereoscope.

Focal length: The length from the principal Point to the perspective centre is called the focal length. The focal length is also called the principal distance. The image plane is commonly referred to as the focal plane. For wide-angle aerial cameras, the focal length is approximately 152 mm, or 6 in. For some digital Cameras, the focal length is reduced up to 28 mm. Prior to conducting camera is accurately determined photogrammetric projects the focal length of a metric or calibrated in a laboratory environment.

Lens distortion: Lens distortion deteriorates the positional accuracy of image points located on the image plane. Two types of lens distortion exist: radial and tangential lens distortion. Lens distortion takes place when light rays passing through the lens are bent; thereby changing directions and intersecting the image plane at positions deviated from the normal. The effects of lens distortion are commonly determined in a laboratory during the camera calibration procedure. Lens distortion can be defined as the shifting of the principal point from its normal location.

Exterior Orientation

Exterior orientation defines the position and angular orientation of the camera that captures an image. The ordinary six parameters for the exterior orientation are the 3D coordinates of the perspective centre and the three rotations around the coordinate axes. The exterior orientation is determined directly by resection or indirectly by block adjustment. For resection, the 3D object geometry should be known by at least three control points, but in the case of digital images, more likely by a set of geometric object entities or features. In block adjustment, the exterior orientations are determined for several images simultaneously relative to a given external datum. In the ease where the object geometry is still largely unknown, the block adjustment gives a more precise determination of exterior orientations than the resections using control points.

The variables defining the position and orientation of an image are referred to as the elements of exterior orientation, which define the characteristics associated with an image at the time of exposure or capture. The positional elements of exterior orientation include X_o, Y_0, and Z_0. They define the position of the perspective centre (O) with respect to the ground space coordinate system (X, Y, and Z). Z_0 is commonly referred to as the height of camera above sea level, and is commonly de fine by a datum.

The angular or rotational elements of exterior orientation describe the relationship between the ground space coordinate system (X, Y and Z) and the image space coordinate system (x, y and z). Three rotation angles are commonly used to define angular orientation. They are omega phi, and kappa. Figure above illustrates the elements of exterior orientation. Omega is a rotation about the photographic x-axis, phi is a rotation about the photographic y-axis and kappa is a rotation about the photographic z-axis which is defined as being positive if they are counter-clockwise when viewed from the positive end of their respective axis.

Interior and exterior orientations are also collectively called sensor model. A sensor model describes the properties and characteristics associated with the camera or sensor used to capture photography and imagery. Since digital photogrammetry allows for the accurate collection of 3D information from imagery, all die characteristics associated with the camera/sensor, the image and the ground must be known and determined. This information includes both internal and external sensor model information.

Block Triangulation

Block triangulation (also referred to as block adjustment or bundle adjustment) is used to determine the orientations of all images simultaneously, yielding more accurate and Consistent results across the entire mapping area. Block triangulation is the process of defining the mathematical relationship between the images contained within a block, the camera or sensor model, and the ground. Once the relationship has been defined, accurate imagery and geographic information concerning the earth's surface can be created and collected in 3D.

When processing frame camera, digital camera, videography, and non-metric camera imagery, block triangulation is commonly referred to as aerial triangulation (AT). When processing imagery collected with a push broom sensor, block triangulation is commonly referred to as triangulation.

The AT is the calculation of true ground coordinates, used as the base reference in photogrammetry. This allows aerial imagery to be aligned and georeferenced to reflect their true positions on the earth.

For mapping projects having more than two images, the use of space intersection and space resection techniques are limited. This can be attributed to the lack of information required to perform these tasks. For instance, it is uncommon for the exterior orientation parameters to be highly accurate for each photograph or image in a project, since these values are generated photogrammetrically. Airborne GPS and other techniques normally provide initial approximations to exterior orientation, but the final values for these parameters must be adjusted to attain higher accuracies.

The GCPs serve a vital role in photogrammetry since they are crucial to establish an accurate geometric relationship between the images in a project, the sensor model, and the ground. This relationship is established using the bundle block adjustment approach. The number of GCPs varies from project to projects and software to software. Rarely are there enough accurate GCPs for a project of thirty or more images to perform space resection (i.e., a minimum of three points per image is required). In cases when there are enough GCPs, the time required to identify and measure all the points are costly.

To minimize the costs of a mapping project, fewer GCPs are collected and used. To ensure that high accuracies are attained, an approach block adjustment is used to estimate many numbers of GCPs (also known as tie points). A block of images contained in a project is simultaneously processed in one solution. A statistical technique known as least-squares adjustment is used to estimate the bundled solution for the entire block while also minimizing and distributing error.

Without triangulation, it is necessary for every stereo model to be oriented for 3D coordinate measurements. Triangulation is considered the most important economic factor in photogrammetric mapping. Many photogrammetric software support highly automated triangulation.

Transformation

Transformation is a technique to build the relationships between the pixel and the ground has an x coordinate (column) and a y coordinate (row). The origin of the pixel coordinate system is the upper-left corner of the image having a row and column value of 0 and 0, respectively. Using a polynomial transformation, the relationship between the pixel coordinates system and the ground coordinates system is defined (refer to Appendix B to know more about polynomial transformation).

The polynomial transformation also defines the translation between the origin of the pixel coordinate system and the image coordinate system. Accordingly, the polynomial transformation takes into consideration the rotation of the image coordinates system. The algorithmic approach of the transformation depends upon the type of rectification method to be used. A simple affine polynomial approach requires a minimum of three well-distributed GCPs, whereas more complex approaches require six or more GCPs. Regardless of the approach, more than the minimum number of GCPs should be employed in order to obtain an optimum solution.

Types of Stereoscopic Vision

Stereoscopic vision can be of two types:

- Natural Stereoscopic Vision
- Artificial Stereoscopic Vision

Natural Stereoscopic Vision: Natural Stereoscopic vision is possible due to the Monocular Vision which is possible due to the relative size of the objects, overcutting convergence and accommodation of eyes, haze of atmosphere etc. And Binocular Vision is responsible for perception of depth. Two slightly different images, seen by two eyes simultaneously are fused into one by brain, giving the sensation of a 'model' with three dimensions. The three-dimension effect is reduced beyond viewing distance of one meter. So also, the distance between two eyes, called 'Eye base, affects stereoscopic vision. Wider the eye base, better is the three-dimensional effect.

Artificial Stereoscopic Vision: Artificial stereoscopic vision can be achieved with certain aids and a two-dimensional photograph can provide a three-dimensional effect. This image obtained is comparable to the image that can be obtained if two eyes are placed at two points of exposure stations on a flight line. Here the distance between two exposure stations is called the 'airbase.'

Stereoscopic 3d Viewing

Daily, we unconsciously perceive and measure depth using our eyes. Persons using both eyes to view an object have a binocular vision. The perception of depth through binocular vision is referred to as stereoscopic viewing. Which mean viewing an object from two different locations. Monoscopic or monocular vision refers to viewing surrounding objects with only one eye. Depth is perceived primarily based on the relative sizes of objects and hidden objects; distant objects appear smaller and behind closer objects. However, depth perception is poor with. Monoscopic vision, and distance estimation can be difficult. In stereoscopic vision, Objects are viewed with both eyes, producing a composite 3D image. Stereoscopic vision allows for a far greater degree of depth perception than monoscopic vision. The concept of stereoscopic vision can also be applied to view an aerial photography stereo pair. By viewing the left photograph with the left eye and the right photograph with the right eye, a 3D view of the terrain can be obtained (Lillesand 1994),

With stereoscopic viewing, depth information can be perceived with detail and accuracy. Stereo viewing allows the human brain to judge and perceive changes in depth and volume. In photogrammetry, stereoscopic depth perception plays a vital role in creating and viewing 3D representations of the earth's surface. As a result, geographic information can be collected to a greater accuracy, compared to traditional monoscopic techniques.

Stereoscopy is the science of perceiving depth using two eyes. When our two eyes (binocular vision) are focused on a certain point, the optical axes of the eyes converge on that point, forming a parallactic angle ($\square$). The nearer the object, the greater is the parallactic angle. For instance, in Fig. 2.4 the optical axes of the left and right eyes, L and R, are separated by the eye base (the distance between two eyes). The eye base of the average adult is between 63 and 69 mm. When the eyes are focused on point A, the optical axes converge, forming a parallactic angle $\square_a$. Similarly, when looking at point B, the optical axes converge, forming a parallactic angle $\square_b$. The brain has learned to associate distances D_a and D_b with the nonexpanding parallactic angles $\square_a$ and $\square_b$ and gives the viewer the visual and mental impression that object B. is closer than object A. This is the basis of depth perception. If both objects were exactly at the same distance from the viewer, then $\square_a = \square_b$ and the viewer would perceive them as being the same distance away. In this context, it should be noted that the human eye can only perceive a 3D view, not the actual measurement of the objects.

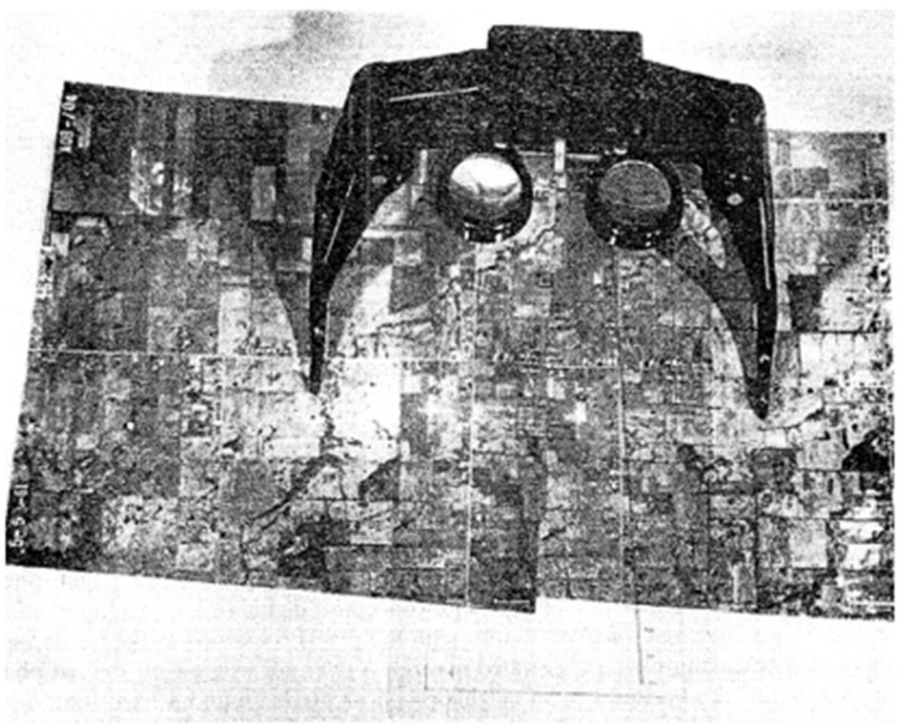

Fig. 2.6: Stereoscopic 3D View.

In digital photogrammetry, a true stereo effect is achieved when two overlapping images (a stereo pair), of a common area captured from two different vantage pouts are rendered and viewed simultaneously. This is analogous to the depth perception we achieve by looking at a feature with our two eyes. Our two eyes represent the two vantage points like two independent photos.

When viewing the features from two perspectives (the left photo and the right photo) the brain automatically perceives the variation in depth between different objects and features as a difference in height. For instance, while viewing a building in stereo, the brain automatically compares the relative positions of the building and finds the two different perspectives (i.e., two overlapping images). The brain also detenni1 which is closer and which is farther from the building roof or the ground. Thus, as the left and right eyes view the overlap area of two images, the depth between the top and bottom of a building is perceived automatically by the brain, and any changes in depth are due to elevation changes.

During the stereo viewing process in digital photogrammetry, the left eye concentrates on the object in the left image and the right eye concentrates on the object the right image. As a result, a single 3D image is formed within the brain. The brain discerns height and variations in height by visually comparing the depths of various features. While the eyes move across the overlap area of the two photographs, a continuous 3D model of the earth is formulated within the brain, since the eyes continuously perceive the change in depth as a function of elevation change.

The 3D image formed by the brain is also referred to as a stereo model. Once the stereo model is formed, we notice relief, or vertical exaggeration, in the 3D model. A digital version of a stereo model, a DSM, can be created when sensor model information is associated with the left and right images comprising a stereo pair. A DSM is formed using a stereo pair and accurate sensor model information. Images of the DSM are then rendered in any stereo-mode (depending upon the software and hardware available), so that the left image becomes visible to the left eye only and the right image to the right eye only. As a result, a single 3D image is formed within the brain.

There are several ways to provide stereo viewing; the choice of device largely depends on operational requirements, cost factors, and photogrammetric software. It should also be realized that many operations in digital photogrammetry do not require stereo viewing, except for 3D coordinate measurement. The basic modes of 3D viewing are as follows:

i. *Split screen mode:* In this mode, the display unit displays two stereo images side by side, and a simple stereoscope is used to get a 3D view.

ii. *Quad buffered mode or image alternating mode:* This option uses the graphics hardware and OpenGL to render the left and right images. It uses a technique called quad-buffering, whereby the contents of a window are swapped/flickered rapidly between the left and right version of the stereo scene. In this method both images of the stereo pair are shown alternating, where both images must be flickered with a frequency of more than 25 Hz. Here, the viewer needs spectacles with liquid crystal lenses. These are synchronized with the computer graphics hardware by an external device such as infrared emitter. The signals cause the liquid crystal shutters to switch in synchronization with the alternating left and right images on the screen. In this way, each eye sees only the image intended for that eye. This is generally the best way to view stereo. However, not all hardware can support this mode.

iii. *Colour anaglyph mode:* This option uses OpenGL's colour masking capability to simultaneously render the left and right images of a stereo scene with different colours. Stereo is then perceived by wearing glasses with differently coloured lenses, so each eye will only see one version of the scene. For instance, the left image is rendered with red colour and right image with blue colour. Now, if we wear spectacles having red glass in left and blue in right, the red light comes from the left image (as it appears red, it emits red light) and is blocked by blue glass of right eye and is allowed to pass with red glass to enter in the left eye. Thus, the left image is viewed by the left eye only, and similarly right image is viewed by the right eye only. This is generally an inexpensive and easy way to see stereo on non-stereo normal hardware. The drawback is that full representation of colour imagery is not possible, although some colour perception can be achieved.

iv. *Line interleaved polarization mode:* This renders the left and right versions of the Stereo scene in alternating pixel scan lines. This move is intended for use with certain stereo display devices that can render alternating scan lines differently, such as special overhead projectors, which can alternately polarize the scan lines vertically and horizontally. The viewer wears a pair of spectacles with corresponding filters. Although viewing of polarized 3D models is very comfortable, the main disadvantage lies in the fact that they cannot be printed. Additionally, special expensive equipment is needed (projectors or hardware and software, glasses with polarizing filters).

To maximize mapping efficiency, accuracy, and operator comfort, many 3D control devices have been used, including free-moving hand controllers, hand wheels, normal mouse, and foot disks. Two types, the free-hand controller and 3D mouse, are popular.

Stereo Model Compilation

By laying a pair of matched and overlapping images, a digital version of a stereo model or 3D view can be created that allows the determination of ground elevations and building, or cultural feature heights. The result of this step in the process is the creation of a digital model of the earth's surface and the features lying on it, commonly called as digital stereo model (DSM). The following general steps are required to create a DSM:

1) Arrange the selected pair of photos in such a way that the shadows on them generally appear to fall toward the viewer.
2) Place the pair of photographs on a flat surface so that the detail on one photograph is directly over the same detail on the other photograph.
3) Place the stereoscope over the photographs so that the left lens is over the left photograph and the right lens is over the right photograph.
4) Separate the photographs along the line of flight until a piece of detail appearing in the overlap area of the left photograph is directly under the left lens and the same piece of detail on the right photo is directly under the right lens.
5) With the photograph and stereoscope in these positions, a three-dimensional image should be seen. A few minor adjustments may be necessary, such as adjusting the aerial photographs of the stereoscope to obtain the correct position for your eyes. The hills appear to rise and the valleys sink so that there is the impression of being in an aircraft looking down at the ground.

This stereo model can be used for 3D viewing, 3D measurement, DTM creation, 3D feature extraction, contour map creation, orthorectification, and 3D scene modeling.

Stereoscopic Measurement

Parallax is the apparent displacement in the position of a stationary object, concerning a frame of reference, caused by a shift in the position of observation. It may be defined as the change in position of an object with height, from one image to the next relative to its background, caused by the imaging platform's motion, and is called stereoscopic parallax or just parallax. We may try it just by viewing an object monoscopically with our left eye (closing right eye) and then the right (closing the left). We may notice that there is an apparent shift in position of the object. Though the object is fixed in a position, the apparent displacement occurs due to displacement of viewing position. As the distance between the observer and object decreases, the apparent position shift increases. Similarly, the change in position of an object from one image to the next by the imaging platform's motion is termed as stereoscopic parallax. Instruments called a stereometer or parallax bar are used to measure differences in parallax between objects in a stereo pair in analog photogrammetry. In digital photogrammetry, it is measured with the help of computer hardware and software, but it is required to understand parallax equations, which are employed to convert measured parallax into object height.

Based on the definitions provided earlier for stereoscopic vision and parallax, the term stereoscopic parallax refers to the perception of depth based on viewing objects from separate points of observation. Stereoscopic parallax is a very important concept in photogrammetry as it allows for the measurement of the height of objects appearing in a stereo pair.

Parallax is a normal characteristic of stereo photography/imaging and is the basis for 3D stereoscopic viewing. Differences in the parallax of various objects of interest (called differential parallax) can be used to measure the differences in height of objects and to extract topographic information from remotely sensed stereo images.

Stereo models provide a permanent record of 3D information pertaining to the given geographic area covered within the overlapping area of two images. Viewing a stereo model in stereo gives an abundant amount of 3D information. The availability of 3D information in a stereo model is made possible by the presence of what is also referred to as stereoscopic parallax.

There are two types of parallaxes, x-parallax, and y-parallax.

x-Parallax: The change in position of the impressions of an object from one photograph/image to the next, parallel to the flight line, caused by the imaging platform's motion is referred to as stereoscopic x-parallax. Figure above illustrates the image positions of two ground points (A and B) appearing in the overlapping areas of two images. Ground point A is the top of a building and ground point B is the ground (Figure 2.12).

A hypothetical example will demonstrate bow the image analyst or a computer perceives the third dimension in stereoscopic imagery. Figure 2.13 illustrates a profile view of the stereoscopic images taken from two different exposure stations (Li and L2) and the corresponding image positions of ground point A (top of very tall building) and ground point

B (top of a small building). Ground points A and B appear on the left image (L1) at positions a and b, respectively. Due to the forward motion of the aircraft during exposure, the same two ground points appear on the right photograph (L2) at image positions a' and b'.

To understand the relationship between these four points (a, b, a', b'), consider Fig. 3.14, which depicts the two photographs taken. At exposure stations L1 and L2 in superposition. Superposition means that we adjust the profile views of photos L1 and L2 so that the vertical lines running through each of the images' principal points (PPI and PP2) are superimposed, one on top of the other. This allows us to determine how much the objects have moved across the image space from one exposure to the next.

Notice that the image of object A moved from a to a' on the two successive images. The parallax of point A is $P_a = x_a — x_a'$. Similarly, the image of object B moved from b to b'. The parallax of point B is $P_b = x_b – x_b'$. Since ground point A is at a. higher elevation, the movement of image point 'a' to position 'a'' on the right image is larger than the movement of image point 'b'. Thus, the amount of x-parallax is influenced by the elevation of a ground point. Since the degree of topographic relief varies across a stereo pair, the amount of x-parallax also varies. It is important to understand that all objects in the scene at the same elevation will have same amount of x-parallax.

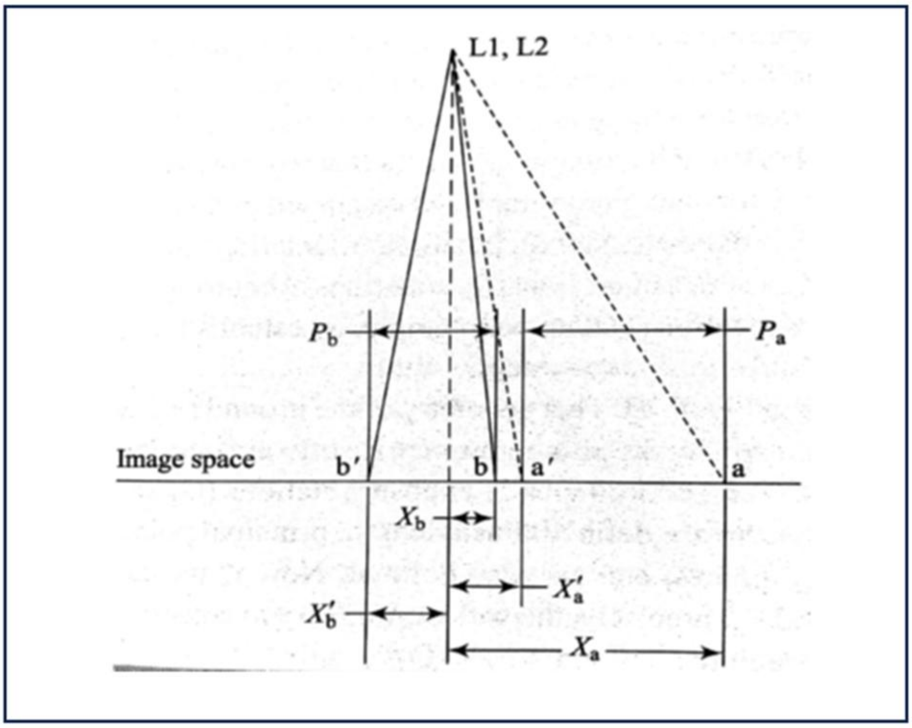

Fig. 2.14: Superposition of two successive exposures.

The difference in parallax is called differential parallax (dp). So, in the above case differential parallax (dp) = $P_a — P_b$. The ability to measure small differences in the parallax (i.e., differential parallax) between any two points using overlapping photographs allow us to determine elevation differences using stereoscopic parallax equations. To compute the height of an (h_o), we use the fundamental stereoscopic parallax equation:

$$h_0 = H \times \frac{dp}{(P + dp)}$$

where H is the altitude of the aircraft above ground level (AGL), P is the absolute stereoscopic parallax at the base of the object being measured (usually the air-base distance or the distance between two successive exposure stations is considered as P), and dp is the differential parallax with respect to the base and top of the object being measured.
However, the following simple equation can also be used to derive the height of an object (e.g., height of point A = h_A):

Height of any point (h_A) =

$$\text{altitude of aircraft (H)} - \frac{\text{air base distance (P)} \times \text{focal length (f)}}{\text{Parallax}(P_a)}$$

Parallax, measurements in digital photogrammetric systems are not considered for these assumptions; they usually involve some form of numerical image correlation to match points on the left photo of a stereo pair to their conjugate images on the right one. Such systems employ mathematical models (DSM) of the imaging process that readily bundle variations in the flying height and attitude for each photograph. As discussed earlier, the relationship among image coordinates, the exposure station position, orientation, etc. of each photograph is normally described by a series of co-linearity equations. Acquiring 3D ground position of any point (X, Y, and Z location) is then very simple, by establishing a relationship between the pixel and ground coordinate system.

y-parallax: The change in position of the impressions of an object from one photograph/image to the next, perpendicular to the flight line is referred to as y-parallax. Due to the presence of y-parallax, viewing and measuring a DSM may be difficult. Unlike x-parallax, y-parallax is an error which is to be removed or reduced. The following factors may introduce y-parallax:

- Unequal flying height between adjacent exposures: This effect causes a difference in scale between the left and right images. As a result, y-parallax is introduced and the 3D stereo view becomes distorted.

- Flight line misalignment during image collection: This results in large differences in image orientation between two overlapping images. As a result, we experience eyestrain and discomfort while viewing the DSM.
- Erroneous sensor model information: Inaccurate sensor model information creates large differences in y-parallax between two images comprising a DSM.

As a result of these factors, the DSMs contain y-parallax. y-parallax introduces discomfort during stereo viewing.

To minimize y-parallax, we are required to scale, translate, and rotate the images until a clear and comfortable stereo view is available. While using DSMs created from sensor model information, photogrammetric software automatically rotates, scales, and translates the imagery to continually provide an optimum stereo view throughout the stereo model. Thus, the parallax is automatically accounted for creating a clear stereo view is referred to as 'epipolar resampling' on the fly. As we roam throughout a DSM, many software account and adjust for y-parallax automatically.

Image Parallax

The term parallax refers to the apparent change in the relative position of stationary objects caused by a change in viewing position. As applied to aerial photos, the parallax of a point is the apparent difference in the position of the point on two consecutive photographs.

This phenomenon is observable when one looks at objects through a side window of a moving vehicle. With the moving window as a frame of reference, objects such as mountains at a relatively great distance from the window appear to move very little within the frame of reference. In contrast, objects close to the window, such as roadside trees, appear to move through a much greater distance. In the same way, terrain features close to an aircraft (i.e., at higher elevation) will appear to move relative to the lower elevation features when the point of view changes between successive exposures. These relative displacements form the basis of three-dimensional viewing of overlapping photography. In addition, they can be measured and used to compute the elevations of terrain points. The parallax can be resolved in two components one in the direction of flight and is known as X-parallax or absolute parallax and the other perpendicular to the flight direction known as Y-parallax. Y- parallax is zero if the photos are tilt-free and have been taken from the same altitude. The absolute stereoscopic parallax is the algebraic difference, in the direction of the flight, of the distance of the two images of the object from their respective principal points. The parallax difference can be used to determine the height of the objects and the dip and slope from the stereo pairs.

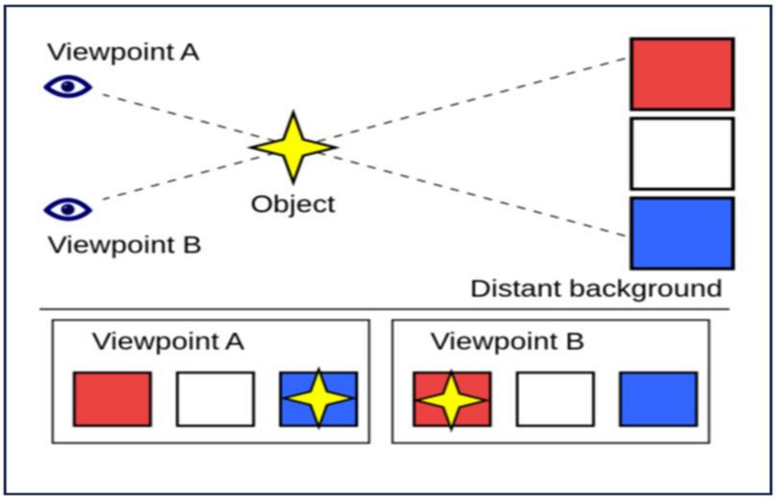

Figure 2.15: Image Parallax in Aerial Photography

Characteristics of Image Parallax: Thus far we have limited our discussion to photogrammetric operations involving only single vertical photographs. Numerous applications of photogrammetry incorporate the analysis of stereopairs and use of the principle of parallax. The term parallax refers to the apparent change in relative positions of stationary objects caused by a change in viewing position. This phenomenon is observable when one looks at objects through a side window of a moving vehicle. With the moving window as a frame of reference, objects such as mountains at a relatively great distance from the window appear to move very little within the frame of reference. In contrast, objects close to the window, such as roadside trees, appear to move through a much greater distance.

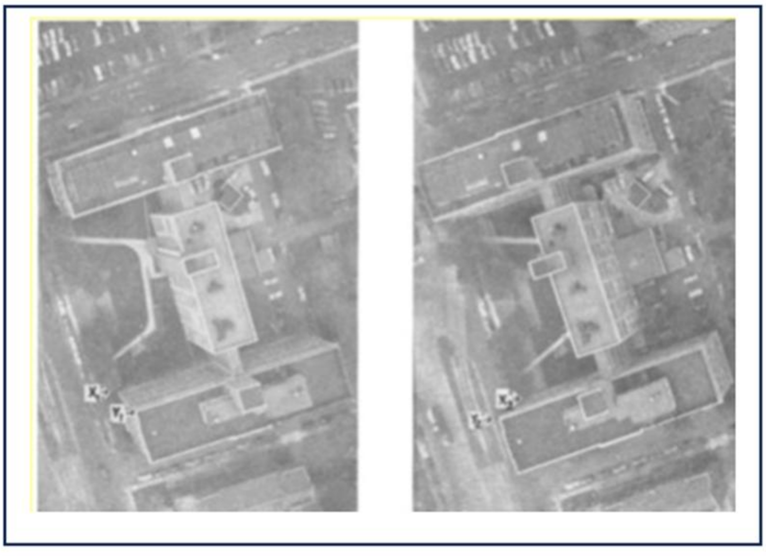

Fig. 2.16: Aerial Photos Showing Image Parallax.

In the same way that the close trees move relative to the distant mountains, terrain features close to an aircraft (i.e., at higher elevation) will appear to move relative to the lower elevation features when the point of view changes between successive exposures. These relative 'displacements form the basis for three-dimensional viewing of overlapping photographs. In addition, there can be measured and used to compute the elevations of terrain points.

Fig. 2.16 illustrates the nature of parallax on overlapping vertical photographs taken over varied terrain. Note that the relative positions of points A and B change with the change in viewing position (in this case, the exposure station). Note also that the parallax displacements occur only parallel to the line of flight. In theory, the direction of flight should correspond precisely to the financial x-axis. However, unavoidable changes in the aircraft orientation will usually slightly offset the financial axis from the flight axis. The true flight line axis may be found by first locating on a photograph the points that correspond to the image centers of the preceding and succeeding photographs. These points are called the conjugate principal points. A line drawn through the principal points and the conjugate principal points defines the flight axis.

Relief Displacement

Relief displacement is another characteristic of the perspective geometry recorded by an aerial photograph. The displacement of an image point caused by changes in ground elevation is closely related to photographic scale variation. Relief displacement is evaluated when analyzing or planning mosaic or orthophoto projects. Relief displacement is also a tool that can be used in photo interpretation to determine the heights of vertical objects.

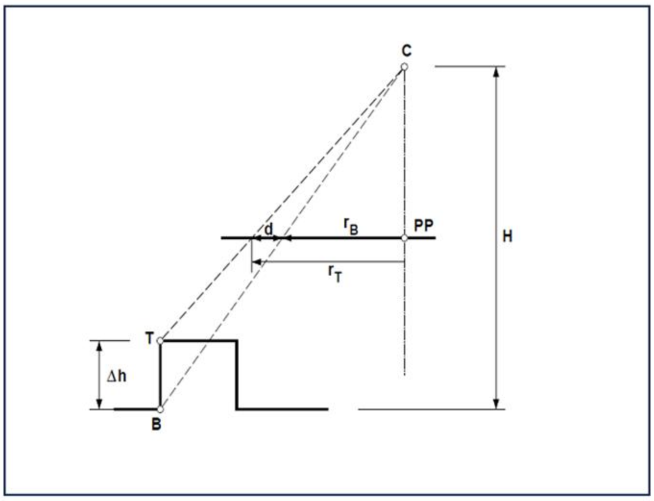

Fig. 2.17: Concept of relief displacement.

The effect of relief does not only cause a change in the scale but can also be considered as a component of image displacement. Fig. 2.17 illustrates this concept. Suppose point T is on top of a building and point B at the bottom. On a map, both points have identical X, Y coordinates; however, on the photograph they are imaged at different positions, namely in T and B. The distance d between the two photo points is called relief displacement because it is caused by the elevation difference Δh between T and B (Figure 2.17)

Figure 2.18 illustrates the geometric distortion called relief displacement, which is present on all vertical aerial photographs that are acquired when the camera is aimed directly down. The tops of objects such as buildings appear to "lean" away from the principal point, or optical center, of the photograph. The amount of displacement increases at greater radial distances from the center and reaches a maximum at the corners of the photograph. Figure 2.19 shows the geometry of image displacement, where light rays are traced from the terrain through the camera lens and onto the film. Prints made from the film appear as though they were in the position shown by the plane of photographic print in Figure 2.19. The vertical arrows on the terrain represent objects of various

heights located at various distances from the principal point. The light ray reflected from the base of object A intersects the plane of the photographic print at position A, and the ray from the top intersects the print at A'. The distance A-A' is the relief displacement (d) shown in the plan view (Figure 2.20).

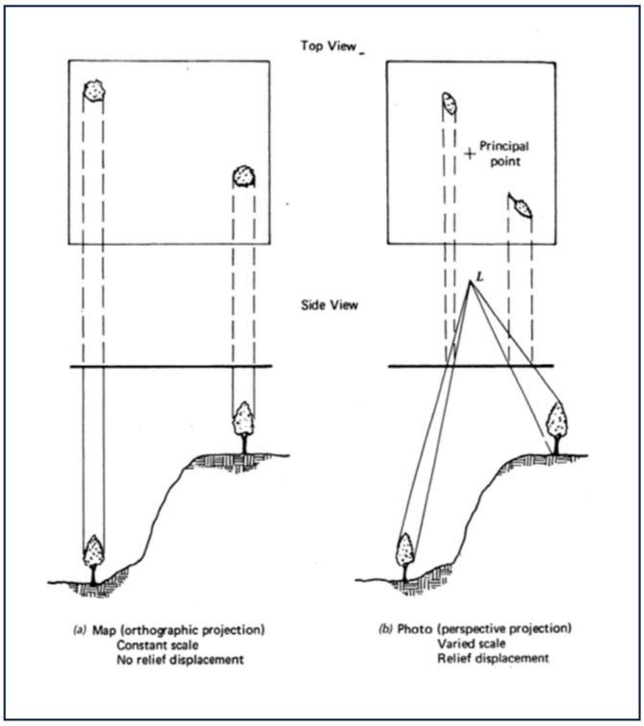

Fig. 2.18: Comparative Geometry of (a) a map and (b) a vertical aerial photograph

The amount of relief displacement (d) on an aerial photograph is

1. Directly proportional to the height (h) of the object. For objects A and C (Figure 2.20) at equal distances from the principal point, d is greater for A, which is the taller object.
2. Directly proportional to the radial distance (r) from the principal point to the top point on the displaced image corresponding to the top of the object (Figure 2.20). For objects A and B, which are of equal height, d is greater for A because it is located farther from the principal point.

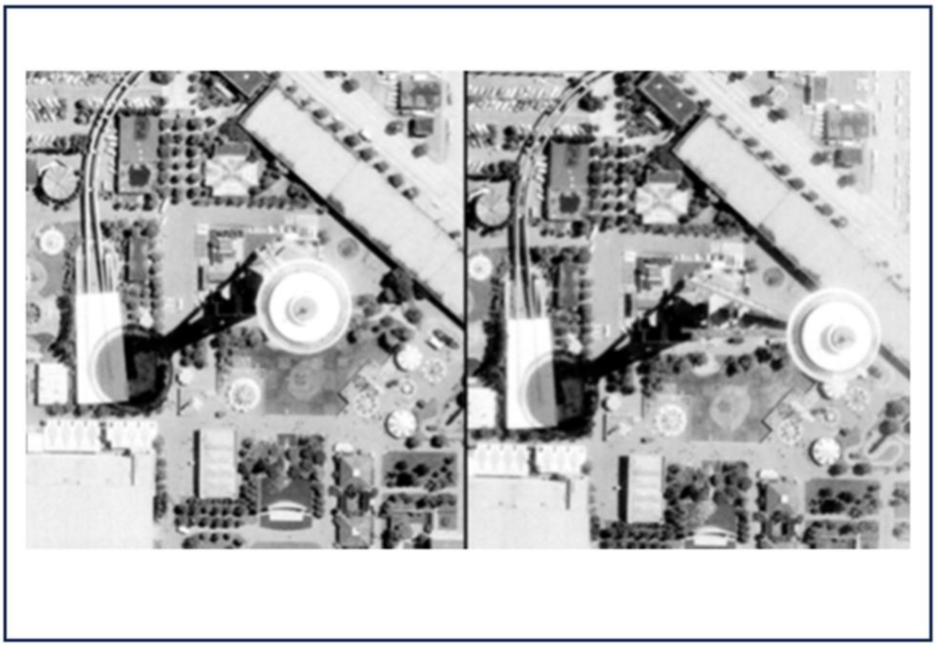

Figure 2.19: Vertical aerial photo showing the relief displacement.

3. inversely proportional to the height (H) of the camera above the terrain,

These relationships are expressed mathematically as

$d = \frac{h.r}{H}$ which may be transposed to $h = \frac{H.d}{r}$ (2-4)

This equation may be used to determine the height of an object from its relief displacement on an aerial photograph. For the building in the lower right corner of Figure 2-8, d and r are measured using the scale of the photograph, and the height is calculated from Equation 2-4 as

$$f = \frac{212m´\ \ 40m}{260m} = 32.6m$$

Orthophotographs are aerial photographs that have been scanned into a digital format and computer-processed to remove the radial distortion. These photographs have a consistent scale throughout the image and may be used as maps.

Causes of Displacement: Camera tilt, earth curvature, and terrain relief all contribute to shifting photo image features away from true geographic location. Camera tilt is greatly reduced or perhaps eliminated by gyroscopically-controlled cameras. Earth curvature is of little consequence on large-scale photography. The relatively small amount of lateral distance covered by the exposure frame introduces only a minimal amount of curvature, if any. Topographic relief can have a great effect on displacing image features. The amount of image displacement increases on high-degree slopes. Feature displacement also increases radially away from the photo centre.

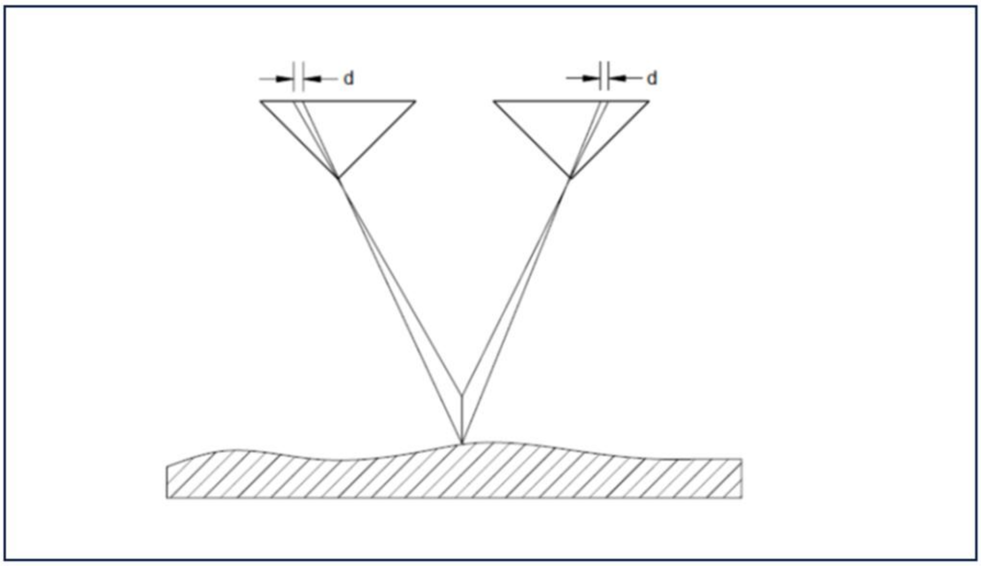

Fig. 2.20: Image displacement.

Effects of Displacement: An aerial photograph is a three-dimensional scene transferred onto a two-dimensional plane. Hence, the photographic process literally squashes a three-dimensional feature onto a plane that lacks a vertical dimension, and image features above or below mean ground level are displaced from their true horizontal location. Figure 2.20 illustrates this phenomenon. If the stack rises straight into the air from the ground, both the top and the base possess the same horizontal (XY) placement.

This diagram belies that fact, because the base and the top are in displaced positions (labelled "d" in Figure 2.20) on the negatives. This separation will not be of the same magnitude on successive photos.

Figure 2.20 illustrates the radial displacement of an object in an aerial photograph. Just as images of fast-rising features are displaced, so are the changes in ground elevations, though not as visibly apparent in the photographs. Figure 2.20 illustrates relief displacement on a straight utility clearing those crosses rolling hills. The clearing is identified as the wavy open strip running diagonally through the woods on the left side of the photo. Even though the indicated utility clearing follows a straight course, relief displacement due to terrain undulations causes this feature to waver.

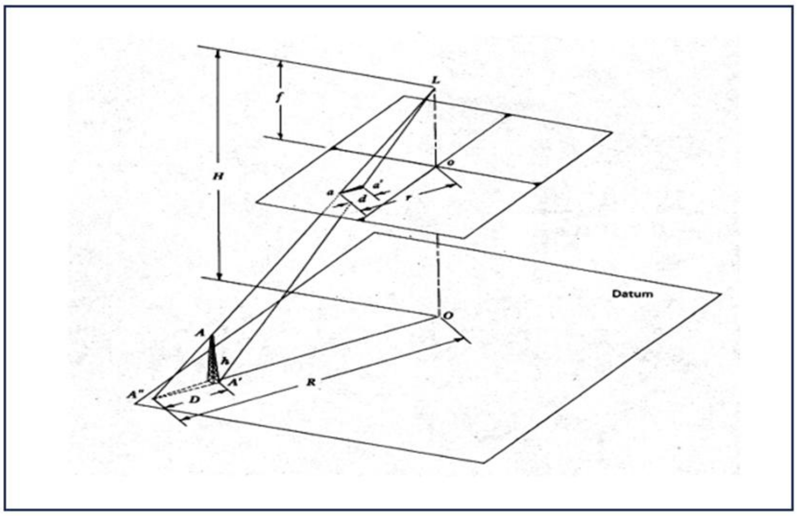

Fig. 2.21: Geometric component of relief displacement.

Distortion vs. Displacement: Often, the term distortion is synonymous with displacement. Distortion implies aberration. It is caused by discrepancies in the photographic, processing, and reproduction systems. This condition is not correctable in the compilation of a stereo model.

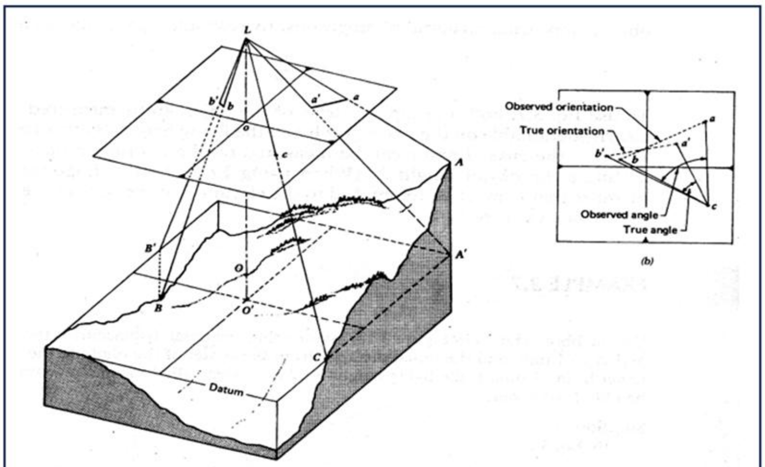

Fig. 2.22: Relief displacement on a photograph taken over varied terrain: (a) displacement of terrain points; (b) distortion of horizontal angles measured on a photograph.

Displacement is a normal inherent condition. Since mapping instruments work with a three-dimensional spatial image formed by a pair of overlapping two-dimensional photos, predictable displacement can be compensated for in the mapping process. Rather than being a fault in the image structure, displacement is the means by which it is possible to extract spatial information from photographs.

Correcting for Relief Displacement: In addition to calculating object heights, quantification of relief displacement can be used to correct the image positions of terrain points appearing in a photograph. Keep in mind that terrain points in areas of varied relief exhibit relief displacement as do vertical objects. This is illustrated in above figure 2.22. In this figure, the datum plane has been set at an average terrain elevation, terrain rain points A and B would be located at A' and B' and would be imaged at points a' and b' on the photograph. Due to varied relief, however, the position of point A is shifted radially outwards on the photograph (to a), and the position of B is shifted radially inwards (to b). These changes in image position are the relief displacement of points A and B. Figure B illustrates the effects they have on the geometry of the photo. Because A' and B' lie at the same elevation, the image line a'b' accurately represents the scaled horizontal length and directional orientation of the ground line AB. When the relief displacement is introduced, the resulting line ab has a considerably altered length and orientation.

Angles are distorted by relief displacement. In fig. b, the horizontal ground angle ACB is accurately expressed by a'cb' on the photo. Due to the displacement, the distorted angles acb will appear on the photograph. Note that, because of the radial nature of relief displacement, angles about the origin of the photo (such as aob) will not be distorted.

Relief displacement can be corrected by using the equation below to compute its magnitude on a point-by-point basis and then laying off the computed displacement distances radially (in reverse) on the photograph. This procedure establishes the datum-level image position of the points and removes the relief distortions, resulting in a planimetrically correct image position at the datum scale. This scale can be determined from the flying height above the datum (S= f/H). Ground lengths, directions, angles and areas may then be directly determined from these corrected image positions.

For example, referring to the vertical photograph depicted in Figure 2.22, assume that the radial distance r_a to point A is 63.84 mm and the radial distance r_b to point B is 62.65 mm. Flying height H is 1220 m above the datum, point A is 152m above the datum, and point B is 168 m below the datum. Find the radial distance and direction one must lay off from points a and b to plot a' and b'.

By equation,

$d_a = r_a h_a = \frac{63.84\text{mm} \times 152\text{m}}{1220 \text{ m}} = 7.95$ mm (plot inward)

$d_b = r_b h_b = \frac{62.65\text{mm} \times (-168\text{m})}{1220 \text{ m}} = -8.63$ mm (plot outwards)

2.4 SUMMARY

At last, in summary, it can be said that Stereo photography techniques are methods to produce stereoscopic images, videos, and films. This is done with a variety of equipment including specially built stereo cameras, single cameras with or without special attachments, and paired cameras. This involves traditional film cameras as well as, tape and modern digital cameras. Several specialized techniques are employed to produce different kinds of stereo images.

2.5 GLOSSARY

Fiducial marks: Fiducial marks is a set of marks located in the corners or edge-centers, or both, of an aerial photographic image. These marks are exposed within the camera onto the original film and are used to define the frame of reference for spatial measurements on aerial photographs.

Relief displacement error: Geometric distortion on remote sensing image or photograph. The tops top objects appear be radially displaced from their base.

Relief: Relief is a sculptural technique where the sculpted elements remain attached to a solid background of the same material. The term relief is from the Latin verb relievo, to raise

Stereo base: Distance between a pair of corrective points in a stereopair that are oriented for stereo viewing.

Stereo model: A stereo model of a mosaic dataset is required for stereo feature collection and 3D point cloud generation. A stereo model, as one of the tables within a mosaic dataset, defines the stereo pairs. The stereo model stores the overlapping polygons, the corresponding image identifiers, and image IDs that compose each pair.

Stereo pair: A stereo-pair image contains two views of a scene side by side. One of the views is intended for the left eye and the other for the right eye. These images are sometimes viewed with special equipment to direct each eye on to its intended target, but they are also often viewed without equipment.

Stereoplotting instrument: An instrument for plotting a map or obtaining spatial solution by observation of stereoscopic formed by stereo pairs.

Stereopsis: the perception of depth produced by the reception in the brain of visual stimuli from both eyes in combination; binocular vision.

Stereoscope: stereoscope is a device for viewing a stereoscopic pair of separate images, depicting left-eye and right-eye views of the same scene, as a single three-dimensional image.

Stereoscopic vision: The single perception of a slightly different image from each eye, resulting in depth perception. Examples from the Web for stereoscopic vision. Binocular instruments should aid the natural spatial or stereoscopic vision, or make it possible if the eyes fail.

2.6ANSWER TO CHECK YOUR PROGRESS

1. Do you know the pocket stereoscope, sometimes known as a lens stereoscope?
2. Do you know stereoscopic vision is broadly categorized into natural stereoscopic vision and artificial stereoscopic vision?
3. Do you know Image parallax refers to the apparent shift in the position of objects or features when observed from different viewing angles, typically caused by the displacement between multiple sensors or cameras?

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2.8 TERMINAL QUESTIONS

Long Questions

1. How the overlapping photographs are captured for the aerial platform? Explain in brief.
2. What are the techniques available for 3D viewing in digital photogrammetry? Explain in brief.
3. Explain different stereo imaging concepts from satellites.
4. Explain how human stereo viewing is done.
5. Calculate the height of a lamp post for which parallax is 30mm. consider flying height 1200m, airbase 600m and focal length 0.1524m.
6. Explain the 3D viewing concept by using a lens stereoscope and mirror stereoscope.
7. Write short notes on the following topics:-
   A. Parallax
   B. Flight line
   C. Lens stereoscope
   D. Fiducial marks
   E. Principal point

Short Questions

1. What is stereoscope?
2. What is Pocket Stereoscope?
3. Define a Mirror Stereoscope.
4. What do you understand by the interior orientation of a camera?
5. What are the key variables used to specify the internal geometry of a camera?

Multiple Choice Questions

1) **What is the primary factor that can significantly affect the displacement of image features in photography, especially when high-degree slopes are involved?**
    a) Camera tilt
    b) Earth curvature
    c) Earth curvature
    d) Lateral distance covered by the exposure frame
2) **What are the two primary types of stereoscopic vision?**
    a) Monocular and binocular
    b) Natural and artificial
    c) Peripheral and central
    d) Static and dynamic
3) **What does the acronym GCP stand for?**
    a) Global Cartographic Projection
    b) Geographic Coordinate Precision
    c) Ground Control Point
    d) Generalized Calibration Procedure
4) **Which of the following is not part of the internal geometry of a camera?**
    a) Fiducial marks
    b) Principal point
    c) Focal length
    d) GCP
5) **What is another name for a pocket stereoscope, which is sometimes used interchangeably?**
    a) Monocular scope
    b) Binocular microscope
    c) Lens stereoscope
    d) Stereographic viewer

Answers) 1.a 2. b 3.c 4. d 5.c

UNIT 3 - MEASUREMENTS AND RECTIFICATION

3.1 OBJECTIVES

After reading this unit you will be able to understand the

- Concept and Importance of Measurement
- Remote Sensing and its Types
- Aerial Photography and its Interpretation
- Different applications of Aerial Photographs

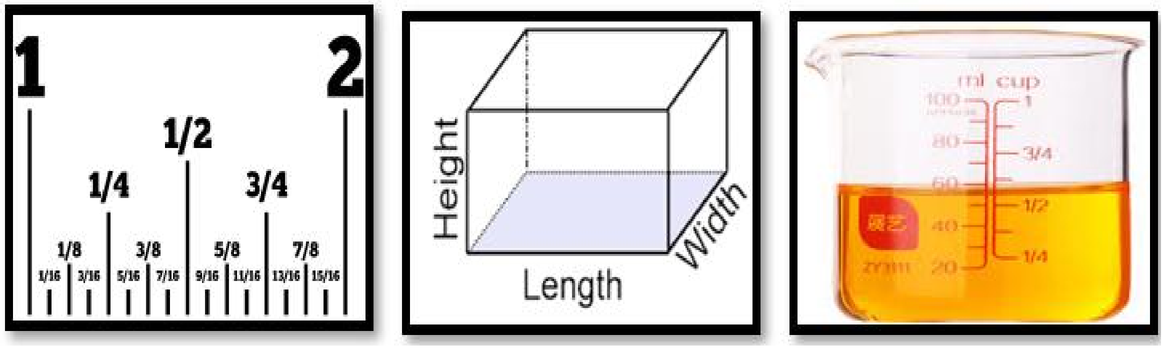
3.2 INTRODUCTION

Measurement

The term measurement is so important and integral to our lives that almost all over workouts from daily tasks to projected tasks we are used to this very much. It comes from the Greek word "metron," which means "limited proportion." For we take tea, which is measured by a cup, office/college goers use this to explain the kilometer/meter distance from their homes, price of objects is also to be calculated w. r. t. its standard unit's liters, Kilograms, Square Meters/Feet, per Hour/Minutes/Seconds etc. We use this term as the assignment of a number to a characteristic of an object or event, which can be compared with other objects or events. The scope and application of a measurement is dependent on the context and discipline. Measurement is a cornerstone of trade, science, technology, and quantitative research in many disciplines. Historically, many measurement systems existed for the varied fields of human existence to facilitate comparisons in these fields.

In the classical definition, which is standard throughout the physical sciences, measurement is the determination or estimation of ratios of quantities. Quantity and measurement are mutually defined: quantitative attributes are those possible to measure, at least in principle.

Properties like distance, height, weight, time, etc. can be measured directly with some standard units such as Kilometer, Meter, Centimeter, Kilogram, Gram, Hours, Minutes, and Seconds while some measurements like speed, an average of POL, etc. can measure by the combination of two or sometimes more units, as a meter per second, Kilometer per Liter of POL, etc.



\Fig. 3.1: Measurement Tapes/Pots.

Measurement is perhaps one of the most fundamental concepts in science. Without the ability to measure, it would be difficult for scientists to conduct experiments or form theories. Not only is measurement important in science and industries, but it is also essential in agriculture, construction, production, and the number of activities. We can expect high accuracy in measuring the length of pipe with a yardstick, but if the concept is abstract and the measurement tools are not standardized, we are less confident about the accuracy of the results of measurement. When we measure, we attempt to identify the dimensions, quantity, capacity, or degree of something.

Remote Sensing

Remote Sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter [2].

OR

Remote Sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation [3].

OR

Remote Sensing is the instrumentation, techniques, and methods to observe the Earth's surface at a distance and to interpret the images or numerical values obtained to acquire meaningful information of objects on Earth [4].

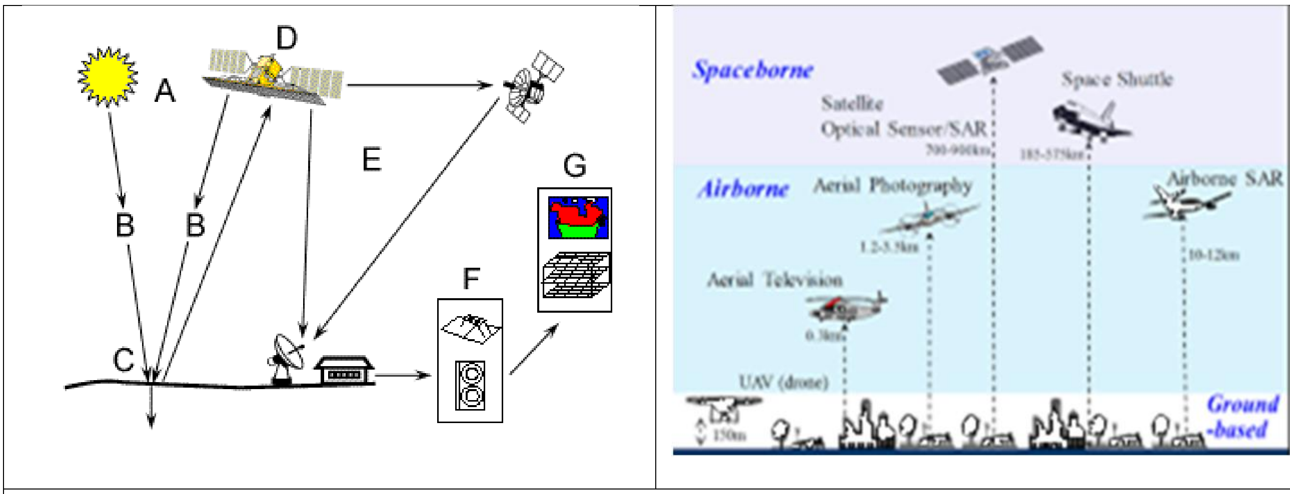


Figure 3.2: The Remote Sensing Fundamentals/Stages covers the following:

A. Energy source

B. Atmospheric interactions

C. Target interactions

D. Sensor records energy

E. Transmission to receiving station

F. Interpretation

G. Application

As per the above definitions, the common thing is that the data related to Earth's surface are acquired by a device called a sensor that is not in contact with the objects being measured. The characteristics measured by a sensor are the electromagnetic energy reflected or emitted by the Earth's surface which is then recorded by the sensors. The resulting data may be used to derive information about surface characteristics. As per application requirements, different types of sensors have been developed and mounted on different platforms. These platforms may be static or dynamic depending on the applications. A platform is a vehicle, such as an aircraft or satellite used for a particular activity or purpose or to carry a specific kind of equipment or instruments.

Aerial and satellite images, known as remotely sensed images, permit accurate mapping of land cover and make landscape features understandable on regional, continental, and even global scales. Transient phenomena, such as seasonal vegetation vigor and contaminant discharges, can also be studied by comparing images acquired at different times.

Sensors used in remote sensing can be carried at heights ranging from just a few centimeters, using field equipment, up to orbits in space as far away as 36,000 km (geostationary orbits) and beyond. Very often, the sensor is mounted on a moving vehicle, which we call the platform, such as aircraft and satellites.

Airborne observations are carried out using different types of aircraft depending on the operational requirements and budget available with specific modifications to carry sensors. An aircraft needs a hole in the floor or a special remote sensing pod for the aerial camera or a scanner. Sometimes Ultra Light Vehicles (UAVs), Unmanned Aerial Vehicles (UAVs), balloons, helicopters, airships, or kites are used for airborne remote sensing. Depending on the platform and sensor, airborne observations are possible at altitudes ranging from less than 100 meters up to 40 kilometers. On the other hand, the navigation of an aircraft is one of the most crucial parts of airborne remote sensing.

Figure 3.3: Different platforms used for aerial photograph.

3.3 MEASUREMENTS AND RECTIFICATION

Measurement of height difference from Aerial Photographs

Aerial Photography

As photography is the science, art, application, and practice of creating durable images by recording light or other electromagnetic radiation, either electronically by means of an image sensor or chemically employing light–sensitive material such as photographic film.

Aerial photography is the taking of photographs from an aircraft or other flying objects on different platforms. Cameras mounted on these platforms triggered or programmed remotely hence acquiring the image on a regular basis. Some of the samples of the aerial imageries are shown below.

Fig. 3.4: Aerial Photograph of different locations (Source: https://earthexplorer.usgs.gov/).

Advantages of Aerial Photographs

- It is a pictorial representation of the ground that shows far greater detail than a paper map.
- It has broader spectral sensitivity than the human eye.
- As aerial photographs are much more cheaply produced than maps, most areas are photographed more frequently than they are mapped and aerial photographs thus are usually more up to date.
- A sequence of images of the features are available which gives more robust output to the interpreter
- Land Use Land Cover (LULC) maps over the different timeline is available from these images.

- It provides a permanent recording.

Disadvantages of Aerial Photographs

- Because of various distortions, aerial photographs rarely show features in their correct horizontal positions.
- It requires special equipment for measuring the heights and slopes which cannot be measured from photographs itself.
- The outcome is very much dependent on the knowledge of the interpreter.

Types of Aerial Photographs

Aerial photographs may be classified according to the camera attitude (angle of photography) and
the type of film used. Depending on the camera angle, an aerial photograph may be

- **Vertical or Oblique**
- **Low Oblique**
- **High Oblique**

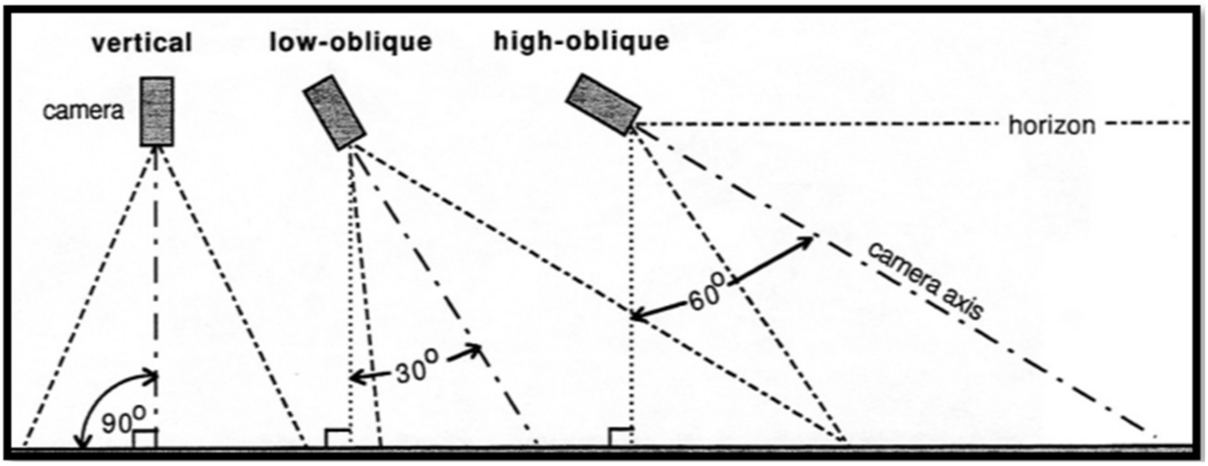


Fig.3.5: Types of Aerial Photographs.

Vertical or Oblique

A vertical aerial photograph is taken with the axis of the camera at right angles to the horizontal. This yields an image that may be unfamiliar in format but which is relatively easy to manipulate photogrammetrically. Almost all modern aerial photography is vertical in orientation.

Low Oblique

All aerial photography taken with the camera axis set at some angle other than 90^o to the horizontal, is referred to as oblique aerial photography. A low-oblique aerial photograph is one taken with the camera axis inclined at about 30^o from the vertical. This type of photography yields a familiar type of view of the landscape (as we would see it from some high vantage point) but it does not allow distance or height measurements in any straightforward way.

High Oblique

A high oblique aerial photograph is one taken with the camera inclined at about 60^o to the vertical so that the horizon appears in the photograph. High oblique photographs have the same photogrammetric limitations as low oblique aerial photographs. Nevertheless, they provide interesting historical detail in some areas and occasionally are used for general illustrative purposes in different reports and books.

Although multiple camera arrays have been used to obtain aerial photographs in the past, all modern aerial photography is obtained from single cameras. Two early formats included fore and aft dual cameras for simultaneously producing pairs of low oblique and the three-camera setup known as the trimetrogon system in which a central camera took a vertical aerial photograph as two side-scanning cameras simultaneously took two adjacent oblique photographs.

In India, Aerial Services & Digital Mapping Area (AS&DMA) of National Remote Sensing Centre (NRSC) [5] of ISRO is the only civilian Government entity in the country with, end-to-end state-of-the-art infrastructure and capability in the domain of aerial photography, LIDAR, and Synthetic Aperture Radar surveys.

Brief description of Aerial Services & Digital Mapping Area (AS&DMA)

- It equipped with two Beechcraft Super King Air B-200 aircraft
- It can host the entire gamut of airborne sensors like LFDC, LIDAR, Airborne SAR, multi-spectral scanner system etc.
- The aircraft can fly from 1000 feet to 30,000 feet above ground level
- Photo scales from 1:400 up to 1:40,000 can be achieved

Depending on the type of film used in the survey camera, an aerial photograph may be panchromatic, colour, or false colour. The details of these are as:

Panchromatic Aerial Photography

It is said to be a 'conventional black and white photography, yields an image in tones of grey with good contrast that aids in the identification of ground features. Panchromatic film is sensitive to all wavelengths of visible light although it is common in such photography to cut out light at the blue (short-wavelength) end of the spectrum by using an appropriate filter on the camera. The reason for this filtering is that blue light sometimes obscures ground detail because it is readily scattered by atmospheric haze.

Colour Aerial Photography

It is not commonly used in for routine surveys although it exists for selected areas where special projects have called for its use. Although these photographs record light across the entire range of the visible spectrum, they are less useful than you might expect. Much of this type of photography is processed as coloured transparencies and are not as readily used in the field as a conventional print. Although prints can be produced, they are relatively expensive and they commonly lack the fine resolution of detail available on conventional panchromatic aerial photography. On the other hand, under suitable conditions, colour photography does allow better penetration of water than conventional photography and thus may be relatively more useful in detailing offshore coastal geomorphology or the configuration of shallow lake bottoms.

False-Colour Aerial Photography

It refers to a special type of film sensitive to near-infrared radiation and light at the red (long wavelength) end of the visible spectrum, because water reflects almost no infrared light, water bodies appear in very dark tones on this type of photography and thus may lend itself to the mapping shorelines. It also is used to map vegetation and crops because it can detect very small differences in the chlorophyll content between different plant species as well as differences within species caused by disease and environmental stress.

Identification/Interpreting of Aerial Photographs

Rarely do we identify and interpret the information on aerial photographs without some clear purpose in mind. A forester, may be interested in vegetation mapping or changes detection in the forest cover. An urban planner concerned with town planning may be interested in encroachments assessment, sewage line planning etc. The reasons are many and varied and the appropriate requisite skills of aerial photograph interpretation are similarly diverse. Nevertheless, there are some useful general principles of interpretation common to any work with aerial photograph interpretation and you should note them well. Photographs should always be arranged so that any shadows fall towards the viewer; like hill shading, shadows can help to convey a sense of the third dimension. Indeed, on some photographs the relief may appear to be inverted if the shadows are falling away from the viewer. Familiar features such as roads and houses provide useful scales. Many other cultural features can be identified by association. For example, noting the presence of an adjacent railroad siding or a playground may be a means of determining whether a building is a school or a factory. The ability to pay attention to detail is important and is the single most important quality distinguishing the novice from the experienced interpreter of aerial photographs. Tonal pattern in conventional aerial photography record reflectivity and not necessarily color. The degree to which light is reflected from surfaces depends in turn on the roughness or texture of the surface. If a surface is very smooth, like an asphalt parking lot, it may reflect a great deal of light and will appear very light in tone even though it may be close to black in color. By the same token, a forest or plowed field may be quite dark in tone because the surface scatters light away from the camera. Water bodies provide a special case in that they often appear to be black because they are 'transparent' and absorb rather than reflect light. An exception occurs when the incident angle of the sun's rays is low and the camera lies in the path of the reflected rays. In this case, the water may act as a mirror, reflecting much of the incident light and appearing a very light and bright shade on the photograph. Calibration and Ground Truthing are important to successful aerial photograph interpretation. The appearance of various kinds of land surfaces on a photograph often is difficult to predict but types can be established in known areas and these then form the basis for interpretation elsewhere.

Most aerial photography is obtained in order to produce topographic maps. This so-called mapping photography is best accomplished with a short focal-length camera lens and at a flight height that gives photographs of appropriate scale for use with specific map-making instruments. The scale of this photograph commonly is 1:20 000 or smaller and may be as small as 1:60 000 or more. Mapping photography generally is taken in the spring or fall when obscuring leafy foliage is at a minimum. Normally photographic flights are made in a north-south or east-west direction unless it is for a special-purpose project such as a floodplain map in a river valley. The flight path for taking aerial photographs consists of a series of parallel flight lines laid out to obtain overlapping photographs that can be used for stereoscopic viewing.

Ideally, each flight line should be a straight course but inevitably cross-winds and other problems of aircraft navigation can modify the flight path. While on the fly, drift occurs when the aircraft is not turned to compensate for a cross-wind component and the plane is blown sideways and off the course of the flight line. All aerial photography inscribes each photograph with a serial number and that number is unique describing the number of flights, and photographs that include the date and time of photography as well as the angle position of the photographs.

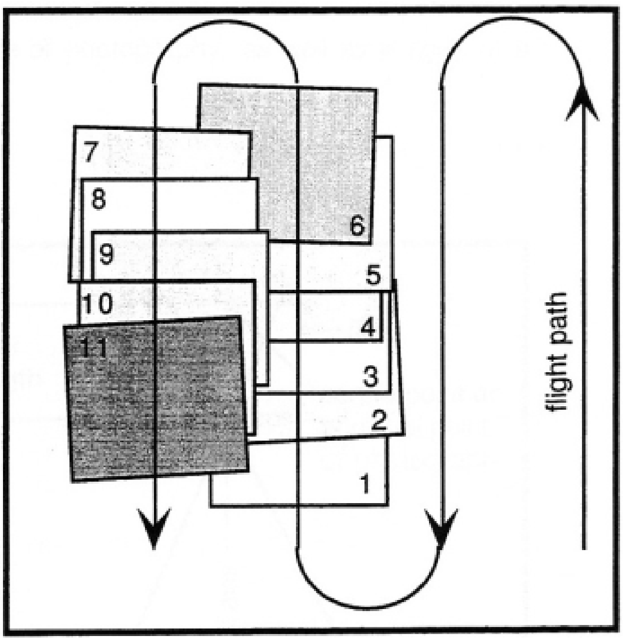


Fig. 3.6: Flight path for an aerial photographic survey as well as under drift conditions.

Processing or interpreting aerial photography is not just about reading newspapers for any important news, or it is not just going about a figure. This includes the study of different disciplines like topography, geology, environmental phenomena, and climate change studies.

The analysis of aerial photos started with photogrammetric processes. The acquired aerial photographs contain lots of distortions due to the environment and limitations of the instruments. These distortions lead to errors in the interpretation and in the required output. So, to minimize these errors these images should be radiometrically and orthogonally rectified with proper ground control points should be spread over the image. Before proceeding with the rectification of the imagery firstly it is important to understand the geometry of the aerial photographs.

Geometry of an Aerial Photograph

The geometry of a single vertical aerial photograph is illustrated in Figure 3.7. In a vertical aerial photograph, the optical axis of the camera is vertical and the plane of the photograph (film) is horizontal. The point where the optical axis intersects the photograph is termed the centre point or principal point of the photograph. This can be located on an aerial photograph as the intersection of lines drawn between opposite

Fiducial marks in the margins of the print. In a perfectly vertical aerial photograph, the principal point also represents the plumb point or nadir point which is the photographic position representing the point on the earth's surface vertically beneath the camera lens at the time of exposure. In practice, a vertical aerial photograph is rarely vertical and the nadir point and the center point do not coincide exactly, the usually small difference being the result of tilt. The distance between the camera lens and the ground represents the flight height of the aircraft and the focal length is the distance between the camera lens and the film.

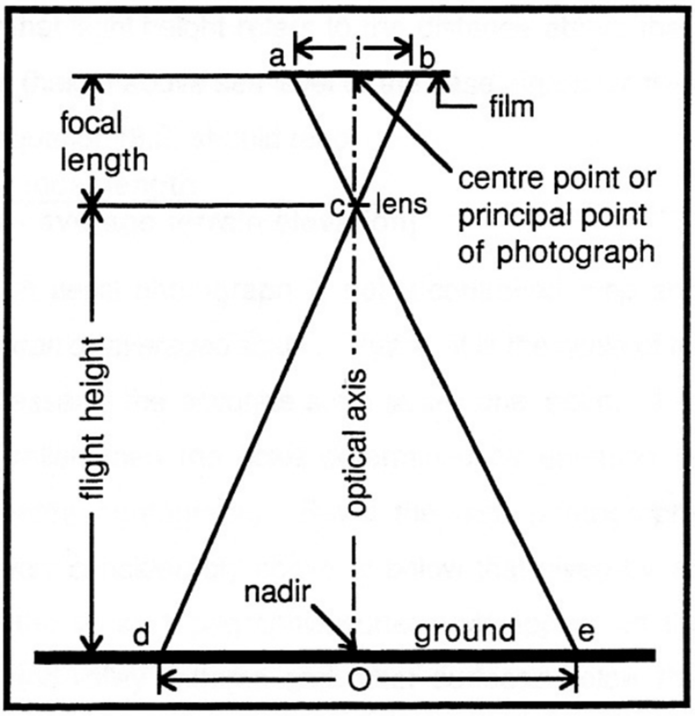


Fig 3.7: Geometry of a vertical aerial photograph.

The Scale of a Vertical Aerial Photograph

One of the most significant geometric relationships of Figure 3.7 is that equal angles are subtended at a camera lens by an object and by its photographic image. In other words, the Δ ABC and Δ CDE are similar and it follows that the ratio of size of an object (O) to the Image size (I) is the same as the ratio of focal length (f) to flight height (H), or

f/H = I/O (Equation – 1)

The ratio of image to object size is the general scale of the aerial photograph and it follows that the scale may be determined if the camera focal length and flight height are known:

Scale = focal length (f)/flight height (H) (Equation – 2)

It also is very important to remember that flight height refers to the distance above the ground directly below and not necessarily to the altitude (height above sea level or the base airport) of the aircraft.

For this reason, a more precise restatement of Equation -2 should be as:

Scale = focal length/ [flight altitude - average terrain elevation] (Equation -3)

It is very important to remember that an aerial photograph is not a controlled map and that a photographic scale determined in this way is a mean or averaged scale. That is, it is the scale of the mean surface of the area photographed and not necessarily the accurate scale at any one point. If the area photographed is horizontal and very flat (low relief) then the scale determined by Equation - 3 will provide a good indication of scale over the entire photograph. But if the area photographed has considerable topographic relief the scale may vary considerably above or below that given by Equation - 3. The tops of mountains that are above the mean topographic surface will appear on the aerial photograph at larger than the calculated scale and valley bottoms and other surfaces below the mean topographic surface will appear on the aerial photograph at less than the calculated scale. The scale variation over an aerial photograph of a mountainous area is considerable and represents one of the important limitations of aerial photographs as maps.

An alternative method of determining the scale of an aerial photograph is by direct comparison of the photograph with a topographic map of known scale. This method commonly is used because information on the focal length and flight height of photography usually are not readily available. Scale of a photograph is determined by this method as follows:

1. Select two points common to both the photograph and the topographic map. They should be as widely spaced as possible in order to keep measurement error to a

minimum. Using the scale of the map measure the terrain distance, Δt between the two points.

2. Measure the distance on the photograph, Δp between the two points in question.
3. If Δt and Δp are expressed in the same units, the scale of the aerial photograph is ***Δp/Δt*** with the numerator reduced to unity in the conventional way.

The photographic scale determined by the map-comparison method is that for the sites A to B on which it is based. For other sites on the same aerial photograph, the scale may differ depending on whether these sites are lower or higher in elevation with respect to A-B. The degree of variation in scale is directly proportional to the amount of relief in the area.

Heights Measurement of an Aerial Photograph

The scale variation on an aerial photograph caused by relief results from the horizontal displacement of images from their correct photograph position as depicted in Figure 4.8. The basic difference between an aerial photograph and a map in this regard can be demonstrated by comparing the central projection of the single photograph, in which all objects are positioned as though viewed from the same point, with the orthographic projection of a map, in which all objects on the ground are positioned as though viewed from vertically above. In a vertical aerial photograph, the displacement of images is in a radial direction from the centre point of the photograph. This displacement is termed the radial displacement due to relief and represents an error in map positioning. For example, point A on the ground depicted in Figure 4.8 has a true vertically-projected horizontal position on the mean topographic surface indicated by A' and a corresponding true image location on the photograph indicated by a'. But point A is above the mean topographic surface and its position on this datum plane appears to be A" and is indicated on the photograph by an image at a".

In other words, the terrain feature A on the ground appears to be displaced radially outwards from its true map position A' to an apparent and incorrect position at A". On the photograph this radial displacement due to relief appears as the interval a' to a".

Similarly, point B which falls below the datum plane of the photograph, has a true location B' on the mean topographic surface and should appear as b' on the photograph. Instead, it has an apparent location at B" and appears on the photograph at b", this time the result of inward radial displacement due to relief.

On any one aerial photograph the degree of displacement due to relief increases with increasing distance from the centre point and with increasing differences in elevation above or below the datum. For example, points A and B in Figure 4.8 B are the same height above the datum plane but point A is more distant from the ground nadir than B. Thus, the radial displacement due to relief is greater for point A than for B. Note also that C is the same distance from the ground nadir as A but because C is not as high above the datum plane as A, it is not radially displaced to the same extent.

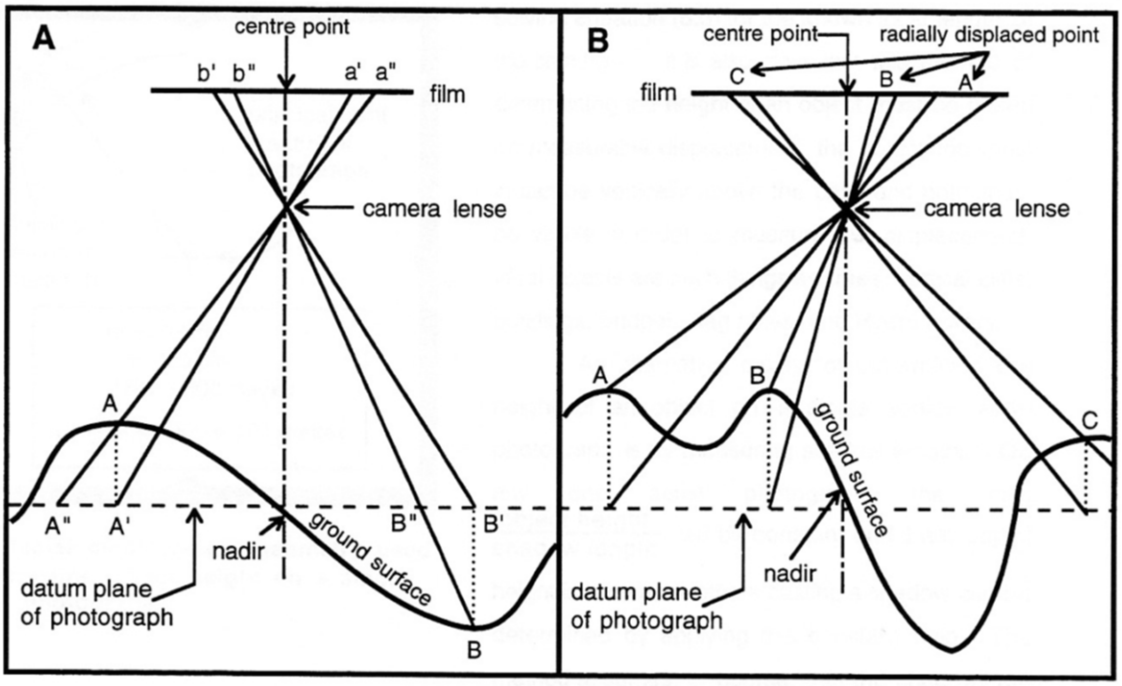


Fig. 3.8: Radial displacement on aerial photographs.

A: Relative positions of correctly plotted features in the orthographic projection of a map and the corresponding displaced images on an aerial photograph.

B: Relative radial displacement of terrain features on an aerial photograph in relation to height above the datum plane and distance from the nadir.

For any one aerial photograph the amount of radial displacement, m, of the top of an object from its base, can be determined by the relation:

$m = r\,h/H$ **(Equation – 4)**

Were:

r = radial distance on the photograph from the centre point to the top of the image displaced,

h = height of the object displaced and

H = the flight height

From Equation – 4, a convenient expression for estimating the height of an object on a photograph by measuring its radial displacement may be derived as:

$h = m/r*H$ **(Equation - 5)**

In Equations – 4, and 5 the photographic measurements m and r must be expressed in the same units and h will be in the units of H.

It is also clear that this method of determining the height of an object must be based on measurable displacement; the object top must in fact be vertically above the base and both must be visible in order to measure the displacement. Ideal objects are such things as trees, vertical cliffs, buildings, bridges, flag poles etc.

An alternative means of determining the height of an object on a single vertical aerial photograph is by measuring the lengths of shadow. On any one aerial photograph the ratio Object Height/Shadow Length will be constant and if any object height is known, all others casting a shadow can be determined by applying this constant ratio. The method assumes, of course, that the shadows are falling on surfaces with the same slope. It is ideally suited to photographs of flat terrain where all the slopes are sensibly horizontal.

If no object of known height is present on the photograph it still may be possible to calculate object heights from shadow length if the angle of inclination of the sun's rays is known. This angle can be determined from tables of sun angle by latitude and time of the year.

Object height (h) can then be determined from

$h = L \tan\beta$ **(Equation – 6)**

Where,

L = the actual length of the shadow on the ground and

β = the angle of inclination of the sun.

The scale of the photograph must be known to use this method.

Stereoscopic viewing of aerial photographs

We know that while acquiring aerial photographs a considerable amount of overlap of images are taken. This is not simply the result of cautious photography; the overlap is designed to provide at least duplicate coverage of all the areas that are being photographed so that it can be viewed stereoscopically. That is, each tract of land appears on at least two and usually several adjacent prints in the photographic run.

Stereoscopic viewing is achieved by simultaneously viewing the same tract of land as it appears in two photographs taken from different camera positions. Just as we use parallax displacement as a cue to perceive depth in ordinary vision (the same view through two spatially separated eyes), a stereoscope reproduces the same parallax-dependent sense of depth by allowing us to view one photograph with the left eye while viewing another spatially displaced photograph with the right eye.

Fig. 3.9: Stereoscopes.

This technique successfully tricks the brain into thinking that the parallax displacement apparent in the merged images of the two adjacent photographs is the result of viewing a truly three-dimensional surface through unaided eyes. Consequently, stereoscopic viewing allows us to see the area photographed in three dimensions; it is a very powerful analytical technique that is an important part of the geographer's 'tools of trade'.

The geometry of the stereoscopic model allows us to determine the height of the land surface based on parallax displacement between adjacent photographs. This principle is the basis of all photogrammetry and topographic mapping from aerial photographs. The purpose of the stereoscope is to facilitate the merging of the two photographic images into one unified view. Stereoscopic vision can be achieved by most (but not all) people after a little perseverance. Initial stereovision may take some time to establish but once achieved it can be readily reestablished on subsequent occasions.

Stereoscopes may be simple but quite effective pocket stereoscopes for viewing prepared stereograms or they may be larger mirror stereoscopes for convenient viewing of pairs of contact prints. Regardless of the type of instrument being used the procedure for stereoscopic viewing is the same. The pair of photographs should be arranged so that a common field of vision can be observed through each lens of the stereoscope. It may help to place a finger on each image of a feature common to both photographs and adjust the photograph orientation until you see the fingernails on each finger merge into one under the stereoscope. At that point the photographs should be correctly adjusted for stereoscopic viewing. There will be no mistaking the onset of stereovision; the entire field of stereovision will be thrown into an unequivocally three-dimensional view.

3.4 SUMMARY

The major advantages of aerial photographs in Land Use Land Cover, Climate Change, Vegetation, and different surveys lies in the fact that they provide a permanent record of conditions which is available in the office for detailed analysis. When studied with the aid of the stereoscope, they present a three-dimensional picture of the terrain seen from directly above. Species may be identified and their images measured with a surprising degree of accuracy. Maps can quickly and accurately be prepared from photographs. In using aerial photographs, as with using any other tool, the first concern must be to select a tool of high quality, tailored to fit individual needs. Only by so doing will the interpreter possess a tool of the greatest possible usefulness.

Aerial photography may also be used to study the process of climate change phenomenon over time, as well as estimation of changes to the topography of the earth. In India, the Survey of India (SoI) has used aerial photographs on different scales for thematic as well as topographic surveys. The Pre-Investment Survey of Forest Resources (PISFR) of the Ministry of Agriculture and Co-operation, Govt. of India utilized air photos from 1965 onwards to assess commercially available forest resources. The Forest Survey of India (FSI), Ministry of Environment, Forest and Climate Change, Govt. of India, has undertaken forest inventory and growing stock estimation in the forests based on aerial photographs. Although air photograph images still have various practical applications like for urban planning, mineral science and locating fuel deposits etc. in other alternatives have their own limitations.

3.5 GLOSSARY

Aerial Photograph: An aerial photograph made with the optical axis of the camera approximately perpendicular to the earth's datum plane.

Drift: A gradual change that seems to be controlled by outside forces.

Fiducial Marks: These marks are located in the picture plane, in contact with the photographic film, and are photographed along with the image of the object. This provides reference lines for various measurements on the image.

Nadir: Most of the vertical aerial photographs are taken with frame cameras along flight lines or flight strips. The line traced on the ground directly beneath the aircraft during the acquisition of photography is called the nadir line. This line connects the image centers of the vertical photographs.

Photogrammetry: It is defined as the art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomenon. It a a science of analyzing photographs.

3.6ANSWER TO CHECK YOUR PROGRESS

1) Do you know that a thematic map is a type of map that focuses on representing specific themes, patterns, or attributes, such as population density, land use, or climate, rather than showing geographic features like roads or rivers?
2) Do you know that geostationary satellites are positioned at an altitude of about 3600 kilometers above the Earth's surface?
3) Survey of India is responsible for publishing topographic maps of India.
4) Do you know that LIDAR stands for Light Detection and Ranging?
5) There are two types of sensors in Remote Sensing i.e., Active and Passive.

3.7 REFERENCES

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3.8TERMINAL QUESTIONS

Long Questions

1) Write a short note on measurement.
2) Explain the importance of rectification.
3) What does the process of identification and interpretation involve when working with aerial photographs?
4) What is the difference between Panchromatic aerial photography and Colour aerial Photography?

Short Questions

1) What is the meaning of photography?
2) Why are Aerial Photographs important?
3) Explain the sensor–platform concept.
4) Define Nadir Line.
5) What do you mean by Panchromatic aerial photography?

Multiple Choice Questions

1. What is the full form of LULC?

a) Line Use and Land Cover
b) Land Use and Land Cover
c) Light Unit and Light Camera
d) Local Urban Level City

2. **In the context of cartography and map-making, what does ground truthing involve?**

a) Creating digital maps using software
b) Collecting data from satellite images
c) Confirming the accuracy of map features by on-site observations

d) Drawing maps by hand

3. What is stereoscopic vision primarily responsible for?

a) Hearing and auditory perception

b) Depth perception and 3D vision

c) Taste and olfactory perception

d) Thermal sensation and temperature perception

4. What is the nadir line?

a) A line connecting the North and South Poles on a map

b) A line connecting the highest and lowest points on a satellite image

c) An imaginary line from the sensor or camera to the center of the Earth's surface directly below it.

d) A line connecting the easternmost and westernmost points on a remote sensing image.

5. What does UAV stand for?

a) Unmanned Aerial Vehicle

b) Unarmed Aerial Vehicle

c) Unmanned Artificial Vehicle

d) Unidentified Aerial Vehicle

Answers) 1.b 2.c 3.b 4.c 5.a

UNIT 4 - AERIAL PHOTOS AND TYPES OF AERIAL PHOTOGRAPHY

4.1 OBJECTIVES

After reading this unit you will be able to understand

- Definition and Characteristics of Aerial Photograph
- Types of Aerial Photographs
- Scale calculation
- Geometric Calculation of Aerial Photo

4.2 INTRODUCTION

Aerial photography is the basic data source for making maps by photogrammetric means. The photograph is the result of the data acquisition process discussed in the previous chapter. Actually, the net result of any photographic mission is to get the photographic negatives. Of prime importance for measuring and interpretation are the positive reproductions from the negatives, called diapositives. Many factors determine the quality of aerial photography, such as • design and quality of the lens system • manufacturing of the camera • photographic material • development process • weather conditions, and sun angle during photo flight.

4.3 AERIAL PHOTOS AND TYPES OF AERIAL PHOTOGRAPHY

Aerial photographs are snapshots of the earth taken by calibrated cameras at a particular instant of time in analog form. Though they provide a holistic view of the area of interest and the third dimension too, but are considered as a model of the earth because they don't provide spatially referenced data. An aerial photograph is a central perspective projection. Aerial photography can be conducted from space, high or low-altitude aircraft, or near ground platforms.

Each aerial photograph contains in its margin important information for the photo user. The arrangement, type, and amount of this information are standardized; however, the rapid development of cameras, film and aeronautical technology since World War II has caused numerous changes in the numbering and tilting of aerial photographs. With certain camera systems, some of the data are automatically recorded on each exposure, while other systems require that all tilting data be added to the film after processing.

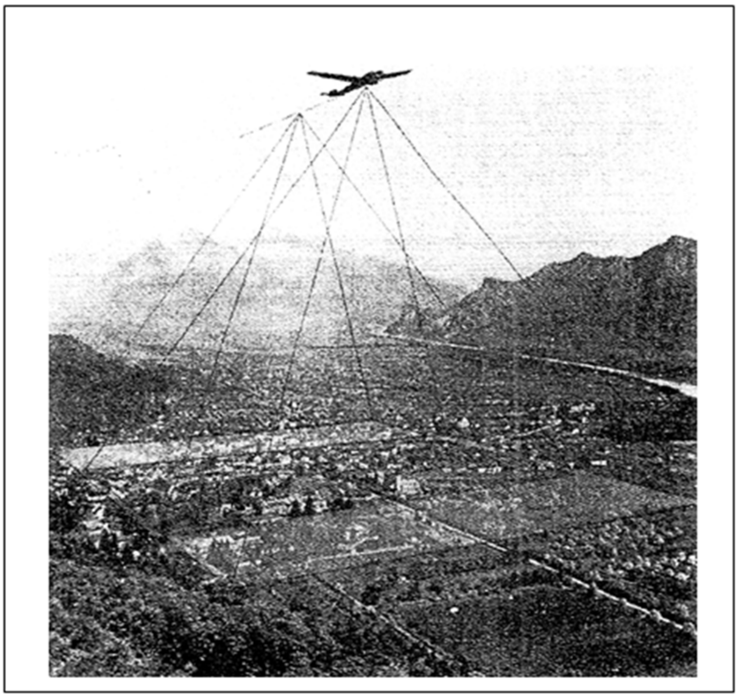

Fig. 4.1: Acquisition of Successive Photograph Yielding a Stereopairs.

GROUND COVERAGE OF AERIAL PHOTOGRAPHS

The ground coverage of a photograph is, among other things, a function of camera format size. For example, an image taken with a camera having a 230 X 230-mm format (on 240-mm film) has about 17.5 times the ground area coverage of an image of equal scale taken with a camera having a 55 X 55-mm format (on 70-mm film) and about 61 times the ground area coverage of an image of equal scale taken with a camera having a 24 X 36-mm format (on 35-mm film). As with photo scale, the ground coverage of photography obtained with any given format is a function of focal length and flying height above ground, H'. For a constant flying height, the width of the ground area covered by a photo varies inversely with focal length. Consequently, photos taken with shorter focal length lenses have larger areas of coverage (and smaller scales) than those taken with longer focal length lenses. For any given focal length lens, the width of the ground area covered by a photo varies directly with flying height above the terrain, with image scale varying inversely with flying height.

The effect that flying height has on ground coverage and image scale is illustrated in Figures 4.2a and b. Figure 4.2a is a high-altitude, small-scale image. Figure 4.2 is a lower

altitude, larger scale image of the area outlined in Figure 4.2b. Note the trade-offs between the ground area covered by
an image and the object detail available in each of the photographs.

Fig. 4.2: Aerial Photograph Ground Coverage, Resolution and Scale.

AREA MEASUREMENT

The process of measuring areas using aerial photographs can take on many forms. The accuracy of area measurement is a function of not only the measuring device used but also the degree of image scale variation due to relief in the terrain and tilt in the photography. Although large errors in area determinations can result even with vertical photographs in regions of moderate to high relief, accurate measurements may be made on vertical photos of areas of low relief.

Simple scales may be used to measure the area of simply shaped features. For example, the area of a rectangular field can be determined by simply measuring its length and width. Similarly, the area of a circular feature can be computed after measuring its radius or diameter.

Numerous methods can be used to measure the area of irregularly shaped features on a photograph. One of the simplest techniques employs a transparent grid overlay consisting of lines forming rectangles or squares of known area. The grid is placed over the photograph and the area of a ground unit is estimated by counting grid units that are all within the unit to be measured. Perhaps the most widely used grid overlay is a dot grid. This grid, composed of uniformly spaced dots, is superimposed over the photo, and the dots falling within the region to be measured are counted. From knowledge of the dot density of the grid, the photo area of the region can be computed.

CHARACTERISTICS OF AERIAL PHOTOGRAPHS

Aerial photographs are acquired with a variety of cameras, films, and filters. Characteristics such as resolution, scale, and relief displacement are common to all aerial photographs. The sections that follow discuss these characteristics in some detail.

Spatial Resolution of Photographs: Spatial resolution, or resolving power, of aerial photographs is influenced by several factors:

i. Atmospheric scattering, which was discussed earlier.
ii. Vibration and motion of the aircraft which are minimized by vibration-free camera mounts and motion compensation devices.
iii. Resolving power of lenses.
iv. Resolving power of films.

All of these factors combine to determine the spatial resolution of a photograph.

Fig. 4.3: Spatial Resolution of Aerial Photographs.

Resolving Power of Lenses: The resolving power of a lens is determined by its optical quality and size. If a lens is used to photograph a resolution target, such as those shown in Figure 4.3, there is an upper limit to the number of line pairs within the space of a millimeter that can be resolved on the resulting photograph. This maximum number of resolvable line pairs per millimeter is a measure of the resolving power of the lens.

Resolving Power of Film: The resolving power of film is determined by several factors, the most important of which is granularity. The two factors that largely determine granularity are the size distribution of silver halide grains in the emulsion and the nature of the development process. Films with high granularity have lower resolving power than those with low granularity. There is a trade-off between granularity and the speed of film: films with high granularity are faster, meaning they are more sensitive to light.

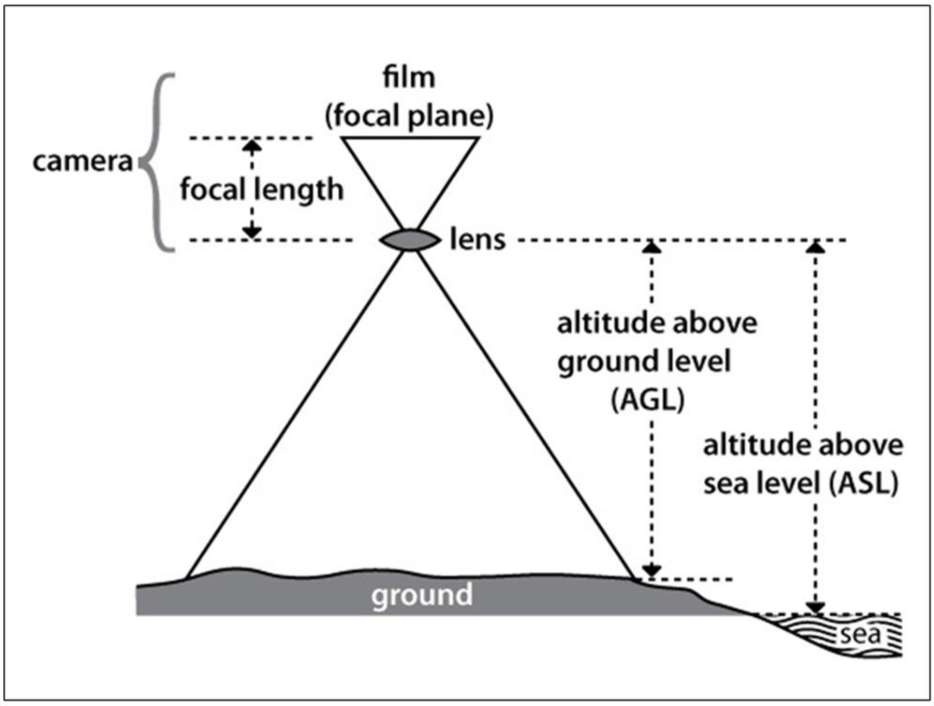

Fig. 4.4: Ground Resolution and Minimum Ground Separation on Aerial Photograph.

Ground Resolution: Ground resolution expresses the ability to resolve ground features on aerial photographs. System resolution is converted into ground resolution by the formula

$$R_g = \frac{R_s f}{H} \quad (2\text{-}1)$$

Where,

R_g = ground resolution in line pairs per millimeter

H = camera height above ground in meters. (Do not confuse this with aircraft altitude above mean sea level.)

R_s = system resolution in line pairs per millimeter

f = camera focal length in millimeters

Figure 2.4 shows the geometric basis for this relationship. For a camera lens with a focal length of 152 mm producing photographs with a system resolution of 20 line-pairs mm^{-1} acquired at a camera height of 6100 m, the ground resolution, using Equation, is

$$R_g = \frac{R_s f}{H} \quad (2\text{-}1)$$

$$= \frac{20 \text{ line-pairs.mm}^{-1} \times 152\text{mm}}{6100\text{m}}$$

= 0.5 line-pairs. mm^{-1}

Under the conditions specified in this example, the most closely spaced resolution target on the ground that can be resolved on the photograph consists of 2.0 line-pairs. m^{-1}. The width of an individual line-pair in meters is determined by the reciprocal

$$\frac{1.0 \text{ line-pairs}}{R_g}$$

and is 0.5 m in this example. Minimum ground separation is the minimum distance between two objects on the ground at which they can be resolved on the photograph. It is the separation between lines or bars in the resolution target and is determined by

$$\text{Minimum ground separation} = \frac{1.0 \text{ line-pairs}/R_g}{2} \quad (2\text{-}$$

$$= \frac{1.0 \text{ line-pairs} / 2.0 \text{ line-pairs . m}^{-1}}{2} = 0.25\text{m}$$

Recognizable features: Table 4.1 lists features that may be identified on photographs with different ground separation values. These are only guidelines to illustrate the general relationship between ground resolution and recognition.

Table 4.1: Minimum Ground Separation on typical Aerial Photographs acquired at different Height.

Camera Height	Scale of photograph	40 line-pairs mm^{-1}	100 line-pairs mm^{-1}
1525	1:10,000	0.12	0.05

3050	1:20,000	0.25	0.10
4575	1:30,000	0.37	0.15
6100	1:40,000	0.50	0.20

Source: Sabins, F.F. 2013, Remote Sensing, Waveland Press, Kolkata

PHOTOGRAPHIC BASICS

Basic Concepts of Aerial Photography

1) **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.
2) **Focal length:** 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 precisely measured when the camera is calibrated.
3) **Scale:** 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). If a 1 km stretch of highway covers 4 cm on an air photo, the scale is calculated as follows:

$$\frac{\text{PHOTO DISTANCE}}{\text{GROUND DISTANCE}} = \frac{4\text{ cm}}{1\text{ km}} = \frac{4\text{ cm}}{100\,000\text{ cm}} = \frac{1}{25\,000} \quad \text{SCALE: } 1/25\,000$$

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.

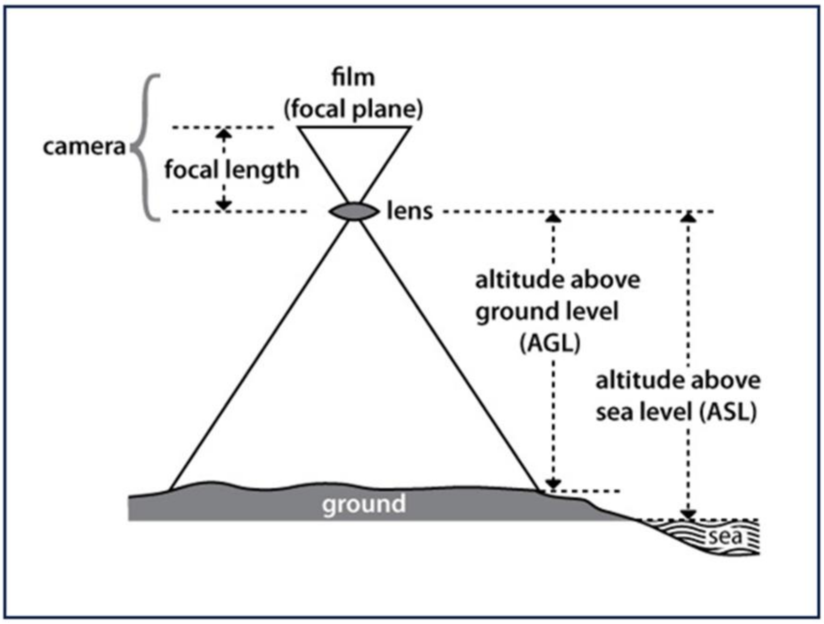

Fig. 4.5: Geometry of aerial Photograph.

If a camera's focal length is 152 mm, and the plane's altitude Above Ground Level (AGL) is 7 600 m, using the same equation as above, the scale would be:

$$\frac{\text{FOCAL LENGTH}}{\text{ALTITUDE (AGL)}} = \frac{152\text{ mm}}{7\,600\text{ m}} = \frac{152\text{ mm}}{7\,600\,000\text{ mm}} = \frac{1}{50\,000} \quad \text{SCALE: } 1/50\,000$$

Scale may be expressed three ways:

- **Unit Equivalent**
- **Representative Fraction**
- **Ratio**

A photographic scale of 1 millimetre on the photograph represents 25 metres on the ground would be expressed as follows:

- Unit Equivalent - 1 mm = 25 m
- Representative Fraction - 1/25 000
- Ratio - 1:25 000

Two terms that are normally mentioned when discussing scale are:

i. **Large Scale** - Larger-scale photos (e.g., 1:25 000) cover small areas in greater detail. A large-scale photo simply means that ground features are at a larger, more detailed size. The area of ground coverage that is seen on the photo is less than at smaller scales.

ii. **Small Scale** - Smaller-scale photos (e.g., 1:50 000) cover large areas in less detail. A small-scale photo simply means that ground features are at a smaller, less detailed size. The area of ground coverage that is seen on the photo is greater than at larger scales.

The National Air Photo Library has a variety of photographic scales available, such as 1:3 000 (large scale) of selected areas, and 1:50 000 (small scale).

4) **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.
5) **Overlap:** is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage. The photo survey is designed to acquire 60% forward overlap (between photos along the same flight line) and 30% lateral overlap (between photos on adjacent flight lines).

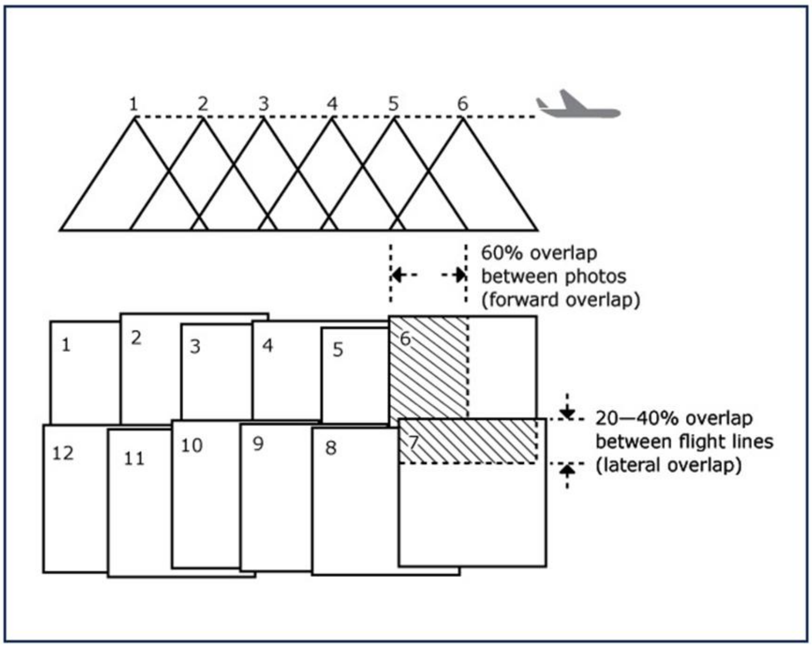

Fig.4.6: Flight Planning and Overlapping of Aerial Photo.

Aerial photo projects for all mapping and most image analyses require that a series of exposures be made along each of the multiple flight lines. To guarantee stereoscopic coverage throughout the site, the photographs must overlap in two directions: in the line of flight and between adjacent flights.

i. **Endlap:** Endlap, also known as forward overlap, is the common image area on consecutive photographs along a flight strip. This overlapping portion of two successive aerial photos, which creates the three-dimensional effect necessary for mapping, is known as a stereomodel or more commonly as a "model." Figure 4.6 shows the endlap area on a single pair of consecutive photos in a flight line. Practically all projects require more than a single pair of photographs. Usually, the aircraft follows a predetermined flight line as the camera exposes successive overlapping images.

ii. **Sidelap:** Sidelap, sometimes called side overlap, encompasses the overlapping areas of photographs between adjacent flight lines. It is designed so that there are no gaps in the three-dimensional coverage of a multiline project. Figure 4.6

iii. shows the relative head-on position of the aircraft in adjacent flight lines and the resultant area of exposure coverage. Usually, sidelap ranges between 20 and 40% of the width of a photo, with a nominal average of 30%. Figure 4.6 portrays the sidelap pattern in a project requiring three flight lines.

6) **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.

7) **Roll and Photo Numbers:** each aerial photo is assigned a unique index number according to the photo's roll and frame. For example, photo A23822-35 is the 35th annotated photo on roll A23822. This identifying number allows you to find the photo in NAPL's 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.

8) **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 centres are represented by small circles, and straight lines are drawn connecting the circles to show photos on the same flight line. 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.

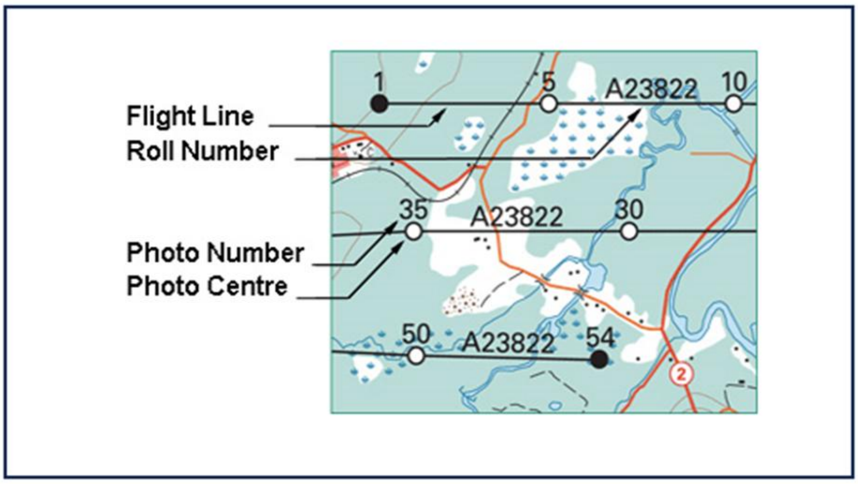

Fig. 4.7: Aerial Photo Numbering and Flight Line.

TYPES OF AERIAL PHOTOGRAPHS

Aerial photographs are usually classified according to the orientation of the camera axis, the focal length of the camera, and the type of emulsion.

Orientation of Camera Axis: Here, we introduce the terminology used for classifying aerial photographs according to the orientation of the camera axis. Figure 4.9 illustrates the different cases.

i. **Vertical Photographs:** While taking aerial photographs, two distinct axes are formed from the camera lens centre, one towards the ground plane and the other towards the photo plane. The perpendicular dropped from the camera lens centre to the ground plane is termed as the vertical axis, whereas the plumb line drawn from the lens centre to the photo plane is known as the photographic/optical axis. When the photo plane is kept parallel to the ground plane, the two axes also coincide with each other. The photograph so obtained is known as vertical aerial photograph (Figure 4.8). However, it is normally very difficult to achieve perfect parallelism between the two planes due to the fact that the aircraft flies over the curved surface of the earth. The photographic axis, therefore, deviates from the vertical axis. If such a deviation is within the range of plus or minus 3 degree, the near-vertical aerial photographs are obtained. Any photography with an unintentional deviation of more than 3degree in the optical axis from the vertical axis is known as a tilted photograph.

Fig.4.8: Vertical Aerial Photograph of Long Beach, California (also showing relief displacement).

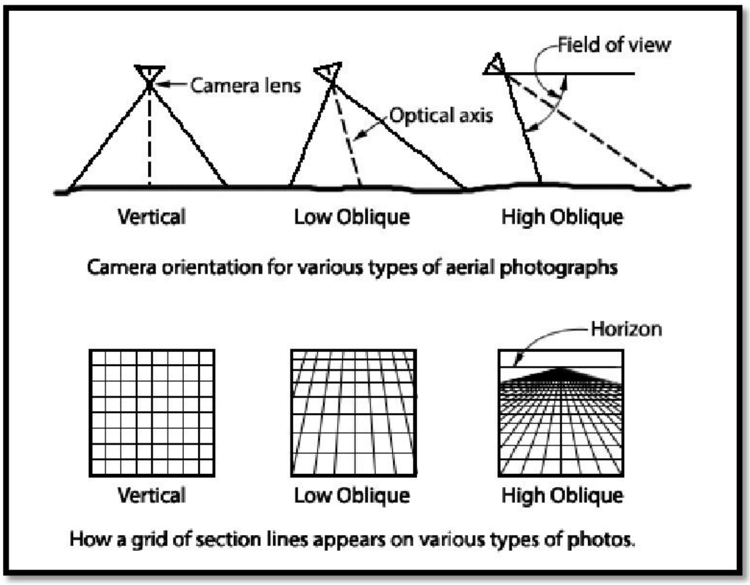

Fig. 4.9: Different Orientation based on Camera Axis in Aerial Photograph.

ii. **Low Oblique:** This is a photograph taken with the camera inclined about 30° from the vertical. It is used to study an area before an attack, to substitute for a reconnaissance, to substitute for a map, or to supplement a map. In a low oblique photograph, the aerial coverage is relatively small, the ground area covered is a trapezoid the objects have a more familiar view, comparable to viewing from the top of a high bill or tail building, distances and directions can not be measured. Relief is discernible but distorted and the horizon is not visible (Figure 4.10).

iii. **High Oblique:** A high oblique photograph is taken with the camera inclined about 600 from the vertical. It has a limited military application; it is used primarily in the making of aeronautical charts. The high oblique photographs cover a very large area, the ground area covered is a trapezoid, but the photograph is square or rectangular, and distances and directions are not measured Relief is generally discernible but distorted as in any oblique view, the relief is not apparent in a high altitude, high oblique and the horizon is always visible.

Fig. 4.10: Images showing Vertical and Oblique Orientation of the Camera.

Table 4.2: Comparison between Vertical and Oblique Photograph.

Attribute	**Vertical**	**Low Oblique**	**High Oblique**
Optical Axis	Tilt < 3 degree i.e. exactly or nearly coincides with the vertical axis.	Deviation is > 30 degree from the vertical axis.	Deviation by axis > 300 from vertical axis.
Characteristics appear	Horizon does not appear.	Horizon does appears.	Horizon appears.
Coverage	Small area	Relatively larger area	Largest area
Shape of the area	Square	Trapezoidal	Trapezoidal
Scale	Uniform	Decreases from foreground to backgrounds	Decreases from foreground to backgrounds

Source: Compiled by Different Sources.

iv. **Convergent Photography:** These are done with a single twin-lens, wide-angle camera, or with two single-tens, wide-angle cameras coupled rigidly in the same mourn so that each camera axis converges when intentionally tilted (usually 15 or 200) from the vertical. Again, the cameras are exposed at the same time. For precision mapping, the optical axes of the cameras arc parallel to the line of flight, and for reconnaissance photography, the camera axes are at high angles to the line of flight (Figure 4.11).

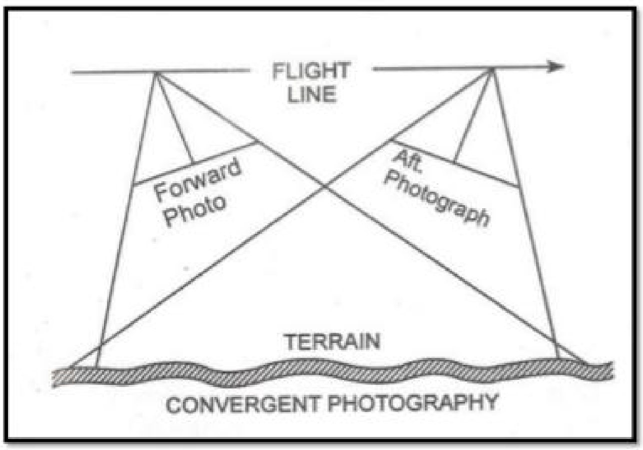

Figure 4.11: Convergent photography

v. **Panoramic:** The development and increasing use of panoramic photography in aerial reconnaissance has resulted from the need to cover in greater detail more and more areas of the world. A panoramic camera is a scanning type of camera that sweeps the terrain of interest from side to side across the direction of flight. This permits the panoramic camera to record a much wider area of ground than either frame or strip cameras. As in the case of time frame cameras, continuous cover is obtained by properly spaced exposures timed to give sufficient overlap between frames. Panoramic cameras are most advantageous for applications requiring the resolution of small ground detail from high altitudes. Aerial photographs are usually taken in sequence along a series of parallel flight lines traversing the area of interest. The information regarding the flight lines is available in the reference system of the photograph. The image reference number always uniquely identifies each air photo.

In addition to the reference number, the photos show important metadata in the margin of the print. This includes a spirit level, a clock, an altimeter, and a frame counter that identifies the frame number which can be used for sequencing images along the fight path and also identifies the focal length of the camera. Besides the prints also show fiducial marks located mid-way along the edges of the print. These are v-shaped notches used to locate the X and Y-axes of the image. The fiducial marks are generated from within the camera and are exposed on the negative as each photo is taken. The intersection of the X and Y axis is the principal point (center) of the photograph.

Fig. 4.12: Panoramic Aerial Photography.

Based on Scale

i. **Large-Scale Photographs:** When the scale of an aerial photograph is 1: 15,000 and larger, the photograph is classified as a large-scale photograph.

ii. **Medium-Scale Photographs:** Aerial photographs with a scale ranging between 1: 15,000 and 1: 30,000 are usually treated as medium-scale photographs.

iii. **Small-Scale Photographs:** The photographs with a scale smaller than 1: 30,000, are referred to as small-scale photographs.

Besides these classes, aerial photographs can be further classified based on emulsion range.

i. **Black-White Photographs:** Several types of black-and-white films are available for acquiring aerial photographs at wavelengths ranging from UV, to visible, and into the photographic portion of the IR region.

ii. **Panchromatic Black-and-White Photographs:** Black-and-white photographs exposed by visible light are called panchromatic photographs. Panchromatic aerial photographs are normally acquired with a minus-blue filter over the lens; as Figure 4.12 shows, this filter eliminates the UV and blue wavelengths selectively scattered by the atmosphere.

iii. **IR Black-and-White Photographs:** By using JR-sensitive film and a filter such as the Kodak Wratten 89B, which transmits only reflected IR energy (Figure 4.12), one can obtain photographs in the portion of the IR spectral region at wavelengths of 0.7 to 0.9 tm. This reflected solar radiation is called photographic IR energy and should not be confused with thermal IR energy, which occurs at wavelengths of 3 to 14 µm.

1. Haze penetration improves because the filter eliminates the severe atmospheric scattering that occurs in the visible and UV regions. Eliminating most scattered light results in a higher contrast ratio and therefore higher spatial resolution on the IR photograph, as discussed earlier.
2. Maximum reflectance from vegetation occurs in the photographic IR region, as shown by the bright tones in the IR photograph. In addition, maximum spectral differences between vegetation types, such as hardwoods and conifers, show up in the photographic IR region, which is advantageous for mapping plant communities.

3. IR energy is almost totally absorbed by water, which causes water to have a dark tone on IR photographs. For this reason, boundaries between land and water show up more clearly on IR photographs than on panchromatic photographs. IR color film, described in a later section. Combines these properties of IR black-and-white film with the advantages of color.

iv. **UV Photographs:** The UV spectral region extends from 3 nm to 0.4 µm; however, the atmosphere only transmits UV wavelengths from 0.3 to 0.4 µm, which is known as the photographic UV region. Photographs may be acquired in the photographic UV region with film and filter combinations such as Kodak Plus-X Aerographic film 2402 and the Kodak Wratten 18A filter. The Kodak Wratten 39 filter transmits both UV and blue energy and, for most applications, is almost as useful as the Wratten ISA filter. Most camera lenses absorb UV energy of wavelengths less than about 0.35 µm, but special quartz lenses transmit shorter wavelengths. UV photographs have low contrast ratios and poor spatial resolution because of severe atmospheric scattering (Figure 4.13). As a result, the UV spectral region is rarely employed in remote sensing, except for special applications such as monitoring oil films on water.

Fig. 4.13: Comparison of Black and White and color aerial photo of the same scene.

v. **Normal Color Photograph:** Normal color photographs record a scene in its true colors. The photographs are recorded on color film, which is a transparent medium that may be either positive or negative. The films are used to produce color prints on an opaque base, such as the aerial photograph in Plate IC. Haze filters are used when acquiring normal color aerial photographs to absorb UV wavelengths that are strongly scattered by the atmosphere (Figure 4.13).

vi. **IR Color Photograph:** In IR color film the spectral sensitivities of the emulsion layers are changed to record energy of other wavelengths, including photographic IR (0.7 to 0.9 μm). This film is sold as Kodak Aerochrome Infrared film, type 2443, which is available only S positive film. Plate ID is an IR color photograph of the area covered by the normal color photograph in Plate IC. IR color film was originally designed for military reconnaissance and was called camouflage detection film. The name false color film is occasionally used, but IR color film is the preferred name.

Fig. 4.14: Infra-red Aerial Photograph (False Color Composite).

Because the term infrared suggests heat, some users mistakenly assume that the red tones on IR color film record variations in temperature. A few moments' thought will show that this is not the case. If the IR-sensitive layer were sensitive to ambient heat, it would be exposed to the warmth of the camera body itself. In addition to large sizes for aerial cameras, IR color film is available in 35-mm size for use in ordinary cameras. The cost of the 20-exposure cassettes and processing is comparable to that of normal color films. A user can evaluate IR color film at minimal expense with this format. It is useful to acquire normal color photographs with a second camera to compare with IR color photographs. (IR color film may deteriorate with time and excessive heat; if keeping the film for more than a few weeks, store it in a freezer. Allow the frozen film to reach room temperature before opening the sealed container to prevent moisture from condensing on the cold film.)

A yellow (minus-blue) filter, such as the Kodak Wratten 12, is used with IR color film. This film-and-filter combination has an approximate speed of ASA 100. Some experimentation will be necessary to determine the optimum exposure because conventional light meters do not measure the same spectral region to which, the film is sensitive. Some cameras have an IR setting on the focusing ring that is intended for IR black-and-white film. Do not use this setting for IR color film because two of the three emulsion layers are sensitive to visible wavelengths.

PLATFORM OF AERIAL PHOTOGRAPHY

There are various ways to capture stunning shots from up above, from conventional ones, such as hot air balloons and cranes or lifts, to modern devices like drones and helicopters.

1) **Hot Air Balloons**: Using a hot air balloon is one of the oldest methods of capturing aerial photos. Because there are no windows in a hot air balloon, the photographer has the opportunity to take pictures in all 360 degrees. Aside from ballooning, other conventional methods of shooting aerial photographs involve the use of kites, rockets, and pigeons.

2) **Cranes**: These lifting devices are typically used in movie-making to capture photos or videos of actors and locations from various angles. A crane shot is achieved by a camera mounted on a platform and connected to a mechanical arm, which can be moved up or down and away from the subject.

3) **Drones**: Using a radio-controlled unmanned aircraft, referred to as an aerial photography drone, brings a whole new freedom when taking pictures in the sky. This unmanned aircraft system (UAS) provides a wider breadth of coverage by giving a limitless view of the locations from above. Businesses operating drones here in Australia are required to hold an operator certificate. The pilots are also required to get a license from the Civil Aviation Safety Authority (CASA).

4) **Helicopters**: Using helicopters is one of the most popular methods of capturing high-angle shots. Today, a helicopter is commonly used in film-making because of its ability to hover over an object. Among the advantages of helicopter aerial photography is that it can be done both during the day and night. The shots are captured with the use of a high-powered camera mounted on the nose or undercarriage of the helicopter, or by a photographer traveling as a passenger and shooting through the windows.

5) **High-altitude Locations (e.g., Skyscrapers and Mountainsides)**: Windows or rooftops in skyscrapers provide good vantage points to capture unique bird's-eye view images of buildings, people, and cities. Other high-altitude locations that can provide you with stunning images are mountainsides and rocky outcrops.

6) **Aerial Camera:** An aerial camera is specially designed for use in aircraft. The camera is a light-proof chamber or box in which the image of an exterior object is projected upon a sensitized plate or film through an opening, usually equipped with a lens, shutter, and variable aperture. In India, the aerial cameras are RC-5(a), RC-8, RC-8(UNIVERSAL), RC-10, RMK 'A' ANS EL-500 etc.

Types of Aerial Cameras:

1) Strip camera:
2) Single lens/Frame camera:
3) Panoramic camera:
4) Multiband camera:
5) Digital Camera

PHOTOMOSAICS

Aerial mosaics are created by assembling adjoining aerial photos, and trimming the edges to match lines. A photo index mosaic overlays multiple flight photos without trimming, forming a continuous representation. Photo maps use photos as a base, adding cartographic details like names and routes.

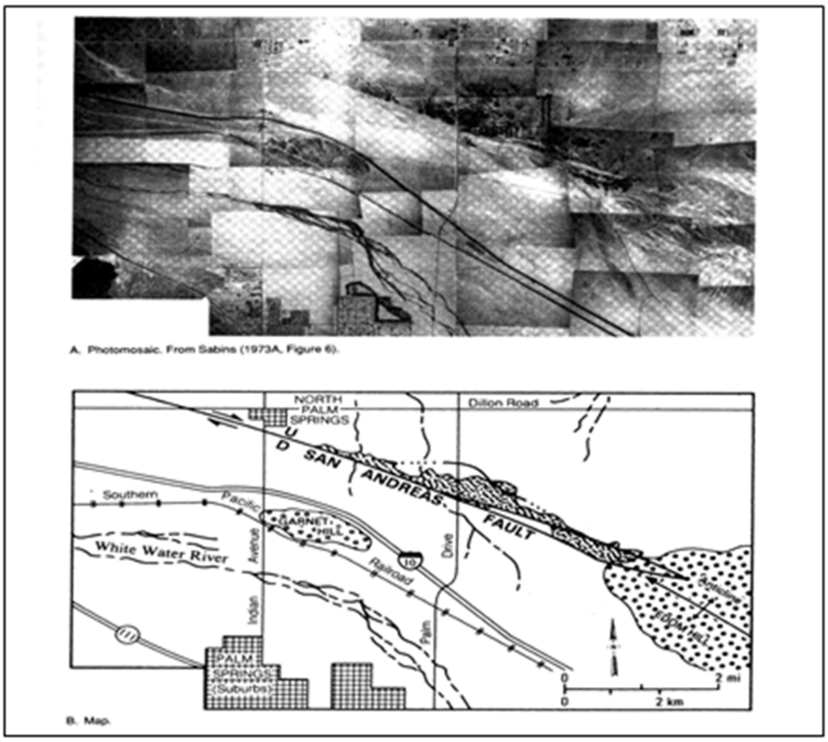

Figure 4.15: Aerial Photo Mosaics

Uses of Mosaics: Aerial mosaics provide synoptic views of large areas and serve as indexes for individual photos, facilitating planning and development visualization. Photo maps are valuable for land use planning, zoning, and engineering design.

SCALE CALCULATION

One of the most fundamental and frequently used geometric characteristics of aerial photographs is that of photographic scale. A photograph "scale", like a map scale, is an expression that states that one unit (any unit) of distance on a photograph represents a specific number of units of actual ground distance.

The scale may be expressed as unit equivalent, representative fractions, or ratios. For example, if 1mm on a photograph represents 25 m on the ground, the scale of the photograph can be expressed as 1 mm = 25 m (unit equivalent), or 1:25,000 (ratio).

Quite often the term "large scale" and "small scale" are confused by those not working with expression of scale on a routine basis. For example, which photographs would have the "larger scale – a 1:10,000 scale photo covering several city blocks or a 1:50,000 photo that covers an entire city? The intuitive n\answer is often that the photo covering the larger area (the entire city) is the larger scale product. This is not the case. The larger scale product is the 1:10,000 image because it shows ground features at a larger, more detailed, size. The 1:50,000 scale photo of the entire city would render ground features at a much smaller, less detailed size. Hence, despite its larger ground coverage, the 1:50,000 photo would be termed the smaller-scale product.

A convenient way to make a scale comparison is to remember that the same objects are smaller on "smaller" scale photographs than on a "larger" scale photograph. Scale comparison can also be made by comparing the magnitudes of the representative fractions involved.

One of the principal differences between a near-vertical aerial photograph and a planimetric map is that, for photographs taken over variable terrain, there are an infinite number of different scales present in the photograph. If topographic elevation decreases within, a certain portion of the photograph will have a smaller scale than the rest of the photograph because the land is 'moved away' from the aerial camera that is flown at a constant altitude. Usually, an average or nominal scale is computed to define the overall scale of a vertical aerial photograph taken over variable terrain—

$S_{avb} = f/H_{avg}$

It should be remembered that the average scale is only precise at those points, which lie at average elevation, and it is only an approximate scale for all other locations on the photograph.

Aerial photographs are recorded with photogrammetric mapping cameras, from altitudes of approximately 300 m to over 20,000 m. If a standard lens focal length of 15 cm is assumed, photo scales will range from about 1:2,000 (very large scale) to approximately 1:135,000 (very small scale) (Fig. 8.10; Welch 1993).

The scale may be represented in several ways. One may state that an inch on a photo represents one mile in reality, or that two centimeters on an aerial photograph represents five kilometers in reality. This form of representation is referred to as a verbal statement. Another form of scale representation is graphic. This form is most common on road maps where a specific line segment, when applied to the map, represents a certain actual distance. Finally, a numerical representation is a common form. The most frequently used numerical representation is the representative fraction (RF). The numerator is always "1" which is the photo distance. The denominator, say 63,360, is the actual distance. Since RF is a ratio, the same units of measurement may be added to the numerator and denominator. For instance, 1/63,360 could refer to 1 inch on the photograph representing 63,360 inches in reality.

1. Verbal Statement - 1 centimeter to 1 kilometer
2. Graphic - kilometers (also known as bar scale)
3. Ratio Fraction (RF) - 1/24,000 or 1:24000

Frequently, a conversion from one scale representation to another form is required. This can be accomplished quite easily if one keeps the definition of scale in mind. For example, if a photo has a scale of 1/2 inch to five miles (verbal statement), this is the same as 1 inch to ten miles. Since there are 63,360 inches in one mile, one can convert to an RF by multiplying 63,360 times ten. Hence, the RF of the photo is 1/633,600 - a ratio of photo distance to real distance.

Method 1: Establishing Relationship Between Photo Distance and Ground Distance: If additional information like ground distances of two identifiable points in an aerial photograph is available, it is fairly simple to work out the scale of a vertical photograph. Provided that the corresponding ground distances (Dg) are known for which the distances on an aerial photograph (Dp) are measured. In such cases, the scale of an aerial photograph will be measured as a ratio of the two, i.e. Dp/ Dg . The most straightforward method for determining photo scale is to measure the corresponding photo and ground distance between any two points.

$$S = \text{Photo Scale} = \frac{\text{Photo distance}}{\text{Ground distance}}$$

For example, The length of a 100 meters dash running track on an aerial photograph is measured to be 1 cm. What is the representative fraction of the aerial photograph?
The scale of aerial photographs is also can be determined by the relationship

$$\text{Scale} = \frac{1}{H/f} \qquad (2\text{-}3)$$

Both H and f must be given in the same units, typically meters, For example, the scale of a photograph acquired at a camera height of 3050 m with a 152-mm lens is

$$\frac{1}{3050mm/0.152mm} = \frac{1}{20,000} \text{or } 1:20,000$$

A scale of 1:20,000 means that 1 cm on the photograph represents 20,000 cm (or 200 m) on the ground (1 in. = 20,000 in. = 1667 ft). Figure 2.10 illustrates the different scales that result from photographing the same area at different altitudes with the same camera.

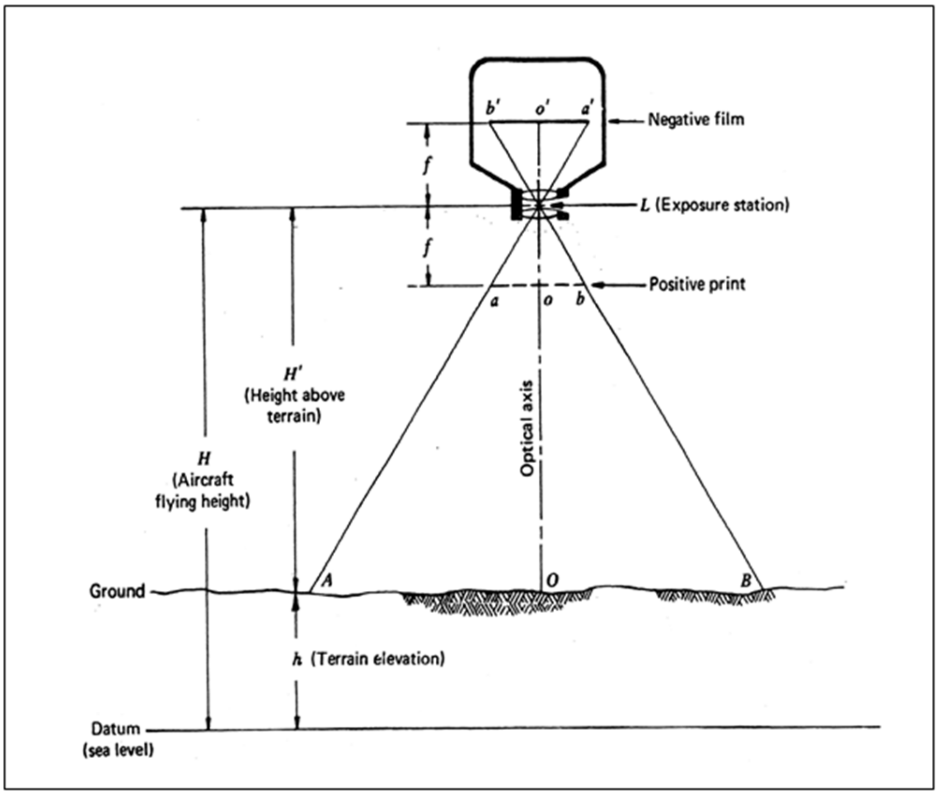

Fig.4.16: Scale of Vertical Photograph taken over flat terrain.

Figure 4.16 illustrates how we arrive at the equation above in this figure is the side view of the vertical photograph taken over flat terrain. Exposure station L is at an aircraft flying height H above some datum, or arbitrary base elevation. The datum most frequently used is mean sea level. If flying height H and the elevation of the terrain h are known, we can determine H' by subtraction (H'=H-h). if we now consider terrain points A, O, and B, they are imaged at points a', o', and b' on the negative film and at a, o, and b on the positive prints. We can derive an expression for photo scale by observing similar triangles Lao and LAO, and the corresponding photo and ground distance.

Method 2: Establishing Relationship between Photo Distance and Map Distance: As we know, the distances between different points on the ground are not always known. However, if a reliable map is available for the area shown on an aerial photograph, it can be used to determine the photo scale. In other words, the distances between two points identifiable both on a map and the aerial photograph enable us to compute the scale of the aerial photograph (Sp). The relationship between the two distances may be expressed as under:

(Photo scale: Map scale) = (Photo distance: Map distance)

We can derive Photo scale (Sp) = Photo distance (Dp) : Map distance (Dm) x Map scale factor (msf)

For example, the distance measured between two points on a map is 2 cm. The corresponding distance on an aerial photograph is 10 cm. Calculate the scale of the photograph when the scale of the map is 1: 50,000.

We can solve it by using the formula, Sp = Dp: Dm x msf

Or = 10 cm: 2 cm x 50,000

Or = 10 cm: 100,000 cm

Or = 1: 100,000/10 = 10,000 cm

Or = 1 unit represents 10,000 units, Therefore, Sp = 1: 10,000

Method 3: Establishing Relationship Between Focal Length (f) and Flying Height (H) of the Aircraft: If no additional information is available about the relative distances on the photograph and ground/map, we can determine the photo-scale provided the information about the focal length of the camera (f) and the flying height of the aircraft (H) are known. The photo scale so determined could be more reliable if the given aerial photograph is truly vertical or near vertical and the terrain photographed is flat. The focal length of the camera (f) and the flying height of the aircraft (H) are provided as marginal information in most of the vertical photographs (Box 6.2). The Fig. 6.15 may be used to derive the photo-scale formula in the following way:

Focal Length (f): Flying Height (H) = Photo distance (Dp): Ground distance (Dg)

For example, compute the scale of an aerial photograph when the flying height of the aircraft is 7500m and the focal length of the camera is 15cm.

Sp = f: H

Or Sp = 15 cm: 7,500 x 100 cm

Or Sp = 1: 750,000/15 Therefore, Sp = 1: 50,000

GEOMETRIC PROPERTIES OF AERIAL PHOTOGRAPHS

To understand the geometric qualities of a photograph, it is necessary to understand the projection in terms of the geometry of an aerial photograph. The important projections used in aerial photography are:

1. Parallel Projection
2. Orthogonal Projection.
3. Central Projection

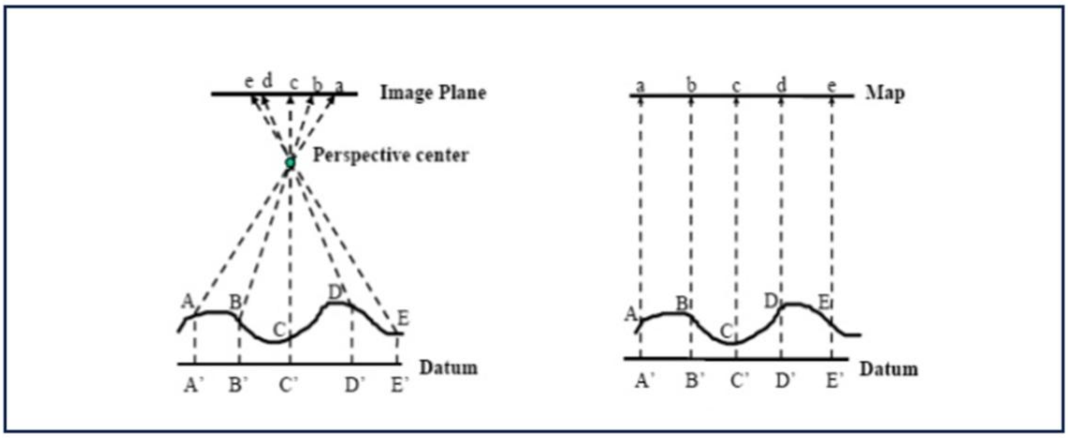

Fig. 4.17: Perspective and orthogonal projection in the photograph.

Parallel Projection

In this projection, the projection rays are parallel. The triangle ABC is projected on the LL'. The projection of the triangle is 'abc'. The projection rays As, Bb, and Cc, are all parallel in this case.

Orthogonal Projection

Fig. 4.17 gives an example; in this case the projecting rays are all perpendicular to the line LL'. This is a special case of parallel projection. Maps are an orthogonal projection of the ground on a certain scale. The advantage of this projection is that, the distances, angles and areas in the plane are independent of the elevation difference of the objects.

Central Projection (Perspective Projection):

Fig. 4.17 shows a central projection. The projecting rays Aa, Bb, Cc pass through one point O, called the Projection Centre or Perspective Centre. The image projected by a lens system is treated as a central projection (though strongly it is not, as the lens is not a single point). The central perspective (a case of central projection) is characterised by the fact that all straight lines joining corresponding points, i.e., straight lines joining object points to their corresponding images, pass through one point. This point is known as the perspective centre.

Fig. 4.18: Aerial Photograph Showing Perspective and Orthogonal Projection.

Air photos used for mapping purposes are usually vertical air photos, but oblique air photos are often used for visual interpretation. The focal length of the camera is an important parameter for determining the scale of the photo. The focal length is the distance from the front of the lens to the film. Using a normal lens, this distance is approximately 153 mm. The focal length of the camera and the altitude of the lens determine the scale of the air photo.

Important Concepts of Geometrics of Aerial Photo

I. **Perspective center C:** The point at which the lines joining the corresponding vertices of the perspective figures intersect is called the center of perspectivity, perspective center, homology center, pole, or archaically prospector. The figures are said to be perspective from this center.

II. **Focal length c:** In cameras, the distance from the optical center of the lens to the plane at which the image of a very distant object is brought into focus.

III. **Principal point PP:** The location on an image where the image optical axis of the lens intersects the image plane.

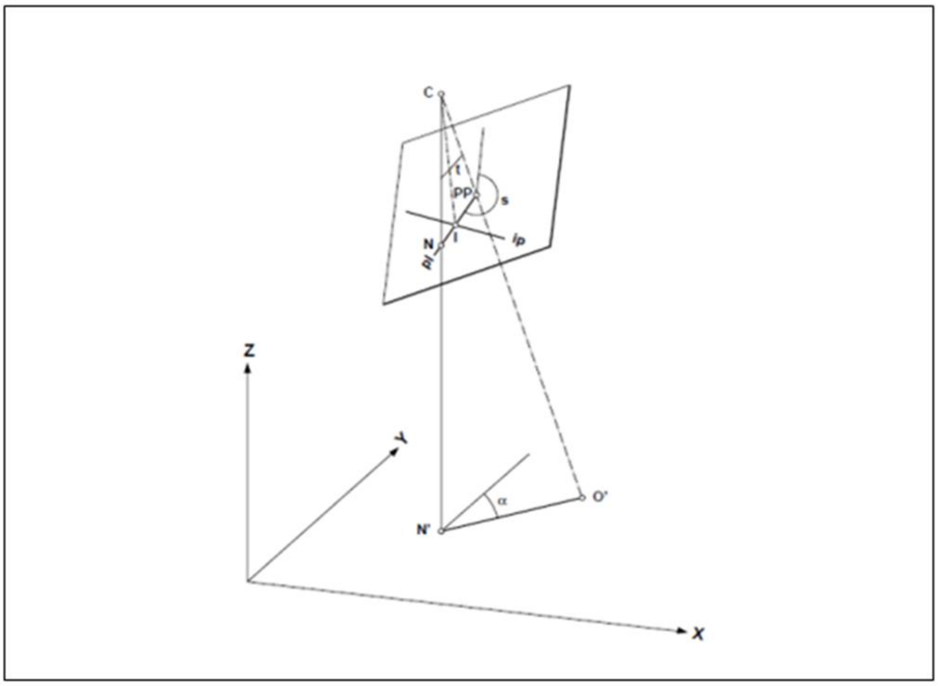

Fig. 4.19: Aerial Photograph in diapositive position and Ground Control Coordinate System.

IV. **Camera axis C-PP:** axis defined by the projection center C and the principal point PP. The camera axis represents the optical axis. It is perpendicular to the image plane

V. **Nadir point N:** also called photo nadir point, is the intersection of vertical (plumb line) from perspective center with photograph.

VI. **Ground nadir point N:** the intersection of vertical from the perspective center with the earth's surface.

VII. **Tilt angle t:** angle between vertical and camera axis.

VIII. **Swing angle s:** is the angle at the principal point measured from the +y-axis counterclockwise to the nadir N.

IX. **Azimuth α:** is the angle at the ground nadir N measured from the +Y-axis in the ground system counterclockwise to the intersection O of the camera axis with the ground surface. It is the azimuth of the trace of the principal plane in the XY-plane of the ground system.

X. **Principal line pl:** the intersection of the plane defined by the vertical through the perspective center and camera axis with the photograph. Both, the nadir N and the principal point PP are on the principal line. The principal line is oriented in the direction of the steepest inclination of the tilted photograph.

XI. **Isocenter I:** is the intersection of the bisector of angle t with the photograph. It is on the principal line.

XII. **Isometric parallel ip:** is in the plane of the photograph and is perpendicular to the principal line at the isocenter.

XIII. **True horizon line:** the intersection of a horizontal plane through the perspective center with the photograph or its extension. The horizon line falls within the extent of the photograph only for high oblique photographs.

XIV. **Horizon point:** the intersection of the principal line with the true horizon line.

AERIAL PHOTOGRAPH COMPARISON WITH MAPS

A topographic map may be obsolete because it was compiled many years ago. A recent aerial photograph shows any changes that have taken place since the map was made. For this reason, maps and aerial photographs complement each other. More information can be gained by using the two together than by using either alone.

a. **Advantages.** An aerial photograph has the following advantages over a map:

(1) It provides a current pictorial view of the ground that no map can equal.

(2) It is more readily obtained. The photograph may be in the hands of the user within a few hours after it is taken; a map may take months to prepare.

(3) It may be made for places that are inaccessible to ground soldiers.

(4) It shows military features that do not appear on maps.

(5) It can provide a day-to-day comparison of selected areas, permitting evaluations to be made of enemy activity.

(6) It provides a permanent and objective record of the day-to-day changes with the area.

b. **Disadvantages.** The aerial photograph has the following disadvantages as compared to a map:

(1) Ground features are difficult to identify or interpret without symbols and are often obscured by other ground detail as, for example, buildings in wooded areas.

(2) Position location and scale are only approximate.

(3) Detailed variations in the terrain features are not readily apparent without overlapping photography and a stereoscopic viewing instrument.

(4) Because of a lack of contrasting colors and tone, a photograph is difficult to use in poor light.

(5) It lacks marginal data.

(6) It requires more training to interpret than a map.

4.4 SUMMARY

In the end, in conclusion, it can be said that aerial photography is the most common, versatile, and economical form of remote sensing. Historically, most aerial photography has been film-based. In recent years, however, digital photography has become increasingly widely used.

4.5 GLOSSARY

1) **ANGLE OF VIEW**: the proportion (measured in degrees) of a scene that can be captured by a particular lens. The focal length of the lens determines the angle of view. (eg a 24mm wide-angle lens allows a greater angle of view to be captured than a 400mm telephoto lens).
2) **FLIGHT LINE**: The flying path an aircraft took when taking photographs during a sortie.
3) **FLYING HEIGHT**: The height at which the aircraft was flying when photographs were taken - this has a direct effect on the photograph scale.
4) **FOCAL LENGTH**: In cameras, the distance from the optical centre of the lens to the optical plane at which of a very distant object is brought into focus.
5) **ORTHOPHOTO**: An aerial photograph which has been orthorectified.
6) **ORTHORECTIFICATION**: The process of rectifying a digital aerial photograph in such a way that terrain induced distortions are removed and all features are in their true planimetric position.
7) **PHOTOGRAPH**: Representation of targets on film that results from the action of light on silver halide grains in the film's emulsion.
8) **PHOTOGRAPHIC RECONNAISSANCE (PR)**: The obtaining of information by air photography, normally carried out by special aircraft.

9) **PHOTOMAP**: A single photograph, composite, or mosaic showing coordinates and adequate marginal information - normally produced in quantity.
10) **PHOTO SCALE**: Scale at which a photograph is taken. The scale is a function of the flying height and the focal length of the camera.

4.6 ANSWER TO CHECK YOUR PROGRESS

1) Do you know Spatial resolution refers to the level of detail or granularity in an image, typically measured in terms of how small or fine objects or features can be distinguished within that image.
2) Do you know that smaller-scale photos (e.g., 1:50,000) cover larger areas with less detail?
3) Aerial photography in remote sensing has its roots in the late 19th century when photographers and inventors began experimenting with attaching cameras to balloons and kites. This allowed them to capture images from above, providing a new perspective on the landscape.
4) Do you know during World War I, military reconnaissance played a significant role in the evolution of aerial photography, as it became a valuable tool for intelligence and mapping?
5) Do you know that Sidelap, along with "endlap" (forward overlap), is essential for creating accurate and complete aerial photo coverage?

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4.8 TERMINAL QUESTIONS

LONG QUESTIONS

1) State any three advantages that an aerial photograph offers over ground-based observations.
2) How is an aerial photograph taken?
3) Present a concise account of aerial photography in India.
4) Elaborate different types of aerial photographs.
5) Answer the following questions in about 125 words: i) what are the two major uses of an aerial photograph? Elaborate. ii) What are the different methods of scale determination?
6) What is the ground resolution for an aerial photograph acquired at a height of 5000m with the camera having a system resolution of 30 line pair's mm and a focal length of 304mm?

SHORT QUESTION

1) What is focal length?
2) What do you mean by Orthorectification?
3) What is the Principal point in aerial photography?
4) Write down the important projections used in aerial photography.
5) Write down the short note on Convergent Photography.

Multiple Choice Questions

1) In which of the following aerial photographs the horizon appears?

a) Vertical
b) Near-vertical

c) Low-oblique
d) High-oblique

2) **In which of the following aerial photographs the Nadir and the principle points coincide?**
   a) Vertical
   b) Near-vertical
   c) Low-oblique
   d) High-oblique
3) **Which type of the following projections is used in aerial photographs?**
   a) Parallel
   b) Orthogonal
   c) Central
   d) None of the above
4) **What is another name for central projection in aerial photography?**
   a) Perspective Projection
   b) Parallel Projection
   c) Orthogonal Projection
   d) Conical Projection
5) **What is the purpose of endlap (forward overlap) in aerial photography?**
   a) To reduce distortion in images
   b) To ensure complete coverage of the area
   c) To enhance color saturation
   d) To increase the altitude of the aircraft

Answers)1. d 2.a 3.c 4.a 5. b

BLOCK-II REMOTE SENSING

UNIT 5 - FUNDAMENTALS OF REMOTE SENSING

5.1 OBJECTIVES

By the end of this unit the learners will be able to understand the following:

- Definition and scope of remote sensing
- Technology development of remote sensing
- Importance and different applications of remote sensing

5.2 INTRODUCTION

While going to the literal meaning of 'Remote' that implies something far away and the meaning of 'Sensing' implies observing or acquiring some information. The combined term 'Remote Sensing' explains the meaning in terms of acquiring information about any object from a distance. We are well aware that we are blessed with five senses by nature namely – the sense of sight, sense of smell, sense of hearing, sense of touch and the sense of taste. Out of these five, the sense of touch and taste requires physical involvement with the object, if you wish to know whether the coffee is hot or cold, you have to touch it, only then you will be able to decide whether it is hot or cold, on the same example if you want to know that whether coffee is sweet or sweet-less, a person has to taste it. But the sense of hearing, sighting and smell/feeling does not require any physical involvement with the object. While we have to observe the Earth and its surface for the different objectives the last three senses are being used. And these senses are being used with the help of sensor imageries with a vast knowledge of interpreters. These sensors are like simple cameras except that they not only use visible light but also other bands of the electromagnetic spectrum such as infrared, microwaves and ultraviolet regions. These sensors are installed on different platforms like airborne, and space-borne and from a high height in space record images of a very large area. Today, remote sensing is mainly done from space using satellites.

A formal and comprehensive definition of applied remote sensing, as given by the National Aeronautics and Space Administration (NASA) is as follows:

The acquisition and measurement of data/information on some property (ies) of a phenomenon, object or material by a recording device not in physical, intimate contact with the feature(s) under surveillance; techniques involve amassing knowledge pertinent to environments by measuring force fields, electromagnetic radiation, or acoustic energy employing cameras, radiometer and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, seismographs, magnetometers, gravimeters, scintillometers and other instruments.

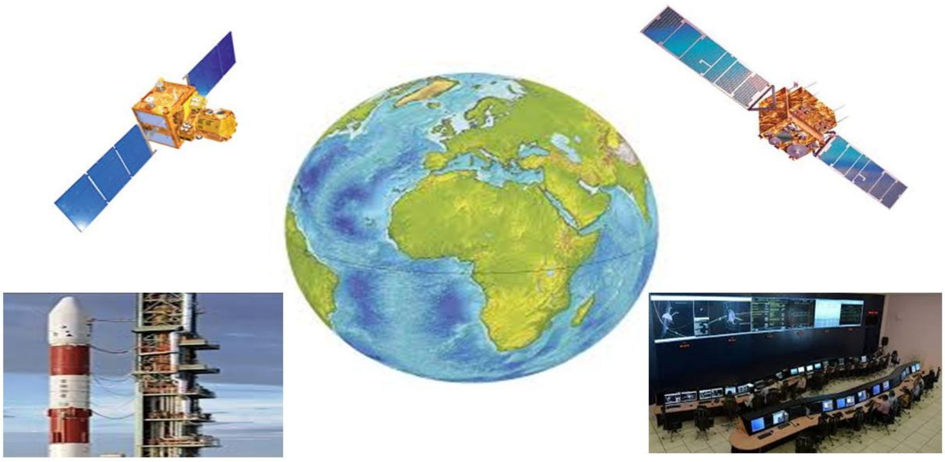

Fig. 5.1: Diagrammatic presentation of the Remote Sensing.

5.3 FUNDAMENTALS OF REMOTE SENSING

Definition:

A simplified definition given by the Canada Centre for Remote Sensing (CCRS) is given as "Remote sensing is the science (and to some extent art) of acquiring information about the earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information".

In other words, remote sensing can be defined as, remote sensing is a technology for sampling radiation and force fields to acquire and interpret geospatial data to develop information about features, objects and classes on the Earth's land surface, oceans, and atmosphere (and where applicable, on the exterior's of other bodies in the solar system, or, for that matter, many of celestial bodies such as stars and galaxies).

John R. Jensen, University of South Carolina has given two definitions of remote sensing. These are- Maximal definition: Remote sensing is the acquiring of data about an object without touching it. This definition is short, simple, general and memorable. Unfortunately, it excludes little from the province of remote sensing of the Earth's environment. It encompasses virtually all remote sensing devices, including cameras, optical–

mechanical scanners, linear and area arrays, lasers, radio–frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, X-rays and other medical applications etc.

Minimal definition: Remote sensing is the non-contact recording of information from the ultraviolet, visible, infrared and microwave regions of the electromagnetic spectrum employing instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or spacecraft, and the analysis of acquired information by means of visual and digital image processing.

India's National Remote Sensing Centre (NRSC) defined it as "Remote sensing is the technique of deriving information about objects on the surface of the earth without physically coming into contact with them". When comes to the correctness of the above definitions, each one is correct within an appropriate context.

Scope of Remote Sensing

Since Remote Sensing data provide a permanent record of topographical features of the area, and adding to it, is the fourth dimension of time. The camera or sensor often reveals the ground information that would have been ordinarily missed by a human eye. Development in space technology has greatly enhanced the capabilities of resource survey and mapping. Remote sensing has found many applications in the study of Earth's resources, mainly because of its synoptic and repetitive coverage, to gather real–time information. Data acquired by aerial as well as remote sensing has come to be accepted as a useful source for mapping and making inventories of natural resources. This data has been successfully used in the fields of forest mapping, snow hydrology, reservoir sedimentation, river morphology, watershed conservation, flood estimation, geological investigation, soil mapping, landuse/landcover mapping, crop yield forecasting and many more. An important subject before the engineering and scientific community is the processing scene of Earth's tracts as viewed from above. The basic processing goal is to locate "objects" and map them. The increasing availability of information products generated from satellite imageries has greatly increased the scope of understanding the patterns and dynamics of the Earth's resource system at all scales.

The result emphasizes that the classification of an image is shifting to feature identification and extraction, because of the higher details of the Earth's surface available on the imageries. Each application itself has specific demands, for spectral resolution, spatial resolution, and temporal resolution. There can be many applications for Remote Sensing in different fields, as described below.

Agriculture Management

Agriculture plays a dominant role in the economies of both developed and under-developed countries. Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices. The planners and managers have long recognized that an accurate and timely crop production forecasting system is an essential element in strengthening the food security and distribution system in the country. Periodic estimates of crop hectares and yield and accurate forecasts of the most likely range of growth conditions help in organizing the availability of inputs (pesticides, fertilizers etc.). Pre-harvest estimates of crop production guide the decision to formulate optimal strategies for planning, distribution, price fixations, procurement, transportation & storage of essential agricultural products.

Fig. 5.2: The Remote Sensing in Agriculture.

Satellite remote sensing has provided a tool for acreage estimation in advance with very satisfactory accuracy. Incorporating field-level management information further refines the satellite-based yield models. On the other hand, the task of increasing crop production would necessarily require more timely data for addressing issues of criticality in crop growth. The main application areas where satellite remote sensing has been used in India are:

- Crop type classification
- Crop condition assessment
- Crop yield estimation
- Mapping of soil characteristics
- Mapping of soil management practices

Forest and Vegetation Management

The forest is a natural resource that provides mankind with numerous benefits both in goods and services. Managing this important resource base both spatially as well as temporally dynamic, can be a daunting task without the utilization of proper spatial tools. Spatial technology has immense influence in the decision-making process especially in areas like forest resources management. Remote sensing as a tool has facilitated a systematic and hierarchical approach to forest resources assessment and its monitoring using sensors of different spatial and spectral capabilities., the characterization, quantification and monitoring include specific efforts toward understanding the structure, composition and function of different natural habitats/ecosystems. These studies have provided key inputs for the regulation of the impact of developmental activities and for sustaining the delivery of natural ecosystem goods and services. Forest resource assessment in India is being carried out in different levels, e.g., biannually forest cover mapping using satellite remote sensed data.

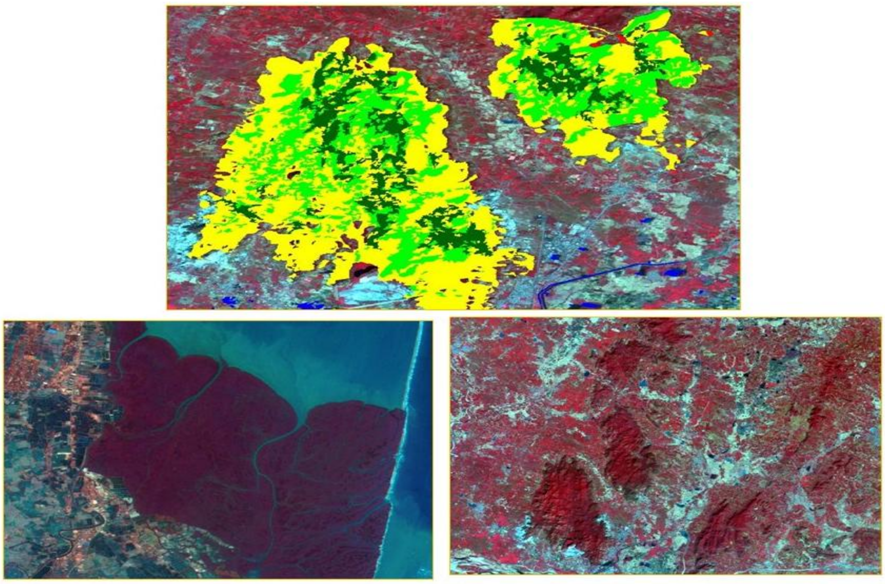

Fig. 5.3: The application of remote sensing in Forestry.

Forest Survey of India (FSI) an organization under the MoEF & CC is carry out a regular assessment of country's forest cover and forest resources. This assessment of forest cover for the whole country is done on the basis of extensive use of remote sensing. Apart for assessment of forest cover remote sensing supports number of applications which directly benefitting in managing the forest resouces. Some of them are:

Environmental Monitoring

Environmental monitoring includes the density, health, and diversity of the forests. This type of periodic monitoring helps planners and decision-makers to make timely decisions for the development of the nation on time. A few main studies in this category are:

- Deforestation and plantation
- Forest inventories within and outside the forest areas
- Watershed protection
- Knowing the status of mangrove forests for coastal life
- Studies of forest health and invasive species

General forest cover information is valuable for developing countries with limited previous knowledge of their forestry resources. General forest cover type mapping, shoreline and watershed mapping and monitoring for protection, monitoring of rotational felling practices and regeneration, and forest fire/burnt area mapping are global needs that are currently being actively addressed by India by employing remote sensing technology as part of their information solutions to the user.

Urban and Infrastructure Development

Infrastructure forms an integral part for the growth and development of any region. Satellite images, owing to their spatial, temporal and spectral characteristics, provide valuable information about the landuse/ land cover (present and past), existing infrastructure, terrain characteristics etc., which are vital to facilitate infrastructure planning, monitoring and management in a timely and cost-effective manner. Geographical Information System (GIS) with customized decision support tools facilitate integrated analysis of different datasets and their visualization. Space-based inputs along with other geospatial tools support efficient and cost-effective planning, monitoring & management of Infrastructure projects, apart from this other benefits include:

- Satellite data provide baseline information on landuse/land cover, topography, vegetation cover, water bodies, etc., which are vital for infrastructure planning.
- Space-based information & geospatial analysis tools support many applications like Urban and regional planning and Route alignment (road, rail, oil/ gas pipeline, etc.) Site suitability analysis (hydroelectric project, new township, etc.) Facility and utility planning landfill sites, schools, hospitals, etc.)
- 3-D city modeling to assess rooftop solar potential
- Urban growth prediction and land-use/ land-cover change modeling for futuristic planning
- Effect of climate change on river basin and urban hydrology
- Geotechnical investigations and sub-surface utility mapping using Ground Penetrating Radar
- Advanced terrain modeling (using high-resolution stereo satellite/ LiDAR data) for feasibility studies of infrastructure projects
- Primary thematic maps, e.g. present & past land-use/ land-cover (LULC), existing infrastructure, topography, geology, geomorphology, soil, etc.
- Utilitarian information from thematic maps, e.g., groundwater potential, vegetation type and distribution, wastelands, etc.
- GIS-based analysis, e.g. route or corridor planning, development plans, site suitability analysis, etc.

Pollution Monitoring

Continuous & effective monitoring of the source, effect and extent of pollution and formulating appropriate management plan is not possible through the conventional method, which is time time-bound job. Remote sensing technology has proved its capability to identify the source of pollution and accurately determine the location, extent and type of pollutants. However, the variety of environmental problems on land, air, and sea can only be effectively dealt with using a multisensory remote sensing approach. 3–D modeling of various parametric functions using multi-sensor output needs to be developed to predict both short–term and long–term effects of environmental pollution on a regional as well as global scale. Even though the operational status of using remote sensing techniques to deal with all aspects of the environment is yet to be achieved; the progress to date has established its capacity for tackling several specific areas of environmental pollution.

Water Pollution

Satellite remote sensing techniques are now being employed to obtain information on water quality parameters such as turbidity, suspended particles, chlorophyll concentration and the presence of large-sized aquatic weeds. The extent of light penetration in different spectral bands provides the amount of information on water quality.

Marine Pollution

Some of the capabilities of remote sensing in governing marine pollution are:

- Detection and monitoring of the rate of spread of dumped industrial waste along seacoasts
- Detection and mapping of oil slicks

It takes advantage of the difference in the emissive properties of petroleum products from that of the surrounding sea surface. With these remote sensing data, the observations have been used to estimate the long-term climate effects on marine life.

Land Pollution

Mining and landuse planners can study the environmental impacts of mining and encroachment by using remote sensing technology. Temporal data of imageries provide an effective means for monitoring mining activities. Remote Sensing in the thermal infrared region usually during the night or early morning hours is particularly useful for the detection and monitoring of surface and subsurface fire incidences.

Air Pollution

The atmosphere is an insulating blanket around the Earth. It is probably the most vital component of the life system on Earth. Greenhouse gases in the atmosphere, agriculture smoke, and acid rain are the major byproducts of air pollution. Using different data like SAR (Synthetic Aperture Radar) or hyperspectral data is widely useful in monitoring and assessment of its impacts on the Earth and life on the Earth.

Disaster Management and Mitigation

India has experienced many natural disasters which is faced by the people of the country in the form of drought, floods, forest fires, cyclones, earthquakes, landslides, cloud bursts etc. Occurrences of such calamities cannot be prevented but systematic scientific knowledge before, during and after the occurrence can minimize the consequences. Space technology with the combined use of satellite communication and satellite remote sensing provides valuable, accurate and timely information like, early warning, progressive dangers, impact analysis, and damage assessment, speeding up the decision-making of disaster mitigation measures.

In most tropical countries like India, which are very much dependent on the timely occurrence of monsoons, drought is most often the result of deficient rainfall. Satellite-derived information like area-averaged surface temperature and rainfall information is essential for mapping and monitoring land use, land cover, soil moisture, water resource potential, geomorphological features, and environmental impact. Integration of these parameters with crop yield estimates and social–economic as well as demographic information using GIS can lead to the development of strategies for drought management.

Fig. 5.4: Disaster Management and Mitigation through Remote Sensing.

Earthquakes and Volcanoes

Earthquakes and Volcanoes are the most violent and extreme geophysical events in nature. The analysis of satellite imageries along with other collateral data for identifying alternate sites of relocated earthquake-affected habitats has been very successfully demonstrated in these kinds of events. Space technology has particularly proved itself very useful in monitoring volcanic activities after its eruption or even in the initial stages of eruptions.

Floods

Floods have become an unfailing annual event in many of the major river basins all over the world causing great havoc and extensive damage to agricultural crops and loss of properties including life. Implementation of effective flood control measures and development of scientific planning procedures for efficient management can only be done on timely availability of accurate information of rainfall precipitation, river flood canalization, terrain information, pattern of watershed behavior, and regular monitoring of cloud cover and meteorological information over inaccessible areas. It is in this context that remote sensing satellites by virtue of their ability to provide repetitive multispectral imageries over large areas of the globe stand out as the obvious choice for forecasting, monitoring and management of flood disasters in the most economical manner. An integrated approach to the management and conservation of land and water resources alone can assist in reducing the damage of a major disaster like a flood.

Geosciences and Geology

Satellite images offer a wide variety of applications in the field of Earth Sciences. Geology involves the study of landforms, structures, and the subsurface, to understand physical processes creating and modifying the earth's crust. It is most commonly understood as the exploration and exploitation of mineral and hydrocarbon resources, generally to improve the conditions and standard of living in society., e.g. geological and geomorphological mapping, hydrogeology, mineral exploration, monitoring of mining activity, engineering geology, environmental geology, geohazards, etc.

Mineral Exploration

India has vast resources of minerals and satellite remote sensing is essentially used in regional surveys to narrow down potential belts of mineralization. Some of the guides for mineralization especially geological, geomorphological and structural can be deciphered from satellite data for narrowing zones for detailed explorations. Remote sensing has a significant role in geo-exploration studies. Geo-exploration studies include mapping of litho units known for hosting mineral deposits, mapping of structural controls of mineralization and mapping of surface signatures (i.e. alteration minerals like gossans, phyllic, argillic zones with different assemblages of clay minerals associated with hydrothermal deposit) associated with mineralization. High to moderate spatial resolution data are used to often control the emplacement of economic rock like kimberlite. Hyperspectral data collected in a laboratory environment can be upscaled to the bandwidth of hyperspectral or advanced multispectral data for mapping surface mineralogy of proxies of mineralization.

Water Resources Management

The requirements of a constantly increasing population in India have placed stringent demand for a variety of purposes like living, agriculture, industry etc. The country is placed with unequal distribution of water resources in space, time, and quantity. Hence, water is the most important natural resource, and effective planning with adequate knowledge is required for managing these resources. Satellite remote sensing has made it possible for many operational applications in the field of hydrology and water resources. All the water resources studies are confined to a cycle called, in hydrological cycle as the water existing on and around the earth's surface moves cyclically. Study of various components of the hydrological cycle such as precipitation, interception, evaporation, surface runoff and groundwater etc important, and accurate quantification of these components is required to take up any work related to water resources. To name a few are:

- Rainfall and runoff water management
- Monsoon forecasting and its estimation
- Different hydrological modeling
- Watershed delineation and formation of drainage pattern and its ordering
- Assessment of catchment area of dams etc.
- Mapping of flood-prone areas and calculation of risk associated with it
- Wetlands mapping and monitoring
- Snowpack monitoring/delineation of the extent
- River and lake ice monitoring
- Flood mapping and monitoring

Land Cover & Land Use (LULC) Management

Although the terms land cover and land use is often used interchangeably, their actual meanings are quite distinct. Land cover refers to the surface cover on the ground, while Land use refers to the purpose the land serves. The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge.

Landuse applications of remote sensing include the following:

- Natural resource management.
- Wildlife habitat protection.
- Baseline mapping for GIS input.
- Urban expansion/encroachment.
- Routing and logistics planning for seismic/exploration/resource extraction.
- Activities.
- Damage delineation (tornadoes, flooding, volcanic, seismic, fire).
- Legal boundaries for tax and property evaluation.
- Target detection - identification of landing strips, roads, clearings, bridges,
- Land/water interface

Mapping

Mapping constitutes an integral component of the process of managing land resources, and mapped information is the common product of analysis of remotely sensed data. Mapping applications of remote sensing include the following:

Planimetry

Land surveying techniques accompanied by the use of a GPS can be used to meet high accuracy requirements, but limitations include cost effectiveness, and difficulties in attempting to map large, or remote areas. Remote sensing provides a means of identifying and presenting planimetric data in a convenient media and efficient manner. Imagery is available in varying scales to meet the requirements of many different users. Defense applications typify the scope of planimetry applications - extracting transportation route information, building and facilities locations, urban infrastructure, and general land cover.

Digital Elevation Models (DEM)

Generating DEMs from remotely sensed data can be cost-effective and efficient. A variety of sensors and methodologies to generate such models are available and proven for mapping applications.

Baseline thematic mapping / topographic mapping

As a base map, imagery provides ancillary information to the extracted planimetric or thematic detail. Sensitivity to surface expression makes radar a useful tool for creating base maps and providing reconnaissance abilities for hydrocarbon and mineralogical companies involved in exploration activities. This is particularly true in remote northern regions, where vegetation cover does not mask the micro topography and generally, information may be sparse. Multispectral imagery is excellent for providing ancillary land cover information, such as forest cover. Supplementing the optical data with the topographic relief and textural nuance inherent in RADAR imagery can create an extremely useful image composite product for interpretation.

Oceans & Coastal Monitoring

The oceans not only provide valuable food and biophysical resources, they also serve as transportation routes, are crucially important in weather system formation and CO_2 storage, and are an important link in the earth's hydrological balance. Coastlines are environmentally sensitive interfaces between the ocean and land and respond to changes brought about by economic development and changing land-use patterns.

Often coastlines are also biologically diverse inter-tidal zones, and can also be highly urbanized. Ocean applications of remote sensing include the following:

- Ocean pattern identification:
- Water bathymetry,
- Storm forecasting
- Water quality and temperature monitoring
- Monitoring Oil spill events
- Shipping and navigation route identification
- Mapping shoreline features/beach dynamics detection
- Human activity/impact

Development of Remote Sensing Technology (Indian scenario)

Starting with IRS-1A in 1988, ISRO has launched many operational remote sensing satellites. Today, India has one of the largest constellations of remote sensing satellites in operation. Currently, eleven operational satellites are in orbit – RESOURCESAT-1 and 2, CARTOSAT-1, 2, 2A, 2B, RISAT-1 and 2, OCEANSAT-2, Megha-Tropiques and SARAL. Varieties of instruments have been flown onboard these satellites to provide necessary data in a diversified spatial, spectral, and temporal resolution to cater to different user requirements in the country and for global usage.

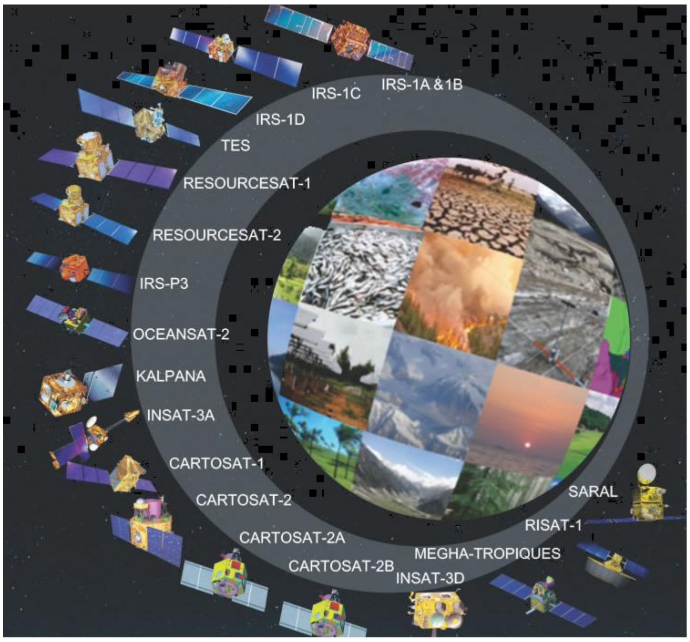

Fig. 5.4: Development of Remote Sensing Technology (source: www.nrsc.gov.in).

The data from these satellites are used for several applications covering agriculture, water resources, urban planning, rural development, mineral prospecting, environment, forestry, ocean resources, and disaster management. The National Remote Sensing Centre (NRSC) is the focal point for distribution of remote sensing satellite data products in India and its neighboring countries

Different Earth Observation Missions

Earth Observation (EO) from satellite platforms has proved to be an indispensable tool for natural resources mapping, monitoring, and management, including environmental assessment at global, regional, and local levels. This is particularly due to multi-platform, multi-resolution, multi-temporal, and synoptic viewing capabilities from space platforms.

Over time, the Indian EO program has evolved into a fully operational system providing rich data services to the user community. Data from EO satellites support a wide range of information needs of the user community for a better understanding of the Earth system at the global to local scale and helps in providing information on natural resources, agriculture, water, landuse, forests, weather, natural disasters and so on. Today, India is one of the leading countries in the world for the operational use of satellite remote sensing for national development. The Indian EO System is widely acclaimed around the world for its application-driven approach. These satellite data are acquired, processed, and disseminated to the user community as standard/value-added products to the Indian and international user communities.

Table 5.1: Some of IRS Satellite Data Products which are provided by NRSC.

Mission	Year of Launch	Launch Vehicle	Payloads	Data Availability
SARAL	2013	PSLV-C20	Ka band Altimeter, ALTIKA ARGOS Data Collection System Solid State C-band Transponder (SCBT)	Since Mar 13, 2013
RISAT-1	2012	PSLV-C19	SAR	Since Jul 1, 2012
Megha-Tropiques	2011	PSLV-C18	MADRAS, SAPHIR, ScaRaB and ROSA	
RESOURCESAT-2	2011	PSLV-C16	LISS III,LISS IV Mx,AWiFS	Since May 8, 2011
Oceansat-2	2009	PSLV-C14	OCM,SCAT	OCM Since Jan 1, 2010 SCAT from Jan 1, 2010-Jan 30, 2014.
RISAT-2	2009	PSLV-C12	SAR	Since Apr 22, 2009
IMS-1	2008	PSLV-C9	IMS-1 Mx, HySI	Apr 30, 2008 to Sep 20, 2012
CARTOSAT-2A	2008	PSLV-C9	PAN	
CARTOSAT - 2	2007	PSLV-C7	PAN	Since Apr 14, 2007
CARTOSAT-1	2005	PSLV-C6	PAN	Since May 8, 2005
Resourcesat-1(IRS-P6)	2003	PSLV-C5	LISS - III, LISS – IV, Mx, AWiFS	Since Dec 7, 2003
Tech. Exp. Satellite (TES)	2001	PSLV-C3	PAN	Nov 1, 2001 to Dec 12, 2011

Apart from supplying the data for the Indian Remote Sensing Satellites, NRSC acquires and distributes data from a number of foreign satellites. It has been acquiring microwave Synthetic Aperture Radar (SAR) data from the ERS-1/2 satellites from 1992 onwards. Products can be supplied from archived data or through programming for future acquisitions. ERS data have been acquired against user requests from 1991 and Tandem data from ERS-1 and ERS-2 during 1995-96.

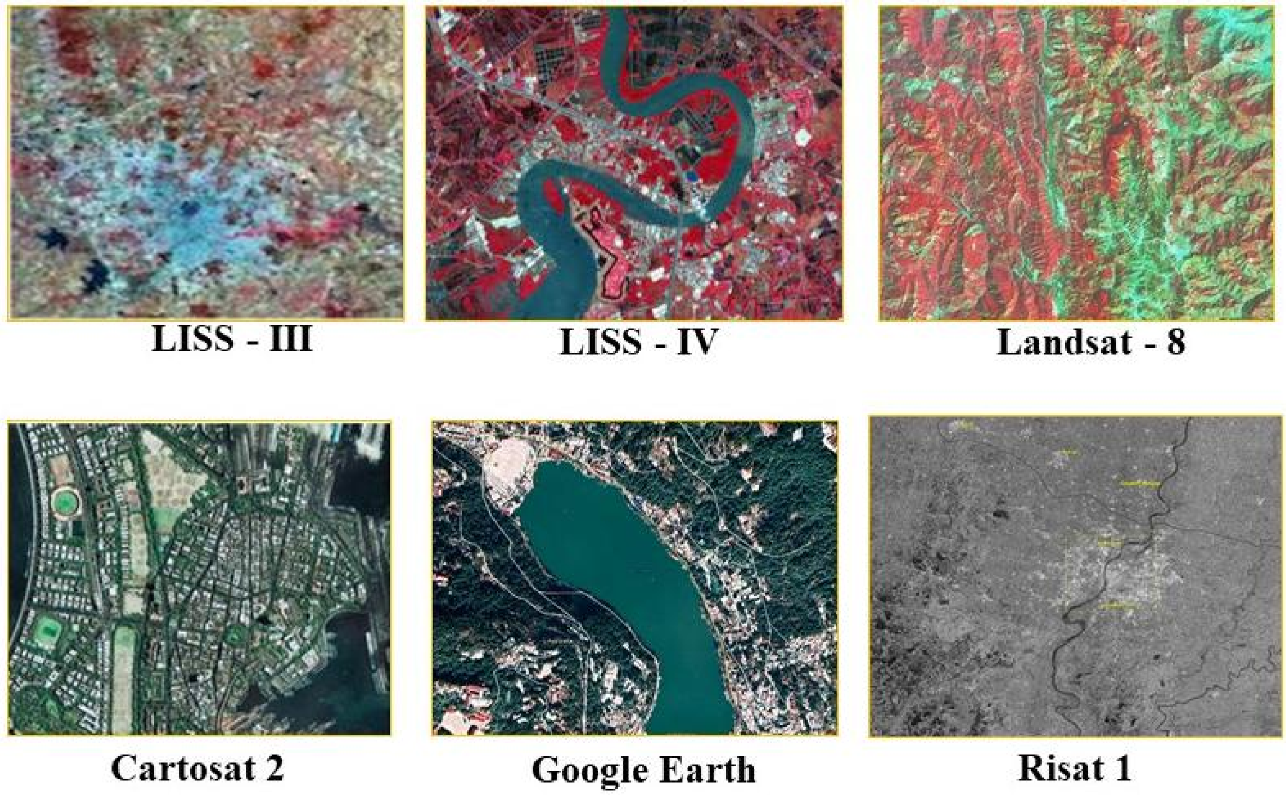

Fig. 5.5: The Remote Sensing data for various applications.

Table 5.2: Some of the important Satellite and Sensor Details.

S. No.	Satellite	Particulars (Sensor/No. of bands/resolution)
1	LANDSAT	Multispectral – 80 m (four), TMM – 30 m (seven)
2	ERS-1/2	SAR – 30 m (four)
3	NOAA	1.1 Km (five)
4	TERRA and AQUA	MODIS - 1 and 2 at 250 m, 3-7 at 500 m - (Thirty)
4	SPOT	Multispectral - 20 m and Panchromatic Linear Array (PLA) (10 m)
5	RADARSAT	SAR operates in C-band (5.6cm), at a frequency of 5.3 GHz with HH polarization, fine beam mode (50X50 Km area in 10m resolution) to wide (which covers 500 X 500 Km area in 100 m resolution).
6	IKONOS	Panchromatic - 1m and Multi-spectral - 4m

S. No.	Satellite	Particulars (Sensor/No. of bands/resolution)
7	QUICKBIRD	Pan-sharpened composite products 60 cm - 70 cm Multispectral with a 2.4 or 2.8-m
8	ENVISAT	The satellite carries a number of instruments which aid in land, oceanographic, and atmospheric studies.

Limitations of Remote Sensing

Until now various advantages with applications of remote sensing have been discussed. But extracting the optimum information of a particular area or object, the supported information is required. For full utilization of any technology, the user should know the limitations associated with that. Like other technology remote sensing technology also has some limitations, stakeholders while applying this, should be aware of these also. Some of the basic limitations of remote sensing are:

- They must be corrected geometrically and georeferenced to be useful as maps, not only as pictures.
- Distinct phenomena can be confused if they look the same to the sensor, leading to classification errors. For example, artificial and natural grass in green light.
- A phenomenon that was not meant to be measured can interfere with the image and must be accounted for.
- The resolution of satellite imagery is too coarse for detailed mapping and for distinguishing small contrasting areas.

5.4 SUMMARY

Remotely sensed data is important to a broad range of disciplines. This will continue to be the case and will likely grow with the greater availability of data promised by an increasing number of operational systems. The availability of this data, coupled with the computer software necessary to analyze it, provides opportunities for environmental scholars and planners, particularly in the areas of land use mapping and change detection that would have been unheard of only a few decades ago. Developing countries like India have achieved a viable self–reliant remote sensing program with the establishment of expertise and self-sufficiency in the operationalization of the Indian Remote Sensing Satellite series, the establishment of a well-knit infrastructure for reception, processing, dissemination, analysis and interpretation of remote sensing data, operationalization of remote sensing applications to a wide range of resource themes and developmental sectors and lastly development of resource information system using geographic information techniques. With the launching of a unique planning system of integrated missions for sustainable development using space remote sensing inputs coupled with GIS to provide a holistic approach and to meet the growing demands of the increasing population, remote sensing is poised to play a key role in the overall development of the nation. The availability of high/very high-resolution data will further enhance the effectiveness of the missions for the nation's development.

5.5 GLOSSARY

Albedo	The ratio of the amount of EMR reflected by a body to the amount incident upon it is often expressed as a percentage, e.g., the albedo of the Earth is 34 percent. It is the reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun and normal to the incident radiation.
Aperture	Opening in a remote sensing system that admits electromagnetic radiation to the film in camera/sensor/radar systems.
AVHRR	Advanced Very High Resolution Radiometer instrument is a type of space–borne sensor that measures the reflectance of the Earth in five spectral bands that are relatively wide by today’s standards.
ENVISAT	An Environmental Satellite is a large inactive Earth-observing satellite that is still in orbit. Operated by the European Space Agency (ESA), it was the world’s largest civilian Earth observation satellite.
Image	The representation of a scene by optical, electro–optical, optomechanical or electronic means. The term is generally used when the scene has been recorded directly onto magnetic media as against directly onto photographic film.
Image analysis	The process of analyzing the data contained in an image and extracting information about the land/sea cover to represent and draw conclusions from this extracted information.

MODIS	Moderate Resolution Imaging Spectro Radiometer is the key instrument in EOS Satellites. It is a passive imaging spectroradiometer. It scans across, a swath of 2330 km using 36 discrete spectral bands (visible, near and thermal infrared) between 0.41 and 14.2 micrometers. MODIS data comes in a Hierarchical Data Format file which enables the storing of multi-type data sets.
Multi-Spectral Scanner (MSS)	Scanner system that simultaneously acquires images of the same scene at different wavelengths. A remote sensing device that operates on the same principle as the infrared scanner, except that it is capable of recording data in the ultraviolet and visible portions of the spectrum as well as the infrared.
NOAA	The National Oceanic and Atmospheric Administration is an American scientific agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways and the atmosphere.
Resolution	The ability of an entire remote sensor system including lens, antennas, display, exposure, processing, and other factors, to render a sharply defined image. It may be expressed as line pairs per millimeter or meter or in many ways.
SAR	Synthetic Aperture Radar data can penetrate darkness, clouds, rain, and haze. It provides the solution for acquiring data over dynamic areas like tropical, coastal, and polar regions.
Scintillometer	A scientific device used to measure small fluctuations of the refractive indeed of air caused by variations in temperature, humidity, and pressure. It consists of an optical or radio wave transmitter and a receiver at opposite ends of an atmospheric propagation path.
Thematic Mapper (TM)	A cross–track scanner deployed on Landsat records seven bands of data from the visible through the thermal IR regions.

5.6 ANSWER TO CHECK YOUR PROGRESS

1. Remote sensing is a technology that involves gathering information about the Earth's surface from a distance, typically using satellites or aircraft.
2. One of the key principles of remote sensing is that it allows us to collect data without direct physical contact with the object or area being studied.
3. Remote sensing data can be used to monitor changes in land use, track environmental changes, and even predict natural disasters.
4. Remote sensing relies on sensors that capture electromagnetic radiation, such as visible light or infrared, to create images and data for analysis.
5. Understanding the basics of remote sensing involves learning about different types of sensors, data processing techniques, and the interpretation of remote sensing imagery.
6. Remote sensing is widely applied in agriculture to monitor crop health, assess soil moisture, and optimize farming practices.
7. In urban planning, remote sensing is used to analyze land use patterns, monitor urban growth, and plan infrastructure development.
8. Environmental scientists utilize remote sensing to track deforestation, assess water quality, and study climate change impacts on ecosystems.
9. Remote sensing is employed in disaster management to assess the extent of natural disasters like wildfires, floods, and earthquakes, aiding in emergency response efforts.
10. The application of remote sensing extends to archaeology, where it helps uncover hidden historical sites and map ancient landscapes, contributing to cultural heritage preservation.
11. India has made significant progress in remote sensing technology over the years, with the launch of its first satellite, Aryabhata, in 1975.
12. The Indian Space Research Organisation (ISRO) has played a pivotal role in advancing remote sensing capabilities by launching satellites like IRS-1A, which began operational remote sensing missions in 1988.
13. India's remote sensing satellites, including the Resourcesat series and Cartosat series, provide high-resolution imagery and data for applications ranging from agriculture and forestry to urban planning and disaster management.

14. The Bhuvan platform, developed by ISRO, allows users to access and utilize Indian remote sensing data for various applications, making it a valuable resource for researchers, policymakers, and the public.

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5.8 TERMINAL QUESTIONS

Long Questions

1. Name three different satellites with sensors on board to it. Also explain their application in different fields.
2. Explain the significance of Multispectral and Panchromatic data with examples.

Short Questions

1. Write a brief note about the evolution of remote sensing.
2. Write a short note on remote sensing and its importance.
3. What is remote sensing, and how does it work?
4. How do electromagnetic waves play a role in remote sensing?
5. What are the main types of remote sensing platforms, such as satellites or drones?
6. How can remote sensing be used for agricultural monitoring?
7. What applications does remote sensing have in environmental monitoring and natural resource management?
8. How does remote sensing contribute to disaster management and response efforts?
9. Can remote sensing assist in urban planning and infrastructure development? How?

10. How does remote sensing support climate studies and research related to climate change?

Multiple Choice Questions

1. What is the primary source of data in remote sensing?

a) Ground-based sensors

b) Radio waves

c) Electromagnetic radiation

d) Infrared cameras

2. Which of the following remote sensing platforms is placed in Earth's orbit?

a) Radar

b) Lidar

c) Satellite

d) Sonar

3. Which application of remote sensing involves the assessment of land cover changes over time?

a) Meteorology

b) Agriculture

c) Urban planning

d) Land-use mapping

4. Remote sensing can be used to monitor which of the following natural disasters?

a) Earthquakes

b) Volcanic eruptions

c) Tornadoes

d) All of the above

5. Which remote sensing application involves using radar to measure the height of objects on Earth's surface?

a) Soil moisture monitoring

b) Bathymetry

c) Vegetation analysis

d) Oceanography

6. How does LiDAR technology work in remote sensing?

a) It uses radio waves to measure distance.

b) It relies on passive sensors to collect data.

c) It measures the time it takes for laser pulses to reflect off objects.

d) It captures thermal images of the Earth's surface.

7. How can remote sensing contribute to disaster management?

a) By predicting earthquakes

b) By monitoring the spread of wildfires

c) By providing real-time weather updates

d) By conducting rescue operations on the ground

8. Which remote sensing application involves the study of ocean currents, temperatures and marine life?

a) Meteorology

b) Oceanography

c) Archaeology

d) Forestry

9. What does the term "hyperspectral remote sensing" refer to?

a) Capturing images in a single wavelength

b) Capturing images in black and white

c) Capturing images in a wide range of narrow, contiguous wavelengths

d) Measuring the altitude of objects on Earth's surface

10. In remote sensing, what is NDVI commonly used to measure?

a) Soil moisture

b) Temperature

c) Vegetation health

d) Atmospheric pressure

11. What type of sensor is typically used for thermal infrared remote sensing?

a) Passive sensor

b) Radar sensor

c) LiDAR sensor

d) Active sensor

12. How can remote sensing aid in urban planning?

a) By predicting earthquakes in urban areas

b) By monitoring air quality in cities

c) By assessing traffic patterns and infrastructure development

d) By conducting archaeological excavations in urban centers

Answers: 1-c, 2-c, 3-d, 4-d, 5-b, 6-c, 7-b, 8-b, 9-c, 10-c, 11-a, 12-c.

UNIT 6 – BASICS OF ELECTROMAGNETIC RADIATION (EMR) AND REMOTE SENSING

6.1 OBJECTIVES

By the end of this unit, you will be able to understand:

- Different methods of remote sensing
- About Electromagnetic Radiation
- Different components of remote sensing
- Concept of different platforms and sensors

6.2 INTRODUCTION

Nowadays, most of us by one or another, deal with geographic and georeferenced data either by using extensive use of electronic equipment like mobiles, laptops, palmtops etc. We might be involved in the collection, processing, and analysis of this data for the achievement of different objectives. These objectives involve forecasting the overall agricultural production of a large area in the field of agriculture, for town planners, it may be an assessment of house tax as per area, installation of sewage lines, identifying the encroachments etc., forester use these data for assessment of different density classes as well as changes in the forest cover of a particular area like these so many applications are using these geographic data for various assessments. For collecting these data variety of methods will be used, these include questionnaires, sample measurements, surveying, interpretation of satellite imageries and aerial photographs etc. These data collection schemes make sense to distinguish between ground-based and remote sensing methods.

While acquiring the spatial data, there are two basic methods are to be discussed, these are:

Ground-Based Methods: Such as making field observations, taking in situ measurements and performing land surveying. By using ground-based method you operate in real world environment.

Remote Sensing Methods: This method includes the acquisition of image data by a sensor such as an aerial camera, scanner or radar. Taking a remote sensing approach means that information is derived from the image data, which forms a (limited) representation of the real world.

Definition of Remote Sensing

Remote Sensing is the science of acquiring, processing, and interpreting images that record the interaction between electromagnetic energy and matter [2].

OR

Remote Sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation [3].

OR

Remote Sensing is the instrumentation, techniques, and methods to observe the Earth's surface at a distance and to interpret the images or numerical values obtained in order to acquire meaningful information of particular objects on Earth [4].

Common to the three definitions is that data on characteristics of the Earth's surface are acquired by a device (sensor) that is not in contact with the objects being measured. The result is usually, though not necessarily, stored as image data. The characteristics measured by a sensor are the electromagnetic energy reflected or emitted by the Earth's surface. This energy relates to some specific parts of the electromagnetic spectrum usually visible light, but it may also be infrared light or radio waves.

There is a wide range of remote sensing sensors, which, linked to a certain platform, can be classified according to their distance from the Earth's surface, airborne, spaceborne or even ground-based sensors. The term Remote Sensing is nowadays, used for all of these methods. Earth Observation (EO) is another important term while studying remote sensing, which usually refers to spaceborne remote sensing, but strictly speaking, would also include the ground-based use of remote sensing devices.

Before the image data can yield the required information about the objects or phenomena of interest, they need to be processed. The analysis and information extraction or information production is a part of the overall remote sensing process.

6.3 BASICS OF ELECTROMAGNETIC RADIATION (EMR) AND REMOTE SENSING

Electromagnetic Radiation

Electromagnetic (EM) energy can be modeled in two ways: by waves or energy-bearing particles called photons. In the wave model, electromagnetic energy is considered to propagate through space in the form of sine waves. These waves are characterized by electrical (E) and magnetic (M) fields, which are perpendicular to each other. For this reason, the term electromagnetic energy is used. The vibration of both fields is perpendicular to the direction of travel of the wave. Both fields propagate through space at the speed of light c ($3*10^8$ mt./sec.).

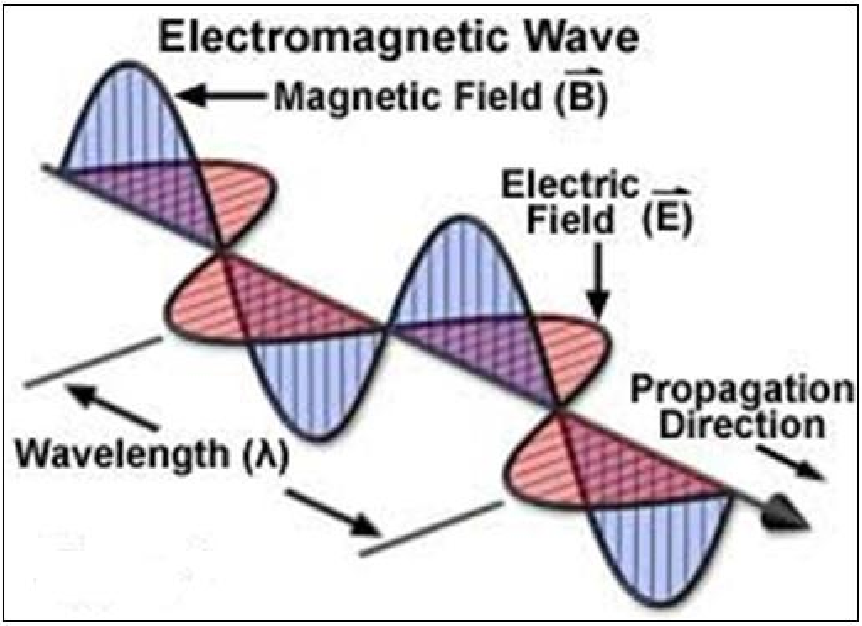

Fig. 6.2: Electromagnetic wave propagation model.

For understanding remote sensing an important characteristic, i.e., wavelength of electromagnetic waves is to be considered particularly. This is the wavelength λ, that is defined as the distance between successive wave crests. Wavelength is measured in meters (m) and nanometers (1 nm = 10^{-9} mt.).

The frequency, υ, is the number of cycles of a wave passing a fixed point over a specific period. Frequency is normally measured in hertz (Hz), which is equivalent to one cycle per second. Since the speed of light is constant, wavelength and frequency and inversely related to each other.

$c = \lambda * \upsilon$ (Equation – 1)

Where

c = Speed of light ($3*10^8$ mt./sec)

λ = Wawelength (mt.)

υ = Frequency (cycles per second, Hz)

The shorter the wavelength, the higher the frequency, and vice versa. However, EM energy is more conveniently modeled by the particle theory, in which EM energy is composed or discrete units called photons. This approach is taken when quantifying the amount of energy measured by a multispectral sensor. The amount of energy held by a photon of a specific wavelength is then given by

$Q = h * \upsilon = h * c/ \lambda$ (Equation – 2)

Where

Q = Energy of a photon (Joule)

h = Planck's constant (6.6262*10-34 Joule/Second)

υ = Frequency (cycles per second, Hz)

From Equation (2), it follows that the longer the wavelength, the lower its energy content. Gamma rays (around 10^{-9} mt.) are the most energetic and radio waves (> 1mt.) are the least energetic. An important consequence of remote sensing is that it is more difficult to measure the energy emitted in longer wavelengths than in shorter wavelengths.

Source of Electromagnetic Energy

All matter with a temperature above absolute zero (0 Kelvin, where n ^{0}C = n + 273 ^{0} Kelvin) radiates EM energy due to molecular agitation. Agitation is the movement of the molecules. This means that the Sun, and also the Earth, radiates energy in the form of waves. Matter that is capable of absorbing and re-emitting all EM energy that it receives is known as a blackbody. For black bodies, the emissivity, i.e., and the absorptivity, ∞ are equal to (the maximum value of 1.

The amount of energy radiated by an object depends on its absolute temperature and its emissivity and is a function of the wavelength. In physics, this principle is defined by Stefan-Boltzmann's Law. A blackbody radiates a continuum of wavelengths. The radiation emitted by a blackbody at different temperatures is shown in Figure. Note the units in the Figure: the X-axis indicates the wavelength and the Y-axis indicates the amount of energy per unit area. The area below the curve, therefore, represents the total amount of energy emitted at a specific temperature. From Figure, it can be concluded that a higher temperature corresponds to a greater contribution of shorter wavelengths. The peak radiation at 400 ^{0}C (673 ^{0}K) is around 4 µm while the peak radiation at 1000 ^{0}C is at 2.5 µm. The emitting ability of a real material compared to that of the blackbody is referred to as the material's emissivity. In reality, black bodies are rarely found in nature, most natural objects have an emissivity of less than one. This means that only part, usually between 80% – 90%, of the received energy is reemitted. Consequently, part of the energy is absorbed. These physical properties are relevant in, for example, the modeling of climate change processes.

Electromagnetic Spectrum

All matter with a temperature above absolute zero (K) radiates electromagnetic waves of various wavelengths. The total range of wavelengths is commonly referred to as the electromagnetic spectrum (Figure). It extends from gamma rays to radio waves.

Remote Sensing operates in several regions of the electromagnetic spectrum. The optical part of the EM spectrum refers to the part of the EM spectrum in which the optical phenomenon of reflection and refraction can be used to focus the radiation. The optical range extends from X-rays (0.02 µm) through the visible part of the EM spectrum up to and including far–infrared (1000 µm). The ultraviolet (UV) portion of the spectrum has the shortest wavelengths that are of practical use for remote sensing. This radiation is beyond the violet portion of the visible wavelengths. Some of the Earth's surface materials, in particular rocks and minerals, emit or fluoresce visible light when illuminated with UV radiation. The microwave range covers wavelengths from 1 mm to 1 m.

The visible region of the spectrum (Figure: 7.3) is commonly called light. It occupies a relatively small portion of the EM spectrum. It is important to note that this is the only portion of the spectrum that we can associate with the concept of colour. Blue, Green, and Red are known as the primary colours or wavelengths of the visible spectrum.

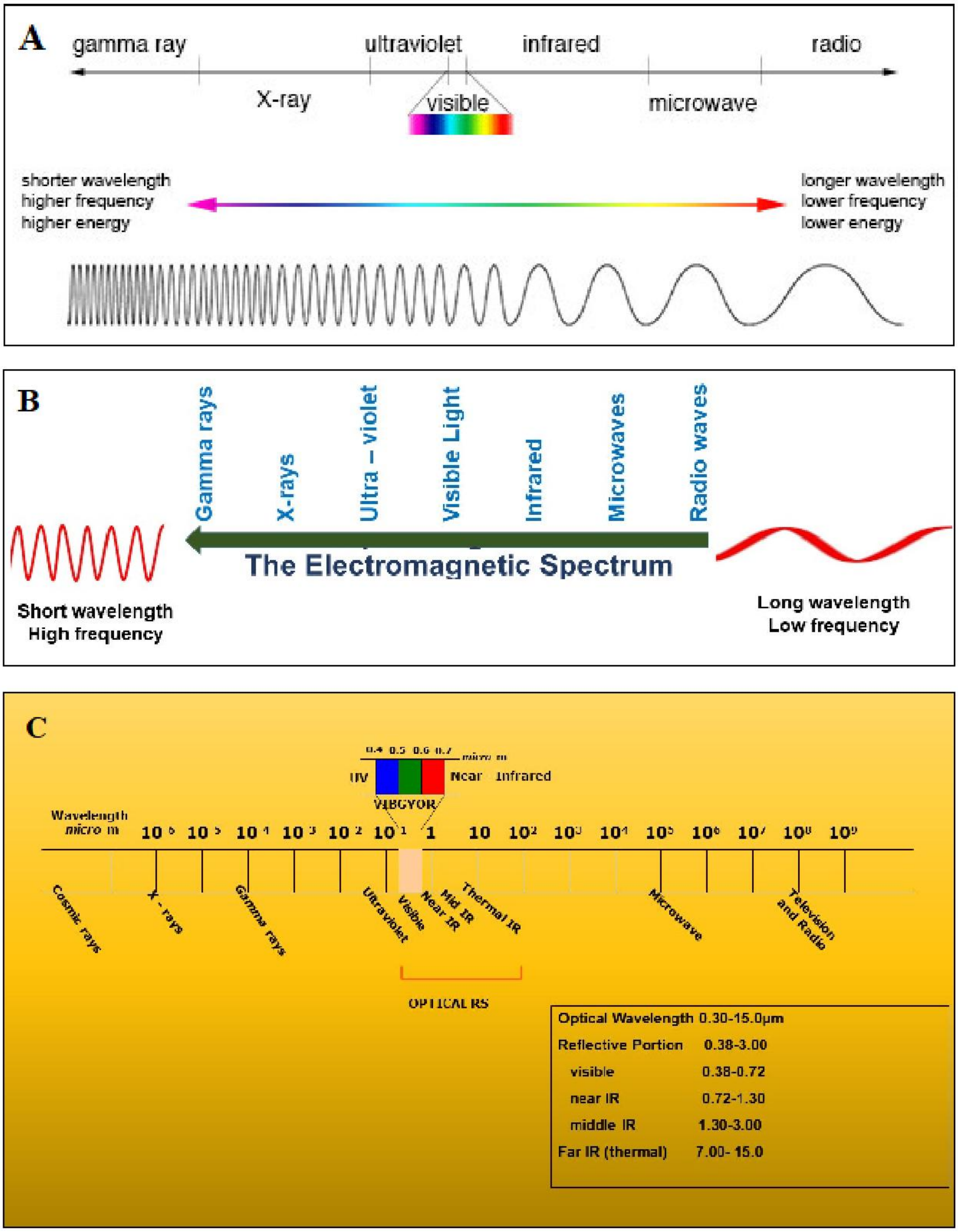

Fig. 7.3: Presentation of electromagnetic Spectrum in different ways (a), (b) and (c).

The longer wavelengths used for remote sensing are in the thermal infrared and microwave regions. Thermal infrared gives information about surface temperature. Surface temperature can be related, for example, to the mineral composition of rocks or the conditions of vegetation. Microwaves can provide information on surface roughness and the properties of the surface such as water content. A brief description of Electro Magnetic Spectrum along with their ranges is given in Table 7.1

Table 7.1: Description of Different Regions of Electro Magnetic Spectrum.

Wavelength	Description
Ultraviolet (UV) Region **0.30 µm - .038 µm** **(1 µm = 10^{-6} m))**	This region is beyond the violet portion of the visible wavelength, and hence its name. Some of Earth's surface material primarily rocks and minerals emit visible UV radiation. However, UV radiation is largely scattered by Earth's atmosphere and hence not used in the field of remote sensing.
Visible Spectrum **0.4 µm – 0.7 µm** **Violet 0.4 µm – 0.446 µm** **Blue 0.446 µm – 0.5 µm** **Green 0.5 µm – 0.578 µm** **Yellow 0.578 µm – 0.599 µm Orange 0.592 µm – 0.62 µm** **Red 0.62 µm – 0.7 µm**	This is the light which our eyes can detect. This is the only portion of the spectrum that can be associated with the concept of colour. Blue, Green and Red are the three primary colours of the visible spectrum. They are defined as such because no signal primary colour can be created from the other two, but all other colours can be formed by combining the three in various proportions. The colour of an object is defined by the colour of the light it reflects.
Infrared (IR) Spectrum **0.7 µm – 100 µm**	Wavelengths longer than the red portion of the visible spectrum or designated as the infrared spectrum. These regions are further divided into three categories; Reflected IR (0.7 µm – 3.0 µm) is used for remote sensing; Thermal IR (0.3 µm – 100 µm) is the radiation emitted from Earth's surface in the form of heat.
Microwave Region **1 µm – 1 m**	This is the longest wavelength used in remote sensing. The shortest wavelengths in this range have properties similar to the thermal infrared region. The main advantage of this spectrum is its ability to penetrate through clouds.
Radio Waves	This is the longest portion of the spectrum mostly used for

(> 30 cm)	commercial broadcast and meteorology.

Electromagnetic Radiation and its Interaction with Earth's Surface

Satellite sensors record the intensity of electromagnetic radiation (sunlight) reflected from the earth at different wavelengths. The energy that is not reflected by an object is absorbed. Each object has its unique spectrum, some of which are important in Earth's surface like vegetation, water, and soil according to their spectral reflectance which has been described as:

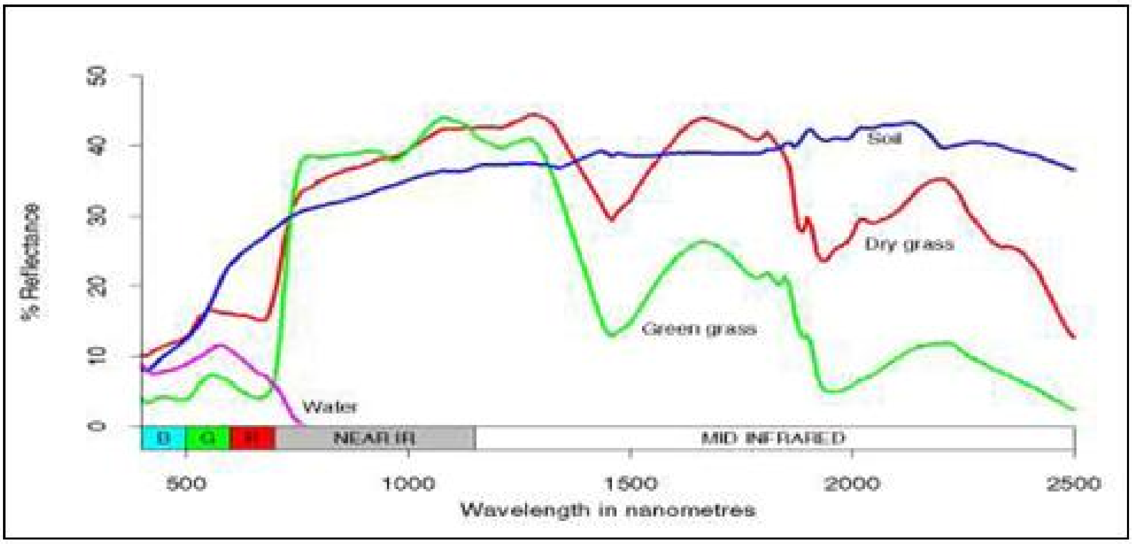

Figure 7.1: Spectral Reflectance of different features on Earth's surface.

Vegetation

The spectral characteristics of vegetation vary with wavelength. A compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects the green wavelength. The internal structure of healthy leaves acts as a diffuse reflector of near-infrared wavelengths. Measuring and monitoring the near-infrared reflectance is one way that scientists determine how healthy particular vegetation may be.

Water

The majority of the radiation incident upon water is not reflected but is either absorbed or transmitted. Longer visible wavelengths and near-infrared radiation are absorbed more by water than by the visible wavelengths. Thus water looks blue or blue-green due to stronger reflectance at these shorter wavelengths and darker if viewed at red or near infrared wavelengths. The factors that affect the variability in reflectance of a water body are depth of water, materials within water, and surface roughness of water.

Soil

The majority of radiation incident on a soil surface is either reflected or absorbed and little is transmitted. The characteristics of soil that determine its reflectance properties are its moisture content, organic content, texture, structure, and iron oxide content. The soil curve shows less peak and valley variations. The presence of moisture in soil decreases its reflectance.

By measuring the energy that is reflected by targets on Earth's surface over a variety of different wavelengths, we can build up a spectral signature for that object. And by comparing the response pattern of different features we may be able to distinguish between them, while we might not be able to if we only compared them at one wavelength. For example, water and vegetation reflect somewhat similarly in visible wavelength but not in the infrared.

Remote sensing relies on the measurement of electromagnetic energy (EM). The fact is that particular features of the landscape such as bushes, crops, settlements, land, and water reflect light differently in different wavelengths. Grass looks green, for example, because it reflects green light and absorbs other visible wavelengths. This can be seen as a peak in the green band in the reflectance spectrum for green grass above. The spectrum also shows that grass reflects even more strongly in the infrared part of the spectrum. While this can't be detected by the human eye, it can be detected by an infrared sensor.

Instruments mounted on satellites detect and record the energy that has been reflected. The detectors are sensitive to particular ranges of wavelengths, called bands. The satellite systems are characterized by the bands at which they measure the reflected energy. Hence a basic understanding of EM energy, its characteristics and its interactions is required to understand the principle of the remote sensor. This knowledge is also needed to interpret remote sensing data correctly.

Components of Remote Sensing

An Image

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

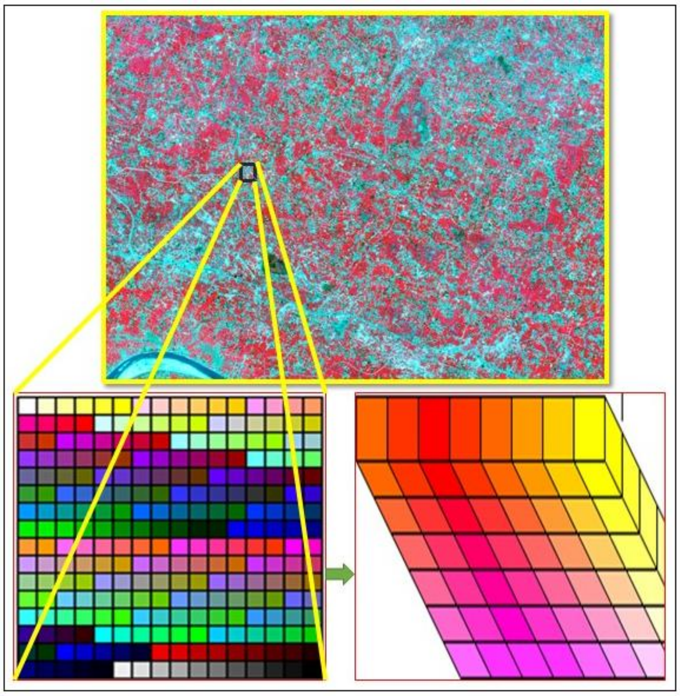

Fig. 7.4: Digital Format.

A photograph could also be represented and displayed in a digital format by subdividing the image into small equal-sized and shaped areas, called picture elements or pixels (Fig. 7.4) and representing the brightness of each area with a numeric value or digital number. The computer displays each digital value as different brightness levels. Sensors that record electromagnetic energy, electronically record the energy as an array of numbers in digital format right from the start.

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

Spectral Response

For any given material, the amount of solar radiation that it reflects, absorbs, transmits, or emits varies with wavelength. When that amount (usually intensity, as a percent of maximum) coming from the material is plotted over a range of wavelengths, the connected points produce a curve called the material's spectral signature (spectral response curve). Figure 7.5 shows the reflectance plot for some common Earth's features with the influencing interval on the wavelength indicated.

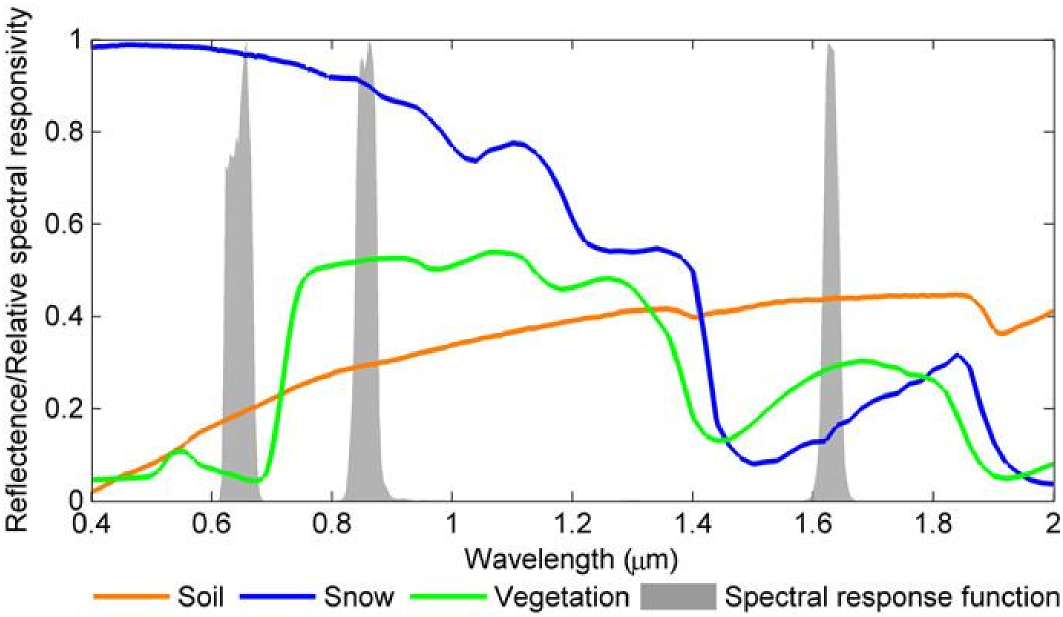

Fig. 7.5: Spectral response curve.

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

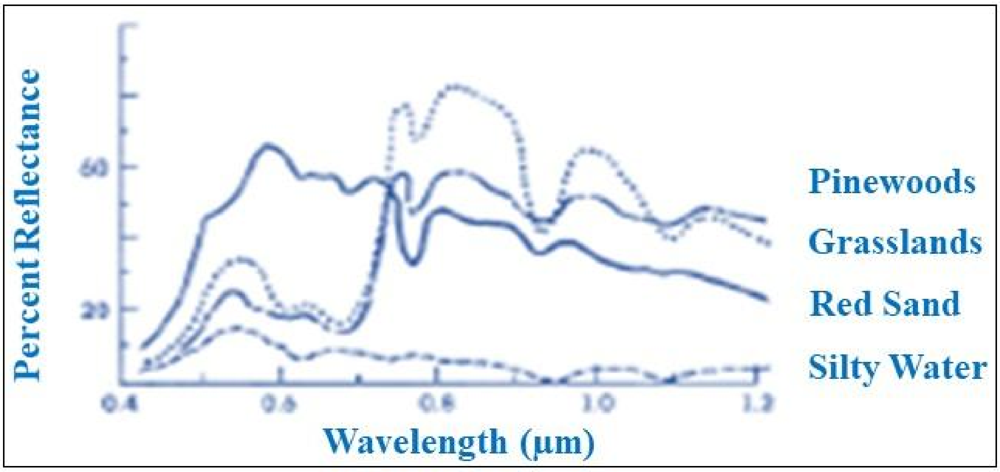

Fig. 7.6: Wavelength and reflectance curve.

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

Mechanical Scanning Radiometer (Whisk Broom)

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

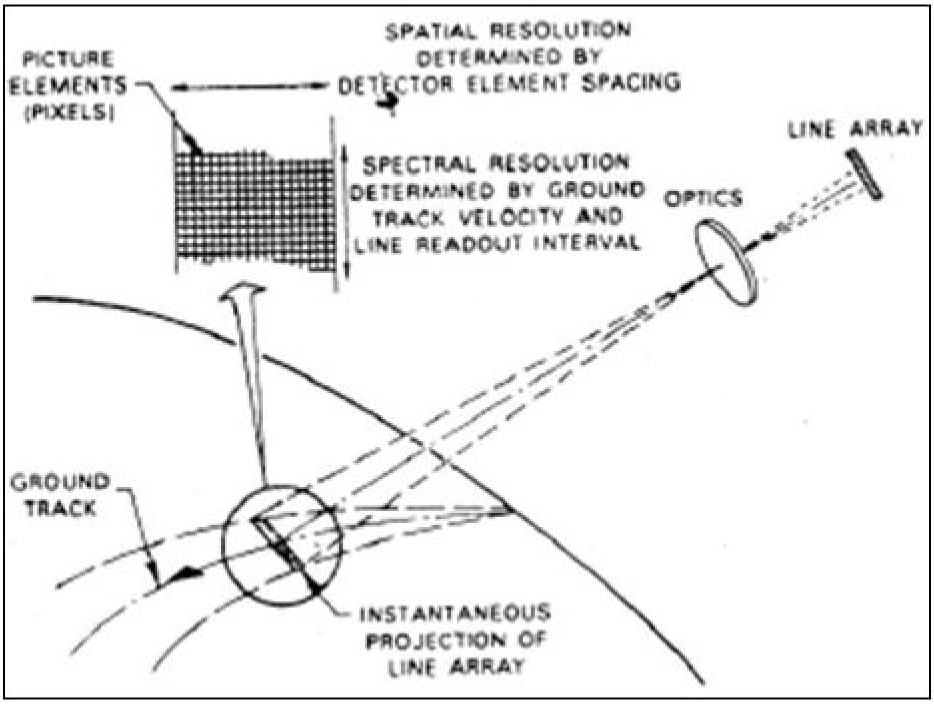

Fig 7.7: Mechanical scanning radiometer.

Platforms

Since electromagnetic energy from the Sun, emitted by the Earth itself or reflected by any active sensor is solely dependent on the surface characteristics. This energy is measured and recorded by the sensors. The resultant data can be used to derive information about surface characteristics.

The measurements of electromagnetic energy are made by sensors that are attached to a static or moving platform. Different types of sensors have been developed for different applications. Aircraft and Satellites are generally used to carry one or more sensors.

The combination of sensor and platform determines the characteristics of the resulting data. For example, when a particular sensor is operated from a higher altitude, the total area imaged is increased, while the level of detail that can be observed is reduced. Based on your information needs and on time and budgetary criteria, you can determine which image data are most appropriate.

A platform is a vehicle, such as a satellite or an aircraft, used for a particular activity or purpose or to carry specific kinds of equipment or instruments. They broadly may be classified into three categories, that are Ground borne, Air-borne, and Spaceborne.

Ground-based platform systems are mainly used for collecting ground truth data for lab experiments and sometimes for simulation studies. Air borne and spaceborne platforms have been used in sensing the Earth's features. Earth resources remote sensing operational activities are carried out using aircraft and spacecraft.

Airborne Platforms

Airborne platforms can be further classified into balloon and aircraft-based platforms. The use of balloons for remote sensing started in the late 1800s. Balloons going up to approx. 50 km altitude was developed for studying the earth's surface, the atmosphere, and celestial bodies. Balloons are used for checking the performance of sensors and carriers at different altitudes. The use of balloons is generally restricted by meteorological factors, especially wind velocity. Aircraft are commonly used as remote sensor platforms for obtaining photographs and digital data. The aircraft should have maximum stability, be free from vibrations and oscillations and be capable of flying at a uniform speed. Ceiling height is the most important criterion for classifying aircraft. As the user can choose the altitude of an aircraft platform to a good extent, images of different scales can be obtained with different ground resolutions for specific applications. The resolution obtainable from an aircraft-based survey is quite high when compared to that from satellites. As aircraft operations are very expensive. Activity is seasonally dependent and for India, the rainy season poses serious limitations. Aircraft photographic capabilities are restricted to the film length on the spool. Flight parameters should adhere to the design values as too much fluctuation hinders the establishment of a stereo–model.

Spaceborne Platforms

Platforms in space are not affected by the atmosphere. Hence orbits can be defined. The entire earth or any part of the earth can be covered at specified intervals. The mode can be Geostationary permitting continuous sensing of a portion of the earth, or Sun-synchronous with a low altitude polar orbit covering the entire earth at the same equator crossing time. Here, the initial development cost is high, but taking into account the global repetitive service, spacecraft remote sensing is cheaper than aircraft remote sensing. Since the altitude of an orbiting or geostationary satellite is very high, the resolution is poor. The orbit period varies as per the sensor on board, for example, LISS – III (Resourcesat 2) has a repetivity of 24 days.

Sensors

A sensor is a device comprising of optical component of a system and a detector with electronic circuitry. All sensors employed on the earth observation platform use EMR to observe the land features. Sensors can be divided into two groups:

Passive Sensors

Passive sensors depend on an external source of energy, usually the Sun, and sometimes the Earth itself. Current operational passive sensors cover the electromagnetic spectrum in the wavelength range from less than 1 pico meter (gamma rays) to larger than 1 meter (microwaves). The oldest and most common type of passive sensor is the photographic camera.

Non-imaging types of sensors are used to record a spectral quantity or a parameter as a function of time or distance (such as Gamma radiation, magnetic field, temperature measurement etc.) They are mostly used for ground observation and in the study of atmosphere and meteorology. These sensors do not form images and as such, are not used in operational remote sensing but give detailed information on spectral characteristics of the target.

A remote sensing system needs the radiant energy to be reflected or emitted by the object or target, which must reach the sensor/detector of the recording system. The response of the detector to the incident energy is recorded as data or image, which is analyzed to derive the information about the object.

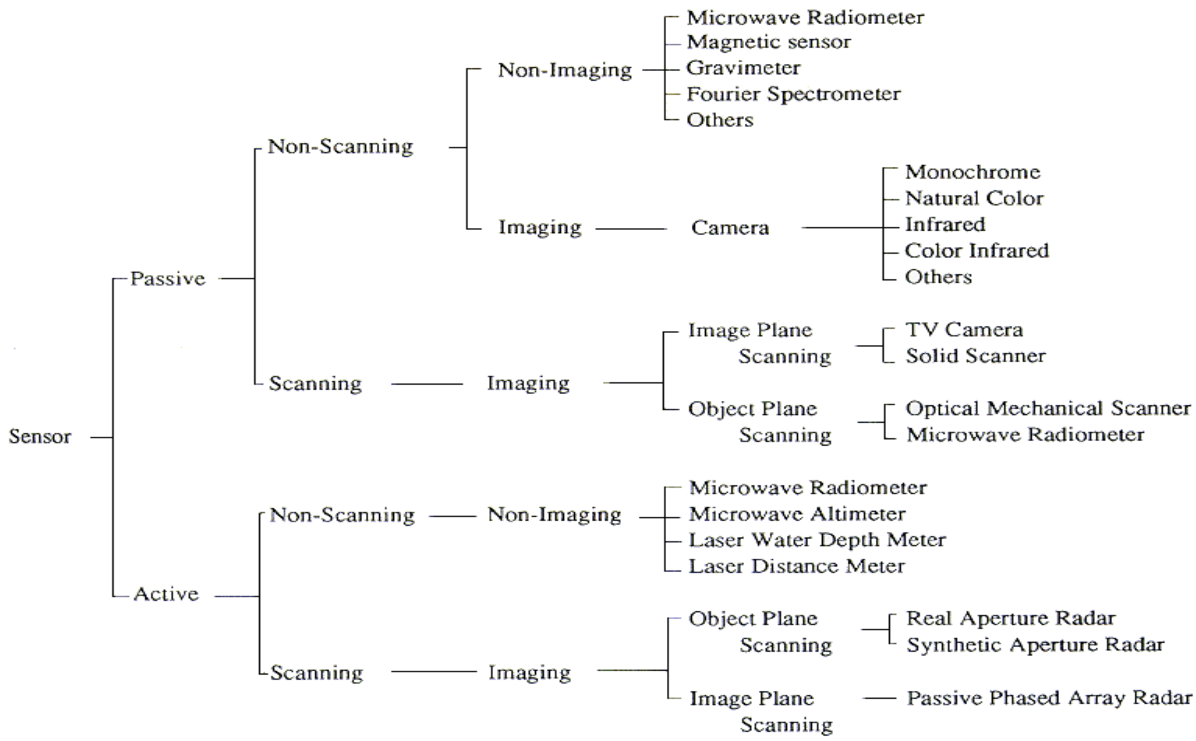

Fig. 7.8: Sensors and their classifications.

Gamma-ray Spectrometers

The gamma–ray spectrometer measures the amount of gamma rays emitted by the upper soil or rock layers due to radioactive decay. The energy measured in specific wavelength bands provides information on the abundance of (radioisotopes that relate to) specific minerals. Therefore, the main application is found in mineral exploration. Gamma rays have a very short wavelength on the order of pico meters. Because of the large atmospheric absorption of these waves, this type of energy can only be measured up to a few hundred meters above the Earth's surface.

Aerial Camera

The digital camera system, lens, and film or CCD are mostly found in aircraft for aerial photography. Low-orbiting satellites and NASA Space Shuttle missions also apply conventional camera techniques. The film types used in the camera enable electromagnetic energy range between 400 nm and 900n wi nm to be recorded. Aerial photographs are used in a wide range of applications. The rigid and regular geometry of aerial photographs in combination with the possibility of acquiring stereo–photography has enabled the development of photogrammetric procedures for obtaining precise 3D coordinates. Although aerial photos are used in many applications, principal applications include medium and large-scale (topographic) mapping and cadastral mapping.

Video Camera

Video Cameras are frequently used to record data. Most video sensors are only sensitive to the visible spectrum, although a few can record the near-infrared part of the spectrum. A development of thermal infrared video camera is said to be used for recording the movement of living beings. Mostly, video images serve to provide low-cost image data for qualitative purposes and most of the image processing methods can be applied to these images.

Multispectral Scanner

An instrument is a measuring device for determining the present value of a quantity under observation. A scanner is an instrument that obtains observations in a point–by–point and line–by–line manner. In this way, a scanner fundamentally differs from an aerial camera, which records an entire image in only one exposure. The multispectral scanner is an instrument that measures the reflected sunlight in the visible and infrared spectrum. A sensor systematically scans the Earth's surface, thereby measuring the energy reflected by the viewed area. This is done simultaneously for several wavelength bands, hence the name multispectral scanner. A wavelength band or spectral band is an interval of the electromagnetic spectrum for which the average reflected energy is measured. Typically, a number of distinct wavelength bands are recorded, because these bands are related to specific characteristics of the Earth's surface.

Fig. 7.9: Multispectral Images.

Thermal Scanners

These scanners measure thermal data in the range of 8 µm to 14 µm. Wavelengths in this range are directly related to an object’s temperature. For instance, data on cloud, land, and sea surface temperatures are indispensable for weather forecasting. For this reason, most remote sensing systems designed for meteorology, and forest fire assessment include a thermal scanner. These scanners are extensively used to study the effects of drought on crops and monitor the temperature of cooling water discharged from thermal power plants.

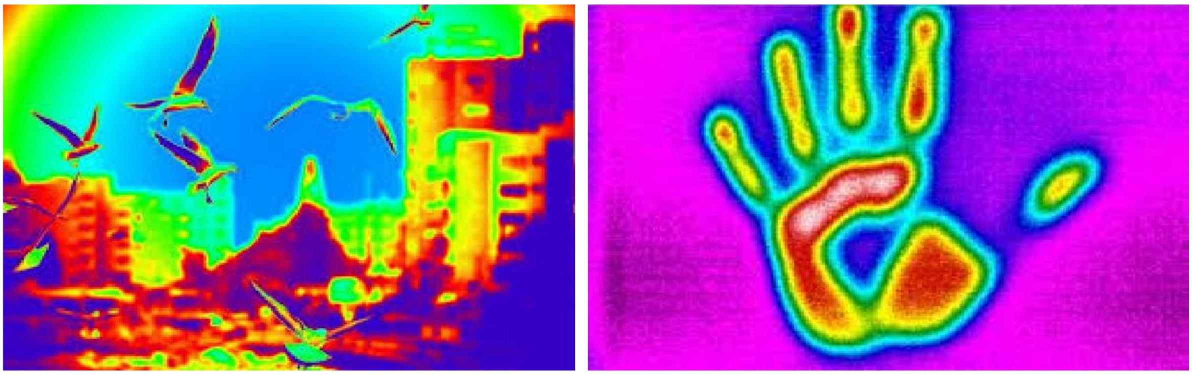

Fig. 7.10: Thermal Images.

Microwave Radiometer

Long wavelength Electromagnetic Energy (1 cm to 100 cm) emitted from the objects or just below the Earth’s surface. Every object with a temperature above the absolute temperature of zero Kelvin emits radiation, called blackbody radiation. Natural materials may emit radiation that is somewhat lower than the ideal case of a blackbody, which is demonstrated by an emissivity smaller than 1. A microwave radiometer records this emitted radiation of objects. The depth from which this emitted energy can be recorded depends on the properties of the specific material, such as the water content. The recorded signal is called the brightness temperature. The physical surface temperature can be calculated from the brightness temperature, but then the emissivity must be known. With an emissivity of 98% to 99% water behaves almost like a blackbody, while land features may vary with changing conditions. For instance, wet soil may have a considerably higher emissivity than dry soil.

Active Sensors

Active sensors have their own source of energy. Measurements by active sensors are more controlled because they do not depend upon varying illumination conditions. Active sensing methods include RADAR (Radio Detection and Ranging), LIDAR (Light Detection and Ranging), and SONAR (Sound Navigation Ranging), all of which may be used for altimetry as well as imaging.

Laser Scanners

A very interesting active sensor system, similar in some respects to RADAR, is LIDAR (Light Detection and Ranging). A LIDAR transmits coherent laser light, at a certain visible or near-infrared wavelength, as a series of pulses (thousand per second) to the surface, from which some of the light reflects. Travel time for the round-trip and the returned intensity of the reflected pulses are the measured parameters. LIDAR instruments can be operated as profilers and as scanners on airborne and space-borne platforms, day and night. LIDAR can serve either as a ranging device to determine altitude and measure speeds or as a particle analyzer for air. Light penetrates certain targets, which makes it possible to use it for assessing tree height or canopy conditions like that.

Imaging RADAR

RADAR (Radio Detection and Ranging) instrument operate in the 1 cm to 100 cm wavelength range. Different wavelength bands are related to particular characteristics of the Earth's surface. The RADAR backscatter is influenced by the emitted signal and the illuminated surface characteristics. Since RADAR is an active sensor system and the applied wavelengths can penetrate clouds, it can acquire images day and night and under all weather conditions, although the images may be affected somewhat by heavy rainfall.

In Figure advanced radar imaging that will provide an unprecedented, detailed view of Earth, the NASA-ISRO Synthetic Aperture Radar, or NISAR, the satellite is designed to observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes, and landslides. The mission is a partnership between NASA and the Indian Space Research Organization [9].

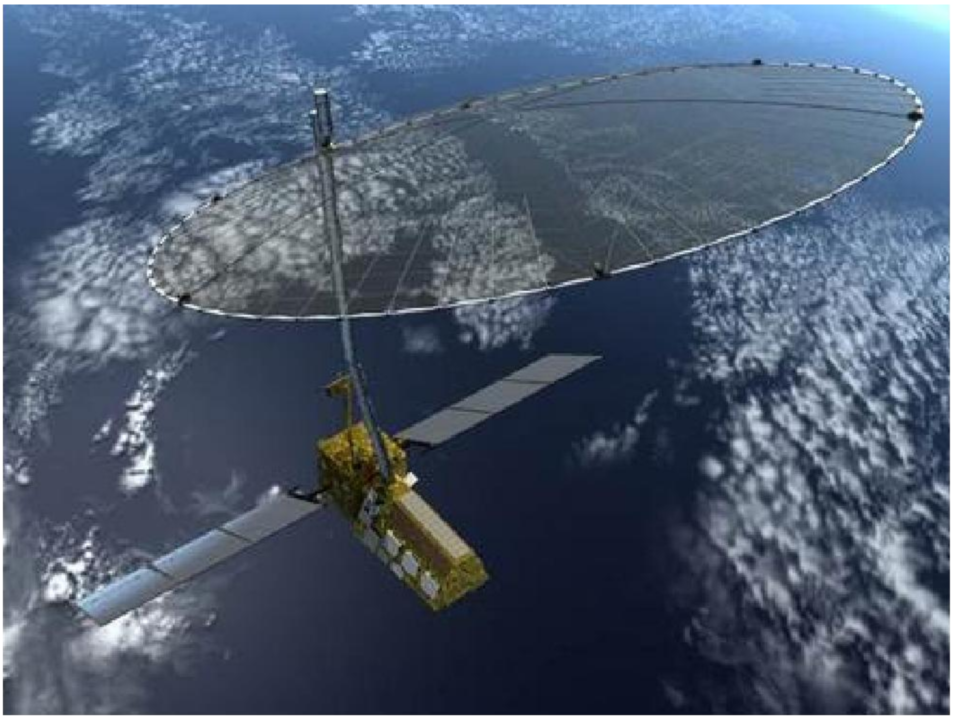

Fig 7.11: NASA-ISRO Synthetic Aperture Radar, or NISAR.

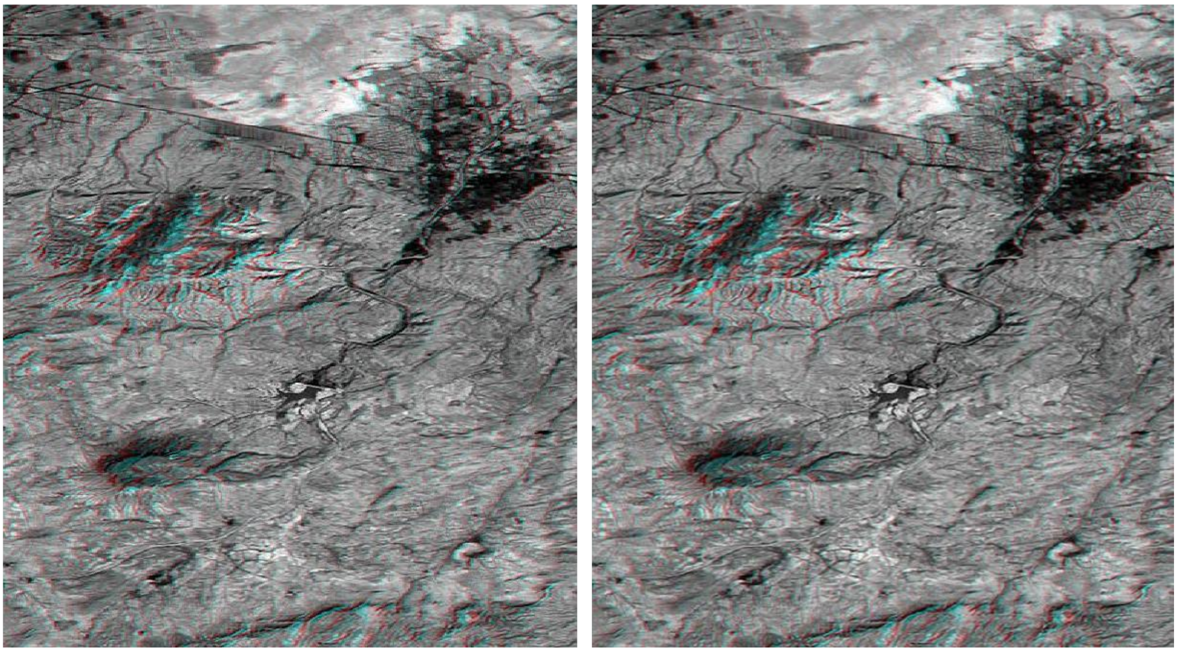

Fig. 7.12: Radar Images.

The combination of two stereo radar images of the same area can provide information about terrain height. Similarly, SAR Interferometry (INSAR) combines two radar images acquired at almost the same locations. These images are acquired either at different moments or at the same moment using two systems on either end of a long boom and can be used to assess changes in height or vertical deformations with great precision (5 cm or better). Such vertical motions may be caused by oil and gas exploitation or crustal deformation related to earthquakes.

6.4 SUMMARY

As of now, it is very much clear the importance of energy as well as its different concepts like radiance, emittance, its values into the digital numbers etc. Moreover while recording these energy levels different sensors are being used. These sensors are used according to the characteristics and objectives of the interpreters. An interpreter should choose the sensor/satellites with a more concentric approach toward his/her objectives.

Apart from direct benefits, space technology has clearly demonstrated the interconnectivity of both natural and human-made phenomena occurring anywhere on the Earth, through weather, climate changes, and various natural and human disturbances. Unless a sustainable integrated approach based on remote sensing and ground reality is adopted, it will not be possible to provide environmental security to society.

6.5 GLOSSARY

Electric Field Mathematically the electric field is a vector field that associates to each point in space the force, called the Coulomb force that would be experienced per unit of charge, by an infinitesimal test charge at that point. Electric fields are created by electric charges, and by time-varying magnetic fields.

Photons A particle representing a quantum of light or other electromagnetic radiation. It carries energy proportional to the radiation frequency but has zero rest mass.

Radiation The emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles causes ionization.

Radiometer An instrument for detecting or measuring the intensity or force of radiation.

Resolution The quality of being determined or resolute.

Spectral Used to classify something in terms of its position on a scale between two extreme points.

Spectrum A band of colours, as seen in a rainbow, is produced by the separation of the components of light by their different degrees of refraction according to wavelength.

Wavelength The distance between successive crests of a wave especially points in a sound wave or electromagnetic wave.

6.6 ANSWER TO CHECK YOUR PROGRESS

1. Electromagnetic radiation includes a range of energy wavelengths, from gamma rays to radio waves, with visible light falling within this spectrum.
2. Remote sensing using electromagnetic radiation allows us to capture information about the Earth's surface without physical contact, using sensors on satellites, aircraft, or ground-based equipment.
3. GIS, or Geographic Information System, is a technology that uses spatial data to analyze, interpret, and visualize various aspects of the Earth, such as land use, terrain, and demographics.
4. GIS software enables users to create maps, perform spatial analysis, and make informed decisions by integrating data from different sources, including remote sensing data.
5. Combining remote sensing with GIS allows for the creation of detailed maps and the analysis of phenomena like urban growth, environmental changes, and disaster response planning.
6. Remote sensing sensors collect data from Earth's surface or atmosphere using various technologies.
7. Passive sensors detect natural radiation (e.g., sunlight) reflected or emitted from objects, while active sensors emit their own energy (e.g., RADAR or LIDAR) and measure the returned signals.
8. Multispectral sensors capture data in several specific wavelength bands to create images with different spectral information.

9. Hyperspectral sensors have the ability to capture data in numerous narrow and contiguous spectral bands, providing detailed information about materials and substances.
10. Infrared sensors are particularly useful for detecting temperature variations on Earth's surface and can be used for applications like thermal imaging and fire detection.
11. Remote sensing is a technology used to gather information about the Earth's surface from a distance using sensors and instruments.
12. Satellites, aircraft, and ground-based sensors are common platforms for collecting remote sensing data.
13. Multispectral imagery captured by remote sensing can help monitor land use changes and assess vegetation health.
14. Remote sensing plays a crucial role in applications such as environmental monitoring, disaster management, and urban planning.

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6.8 TERMINAL QUESTIONS

Long Questions

1. How are wavelengths and frequency related to each other? Explain with a formula.
2. Explain the Electromagnetic Spectrum in detail.
3. What is a platform and how many types of platforms? Describe in detail.
4. What is a sensor in remote sensing and how they are important for this technology?

Short Questions

1. Define sensors and their classifications.
2. Draw an electromagnetic spectrum diagram and describe it.
3. Define different types of imagery and their usage.
4. What is the primary purpose of a sensor in remote sensing?
5. How does a passive sensor differ from an active sensor in remote sensing?
6. Name one type of sensor commonly used for capturing visible and infrared light.
7. How do sensors on satellites and aircraft collect data from the Earth's surface?
8. What is electromagnetic radiation?
9. What is the relationship between wavelength and frequency in the electromagnetic spectrum?
10. Name three types of platforms commonly used for remote sensing missions.

Short Questions

1. Which of the following is not part of the electromagnetic spectrum?

a) X-rays

b) Sound waves

c) Infrared radiation

d) Radio waves

2. In which part of the electromagnetic spectrum do microwaves fall?

a) Ultraviolet

b) Visible

c) Infrared

d) Radio waves

3. Which electromagnetic wave is used in communication via satellite TV?

a) Gamma rays

b) Infrared

c) X-rays

d) Radio waves

4. Which sensor is commonly used in digital cameras to capture images?

a) Thermocouple

b) CCD (Charge-Coupled Device)

c) Geiger-Muller tube

d) Doppler radar

5. Which sensor is used to measure temperature by detecting the heat emitted by an object?

a) LIDAR

b) Thermistor

c) GPS

d) Sonar

6. What type of sensor is typically used in burglar alarms to detect motion?

a) Capacitive sensor

b) Passive infrared sensor (PIR)

c) Ultrasonic sensor

d) Photoresistor

7. In remote sensing, what kind of platform is commonly used for capturing images of the Earth's surface?

a) Airplane

b) Submarine

c) Helicopter

d) Space shuttle

8. Which of the following is not a satellite-based navigation system?

a) GPS (Global Positioning System)

b) GLONASS

c) SONAR

d) Galileo

9. Which platform is used for studying the deep ocean and its ecosystems?

a) Space telescope

b) ROV (Remotely Operated Vehicle)

c) Weather balloon

d) Solar-powered drone

10. Which part of the electromagnetic spectrum is used in night vision goggles?

a) Infrared

b) Ultraviolet

c) Microwave

d) Gamma rays

11. What is the primary function of a Geiger-Muller tube sensor?

a) Measure air pressure

b) Detect radiation

c) Determine humidity

d) Detect sound waves

12. Which type of waves are commonly used in radar systems?

a) Radio waves

b) Gamma rays

c) X-rays

d) Ultraviolet rays

13. What does LIDAR stand for?

a) Light Identification and Ranging

b) Laser Imaging Detection and Ranging

c) Long-Range Infrared Detection and Ranging

d) Low-Intensity Distance Assessment and Recognition

14. Which sensor is used to measure the speed of a moving vehicle?

a) Tachometer

b) Altimeter

c) Anemometer

d) Hygrometer

15. Which of the following platforms is used for weather forecasting and monitoring?

a) Submarine

b) Weather satellite

c) Space shuttle

d) Hot air balloon

16. In which part of the electromagnetic spectrum do sunscreens typically block radiation?

a) Infrared

b) Ultraviolet

c) X-rays

d) Radio waves

17. What is the primary function of a seismometer sensor?

a) Detect earthquakes and seismic activity

b) Measure air temperature

c) Monitor ocean currents

d) Record atmospheric pressure

18. Which of the following is not a property of electromagnetic waves?

a) They can travel through a vacuum.

b) They require a medium to propagate.

c) They can travel at the speed of light.

d) They can be reflected and refracted.

19. Which platform is commonly used for conducting experiments in microgravity environments?

a) Hot air balloon

b) Space station

c) Glider aircraft

d) Submarine

20. What is the unit of frequency used to measure radio waves?

a) Hertz (Hz)

b) Newton (N)

c) Joule (J)

d) Pascal (Pa)

Answers: 1-b), 2-d, 3-d, 4-b, 5-b, 6-b, 7-a, 8-c, 9-b, 10-a, 11-b, 12-a, 13-b, 14-a, 15-b,16-b,17-a,18-b,19-b and 20-a.

UNIT 7 - BASICS OF THERMAL AND RADAR IMAGERY

7.1 OBJECTIVES

After the completion of this unit you will be able to understand:

- Concepts of images and different imaging systems
- Thermal and RADAR imageries
- Ground truthing of remote sensing data

7.2 INTRODUCTION

Imaging allows organizations to capture paper-based information and convert it to electronic images that are stored in a computer electronically. Whether you call it imaging, electronic imaging or document imaging is the technology that enables users to scan hard-copy documents into a computer system and store them in digital format. These technologies enable users to index or enter "metadata" into the system and always utilize some form of storage technology to save the digital version of the document. As per definition, Document imaging may be defined as the process of capturing, storing, and retrieving documents regardless of original format, using micrographics and/or electronic imaging (scanning, OCR, ICR, etc.). Electronic imaging is a technique for inputting, recording, processing, storing, transferring and using these images.

Most documents are created and stored electronically. Nearly every organization, however, has a large volume of documents that currently only exist in a paper format. Document imaging or imaging, allows organizations to capture paper-based information and convert it to electronic images that are stored in a computer electronically.

7.3 BASICS OF THERMAL AND RADAR IMAGERY

Advantages of Digital data over Analogue data

Dealing with digital data having the much advantages and provides fast and accurate reports, which can be used as input to the various other objectives of the particular organizations. Out of various advantages, the main advantages are accessibility, ease of access, full-text search, security space savings etc.

In general, there are four basic components to be considered for document imaging systems, which include input, identification (indexing), storage, and retrieval.

As different imaging systems are used to meet their objectives by particular organizations, for the assessment of natural resources remote sensing and GIS (Geographical Information System) are being extensively used and considered an imperative tool for the planning and development of the society. India with its vast natural resources and population to support its needs requires very effective mapping, monitoring, analysis, and implementation. The effectiveness of the development lies in the success of integrating, technology, economics, resources, and social needs. Increasing human intervention in natural systems, environmental pollution, and accelerating the process of development beyond the carrying capacity have shown warning signals in the form of climate and environmental change. To resolve the rising issues of the environment and further its development a proper strategy is required for it.

Earth observation is the most spectacular peaceful use of space-based endeavor. It has introduced new dimensions in the study and understanding of the environment and the earth's process, and in improving the quality of human life. The satellite remote sensing program has had immediate social and economic impacts on natural resource management. Space technology in totality covers a large canvas of benefits for many applications like environment, climate change, education, weather forecasting, monitoring land use and land cover, disaster management and the number is endless. Thus, addressing almost every aspect of our need.

Remote Sensing program is an important component in space science and technology. The Geographical Information System (GIS), which allows the integration of spatial and non-spatial data, has opened up applications for integrated resource analysis and developing decision support systems. The technology has great relevance in developing countries for various applications of natural resource management and monitoring. The application-driven approach adopted by the Indian Remote Sensing program has enabled the optimum utilization of this technology to address national issues. The National Natural Resource Management System (NNRMS) - an integrated resource management system aimed at optimal utilization of a country's natural resources by a systematic inventory of resources using remote sensing data in conjunction with conventional techniques has evolved as a national initiative. This understanding of global-scale problems of various natural and man-made can be optimally resolved.

While handling the spatial data an understanding of its basic imaging system and the understanding of image formation is essentially required. For that few terms to be taken into account. These are:

Pixels

Each picture element in an image called a pixel, has coordinates of (x, y) in the discrete space representing a continuous sampling of the earth's surface. Image pixel values represent the sampling of the surface radiance. The pixel value is also called image intensity, image brightness, or grey level. In a multispectral image, a pixel has more than one grey level. Each grey level corresponds to a spectral band. These grey levels can be treated as grey-level vectors.

From the continuous physical space to the discrete image space, a quantization process is needed. The details of quantization are determined by how we do sampling and what kind of resolution we use.

Two concepts are of particular importance; image space and feature space. Image-space refers to the spatial coordinates of an image(s) which are denoted as I with $m \ x \ n$ elements, where m and n are respectively the number of rows and the number of columns in the image(s). The elements in image space,

$I(i,j)$ $(i = 1, 2,..., m; j = 1, 2,..., n)$ are image pixels.

They represent spatial sampling units from which electromagnetic energy or other phenomenon is recorded. All possible image pixel values constitute the feature space V. One band of the image constitutes a one-dimensional feature space. k bands in an image denoted as I_k construct a k-dimensional feature space V_k. Each element in V_k is a unit hypercube whose coordinate is a k-dimensional vector $v = (v_1, v_2..., vk)T$.

When $k = 1, 2, and\ 3$ the hypercube becomes a unit line, a unit area, and a real unit cube. Each pixel in the image space has one and only one vector in the feature space. Different pixels may have the same vector in feature space.

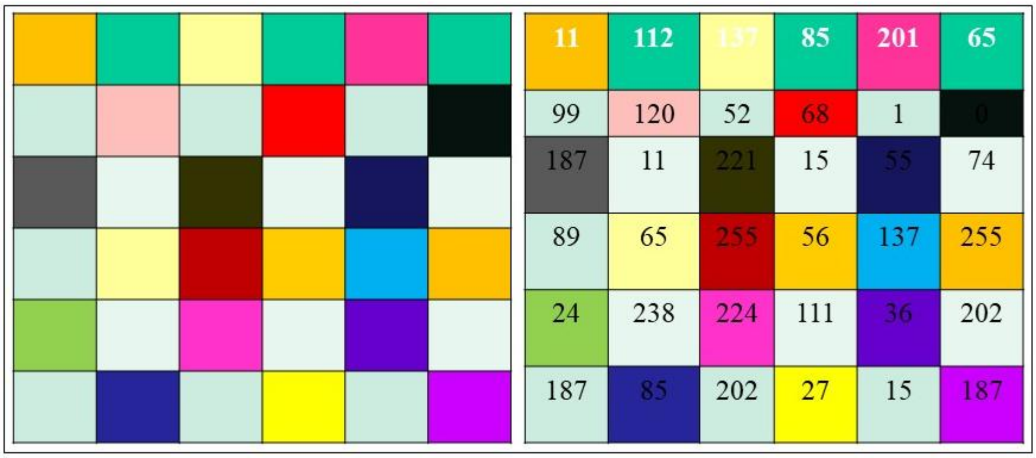

Fig. 7.1: The Pixel.

Multispectral images construct a special feature space, a multispectral space S_k. In S, each unit becomes a grey-level vector $g = (g_1, g_2, \ldots, g_k)T$. In multispectral images, each pixel has a grey-level vector. Other types of images add additional dimensions to the feature space. In the feature space, various operations can be performed. One of these operations is to classify feature space with similar grey-level vectors and give each group a same label that has a specific meaning. The classification decision made for each image pixel is in feature space and the classification result is represented in image space. Such an image is a thematic image that could also be used as an additional dimension in feature space for further analysis.

Pixel Window

A pixel window is defined in image space as a group of neighboring pixels. For the computation simplicity, a square pixel neighborhood $wl(i, j)$ centered at pixel $I(i, j)$ with a window lateral length of l is preferred. Referring to a pixel window as $wl(i, j)$, in order to ensure that $I(i, j)$ is located at the center of the pixel window, it is necessary for l to be an odd number. It is obvious that the size of a pixel window $wl(i, j)$ is $l \ X \ l$. The minimum pixel window is the centre pixel itself, and the maximum pixel window could be the entire image space, provided that the image space is a square with an odd number of rows and columns. When the image space has more than one image, a pixel window can be used to refer to a window located in any one image or any combination of those images.

Image Histogram

A histogram sometimes has two means: a table of occurrence frequencies of all vectors in feature space or a graph plotting these frequencies against all the grey-level vectors. The occurrence frequency in the histogram is the number of pixels in the image segment having the same vector. When the entire image space is used as the image segment, the histogram is referred to as *h(I)*. When a histogram is generated from a specific pixel window, it is identified as *hl(i, j)* where l, i, and j are the same as above. In practice, one-dimensional feature space is mainly used. In this case, a histogram is a graphical representation of a table with each grey level as an entry of the table. Corresponding to each grey level is its occurrence frequency

f(vi) , *i = 0, 1, 2, ..., Nv-1* and *Nv* are the numbers of grey levels of an image

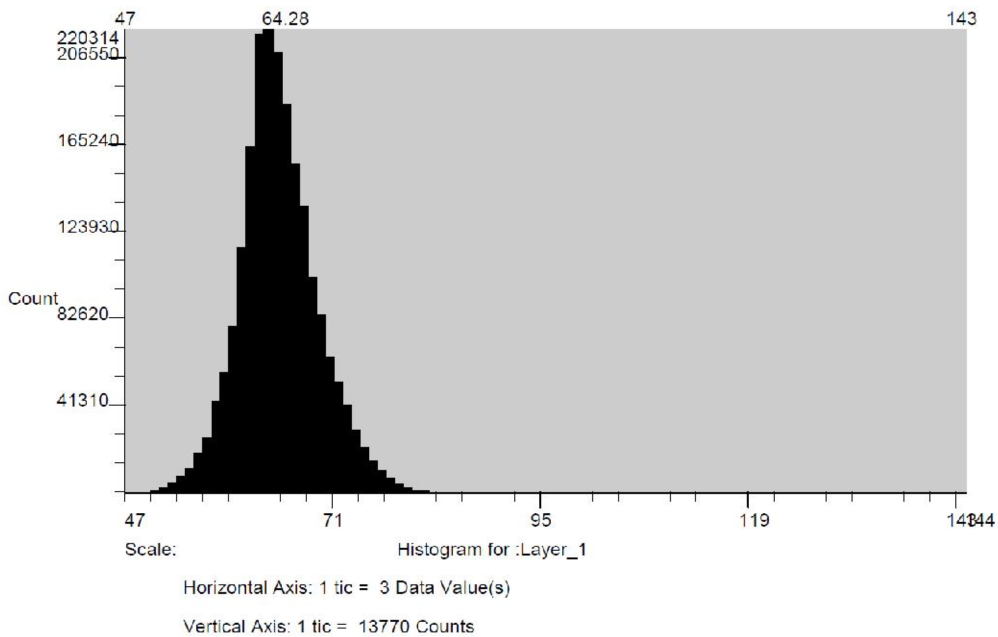

Fig. 7.2: Image histogram.

From a histogram *h(I)* we can derive the cumulative histogram *hc(I)={fc(vi)* , *i = 0, 1, 2, ..., Nv-1}*. This is obtained for each grey level by summing up all frequencies whose grey levels are not higher than the particular grey level under consideration.

Quality of a Digital Image

Two parameters of a sensor system at a specific height determine the quality of a digital remote sensing image for a given spectral range; the spatial resolution (rs) and the radiometric resolution (rr). As you are aware, the spatial resolution determines how finely the spatial detail of the real world an image can record (i.e., how small the spatial sampling unit is) and therefore the number of pixels in the image space. The radiometric resolution determines how finely a spectral signal can be quantized and therefore the number of grey levels that are produced. The finer these resolutions are, the closer is the information recorded in the image to the real world, and the larger are the sizes of the image space and the grey-level vector space. The size (or alternatively the number of pixels) of image space, *S(I)*, has an exponential relation with the spatial resolution, and so does the size (or the number of vectors) of the feature space, *S(V)*, with the radiometric resolution.

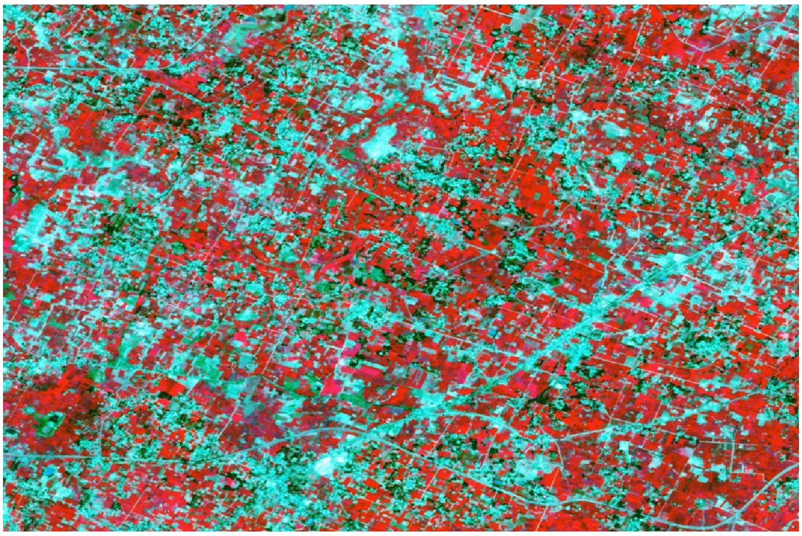

Fig. 7.3: The satellite image (good quality).

Image Formats

A single image can be represented as a 2-dimensional array. A multispectral image can be represented in a 3-dimensional array. In a computer, image data can be stored in many formats and the most popular ones include Band Sequential (BSQ), Pixel Interleaved, Line Interleaved (BIL), TIFF, Geo TIFF, png, and Img etc. The brief about these supported formats is presented below:

BIL: format is suitable for data transfer from the sensor to the ground. It does not need a huge buffer for data storage on the satellite if the ground station is within the transmission coverage of the satellite.

Pixel interleaved: is suitable for pixel-based operation or multispectral analysis.

BSQ - Band sequential: and separate file formats are the proper forms to use when we are more interested in single-band image processing, such as image matching, correlation, and geometric correction, and when we are more concerned with spatial information processing and extraction. For example, we use these files when linear features or image texture are of concern.

BIP: Band Interleaved by Pixel: The red value for the first pixel is written to the file, followed by the green value for that pixel, followed by the blue value for that pixel, and so on for all the pixels in the image.

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 Intergraph part of Hexagon. The lossy compression format efficiently compresses very large images with fine alternating contrast while retaining their visual quality.

GRID: developed by ESRI; supported by some remote sensing software packages, but not as common as other formats. ESRI grid is a raster GIS file format developed by ESRI, which has two formats, A proprietary binary format, also known as an ARC/INFO GRID, ARC GRID, and many other variations and another is a non-proprietary ASCII format, also known as an ARC/INFO ASCII GRID.

The formats were introduced for ARC/INFO. The binary format is widely used within ESRI programs, such as ArcGIS, while the ASCII format is used as an exchange, or export format, due to the simple and portable ASCII file structure. The grid defines geographic space as an array of equally sized square grid points arranged in rows and columns. Each grid point stores a numeric value that represents a geographic attribute (such as elevation or surface slope) for that unit of space. Each grid cell is referenced by its (x, y) coordinate location.

IMG: developed by ERDAS for Imagine to store raster data, it is supported by many GIS and remote sensing software packages. These files use the ERDAS IMAGINE Hierarchical File Format (HFA) structure. Each .img file stores basic information about the file including file name, layer name, number of layers, and date the file was last modified, this information applies to all of the layers.

JPEG: JPEG 2000, developed by the Joint Photographic Experts Group (JPEG) group. Widely supported by most of the GIS and remote sensing software. JPEG 2000 code streams are regions of interest that offer several mechanisms to support spatial random access or region of interest access at varying degrees of granularity. It is possible to store different parts of the same picture using different quality.

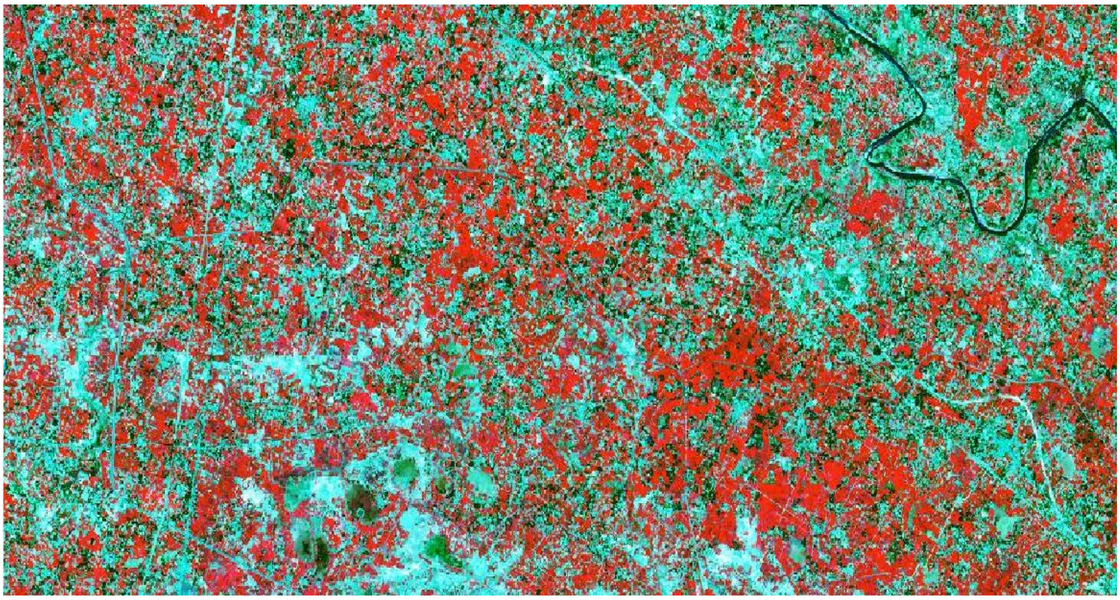

Fig. 7.4: The Satellite Image (*.JP2 Format).

TIFF: Tagged Image File Format data is a raster file format developed by Aldus, Corp. (Seattle, Washington), in 1986 for the easy transportation of data. This computer file format is used for storing the raster graphics images and widely supports scanning, faxing and image manipulation etc. It is a flexible, adaptable file format for handling images and data within in single file.

SID: Mr. Sid, developed by Lizard Tech. Uses wavelet compression to reduce file size. Read by many software packages, but requires a proprietary software license to create. With this format, large raster image files such as aerial photographs or satellite imagery are compressed and can be quickly viewed without having to decompress the entire file. This (.sid) format is supported in major GIS applications such as Autodesk, CARIS, ENVI, ERDAS, ESRI, Intergraph, MapInfo, and QGIS.

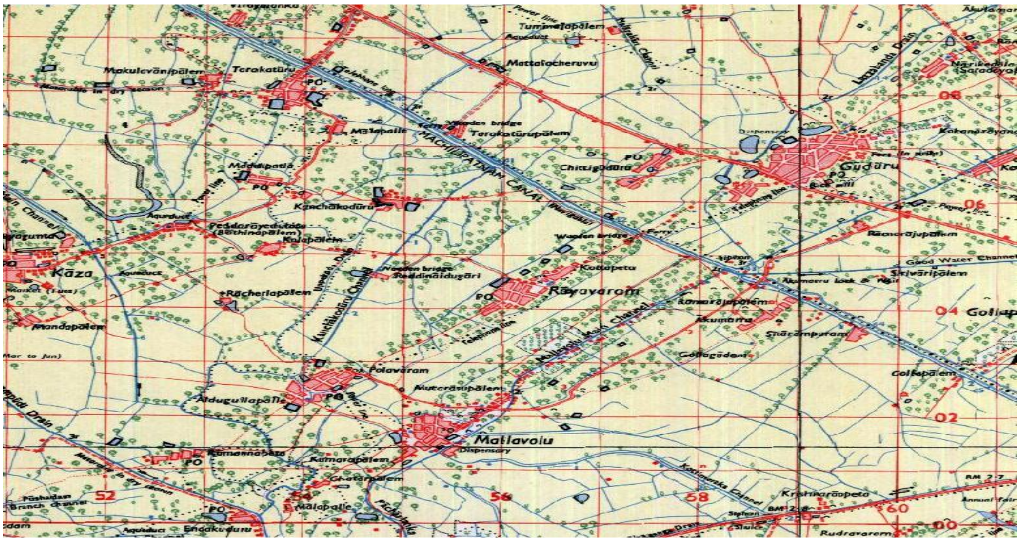

Fig. 7.5: The toposheet image (*.TIFF Format).

Thermal imaging system, Radar imagery, Ground truth

Thermal Scanners

The earth-atmosphere system derives its energy from the sun which being at a very high temperature, radiates maximum energy in the shorter wavelengths (visible – 0.20 to 0.80 μm). The earth-atmosphere system absorbs part of this energy (part due to its reflective properties due to surface albedo, clouds and other reflectors/scatters in the atmosphere), which in turn heats it up and raises its temperature. This temperature being in the range of 300 degrees Kelvin will emit its own radiation in the longer wavelengths called 'thermal' infrared. The observation in the thermal wavelength of the electromagnetic spectrum (3 – 35 μm) is generally referred to as thermal remote sensing. In this region the radiations emitted by the earth due to its thermal state are far more intense than the solar reflected radiations, therefore any sensor operating in this wavelength region would primarily detect the thermal radiative properties of ground material.

All material having a temperature above absolute zero (-273 ^{0}C or ^{0}K) both day and night emit infrared energy. Infrared sensing refers to the detection of remote objects by recording the amount of infrared energy emitted from various surfaces as a continuous tone image on photographic film. Thermal IR imagery is usually obtained in the wavelength region 3 to 5.5 μm and 8 to 14 mm because of atmospheric absorption at other wavelengths.

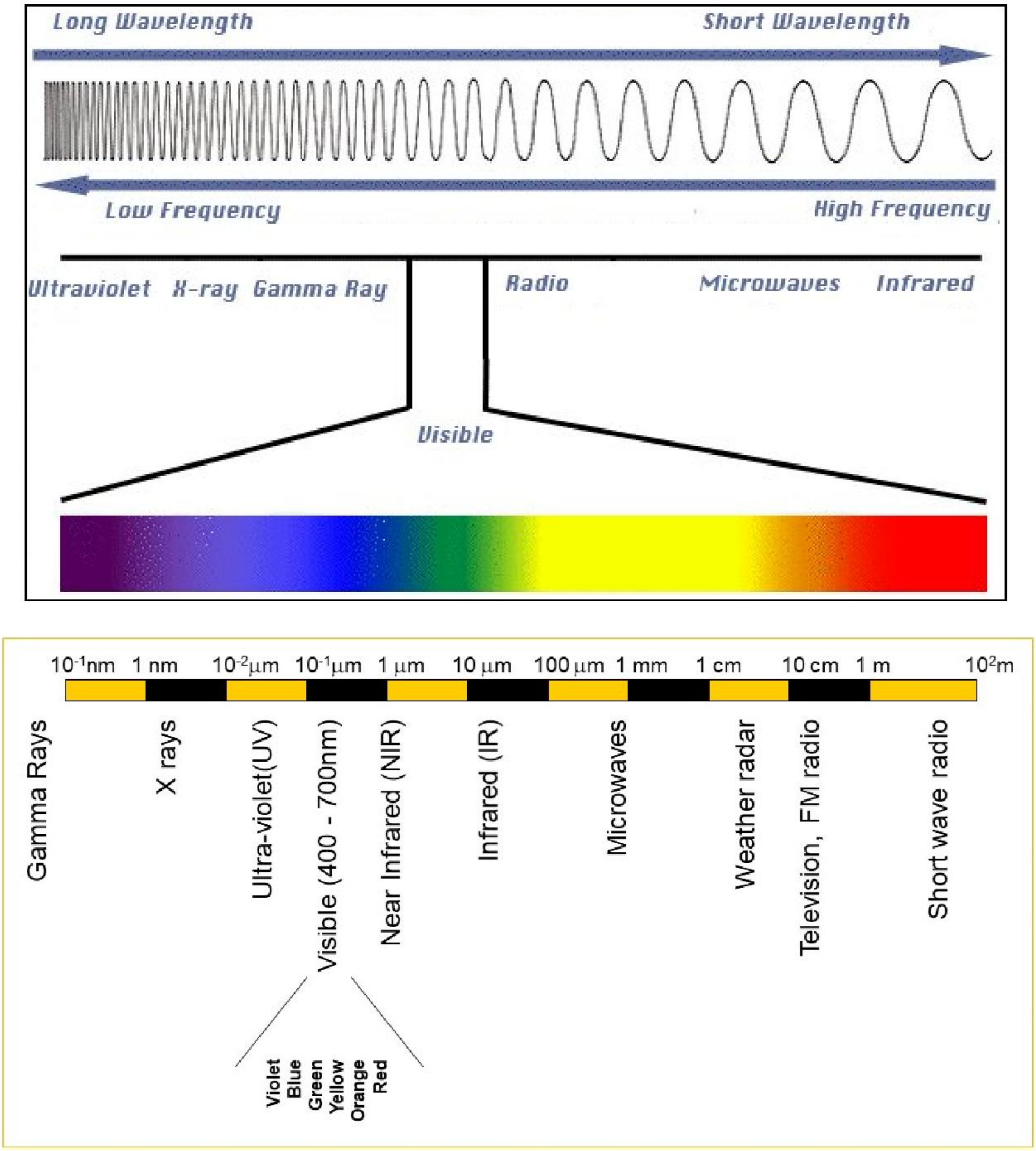

Figure 7.6: The electromagnetic spectrum.

Infrared Region of the Electromagnetic Spectrum

The IR region covers wavelengths from 0.7 to 300 µm. The reflected IR region ranges from wavelengths 0.7 to 3 µm and includes the photographic IR band (0.7 to 0.9 µm) that may be detected from IR film. IR radiation at wavelength 3 to 14 mm is called the thermal IR region. Since thermal IR radiation is absorbed by glass lenses of conventional cameras and cannot be detected by photographic film. Special optical mechanical scanners are used to detect and record images in the thermal IR region. IR radiation at wavelengths larger than 14 µm is not utilized in remote sensing as the radiation is absorbed by the Earth's atmosphere.

Atmospheric Transmission

Not all wavelengths of thermal IR radiation are transmitted uniformly through the atmosphere. Carbon dioxide, Ozone and water vapor absorb energy at certain wavelengths. IR and radiation at wavelengths from 3 – 5 µm and from 8 – 14 µm is readily transmitted through the atmosphere windows. A narrow absorption band occurs from 9 – 10 µm due to the Ozone layer present at the top of the Earth's atmosphere. To avoid the effect of this absorption band, satellite thermal IR systems operate in 10.5 – 12.5 µm. Systems on aircraft flying below the Ozone layer are not affected and record the full 8 -14 µm band.

Kinetic and Radiant Temperature

Kinetic heat is the kinetic energy of particles of matter in random motion. This internal or kinetic heat energy of matter is converted into radiant energy. The concentration of kinetic heat of a material is called kinetic temperature and is measured with a thermometer placed in direct contact with the material. The concentration of radiant flux of a body is the radiant temperature. This radiant temperature can be measured remotely by devices/sensors operating in the Thermal Infrared Region. The radiant temperature is always less than the kinetic temperature.

Thermal Properties of Materials

Radiant energy striking the surface of a material is partly reflected, partly absorbed and partly transmitted through material. Therefore

Reflectivity + Absorptivity + Transmissivity = 1

For materials having negligible transmissivity, it is reduced to

Reflectivity + Absorptivity = 1

The absorbed energy causes an increase in the kinetic temperature of the material.

Table 7.1: Emissivity of material measured in 8 -12 µm region.

Material	**Emissivity**
Granite	0.815
Quartz sand, large grains	0.914
Asphalt paving	0.959
Concrete walkway	0.966
Water with a thin film of petroleum	0.972
Water (pure)	0.993
Polished metal surfaces	0.060

The emissivities of most of the substances fall within the relatively narrow range of 0.81 0.96. Out of these factors like radiant temperature, thermal conductivity also plays a significant factor while dealing with thermal images. Thermal remote sensing data is collected by radiometers and scanners. The most basic form of radiant temperature is the thermal radiometer. This non–imaging device measures the radiant temperature using detectors sensitive to 8 – 14 mm wavelengths.

Thermal scanners are imaging devices and are used for use in aircraft or spacecraft. The airborne scanner system consists of three basic components – an optical mechanical scanning subsystem, a thermal infrared detector, and an image recording subsystem. Quantum or photon detectors are used as thermal detectors. These detectors operate on the principle of direct interaction between photons of radiation incident on them and the energy levels of electrical charge carriers within the detector material. For maximum sensitivity, the detector is cooled to the temperature approaching absolute zero to minimize its own thermal emissions. Normally the detector is surrounded by liquid nitrogen at 77 ^{0}K. Numbers of aerial scanners are available with different spatial resolutions and different fields of view.

Advantages of Thermal Imagery

The application of thermal infrared remote sensing can be broadly classified into two categories one in which surface temperature is governed by manmade sources of heat and another in which it is governed by solar radiation. In the former case, the technique has been used from airborne platforms for determining heat losses from buildings and other engineering structures. In the latter case, TIR remote sensing has been used for identifying crop types, crop diseases, soil moisture, tracking wildlife movement, forest fires identification, defense operation, measuring water stress etc.

RADAR Imageries

RADAR is the acronym for Radio Detection and Ranging. Using radar, geographers can effectively map out the terrain of a territory. Radar works by sending out radio signals, and then waiting for them to bounce off the ground and return. By measuring the amount of time it takes for the signals to return, it is possible to create a very accurate topographic map. An important advantage of using radar is that it can penetrate thick clouds and moisture. This allows scientists to accurately map areas such as rainforests, which are otherwise too obscured by clouds and rain. Imaging radar systems are versatile sources of remotely sensed images, providing day and night, all-weather imaging capability. Radar images are used to map landforms and geologic structures, soil types, vegetation and crops, and ice and oil slicks on the ocean surface.

Fig. 7.7: The RADAR.

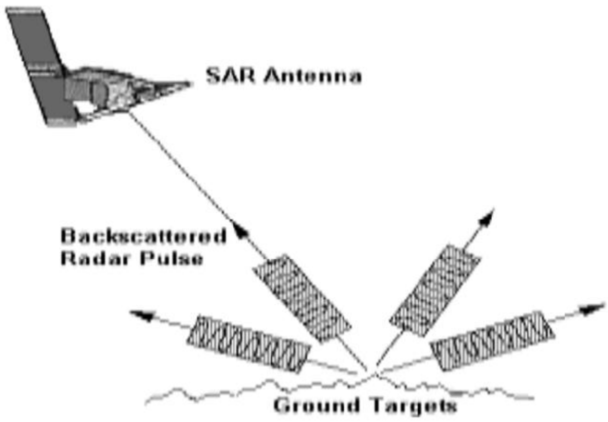

Fig. 7.8 : The RADAR spaceborne system.

There are several present and future sources of RADAR data collected from spaceborne systems: The precursors to these systems were four experimental spaceborne systems. Seaset -1, two Shuttle Imaging Radar (SIR) systems (SIR – A and SIR – B), and Cosmos – 1870 (operated by the Soviet Union). These systems were instrumental in demonstrating the utility of radar remote sensing from space. As real aperture systems have an insufficient resolution, Synthetic Aperture Radar (SAR) systems are used for spaceborne radar remote sensing.

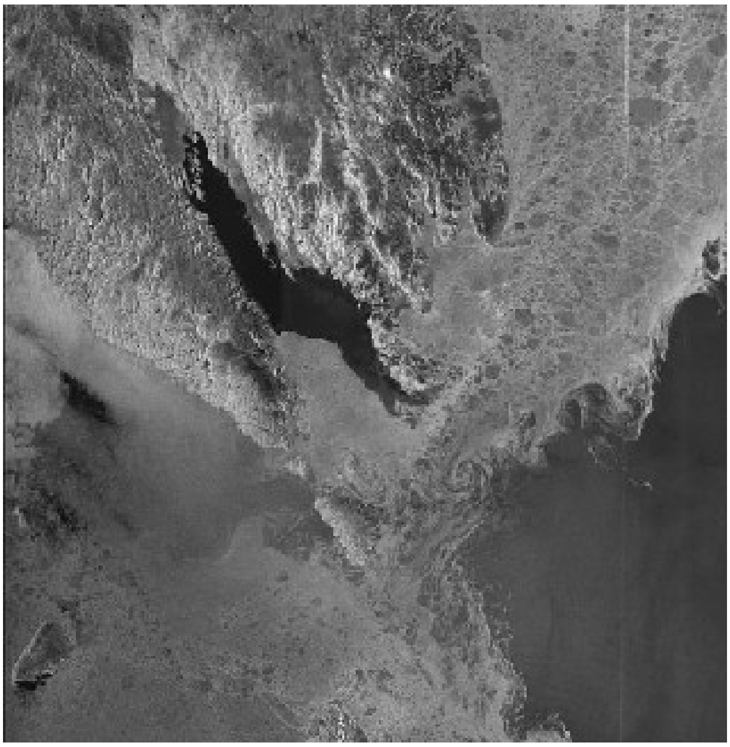

Fig. 7.9: A RADAR Image.

In synthetic aperture radar (SAR) imaging, microwave pulses are transmitted by an antenna towards the earth's surface. The microwave energy scattered back to the spacecraft is measured. The SAR makes use of the radar principle to form an image by utilizing the time delay of the backscattered signals. In real aperture radar imaging, the ground resolution is limited by the size of the microwave beam sent out from the antenna.

Ground Truth of Satellite Data

The term "ground check" refers to the ground data collection exercise carried out after completing the preliminary interpretation. The impact of the ground check and the accuracy of the mapping will vary in different phytogeographical regions. The checks can also be carried out using ancillary data like aerial photographs and other maps. Normally, the ground check should be carried out in the areas where extrapolation is done using ground truth information.

Further, the purpose of ground investigation in remote sensing is to give the interpreter a realistic perception of the area under study. These ground observations or ground truths are necessary for both research and operational applications. Sometimes the ground observations can be obtained from periodic or collateral data, but often a ground truthing data collection program is specifically designed for the particular objective as well as the type of remote sensing data used for achieving that objective.

According to the objective of remote sensing activity and the accuracy level required, the nature of the information to be collected and the quality and quantity requirement for information are determined. Based on these ground truth data the accuracy of the output of remote sensing projects has been evaluated. For proper ground truth, the following are the points to consider for effective and desirable results. These are:

Field Form

A proper field form is required, which consists of the number of columns like project name, GPS ID, topography, date of point taken as well as date of imageries for which ground truth is going, terrain etc.

Printouts of the Toposheets and Imageries

The area for which GT is to be taken, a clear printout of the area's toposheet for place/location identification, and printouts of imageries of the area under study will also be taken. It will help to know the different tones of imageries w. r. t. classification and its updation. As the data source provides the signature for mapping (translating), the calibration of the thematic units is done by establishing the correlation between the signature and ground information.

Time of imagery/ photographs

Lets' we take the example of forest classification. For the identification of forest cover is best when the spectral response of other land cover classes is poor. Since the vegetation's phenological condition is season-dependent and follows a cycle, the repetitive coverage should be used to select the best data for interpretation. For example, the appearance of foliage in deciduous forest, the gregarious flowering of certain species, and the leafless condition of orchards can be used for the identification of forest features more accurately. It has been found that unless the right season data is selected the delineation may have gross inaccuracies. It is observed that in the different physio-geographical regions the suitability of the season of the data varies. In general, October to December season data is found very useful while mapping dry deciduous forest areas of central and western India. However, during this period annual flora and perennial ground flora created problems with discrimination. The forest of eastern and western ghats and areas under moist deciduous forest can be better interpreted using data selected during January and February. In the western Himalayan region, the April-May data has been found most suitable. From October to December, most of the broad-leaved forest of the western Himalayan region remains leafless. In the case of the northeastern region, the proper season of data is mainly dependent on the weather conditions. Fortunately, the cloud-free condition also coincides with the right season of the data needed for interpretation, i.e., February-March. For Mangrove forest areas, the mapping should be carried out using low-tide images between February and March.

7.4 SUMMARY

Remote sensing data are supplied to a variety and number of users for various applications and information extraction, in the form of a 'data product'. The data products are made available to users of our country by the National Data Center (NDC) of the National Remote Sensing Center (NRSC) of the Indian Space Research Organisation (ISRO) located at Hyderabad, India. This image data format can be defined as the sequential arrangement of pixels, representing a digital image in a computer-compatible storage medium such as a compact disk (CDs/DVDs). These images are graphical records of various objects on the Earth's surface in two dimensions. These records are stored with other parameters in the form of X, Y coordinates. However, from these primary measurements, other values such as length, area, volume, height, distance etc. can also be worked out.

In this unit, we have discussed the concept of images and their formation from different sources. The images are to be considered the key component for the extraction of desired output. To obtain the desired result, an interpreter has to choose the particular sensor and platform data w. r. t. its applicability in considering the electromagnetic spectrum. The types of images aid us in understanding the various applications of the available constellations of different sensors/platforms.

7.5 GLOSSARY

Absorption	The amount of radiation absorbed by the atmosphere
AOI	Area of interest
Classification	The process of finding pixels within a scene having spectral properties that are similar to a given signature of an AOI.
Emission source	radiation re-emitted after absorption
Emission source	Radiation re-emitted after absorption
Raster Data	A raster is defined as a set of data that is organized in a 2-dimensional grid, usually with rows and columns.
Scattering	The amount of radiation scattered away from the field of view by the atmosphere.
Signature	A description of the spectral properties of an AOI.
SWIR and LWIR	The near-infrared and middle-infrared regions of the electromagnetic spectrum are sometimes referred to as the short-wave infrared region (SWIR). This is to distinguish this area from the thermal or far infrared region, which is often referred to as the long wave infrared region (LWIR). The SWIR is characterized by reflected radiation whereas the LWIR is characterized by emitted radiation.
Training Set	A set of pixels selected by you that contains the AOI for input to the signature derivation process. The development of a successful signature depends on the quality of the training set.

7.6 ANSWER TO CHECK YOUR PROGRESS

1. Radar remote sensing technology has advanced significantly, leading to better image resolution and data quality.

2. Increased availability of open-access radar data has facilitated research and applications in agriculture, disaster management, and environmental monitoring.
3. Radar remote sensing plays a crucial role in monitoring climate change, aiding in the observation of phenomena like sea-level rise and glacial movements.
4. The integration of radar data with artificial intelligence has improved the automation of feature detection and classification, making data analysis more efficient.
5. Challenges, such as data calibration and privacy concerns, still need to be addressed for further progress in radar remote sensing.
6. Progress in thermal remote sensing has led to more accurate temperature measurements from space.
7. Advances in sensor technology have improved the spatial and temporal resolution of thermal infrared imagery.
8. Researchers are using thermal remote sensing to monitor urban heat islands and climate-related changes.
9. The integration of thermal data with other remote sensing methods is enhancing our understanding of Earth's surface and atmosphere.
10. Ongoing developments aim to make thermal remote sensing data more accessible for various applications, including agriculture and environmental monitoring.
11. Ground truthing in GIS has seen significant advancements, with improved field data collection techniques and the integration of high-resolution satellite imagery.

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7.8 TERMINAL QUESTIONS

Long Questions

1. Write the applications of thermal imageries.
2. How ground truthing is significant for evaluating remote sensing data?
3. Explain the RADAR and thermal remote sensing in detail.

Short Questions

1. What do you understand by remote sensing data products?
2. What are various remote sensing data formats?
3. How can you obtain desired remote sensing data?
4. What is the primary advantage of radar remote sensing over optical remote sensing?
5. How does radar remote sensing work, and what kind of information can it provide?
6. What are some common applications of radar remote sensing in agriculture?
7. What challenges are associated with processing and interpreting radar remote sensing data?
8. What is the primary purpose of thermal remote sensing?

9. How do thermal sensors detect temperature variations from space?

Multiple Choice Questions

1. What does RADAR stand for in RADAR remote sensing?

a) Radio Detection and Ranging

b) Remote Assessment of Data and Ranging

c) Rapid Analysis of Digital Remote Sensing

d) Radiation Assessment and Detection for Atmospheric Research

2. Which of the following is not a common application of RADAR remote sensing?

a) Weather monitoring

b) Earthquake prediction

c) Agriculture

d) Military surveillance

3. RADAR remote sensing uses which type of waves to detect and measure objects on Earth's surface?

a) Sound waves

b) Radio waves

c) Infrared waves

d) Ultraviolet waves

4. What is the primary advantage of RADAR remote sensing over optical remote sensing?

a) Higher spatial resolution

b) Color imagery

c) Lower cost

d) Real-time data acquisition

5. Which of the following is not a characteristic of RADAR waves used in remote sensing?

a) They can penetrate clouds and vegetation.

b) They are affected by atmospheric conditions.

c) They have shorter wavelengths than visible light.

d) They can provide day and night observations.

6. What is the term for the process of measuring the time it takes for a RADAR signal to travel to an object and back to calculate its distance?

a) Sonar

b) Lidar

c) Altimetry

d) Range-Doppler technique

7. Which of the following RADAR modes is commonly used for creating detailed images of the Earth's surface?

a) Synthetic Aperture Radar (SAR)

b) Polarimetric Radar

c) Scatterometer

d) Weather RADAR

8. What does SAR stand for in the context of RADAR remote sensing?

a) Sensor for Aerial Reconnaissance

b) Synthetic Aperture Radar

c) Scanning and Analyzing RADAR

d) Satellite Assessment Radar

9. Which of the following is a disadvantage of RADAR remote sensing?

a) Limited ability to penetrate vegetation

b) Inability to operate at night

c) High data acquisition costs

d) Low spatial resolution

10. What is the term for the process of using multiple RADAR images of the same area taken at different times to detect changes over time?

a) RADAR fusion

b) Interferometry

c) Radiometry

d) Spectroscopy

Answers: 1-a, 2-b, 3-b, 4-a, 5-c, 6-d, 7-a, 8-b, 9-a and 10-b.

BLOCK III: DIGITAL IMAGE PROCESSING

UNIT 8 - INTRODUCTION TO DIGITAL IMAGE PROCESSING

8.1 OBJECTIVES

After reading this unit you will be able to understand:

- Definitions of image, digital image, signal, and digital image processing.
- Types and Formats of Image
- Procurement of Digital Image
- Preliminary concepts for image processing
- Colour composites

8.2 INTRODUCTION

The visual/onscreen method of image interpretation has already been explained to you. You have also learned its related sub-topics namely types of remote sensing and remote sensors, preliminary concepts, criterion of image interpretation, image elements, advantages, and limitations. Here, under this topic of `basics of digital image processing`, you first try to understand the importance of picture/image and how is it most convenient for bringing out detailed useful information and the signal processing followed by the basics of digital image processing.

Pictures are the most common and convenient means of conveying or transmitting information. A picture is worth a thousand words. Pictures concisely convey information about positions, sizes, and inter-relationships between objects. They portray spatial information that we can recognize as objects. Human beings are good at deriving information from such images, because of visual and mental abilities. About 75% of the information received by humans is in pictorial form.

Signal processing is a discipline in electrical engineering and mathematics that deals with the analysis and processing of analog and digital signals, and deals with storing, filtering, and other operations on signals. These signals include transmission signals, sound or voice signals, image signals, and other signals. Out of all these signals, the field that deals with the type of signals for which the input is an image and the output is also an image is done in image processing. As its name suggests, it deals with the processing of images. It can be further divided into analog image processing and digital image processing.

In the present context, the analysis of pictures that employ an overhead perspective, including the radiation not visible to the human eye is considered. Thus our discussion will focus on the analysis of remotely sensed images. These images are represented in digital form. When represented as numbers, brightness can be added, subtracted, multiplied, divided and, in general, subjected to statistical manipulations that are not possible if an image is presented only as a photograph.

Although digital analysis of remotely sensed data dates from the early days of remote sensing, the launch of the first Landsat earth observation satellite in 1972 began an era of increasing interest in machine processing. Previously, digital remote sensing data could be analyzed only at specialized remote sensing laboratories. Specialized equipment and trained personnel necessary to conduct routine machine analysis of data were not widely available, in part because of the limited availability of digital remote sensing data and a lack of appreciation of their qualities.

8.3 INTRODUCTION TO DIGITAL IMAGE PROCESSING

DEFINITIONS:

Image:

- An image is defined as a two-dimensional function, F (x, y), where x and y are spatial coordinates, and the amplitude of F at any pair of coordinates (x, y) is called the intensity of that image at that point.
- In other words, an image can be defined by a two-dimensional array specifically arranged in rows and columns.

Digital Image:

- Digital Image Processing means processing digital images using a digital computer. We can also say that it is a use of computer algorithms, to get enhanced images or to extract some useful information.

- A Digital Image is composed of a finite number of elements, each of which elements have a particular value at a particular location. These elements are referred to as picture elements, image elements, and pixels. A Pixel is most widely used to denote the elements of a Digital Image.

Signal:

- In electronics, a signal is an electric current or electromagnetic field used to convey data from one place to another. The simplest form of signal is a direct current (DC) that is switched on and off; this is the principle by which the early telegraph worked. More complex signals consist of an alternating current (AC) or electromagnetic carrier that contains one or more data streams.
- The signal is a token; indication.
- It may also be defined as an electrical quantity or effect, as current, voltage, or electromagnetic waves that can be varied in such a way as to convey information.

Digital image processing:

- Digital image processing (DIP) deals with the manipulation of digital images through a digital computer. It is a subfield of signals and systems but focuses particularly on images.
- Digital Image processing is a collection of techniques for the manipulation of digital images by computers.

TYPES AND FORMATS OF IMAGE:

Types of an Image:

i. Binary Image: The binary image as its name suggests, contains only two-pixel elements i.e., 0 & 1, where 0 refers to black and 1 refers to white. This image is also known as

Monochrome.

ii. Black and White Image: An image that consists of only black and white color is called a black and white image. This is an analog image without any digital values. Such images or photographs are generally referred to as aerial or terrestrial photography.

iii. 8 bit Image: It is a medium radiometric resolution image type. It has 256 (2^8) different shades of black and white and is commonly known as Grayscale Image. In this format, 0 stands for black, 255 stands for white, and 127 stands for gray. The variability of shades of this image can be divided into 255 categories of gray levels between black and white. In remote sensing it is called 8 bit radiometric resolution data.

iv. 16 bit Image: It is a high radiometric resolution type. It has 65,536 (2^{16}) different shades of black and white shades or colors in it. It is also known as High Color Format type. In this type, the distribution of color is not as same as Grayscale image. A 16 bit format is divided into three further formats which are Red, Green, and Blue. That is the famous RGB format.

Image Formats:

There are 5 main formats in which the images are stored.

i. TIFF (also known as TIF), file types ending in .tiff

TIFF stands for Tagged Image File Format. TIFF images create very large file sizes. TIFF images are uncompressed and thus contain a lot of detailed image data (which is why the files are so big). TIFFs are also extremely flexible in terms of color (they can be grayscale, or CMYK for print, or RGB for web) and content (layers, image tags).

TIFF is the most common file format used in photo software (such as Photoshop), as well as page layout software (such as Quark and Design).

ii. JPEG (also known as JPG), file types ending in .jpg

JPEG stands for Joint Photographic Experts Group. It is a standard type of image formatting. The images of JPEG files are compressed to store a lot of information in a small-size file. Most digital cameras store photos in JPEG format so that one can take more photos on one camera card. While compressing the JPEG images some of the details are likely to be lost that why it is called a “lossy” compression.

JPEG files are usually used for photographs on the web, because they create a small file that is easily loaded on a web page and also looks good.

JPEG files are bad for line drawings or logos or graphics, as the compression makes them look “bitmap” (jagged lines instead of straight ones).

iii. GIF, file types ending in .gif

GIF stands for Graphic Interchange Format. This format compresses images but, as different from JPEG, the compression is lossless (no detail is lost in the compression, but the file can't be made as small as a JPEG).

GIFs also have an extremely limited color range suitable for the web but not for printing. This format is never used for photography, because of the limited number of colors. GIFs can also be used for animations.

iv. PNG, file types ending in .png

PNG stands for Portable Network Graphics. It was created as an open format to replace GIF, because the patent for GIF was owned by one company and nobody else wanted to pay licensing fees. It also allows for a full range of color and better compression.

It's used almost exclusively for web images, never for print images. For photographs, PNG is not as good as JPEG, because it creates a larger file. But for images with some text, or line art, it's better, because the images look less "bitmappy."

When you take a screenshot on your Mac, the resulting image is a PNG–probably because most screenshots are a mix of images and text.

v. Raw image files

Raw image files contain data from a digital camera (usually). The files are called raw because they haven't been processed and therefore can't be edited or printed yet. There are a lot of different raw formats–each camera company often has its own proprietary format.

Raw files usually contain a vast amount of data that is uncompressed. Because of this, the size of a raw file is extremely large. Remote sensing data obtained from different sensor systems are stored in raw image files. Usually, they are converted to TIFF before editing and color-correcting.

Image data are in raster formats, stored in a rectangular matrix of rows and columns. Radiometric resolution determines how many gradations of brightness can be stored for each cell (pixel) in the matrix; 8-bit resolution, where each pixel contains an integer value from 0 to 255, is most common. Modern sensors often collect data at higher bit depth (e.g. 16-bit for Landsat-

8), and advanced image processing software can make use of these values for analysis. The human eye cannot detect very small differences in brightness, and most GIS software stretches data for an 8-bit display.

In a greyscale image, 0 = black and 255 = white; and there is just one 8-bit value for each pixel. However, in a natural color image, there is an 8-bit brightness value for red, green, and blue. Therefore, each pixel in a color image requires 3 separate values to be stored in the file.

The remote sensing industry and those associated with it have attempted to standardize the way digital remote sensing data are formatted in order to make the exchange of data easier and to standardize the way data can be read into different image analysis systems. The Committee on Earth Observing Satellites (CEOS) has specified this format which is widely used around the world for recording and exchanging data.

Following are the three possible ways/formats to organize these values in a raster file.

- **BIP -** Band Interleaved by Pixel: The red value for the first pixel is written to the file, followed by the green value for that pixel, followed by the blue value for that pixel, and so on for all the pixels in the image.
- **BIL -** Band Interleaved by Line: All of the red values for the first row of pixels are written to the file, followed by all of the green values for that row followed by all the blue values for that row, and so on for every row of pixels in the image.
- **BSQ -** Band Sequential: All of the red values for the entire image are written to the file, followed by all of the green values for the entire image, followed by all the blue values for the entire image.

Ortho images are delivered in a variety of image formats, either compressed or uncompressed. The most common are TIF and JPG. Compression eases data management challenges, as large high-resolution Ortho-photo projects can easily result in terabytes of uncompressed imagery. Compression can also speed display in GIS systems. The downside is that compression can introduce artifacts and change pixel values, possibly hampering interpretation and analysis, particularly with respect to fine detail. The decision to compress should be driven by end-user requirements; it is not uncommon to deliver a set of uncompressed imagery for archival and special applications along with a set of compressed imagery for easy use by large numbers of users. If there is an intention for web-based display or distribution of Ortho-imagery, a compressed set of Ortho-imagery is often recommended. In any event, geo-referencing information must also be provided. Both TIFF and JPG image formats can accommodate geo-referencing information, either embedded in the image file itself, as in the case of Geo TIFF, or as a separate file for each image, as in the case of TIFF with a TFW (TIF World) file. The geo-referencing information tells GIS software, i) the size of a pixel, ii) where to place one corner of the image in the real world, and iii) whether the image is rotated with respect to the ground coordinate system.

PROCUREMENT OF DIGITAL IMAGE:

Remote sensing data from foreign countries and Indian Remote Sensing (IRS) data is made available by NDC (National Data Centre), NRSC to all users for various developmental and application requirements as per RSDP policy. The following are the guidelines for data dissemination.

- All data of resolutions up to 1 m shall be distributed on a non-discriminatory basis and an "as requested basis"
- Data better than 1m resolution can be distributed to users after screening and ensuring the sensitive areas are excluded.
- Data better than 1m resolution will be supplied as per RSDP policy. Government users can obtain the data without any further clearance. Public sector undertakings / autonomous bodies / academic institutions/Private users, recommended by at least one Government agency, can obtain data without any further clearance.
- Request for data from all users must be received in the prescribed form duly authorized by the head of the organization that shall be responsible for stating the end application and identifying a senior official for safe keeping of the data.

Ordering Procedure:

User order Processing System (UOPS) is an online web application using which users are requested to specify their area and period of interest along with the sensor and product selection. The user's area of interest (AOI) may be specified in the form of a point, polygon, draw-on-map, location name, map sheet, and shape file. For shape file-based AOI specification, the input shape file should be in ESRI-compatible format (.shx, .shp, .dbf and prj) and the distance between the vertices of the shape file must be a minimum of 5 km. The minimum order is 1 scene for the corresponding sensor.

Based on the proforma invoice generated through UOPS, the user can transfer 100% advance payment to NRSC along with 18% of the GST (as per the applicable guidelines) through NEFT online transfer or a demand draft in favor "Pay and Accounts Officer NRSC" payable at Hyderabad.

All data products will be disseminated to the users as per the Remote Sensing Data Policy and the guidelines provided by the Government of India. The order will be entertained when the required information is furnished in full and payment made. Data orders are to be placed through UOPS along with the required undertakings and certificates. Please ensure the correct product type is chosen. For further details, please contact NDC. Order once processed and confirmed cannot be amended or cancelled unless technical problems are encountered during data generation. NDC reserves the right to refuse/cancel any order in full or part.

Price and Payments:

For detailed price list, you may open the price list of web site of NDC, NRSC. Price list indicates, the product no, product type, accuracy, price etc., Indicate the Satellite and product no details in the order form. Please ensure the correct product type is chosen. For further details, please contact NDC. The price applicable to each order is the price in effect on the date of confirmation of the order with NDC. NDC publishes a price list of data products at periodic intervals.

Discounts:

- 50% discount on respective user category pricing for archived data older than 2 years from the date of acquisition.
- 50% discount for the data less than two years old for academic and research purpose.
- @ 3% for orders more than Rs. 10.0 lakhs
- @ 5% for orders more than Rs. 25.0 lakhs
- @ 10% for orders more than Rs. 1.00 crore placed at a time for IRS products.

Priority Services: The provision for the supply of satellite data within 24 hours (1 day) with additional charge @ 50% is available. Priority orders must be received at NDC before 11 AM on a working day. In case the order is accepted and cannot be shipped within 16 hours, no additional charges will be levied.

Licensing:

NRSC grants only single-user license for the use of IRS images. All products are sold for the sole use of purchasers and shall not be loaned, copied, or exported without express permission of and only in accordance with terms and conditions if any, agreed with the NRSC Data Centre, National Remote Sensing Centre, ISRO, Dept. of Space, and Govt. of India. All data will be provided with encryptions/mechanisms, which may corrupt the data while copying unauthorized or while attempting the same. Every such attempt shall attract criminal and civil liability from the user without prejudice to the corruption of data or software/hardware, for which NRSC will not be liable. NRSC grants the user a limited, non-exclusive, non-transferable license with the following terms and conditions.

Terms and Conditions:

- Users can install the product on their premises (including on an internal computer network) with the express exclusion of the Internet.
- Users can make copies of the product (for installation and backup purposes)
- Users can use the product for his own internal needs
- Users can use the product to produce Value Added Products and/or derivative works
- Users can use any Value-Added Product for their own internal needs
- Users can make the product and/or any Value-Added Product temporarily available to contractors and consultants, only for use on behalf of the user
- Users can print and distribute or post on an Internet site, but with no possibility of downloading, an extract of a product or Value-Added Product (maximum size 1024 x 1024 pixels) for promotional purposes (not including online mapping or geolocation services for online promotion), in each case with an appropriate credit conspicuously displayed.

Limited Warranty and Liability:

NRSC warrants (a) that it has sufficient distribution to make the Product available to the user under the terms hereof, free from the adverse claims of third parties; and (b) that the Product will, for thirty (30) days from the date of receipt, substantially conform to NRSC's specifications when used on appropriate computer hardware and DOS certified Software packages. The high-resolution data products are complex in nature and may contain a few artefacts, which may not affect the usability of the data products supplied. The recommended usage for Cartosat-2 data is up to 1: 4000 scales. There are no expressed or implied warranties of fitness or merchantability given in connection with the sale or use of this product. NRSC disclaims all other warranties not expressly given herein.

Returns and Disputes:

For a period of thirty (30) days, NRSC warrants that the products delivered by NRSC will be limited to the area of interest ordered and the original media NRSA supplied the data product will be free from physical or material defects. If FTP is selected as the mode of data products dissemination, products will be available for 15 days at FTP server for the users to download. No complaint related to the quality and/or quantity of the products will be entertained unless the complaint is lodged at NDC within 30 days from the date of receipt of data. On acceptance of the complaint, products are to be returned in the original media supplied by NDC. NRSC's sole obligation and user's sole remedy under this Limited Warranty is that NRSC either, in its discretion, shall use reasonable efforts to repair or replace the Product or to provide a procedure within a commercially reasonable time so that the Product substantially conforms to the specifications.

This Limited Warranty is void if any non-conformity has resulted from accident, abuse, misuse, misapplication, or modification by someone other than NRSC. The Limited Warranty is for the user's benefit only and is non-transferable. NRSC is not liable for any incidental or consequential damages associated with users’ possession and/or use of the Product.

In case any disputes arise on the applicability or interpretation of the above terms and conditions between the NRSC and the user, the matter shall be referred to the Secretary, Department of Space, Govt. of India, whose decision shall be binding on both parties.

Based on the policies and rules of data procurement and dissemination; you should know the following before ordering the data and mention the correct specification on the data order Performa.

- Satellite platform/mission
- Sensor characteristics (film types, digital systems)
- Season of the year and time of the day
- Atmospheric effects
- Resolution of the imaging system and scale
- Image motion
- Stereoscopic parallax (in case of aerial photographs or sensor type providing stereo image)
- Exposure and processing
- Precision standard of data
- Type of data viz., analog or digital
- Number of spectral bands or FCC and
- The type of digital data format

Digital Data Formats:

The digital data acquired from Remote Sensing Systems are stored in different types of formats *viz.*, (1) band sequential (BSQ), (2) band interleaved by line (BIL), (3) band interleaved by pixel (BIP). It should be noted, however, that each of these formats is usually preceded on the digital tape by 'header' and/ or 'tailer' information, which consists of ancillary data about the date, altitude of the sensor, sun angle, and so on. Such information is useful when geometric or radiometric correction of the data. The data are normally recorded on nine-track CCTs with data density on the tape of 800, 1600, or 6250 bits per inch (bpi). Before ordering the data the user must be aware of the above formats of data so that the correct procedures can be applied for its downloading, correction, and further processing.

PRELIMINARY CONCEPT OF DIGITAL IMAGE PROCESSING:

Digital Image and Digital Number:

A digital remotely sensed image is typically composed of picture elements (pixels) located at the intersection of each row i and column j in each k bands of imagery (Fig. 12.1). Associated with each pixel is a number known as Digital Number (DN) or Brightness value (BV) that depicts the average radiance; of a relatively small area within a scene. A smaller number indicates low average radiance from the area and the high number is an indicator of high radiant properties of the area. The size of this area affects the reproduction of details within the scene. As pixel size is reduced more scene detail is presented in digital representation.

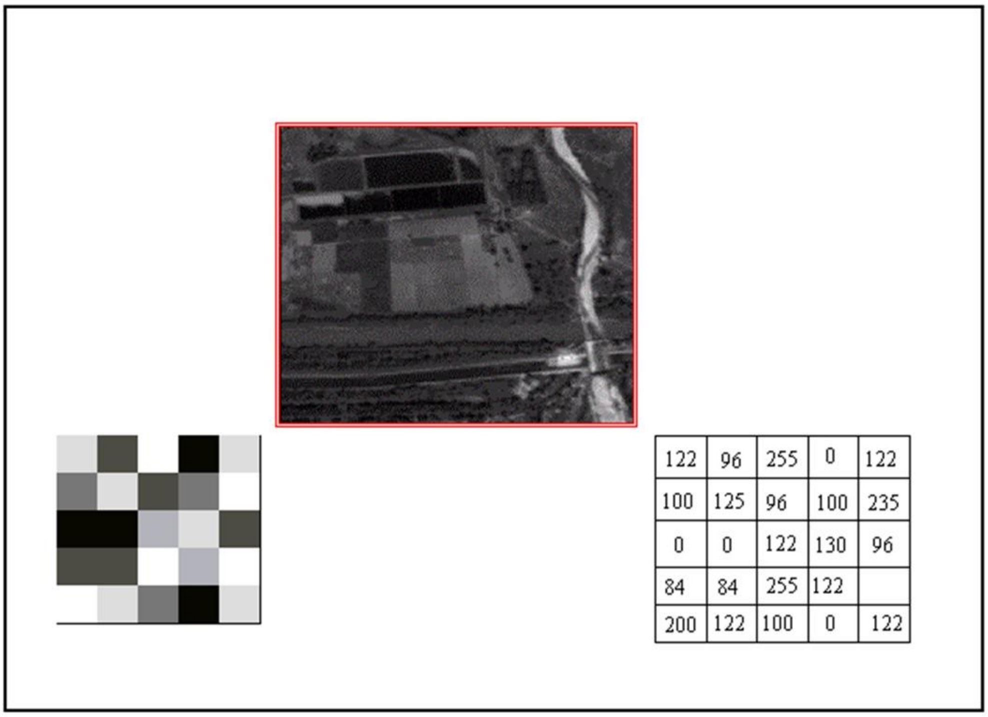

Fig. 8.1: Digital image.

A digital image is a representation of a real image as a set of numbers that can be stored and handled by a digital computer. In order to translate the image into numbers, it is divided into small areas called pixels (picture elements). For each pixel, the imaging device records a number, or a small set of numbers, that describe some property of this pixel, such as its brightness (the intensity of the light) or its color. The numbers are arranged in an array of rows and columns that correspond to the vertical and horizontal positions of the pixels in the image.

Digital images have several basic characteristics. One is the *type* of the image. For example, a black-white image records only the intensity of the light falling on the pixels. A color image can have three colors, normally RGB (Red, Green, Blue) or four colors, CMYK (Cyan, Magenta, Yellow, black). RGB images are usually used in computer monitors and scanners, while CMYK images are used in color printers. There are also non-optical images such as ultrasound or X-ray in which the intensity of sound or X-rays is recorded. In range images, the distance of the pixel from the observer is recorded. *Resolution* is expressed in the number of pixels per inch (ppi). A higher resolution gives a more detailed image. A computer monitor typically has a resolution of 100 ppi, while a printer has a resolution ranging from 300 ppi. to more than 1440 ppi. This is why an image looks much better in print than on a monitor.

To recognize an object, the computer has to compare the image to a database of objects in its memory. This is a simple task for humans but it has proven to be very difficult to do automatically. One reason is that an object rarely produces the same image of itself. An object can be seen from many different viewpoints and under different lighting conditions, and each such variation will produce an image that looks different to the computer. The object itself can also change; for instance, a smiling face looks different from a serious face of the same person. Because of these difficulties, research in this field has been rather slow, but there are already successes in limited areas such as inspection of products on assembly lines, fingerprint identification by the FBI, and optical character recognition (OCR). OCR is now used by the U.S. Postal Service to read printed addresses and automatically direct the letters to their destination, and by scanning software to convert printed text to computer readable text.

Need, scope, and Importance of digital image processing:

Remote sensing data received from satellites, particularly Sun Synchronous Satellite, has many discrepancies like radiometric errors, geometric errors, atmospheric variability, weather fluctuation, atmospheric haze, light intensity variability due to the Sun's inclination above the horizon, cloud cover, shadows, topographic influence and distortion due to earth`s movement under each satellite pass. Therefore, digital image processing certainly needs digital image/data corrections and rectification with respect to those errors through digital processes by using specific computer software. Analog data showing a considerable amount of contrast among features is developed for visual interpretation (already discussed in the previous chapter) after digital processing. Similarly, if required, visual interpretation on a computer screen is also developed for interpretation.

One of the greatest advantages of digital image processing/interpretation over visual interpretation is capturing the maximum amount of information (based on spectral and radiometric resolution) as the computer, having specific software, is capable of acquiring the same. The limitation of visual interpretation is based on the fact that our eyes can identify up to 20-22 colours within a colour composite image and up to 10 shades of grey tone within black-white image.

Another advantage of digital images over traditional ones is the ability to transfer them electronically almost instantaneously and convert them easily from one medium to another such as from a web page to a computer screen to a printer. A bigger advantage is the ability to change them according to one's needs. There are several programs available now that give a user the ability to do that, including Photoshop, Photo Paint, and Gimp. With such a program, a user can change the colors and brightness of an image, delete unwanted visible objects, move others, and merge objects from several images, among many other operations. In this way, a user can retouch family photos or even create new images. Other software, such as word processors and desktop publishing programs, can easily combine digital images with text to produce books or magazines much more efficiently than with traditional methods.

While processing the data digitally we need a lot of storage space and powerful computers to analyze the data from today`s remote sensing systems. The following example highlights the space required for digital image processing:

One 8-bit pixel takes up one single byte of computer disk space. One kilobyte (Kb) is 1024 bytes. One megabyte (Mb) is 1024 kilobytes. How many megabytes of computer disk space would be required to store an 8-bit Landsat Thematic Mapper (TM) image (7 bands), which is 6000 pixels by 6000 lines in dimension?

If we have seven bands of TM data, each 6000 pixels by 6000 lines, and each pixel takes up one byte of disk space, we have:

7 x 6000 x 6000 = 252,000,000 bytes of data

To convert this to kilobytes we need to divide by 1024, and to convert that answer to megabytes we need to divide by 1024 again!

252,000,000 (1024 x 1024) = 240.33 megabytes

So, we would need over 240 megabytes of disk space just to hold one full TM image, let alone analyze the imagery and create any new image variations! Needless to say, it takes a lot of storage space and powerful computers to analyze the data from today's remote sensing systems.

Digital images tend to produce big files and are often compressed to make the files smaller. *Compression* takes advantage of the fact that many nearby pixels in the image have similar colors or brightness. Instead of recording each pixel separately, one can record that, for example, "the 100 pixels around a certain position are all white." Compression methods vary in their efficiency and speed. The GIF method has good compression for 8-bit pictures, while the JPEG is lossy, i.e. it causes some image degradation. JPEG's advantage is speed, so it is suitable for motion pictures.

In today's world of advanced technology where most remote sensing data are recorded in digital format, virtually all image interpretation and analysis involves some element of digital processing. Digital image processing may involve numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer**.**

A very promising use of digital images is automatic object recognition. In this application, a computer can automatically recognize an object shown in the image and identify it by name. One of the most important uses of this is in robotics. A robot can be equipped with digital cameras that can serve as its "eyes" and produce images. If the robot could recognize an object in these images, then it could make use of it. For instance, in a factory environment, the robot could use a screwdriver in the assembly of products. For this task, it has to recognize both the screwdriver and the various parts of the product. At home a robot could recognize objects to be cleaned. Other promising applications are in medicine, for example, in finding tumors in X-ray images. Security equipment could recognize the faces of people approaching a building. Automated drivers could drive a car without human intervention or drive a vehicle in inhospitable environments such as on the planet Mars or in a battlefield.

A digital image processing system consists of computer hardware and image processing software necessary to analyze digital image data. DIP focuses on developing a computer system that can perform processing on an image. The input of that system is a digital image and the system processes that image using efficient algorithms and gives an image as an output. The most common example is Adobe Photoshop. It is one of the widely used applications for processing digital images. Image processing mainly includes the steps i) Importing the image via image acquisition tools ii) Analyzing and manipulating the image iii) Output in which result can be altered image or a report which is based on analyzing that image.

Digital Image Processing is an extremely broad subject and involves procedures, which are mathematically complex. The procedure for digital image processing may be categorized into the following types of computer-assisted operations.

Sequence of activities for digital image processing:

In order to process remote sensing imagery digitally, the data must be recorded and available in a digital form suitable for storage on a computer tape or disk. Obviously, the other requirement for digital image processing is a computer system, sometimes referred to as an image analysis system, with the appropriate hardware and software to process the data. Several commercially available software systems have been developed specifically for remote sensing image processing and analysis.

For discussion purposes, most of the common image processing functions available in image analysis systems can be categorized into the following four categories:

- Preprocessing
- Image Enhancement
- Image Transformation
- Image Classification and Analysis

COLOUR COMPOSITES:

Colour composite provides the maximum amount of spectral variability by assigning different colours to the spectral bands chosen for colour composite. The high spectral resolution is important when producing colour components. For a true colour composite, image data reused in red, green and blue spectral regions must be assigned bits of red, green, and blue image processor frame buffer memory. A colour infrared composite standard false colour composite 'standard false colour composite' is displayed by placing the infrared, red, green and blue frame buffer memory (Fig. 12.2). In this healthy vegetation shows up in shades of red because vegetation absorbs most of green and red energy but reflects approximately half of incidence Infrared energy. Urban areas reflect the equal portion of NIR, R & G, and therefore they appear as steel grey.

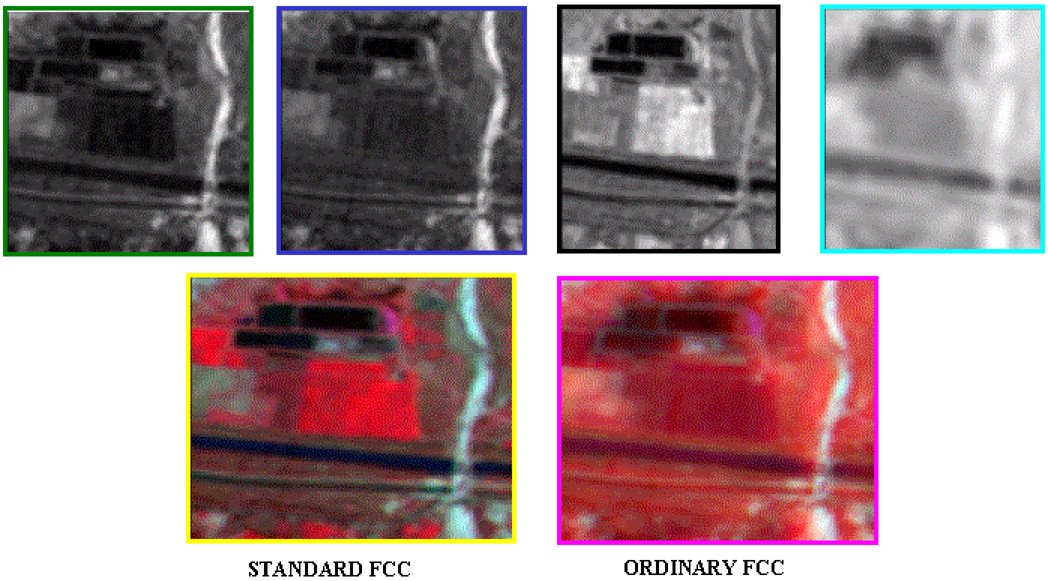

Fig. 8.2: Colour composites

The *color depth* (of a color image) or "bits per pixel" is the number of bits in the numbers that describe the brightness or the color. More bits make it possible to record more shades of gray or more colors. For example, an RGB image with 8 bits per color has a total of 24 bits per pixel ("true color"). Each bit can represent two possible colors so we get a total of 16,777,216 possible colors. A typical GIF image on a web page has 8 bits for all colors combined for a total of 256 colors. However, it is a much smaller image than a 24 bit one so it downloads more quickly. A fax image has only one bit or two "colors," black and white. The *format* of the image gives more details about how the numbers are arranged in the image file, including what kind of compression is used, if any.

8.4 SUMMARY

Digital Image Processing is defined as the processing of digital data/images by means of a digital computer. It is a use of computer algorithms to enhance the image (spectrally and radiometrically) and improve the quality of interpretability for extracting meaningful full and useful information/results. Image processing mainly includes the importing of an image via image acquisition tools, analyzing and manipulating the image and the output in which results are seen as altered images, and a report is based on analyzing that image. An image is defined by a two-dimensional array specifically arranged in rows and columns.

Digital Image is composed of a finite number of elements showing a particular value at a particular location. These elements are referred to as picture elements, image elements, and pixels. A Pixel is most widely used to denote the elements of a Digital Image.

Digital image procurement is the most important task for all individual users and the offices where this technique is being used. Digital image/data of remote sensing from foreign countries and Indian Remote Sensing (IRS) data is made available by NDC (National Data Centre), NRSC to all users for various developmental and application requirements as per RSDP policy. For this, certain guidelines and ordering procedures are followed.

Remote sensing data received from the satellite, particularly Sunsynchronous Satellite, has many discrepancies. Therefore, digital image processing certainly needs digital image/data corrections and rectification concerning those errors through digital processes by using specific computer software.

One of the greatest advantages of digital image processing/interpretation over visual interpretation is capturing the maximum amount of information (based on spectral and radiometric resolution) as the computer, having specific software, is capable of acquiring the same. The limitation of visual interpretation is based on the fact that our eyes can identify up to 20-22 colours within a colour composite image and up to 10 shades of grey tone within black-white image. Another advantage of digital images over traditional ones is the ability to transfer them electronically almost instantaneously and convert them easily from one medium to another such as from a web page to a computer screen to a printer. A bigger advantage is the ability to change them according to one's needs.

While processing the data digitally we need a lot of storage space and powerful computers to analyze the data from today`s remote sensing systems. The following example highlights the space required for digital image processing:

In today's world of advanced technology where most remote sensing data are recorded in digital format, virtually all image interpretation and analysis involve some element of digital processing. Digital image processing may involve numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer**.** A very promising use of digital images is automatic object recognition.

Digital image Processing is an extremely broad subject and involves procedures, which are mathematically complex. The procedure for digital image processing is categorized as the creation of false colour composite, preprocessing, image enhancement, image transformation, image classification, and Analysis

8.5 GLOSSARY

Calibration: The comparison of instrument performance to a standard of higher accuracy. The standard is considered the reference and the more correct measure.

CFA: Colour filter array - Digital image sensors used in scanners and digital cameras do not respond in a manner that differentiates colour. The sensors respond to the intensity of light: the pixel that receives greater intensity produces a stronger signal. A colour filter array (CFA) is a mosaic of colour filters (generally red, green and blue) that overlays the pixels comprising the sensor. The colour filters limit the intensity of light being recorded at the pixel to be associated with the wavelengths transmitted by that colour. A demosaicing algorithm is able to take the information about the spectral characteristics of each colour of a filter array, and the intensity of the signal at each pixel location to create a colour encoded digital image.

File format: Set of structural conventions that define a wrapper, formatted data, and embedded metadata, and that can be followed to represent images, audiovisual waveforms, texts, etc., in a digital object. The wrapper component on its own is often colloquially called a file format. The formatted data may consist of one or more encoded binary bit streams for such entities as images or waveforms.

Bit depth (image): The number of bits used to represent each pixel in an image. The term can be confusing since it is sometimes used to represent bits per pixel and at other times, the total number of bits used multiplied by the number of total channels. For example, a typical colour image using 8 bits per channel is often referred to as a 24-bit colour image (8 bits x 3 channels). Colour scanners and digital cameras typically produce 24 -bit (8 bits x 3 channels) images or 36-bit (12 bits x 3 channels) capture, and high-end devices can produce 48 -bit (16 -bit x 3 channels) images. A grayscale scanner would generally be 1 bit for monochrome or 8- bit for grayscale (producing 256 shades of gray). Bit depth is also referred to as colour

Brightness: The attribute of the visual sensation that describes the perceived intensity of light. Brightness is among the three attributes that specify colour. The other two attributes are hue and saturation.

8.6 ANSWER TO CHECK YOUR PROGRESS

1. Do you know Pixel is the smallest individual unit or dot that makes up a digital image on a screen or sensor?
2. In remote sensing, a digital number (DN) is a numerical value that represents the brightness or radiometric intensity of a pixel in a digital image, typically measured in binary or integer format.
3. Do you know in India, the National Remote Sensing Centre is responsible to acquire, process, and distributing remote sensing satellite data.
4. Do you know in remote sensing everything surrounding us, we see, is in its original colour composition is called True Colour Composite (TCC).
5. Do you know in remote sensing false Colour or false colour composite clearly means that objects are not in their original colour composition. Whenever any object will be shown in any colour rather than its actual colour, then this will be a false colour/false colour composite.

8.7 REFERENCES

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8.8 TERMINAL QUESTIONS

Long Questions

1. Define image and image processing.
2. What are the different image types and their formats?
3. Describe the digital image procurement procedure.
4. What are the guidelines and procedures for the procurement of digital images?
5. Why and how will you create the false colour composite (FCC)?

Short Questions

1. Define image.
2. Define digital image.
3. Define signal.
4. Define digital image processing.
5. Define types and formats of Images?
6. Define preliminary concepts for image processing.

Multiple Choice Questions

1) In which year first Landsat satellite was launched?

a) 1982
b) 1972
c) 1880
d) 1973

2) Landsat Satellite is owned by which country?

a) India
b) Canada
c) China
d) USA

3) What does BIP stand for in Digital Image Processing?

a) Bit Per Inch
b) Byte Per Inch
c) Band Interleaved by Pixel
d) None of Above

4) Which of the following is not image format?

a) TIFF
b) JPEG
c) GIF
d) TIN

5)What is full form of NRSC?

a) National Remote Sensing Centre
b) Nation Remote Sensing Centre
c) National Remote Sensing Cell
d) Norway Remote Sensing Centre

Answers) 1.b 2. d 3. C 4. D 5. a.

UNIT 9 - PREPROCESSING, IMAGE REGISTRATION & IMAGE ENHANCEMENT TECHNIQUES

9.1 OBJECTIVES

After reading this unit you will be able to understand:

- Preprocessing Techniques
- Image Registration
- Digital Image Enhancement Techniques

9.2 INTRODUCTION

In the previous unit, you learned about the basics of digital image processing and under its sub-heads, you got the concepts, definitions, needs, and scope of digital image, and digital image processing; types and formats of digital Image; procurement of digital Image; preliminary concepts for image processing and color composites. But that unit was related to the basics of digital image processing only. This unit includes the details of image processing with respect to preprocessing, digital image registration, and enhancement techniques.

Both visual onscreen/analogue (paper print) data and digital data of remotely sensed image methods of image processing/ interpretation have their own roles based on the objectives and available infrastructure, computer hardware, and software. It is also to be noted that many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images. The choice of specific techniques or algorithms to use depends on the goals of each individual project. In this section, we will examine some procedures commonly used in analyzing/interpreting remote sensing images.

The preprocessing of remote sensing data is a crucial step in the remote sensing analytical workflow and is often the most time-consuming and costly. Examples of preprocessing tasks include geometrically correcting imagery to improve positional accuracy, compressing imagery to save disk space, converting lidar point cloud data to raster models for speeding up rendering in GIS systems, and correcting for atmospheric effects to improve the spectral qualities of an image.

Prior to data analysis, initial processing of the raw data is usually carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Depending on the user's requirement, some standard correction procedures may be carried out by the ground station operators before the data is delivered to the end-user. These procedures include radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to Earth's rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if the accurate geographical location of an area on the image needs to be known, ground control points (GCPs) are used to register the image to a precise map (geo-referencing)

For registration of remote sensing images, the image processing tools provide support point mapping to determine the parameters of the transformation required to align an image with another image. In point mapping, you pick points in a pair of images that identify the same feature or landmark in the images. Then, a geometric mapping is inferred from the positions of these control points. There are many other methods of registration described in this unit. Those methods are based on certain tasks and objectives to be fulfilled.

Keeping in view of contents and sub-topics to be explained under this unit, the lecture note is aimed at the following objectives:

9.3 PREPROCESSING, IMAGE REGISTRATION & IMAGE ENHANCEMENT TECHNIQUES

DEFINITIONS:

Preprocessing - Preprocessing of digital image is the use of computer to download the digital data and make its fitness through computer algorithms to perform the detailed image processing. Preprocessing describes the methods used to prepare images for further analysis, including interest point and feature extraction.

Image Registration:

- Image registration is the process of transforming different sets of data into one coordinate system.
- Image registration is an image processing technique used to align multiple scenes into a single integrated image.
- Image registration is defined as a process that overlays two or more images from various imaging equipment or sensor taken at different times and angles or from the same scene to geometrically align the images for analysis (Zitova and Flusser, 2003)

Image Enhancement:

- Image enhancement refers to improve the appearance of the imagery to assist in visual interpretation and analysis.
- Image Enhancement involves techniques for increasing the visual distinction between features in a scene.
- The objective of image enhancement is to create new images from original data in order to increase the amount of information that can be visually interpreted from the data.

Preprocessing Techniques:

Intelligent use of image pre-processing can provide benefits and solve problems that ultimately lead to better local and global feature detection. Generally, the following steps are taken while preprocessing the digital data:

Reading Image:

The path is stored to an image dataset into a variable then a function is created to load folders containing images into arrays.

Resizing Image:

In this step, in order to visualize the change, we create two functions to display the images; the first being one to display one image and the second for two images. After that, a function is created called processing that just receives the images as a parameter. But why do we resize our image during the pre-processing phase? This is because of the fact that some images captured by camera/scanners and fed to our computer algorithm vary in size; therefore, we should establish a base size for all images fed into our AI (Artificial Intelligence in the computer) algorithm.

Removing Noise (Denoise):

Inside the function processing the code is added to smooth the image for removing unwanted noise. It is generally done by using Gaussian blur. Gaussian blur (also known as Gaussian smoothing) is the result of blurring an image by a Gaussian function. It is a widely used effect in graphics technique a smooth blur resembling that of viewing the image through a translucent screen, distinctly different from the bokeh effect produced by an out-of-focus lens or the shadow of an object under usual illumination. Gaussian smoothing is also used as a pre-processing stage in computer vision algorithms in order to enhance image structures at different scales.

Segmentation & Morphology:

Inside the function Processing the code segmentation and morphology are added. In this function, the image is segmented, separating the background from foreground objects and further improving segmentation with more noise removal.

Preprocessing functions involve those operations that are normally required prior to the main data analysis and extraction of information and are generally grouped **as** radiometric or geometric corrections. Radiometric corrections include correcting the data for sensor irregularities and unwanted sensor or atmospheric noise and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor.

Preprocessing also includes Image Rectification. These operations aim to correct distorted or degraded image data to create a faithful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortion, to calibrate the data radiometrically and to eliminate noise present in the data. Image rectification and restoration procedures are often termed pre-processing operations because they normally precede manipulation and analysis of image data. Geometric corrections include correcting for geometric distortions due to sensor-Earth geometry variations, and conversion of the data to real world coordinates (e.g., latitude and longitude) on the Earth's surface.

Image Registration:

Image registration is the process of aligning two or more images of the same scene. This process involves designating one image as the reference image, also called the fixed image, and applying geometric transformations or local displacements to the other images so that they align with the reference. Images can be misaligned for a variety of reasons. Commonly, images are captured under variable conditions that can change the camera perspective or the content of the scene. Misalignment can also result from lens and sensor distortions or differences between capture devices.

Image registration is often used as a preliminary step in image processing applications. For example, you can use image registration to align satellite images or medical images captured with different diagnostic modalities, such as MRI and SPECT. Image registration enables you to compare common features in different images. For example, you might discover how a river has migrated, how an area became flooded, or whether a tumor is visible in an MRI or SPECT image.

Image Processing Toolbox offers three image registration approaches: an interactive Registration Estimator app, intensity-based automatic image registration, and control point registration. Computer Vision Toolbox offers automated feature detection and matching.

Registration Estimator App:

Registration Estimator app enables you to register 2-D images interactively. You can compare different registration techniques, tune settings, and visualize the registered image. The app provides a quantitative measure of quality, and it returns the registered image and the transformation matrix. The app also generates code with your selected registration technique and settings, so you can apply an identical transformation to multiple images. Registration Estimator app offers six feature-based techniques, three intensity-based techniques, and one non-rigid registration technique.

Image registration can be classified into several categories based on the transformation model. Following are the different kinds of image registration algorithms categories used in the computer:

Intensity-based vs feature-based:

Image registration or image alignment algorithms can be classified into intensity-based and feature-based. One of the images is referred to as the moving or source and the others are referred to as the target, fixed, or sensed images. Image registration involves spatially transforming the source/moving image(s) to align with the target image. The reference frame in the target image is stationary, while the other datasets are transformed to match to the target.[3] Intensity-based methods compare intensity patterns in images via correlation metrics, while feature-based methods find correspondence between image features such as points, lines, and contours. Intensity-based methods register entire images or sub-images. If sub-images are registered, centers of corresponding sub-images are treated as corresponding feature points. Feature-based methods establish a correspondence between a number of especially distinct points in images. Knowing the correspondence between a number of points in images, a geometrical transformation is then determined to map the target image to the reference images, thereby establishing point-by-point correspondence between the reference and target images. Methods combining intensity-based and feature-based information have also been developed.

Transformation models:

Image registration algorithms can also be classified according to the transformation models they use to relate the target image space to the reference image space. The first broad category of transformation models includes linear transformations, which include rotation, scaling, translation, and other affine transforms. Linear transformations are global in nature, thus, they cannot model local geometric differences between images.

The second category of transformations allows 'elastic' or 'non-rigid' transformations. These transformations are capable of locally warping the target image to align with the reference image. Non-rigid transformations include radial basis functions (thin-plate or surface splines and compactly-supported transformations), physical continuum models (viscous fluids), and large deformation models.

Transformations are commonly described by parameterization, where the model dictates the number of parameters. For instance, the translation of a full image can be described by a single parameter, a translation vector. These models are called parametric models. Non-parametric models, on the other hand, do not follow any parameterization, allowing each image element to be displaced arbitrarily.

Transformations of coordinates:

Alternatively, many advanced methods for spatial normalization are building on structure-preserving transformations homeomorphisms, and diffeomorphisms since they carry smooth submanifolds smoothly during transformation. Diffeomorphisms are generated in the modern field of Computational Anatomy based on flows since diffeomorphisms are not additive although they form a group, but a group under the law of function composition. For this reason, flows that generalize the ideas of additive groups allow for generating large deformations that preserve topology, providing 1-1 and onto transformations. Computational methods for generating such transformation are often called LDDMM which provide flows of diffeomorphisms as the main computational tool for connecting coordinate systems corresponding to the geodesic flows of Computational Anatomy. There are a number of programs that generate diffeomorphic transformations of coordinates via diffeomorphic mapping including MRI Studio and MRI Cloud.org.

Spatial vs frequency domain methods:

Spatial methods operate in the image domain, matching intensity patterns or features in images. Some of the feature-matching algorithms are outgrowths of traditional techniques for performing manual image registration, in which an operator chooses corresponding control points (CP) in images. When the number of control points exceeds the minimum required to define the appropriate transformation model, iterative algorithms like RANSAC can be used to robustly estimate the parameters of a particular transformation type (e.g., affine) for registration of the images.

Frequency-domain methods find the transformation parameters for registration of the images while working in the transform domain. Such methods work for simple transformations, such as translation, rotation, and scaling. Applying the phase correlation method to a pair of images produces a third image that contains a single peak. The location of this peak corresponds to the relative translation between the images. Unlike many spatial-domain algorithms, the phase correlation method is resilient to noise, occlusions, and other defects typical of medical or satellite images. Additionally, the phase correlation uses the fast Fourier transform to compute the cross-correlation between the two images, generally resulting in large performance gains. The method can be extended to determine rotation and scaling differences between two images by first converting the images to log-polar coordinates.[13][14] Due to the properties of the Fourier transform, the rotation and scaling parameters can be determined in a manner invariant to translation.

Single- vs multi-modality methods:

Another classification can be made between single-modality and multi-modality methods. Single-modality methods tend to register images in the same modality acquired by the same scanner/sensor type, while multi-modality registration methods tended to register images acquired by different scanner/sensor types.

Multi-modality registration methods are often used in medical imaging as images of a subject are frequently obtained from different scanners. Examples include registration of brain CT/MRI images or whole body PET/CT images for tumor localization, registration of contrast-enhanced CT images against non-contrast-enhanced CT images for segmentation of specific parts of the anatomy, and registration of ultrasound and CT images for prostate localization in radiotherapy.

Automatic vs interactive methods:

Registration methods may be classified based on the level of automation they provide. Manual, interactive, semi-automatic, and automatic methods have been developed. Manual methods provide tools to align the images manually. Interactive methods reduce user bias by performing certain key operations automatically while still relying on the user to guide the registration. Semi-automatic methods perform more of the registration steps automatically but depend on the user to verify the correctness of a registration. Automatic methods do not allow any user interaction and perform all registration steps automatically.

Similarity measures for image registration:

Image similarities are broadly used in medical imaging. An image similarity measure quantifies the degree of similarity between intensity patterns in two images.[3] The choice of an image similarity measure depends on the modality of the images to be registered. Common examples of image similarity measures include cross-correlation, mutual information, sum of squared intensity differences, and ratio image uniformity. Mutual information and normalized mutual information are the most popular image similarity measures for the registration of multimodality images. Cross-correlation, sum of squared intensity differences and ratio image uniformity are commonly used for registration of images in the same modality.

Many new features have been derived for cost functions based on matching methods via large deformations that have emerged in the field of Computational Anatomy including measure matching which are point sets or landmarks without correspondence, Curve matching and Surface matching via mathematical currents and veri-folds.

Intensity-Based Automatic Image Registration:

Intensity-Based Automatic Image Registration maps pixels in each image based on relative intensity patterns. You can register both mono-modal and multimodal image pairs, and you can register 2-D and 3-D images. This approach is useful for:

- Registering a large collection of images
- Automated registration

To register images using an intensity-based technique, use image-register and specify the type of geometric transformation to apply to the moving image. Image-register iteratively adjusts the transformation to optimize the similarity of the two images. Alternatively, you can estimate a localized displacement field and apply a non-rigid transformation to the moving image.

Control Point Registration:

Control Point Registration enables you to select common features in each image manually. Control point registration is useful when:

- You want to prioritize the alignment of specific features, rather than the entire set of features detected using automated feature detection. For example, when registering two images, you can focus the alignment on desired anatomical features and disregard matched features that correspond to less informative anatomical structures.

- Images have repeated patterns that provide an unclear mapping using automated feature matching. For example, photographs of buildings with many windows, or aerial photographs of gridded city streets, have many similar features that are challenging to map automatically. In this case, manual selection of control point pairs can provide a clearer mapping of features, and thus a better transformation to align the feature points.

Control point registration can apply many types of transformations to the moving image. Global transformations, which act on the entire image uniformly, include affine, projective, and polynomial geometric transformations. Non-rigid transformations, which act on local regions, include piecewise linear and local weighted mean transformations. Use the Control Point Selection Tool to select control points. Start the tool with cp select. An illustration is given in Figure 1 for the control point registration of an image.

Control point selection procedure:

To specify control points in a pair of images interactively, use the Control Point Selection Tool, (as seen "cpselect" in the computer). The tool displays the image you want to register, called the moving *image*, next to the reference image, called the fixed image.

Specifying control points is a four-step process:

1. Start the tool, specifying the moving image and the fixed image.
2. Use navigation aids to explore the image, looking for visual elements that you can identify in both images. Cp select provides many ways to navigate around the image. You can pan and zoom to view areas of the image in more detail.
3. Specify matching control point pairs in the moving image and the fixed image.
4. Save the control points in the workspace.

Automated Feature Detection and Matching:

Automated Feature Detection and Extraction (Computer Vision Toolbox) detects features such as corners and blobs, matches corresponding features in the moving and fixed images, and estimates a geometric transform to align the matched features. For an example, see Find Image

Rotation and Scale Using Automated Feature Matching. You must have Computer Vision Toolbox to use this method.

Uncertainty:

There is a level of uncertainty associated with registering images that have any spatio-temporal differences. A confident registration with a measure of uncertainty is critical for many change detection applications such as medical diagnostics.

In remote sensing applications where a digital image pixel may represent several kilometers of spatial distance (such as NASA's LANDSAT imagery), an uncertain image registration can mean that a solution could be several kilometers from ground truth. Several notable papers have attempted to quantify uncertainty in image registration in order to compare results. However, many approaches to quantifying uncertainty or estimating deformations are computationally intensive or are only applicable to limited sets of spatial features.

Image Registration-Based Methods for Correcting Distortions:

Image registration aims to bring two images into the register (i.e. to align them). To do this one needs a transformation model (that specifies the allowed spatial transformations) and an interpolation model that allows calculation of what the image intensity "should have been" at locations between the original voxel centers. A very simple example would be a transformation model where we only allow an image to move (translate) in the *x*-direction. That model, together with some interpolation, allows us to specify a function $F=f(\Delta x;I)$ where I is the original image, Δx is the amount of *x*-translation and F is the image after it has been translated Δx mm. Let us now say we have two images I and J and we want to find out how much the "subject" moved between the two acquisitions. We can then use f to calculate $F=f(\Delta x;I)$ and compare F and J to see how "similar" they are. We do this for many different values of Δx until we find that which maximizes the "similarity" and that value of Δx is said to be the "true movement." As the transform is extended beyond a single translation, it rapidly becomes impractical to perform an exhaustive search of all possible parameter combinations and the task of finding the best parameters is a nonlinear optimization problem. (Press *et al.*, 1992).

Image Enhancement Techniques:

Enhancements are used to make it easier for visual interpretation and understanding of imagery. The advantage of digital imagery is that it allows us to manipulate the digital pixel values in an image. Although radiometric corrections for illumination, atmospheric influences, and sensor characteristics may be done prior to the distribution of data to the user, the image may still not be optimized for visual interpretation. Remote sensing devices, particularly those operated from satellite platforms, must be designed to cope with levels of target/background energy which are typical of all conditions likely to be encountered in routine use. With large variations in spectral response from a diverse range of targets (e.g., forests, deserts, snowfields, water, etc.) no generic radiometric correction could optimally account for and display the optimum brightness range and contrast for all targets. Thus, for each application and each image, a custom adjustment of the range and distribution of brightness values is usually necessary.

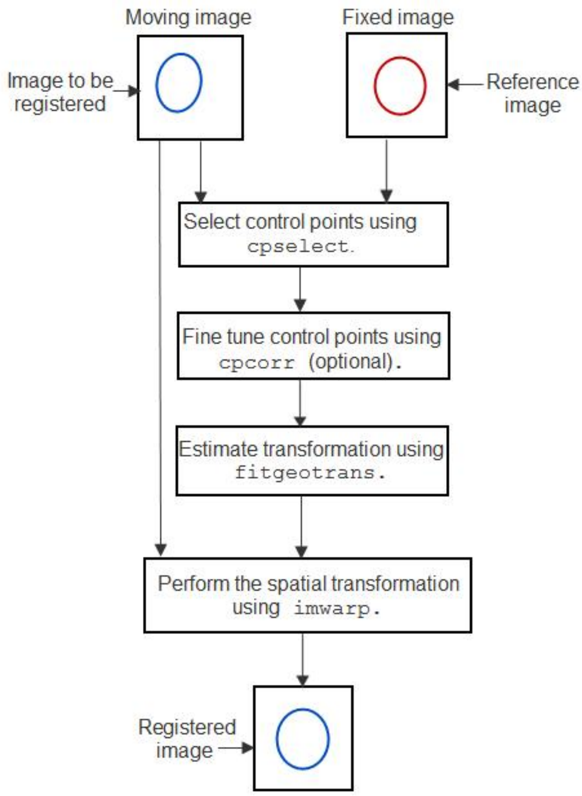

Figure 9.1: Graphic illustration for control point Registration of an image

In raw imagery, the useful data often 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, thereby increasing the contrast between targets and their backgrounds. As shown in figure 9.2, the original values are between 84 to 153 bits which are stretched to 0 to 255. By manipulating the range of digital values in an image, graphically represented by its histogram, we can apply various enhancements to the data. There are many different techniques

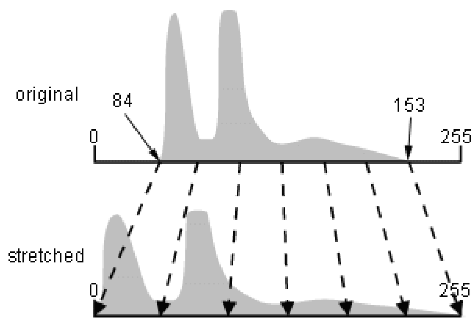

Fig. 9.2: Changing the original digital values between 84 to 153 to new changed as 0 to 255 to enhance the image.

and methods of enhancing contrast and detail in an image; we will cover only a few common ones here. The simplest type of enhancement is a 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. In our example, the minimum value (occupied by actual data) in the histogram is 84 and the maximum value is 153. These 70 levels occupy less than one-third of the full 256 levels available. A linear stretch uniformly expands this small range to cover the full range of values from 0 to 255. This enhances the contrast in the image with light-toned areas appearing lighter and dark areas appearing darker, making visual interpretation much easier. This graphic illustrates the increase in contrast in an image before (left) and after (right) a linear contrast stretch.

The objective of the second group of image processing functions grouped under the term image enhancement is solely to improve the appearance of the imagery to assist in visual interpretation and analysis. These procedures are applied to image data in order to effectively display the data for subsequent visual interpretation. It involves techniques for increasing the visual distinction between features in a scene. The objective is to create new images from the original data in order to increase the amount of information that can be visually interpreted from the data.

Image enhancement techniques improve the quality of an image as perceived by a human. These techniques are most useful because many satellite images when examined on a colour display give inadequate information for image interpretation. There is no conscious effort to improve the fidelity of the image with regard to some ideal form of the image. Image enhancement is attempted after the image is corrected for geometric and radiometric distortions. Image enhancement methods are applied separately to each band of a multi-spectral image. Digital techniques have been found to be more satisfactory than the photographic technique for image enhancement, because of the precision and wide variety of digital processes.

There exists a wide variety of techniques for improving image quality. The following are most commonly used image enhancement techniques:

- The contrast and contrast Enhancement (contrast stretch)
- Density slicing,
- Edge enhancement, and
- Spatial filtering

Contrast:

Contrast generally refers to the difference in luminance or grey level values in an image and is an important characteristic. It can be defined as the ratio of the maximum intensity to the minimum intensity over an image.

$$C = I_{max} / I_{min} \quad (1)$$

The contrast ratio has a strong bearing on the resolving power and detection ability of an image. The larger this ratio, more easier it is to interpret the Image.

Reasons for Low Contrast of Image Data:

Most of the satellite images lack adequate contrast and require contrast improvement. Low contrast may result from the following causes. The individual objects and background that make up the terrain may have a nearly uniform electromagnetic response at the wavelength band of energy that is recorded by the remote sensing system. In other words, the scene itself has a low contrast ratio. Images with a low contrast ratio are commonly referred to as -Washed out, with nearly uniform tones of grey.

Scattering of electromagnetic energy by the atmosphere can reduce the contrast of a scene. This effect is most pronounced in the shorter wavelength portions. The remote sensing system may lack sufficient sensitivity to detect and record the contrast of the terrain. Also, incorrect recording techniques can result in low contrast imagery although the scene has a high-contrast ratio.

Detectors on the satellite are designed to record a wide range of scene brightness values without getting saturated. They must encompass a range of brightness from black basalt outcrops to White Sea ice. However, only a few individual scenes have a brightness range that utilizes the full sensitivity range of remote sensor detectors. The limited range of brightness values in most scenes does not provide adequate contrast for detecting image features. Saturation may also occur when the sensitivity range of a detector is insufficient to record the full brightness range of a scene. In the case of saturation, the light and dark extremes of brightness on a scene appear as saturated white or black tones on the image.

Contrast Enhancement:

Contrast enhancement techniques expand the range of brightness values in an image so that the image can be efficiently displayed in a manner desired by the analyst (Figure 9.3). The density values in a scene are literally pulled farther apart, that is, expanded over a greater range. The effect is to increase the visual contrast between two areas of different uniform densities. This enables the analyst to discriminate easily between areas initially having a small difference in density. Contrast enhancement can be affected by a linear or non-linear transformation.

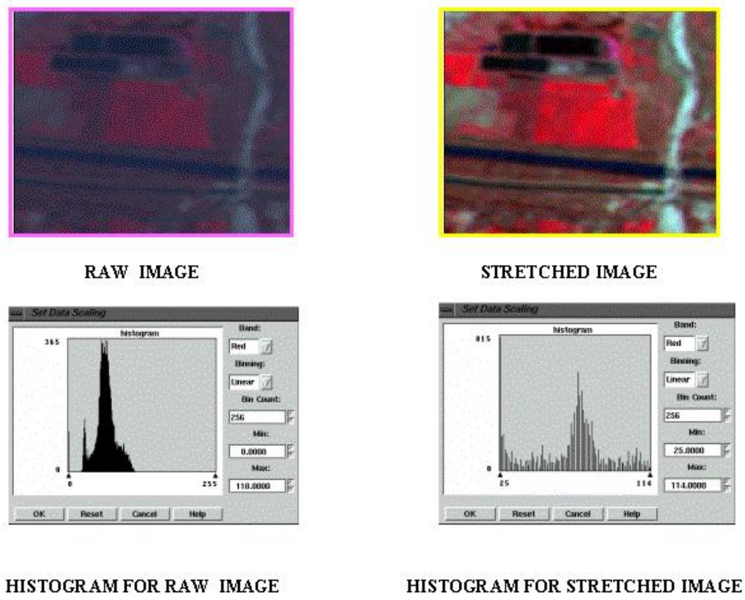

Figure 9.3: Contrast enhancement.

Linear Contrast Stretch:

The grey values in the original image and the modified image follow a linear relation in this algorithm. A density number in the low range of the original histogram is assigned to extremely black, and a value at the high end is assigned to extremely white. The remaining pixel values are distributed linearly between these extremes. The features or details that were obscure in the original image will be clear in the contrast stretched image (Figure 9.4).

In exchange for the greatly enhanced contrast of most original brightness values, there is a trade-off in the loss of contrast at the extreme high and low density number values. However, when compared to the overall contrast improvement, the contrast losses at the brightness extremes are acceptable trade-offs, unless one was specifically interested in these elements of the scene.

The equation y = ax+ b performs the linear transformation in a linear contrast stretch method. The values of 'a' and 'b' are computed from the equations.

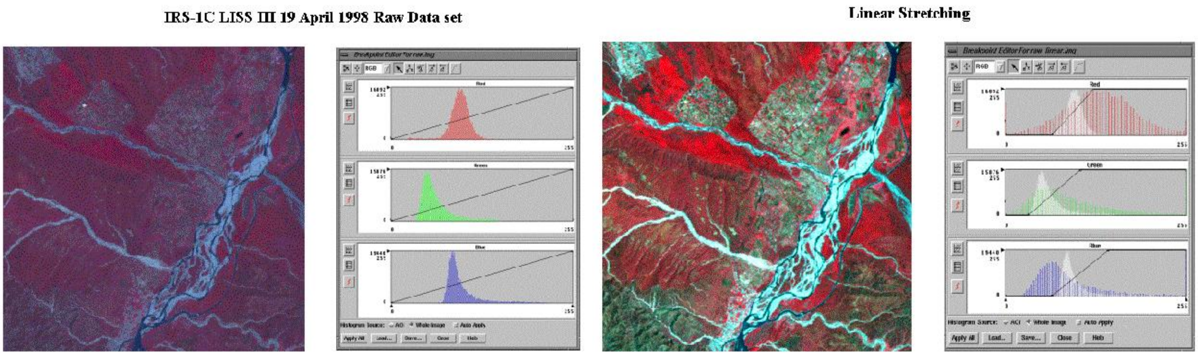

Figure 9.4: Linear enhancement.

Non-Linear Contrast Enhancement:

In these methods, the input and output data values follow a non-linear transformation. The general form of the non-linear contrast enhancement is defined by y = f (x), where x is the input data value and y is the output data value. The non-linear contrast enhancement techniques have been found to be useful for enhancing the colour contrast between the near classes and subclasses of a main class. The type of application restricts the use of non-linear contrast enhancement. Good judgment by the analyst and several iterations through the computer is usually required to produce the desired results. A type of non-linear contrast stretch involves scaling the input data logarithmically. This enhancement has the greatest impact on the brightness values found in the darker part of the histogram. It could be reversed to enhance values in the brighter part of the histogram by scaling the input data using an inverse log function.

Histogram Equalization:

This is another non-linear contrast enhancement technique. In this technique, the histogram of the original image is redistributed to produce a uniform population density. This is obtained by grouping certain adjacent grey values. Thus, the number of grey levels in the enhanced image is less than the number of grey levels in the original image. The redistribution of the histogram results in the greatest contrast being applied to the most populated range of brightness values in the original image. In this process the light and dark tails of the original histogram are compressed, thereby resulting in some loss of detail in those regions. This method gives a large improvement in image quality when the histogram is highly peaked (Figure 9.5).

Gaussian Stretch:

Most of the contrast enhancement algorithms result in loss of detail in the dark and light regions in the image. Gaussian stretch technique enhances the contrast in the tails of the histogram, at the expense of contrast in the middle grey range. When an analyst is interested in knowing the details of the dark and bright regions, he can apply the Gaussian stretch algorithm. This algorithm fits the original histogram to a normal distribution curve between the 0 and 255 limits (Figure 9.6).

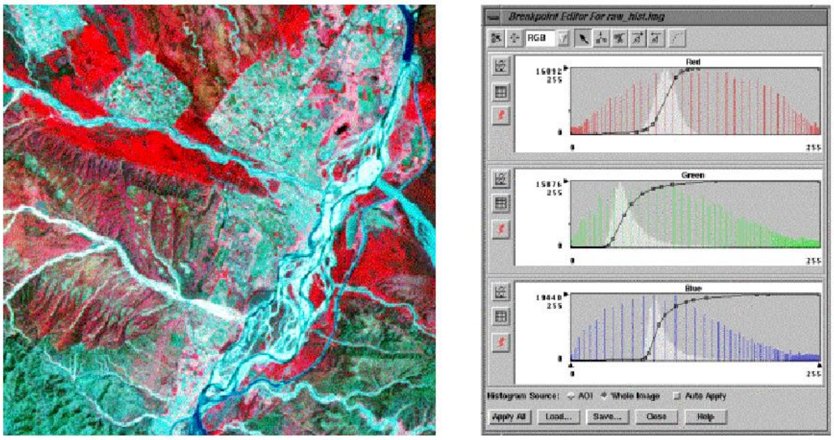

Fig. 9.5: Histogram equalization.

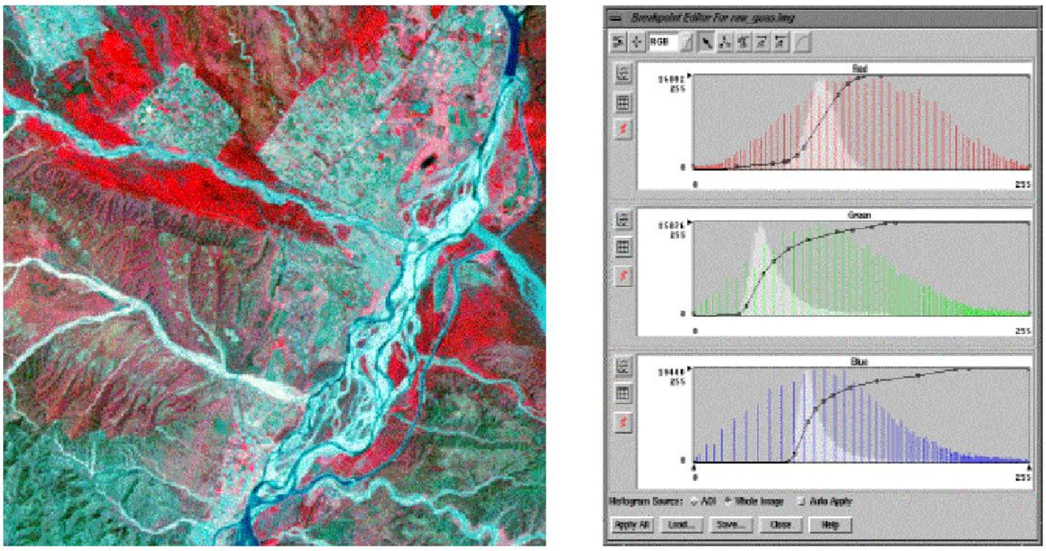

Fig. 9.6: Gaussian stretch.

Simple linear stretching would only increase contrast in the center of the distribution and would force the high and low peaks further toward saturation. With any type of contrast enhancement, the relative tone of different materials is modified. Simple linear stretching has the least effect on relative tones, and brightness differences can still be related to the differences in reflectivity. In other cases, the relative tone can no longer be meaningfully related to the reflectance of materials. An analyst must therefore be fully cognizant of the processing techniques that have been applied to the data.

Density Slicing:

Digital images have high radiometric resolution. Images in some wavelength bands contain 256 distinct grey levels. But a human interpreter can reliably detect and consistently differentiate between 15 and 25 shades of grey only. However, the human eye is more sensitive to colour than the different shades between black and white. Density slicing is a technique that converts the continuous grey tone of an image into a series of density intervals, or slices, each corresponding to a specified digital range. Each slice is displayed in a separate colour, line printer symbol or bounded by contour lines. This technique is applied on each band separately and emphasizes subtle grey scale differences that are imperceptible to the viewer.

Image transformations:

Image transformations are operations similar in concept to those for image enhancement. However, unlike image enhancement operations which are normally applied only to a single channel of data at a time, image transformations usually involve combined processing of data from multiple spectral bands. Arithmetic operations (i.e., subtraction, addition, multiplication, division) are performed to combine and transform the original bands into "new" images that better display or highlight certain features in the scene. You will study in the next chapter for many of these operations including various methods of spectral or band ratioing, and a procedure called principal components analysis which is used to more efficiently represent the information in multichannel imagery.

9.4 SUMMARY

As a subfield of digital signal processing, digital image processing has many advantages over analogue image processing. It allows a much wider range of algorithms to be applied to the input data—the aim of digital image processing is to improve the image data (features) by suppressing unwanted distortions and/or enhancement of some important image features so that our AI-Computer Vision models can benefit from this improved data to work on.

Digital image processing of raw data needs preprocessing to correct for any distortion due to the characteristics of the imaging system and imaging conditions. These procedures include radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to Earth's rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if the accurate geographical location of an area on the image needs to be known, ground control points (GCP's) are used to register the image to a precise map (geo-referencing)

Remote sensing images require image processing tools to register different images and their alignment. The tools provide support point mapping to determine the parameters of the transformation required to bring an image into alignment with another image. In point mapping points are picked up in a pair of images that identify the same feature or landmark in the images. A geometric mapping is inferred from the positions of these control points. The image registration categories described in this unit include **i**) Intensity-based vs feature-based ii) Transformation models iii)Transformations of coordinates iv) Spatial vs frequency domain methods v) Single- vs multi-modality methods vi) Automatic vs interactive methods vii) Similarity measures for image registration viii) Intensity-Based Automatic Image Registration ix) Control Point Registration and x) Automated Feature Detection and Matching.

Image enhancement techniques are most useful because many satellite images when examined on a colour display give inadequate information for image interpretation. There is no conscious effort to improve the fidelity of the image with regard to some ideal form of the image. Image enhancement is attempted after the image is corrected for geometric and radiometric distortions. Image enhancement methods are applied separately to each band of a multi-spectral image.

There exists a wide variety of techniques for improving image quality. The most commonly used image enhancement techniques are i) contrast and contrast Enhancement (contrast stretch) ii) Density slicing iii) Edge enhancement and iv) Spatial filtering.

9.5 GLOSSARY

AI-Computer Vision: Models When the number of control points exceeds the minimum required to define the appropriate transformation model, iterative algorithms like RANSAC can be used to robustly estimate the parameters of a particular transformation type (e.g. affine) for registration of the images.

LANDSAT: This term was used for Earth Resources Technology Satellite (ERTS) by NASA (National Aeronautics and Space Administration), USA.

9.6ANSWER TO CHECK YOUR PROGRESS

1) Do you know Image registration is a crucial process that involves aligning and overlaying different images of the same geographic area taken at different times, from different sensors, or at different spatial resolutions?
2) Pan sharpening is a remote sensing technique that combines a high-resolution panchromatic image with lower-resolution multispectral images to create a high-resolution color image with both spatial and spectral information.
3) Do you know density slicing is a technique used in image processing to enhance specific features or objects within an image by highlighting a particular range of pixel values or densities?
4) Do you know denoising is the process of removing unwanted noise or artifacts from images to improve data quality and clarity?
5) Georeferencing is the process of assigning real-world geographic coordinates (latitude and longitude) to each pixel in an image, allowing it to be accurately placed on Earth's surface.

9.7 REFERENCES

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9.8 TERMINAL QUESTIONS

Long Questions

1) Define the pre-processing technique and explain the steps taken under this technique.

2) What is image registration? Describe Intensity-based vs feature-based image registration.

3) Differentiate spatial vs frequency domain and single- vs multi-modality methods of image registration.

4) Describe control point image registration.

5) List out the digital image enhancement techniques and draw a Graphical illustration for control point registration of an image.

6) What are the steps to improve digital image quality? Explain each of them.

Short Questions

1) Explain Preprocessing techniques, image registration, and digital image enhancement Techniques.

   Explain Different methods of Image enhancement.

2) Explain Histogram Equalization.

3) Define Gaussian Stretch.

4) What do you mean by image registration? Explain it

Multiple Choice Questions

1) What is the full form of GIS?

a) Geography Information System
b) Geographic Information System
c) Geology Information System
d) Globe Information System

2) What does AI stand for in Computers?

a) Artificial Intelligent
b) Animated Image
c) Animated Image
d) Animated Image

3) Which of the following is/are Image Enhancement Techniques?

a) Histogram Equalization
b) Linear Contrast Stretch
c) Contrast Enhancement
d) All of the above

4) What is the full form of NASA?

a) National Aeronautics and Space Administration.
b) National Advance and Space Administration
c) Nation Aeronautics and Space Administration
d) National Aeronautics and Spaceship Administration

5) **Which image enhancement technique involves dividing an image into different density ranges to highlight specific features?**

   a) Histogram Equalization

   b) Edge Enhancement

   c) Density Slicing

   d) Spatial Filtering

Answers) 1.b 2. a 3. d 4. a 5. C.

UNIT 10 - SPATIAL FILTERING TECHNIQUES AND IMAGE TRANSFORMATION

10.1 OBJECTIVES

The role of this chapter is to present spatial filtering and image transformation techniques of value in the enhancement of remote sensing imagery. The spatial and frequency filtering techniques are explained with respect to their types, methods, and characteristics. The image transformation techniques specifically include the principal components transformation, creation of ratio images, and the specialized transformation, such as the Kauth-Thomas tasseled cap transform.

After reading this unit, the learner will be able to understand:

- Characteristics of filter, spatial filters.
- Types and uses of spatial filtering.
- Image transformation types, characteristics, and uses.

10.2 INTRODUCTION

In the previous unit, you have learned about preprocessing, image registration, and image enhancement techniques. This unit is also in the continuation of image enhancement under different filtering techniques and image transformation. The Filter tool can be used to either eliminate spurious data or enhance features otherwise not visibly apparent in the data. Filters essentially create output values by a moving, overlapping 3x3 cell neighborhood window that scans through the input raster. As the filter passes over each input cell, the value of that cell and its 8 immediate neighbors are used to calculate the output value.The spatial filtering technique increases the analyst's ability to discriminate detail.

An image 'enhancement' is basically anything that makes it easier or better to visually interpret an image. In some cases, like 'low-pass filtering', the enhanced image can actually look worse than the original, but such an enhancement was likely performed to help the interpreter see low spatial frequency features among the usual high-frequency clutter found in an image. Also, an enhancement is performed for a specific application. This enhancement may be inappropriate for another purpose, which would demand a different type of enhancement.

Spatial filtering encompasses another set of digital processing functions which are used to enhance the appearance of an image. Spatial filters are designed to highlight or suppress specific features in an image based on their spatial frequency. Spatial frequency is related to the concept of image texture which refers to the frequency of the variations in tone that appear in an image. "Rough" textured areas of an image, where the changes in tone are abrupt over a small area, have high spatial frequencies, while "smooth" areas with little variation in tone over several pixels, have low spatial frequencies.

Spatial filtering includes edge enhancement techniques for sharpening the edges of different feature/cover types seen on remote sensing digital data. Here the filter works by identifying sharp edge boundaries in the image, such as the edge between a subject and a background of a contrasting color. This has the effect of creating bright and dark highlights on either side of any edges in the image, called overshoot and undershoot, leading the edge to look more defined when viewed.

Two-dimensional image transforms are extremely important areas of study in image processing. The image output in the transformed space may be analyzed, interpreted, and further processed for implementing diverse image processing tasks. These transformations are widely used, since by using these transformations, it is possible to express an image as a combination of a set of basic signals, known as the basis functions.

The multispectral or vector character of most remote sensing image data renders it amenable to spectral transformations that generate new sets of image components or bands. These components then represent an alternative description of the data, in which the new components of a pixel vector are related to its old brightness values in the original set of spectral bands via a linear operation. The transformed image may make evident features not discernable in the original data or alternatively, it might be possible to preserve the essential information content of the image (for a given application) with a reduced number of the transformed dimensions. The last point has significance for displaying data in the three dimensions available on a colour monitor or colour hardcopy and for transmission and storage of data.

10.3 SPATIAL FILTERING TECHNIQUES & IMAGE TRANSFORMATION

Definitions

Filter

- In general terms, a filter is a porous article or mass through which a gas or liquid is passed to separate out matter in suspension.
- A colour filter is a transparent material (such as colored glass) that absorbs light of certain wavelengths or colors selectively and is used for modifying light that reaches a sensitized photographic material.
- We may also define a filter as software for sorting or blocking access to certain online material.
- In image processing filters are mainly used to suppress either the high frequencies in the image, *i.e.,* smoothing the image, or the low frequencies, *i.e.,* enhancing or detecting edges in the image.

Filtering

- Filtering is a technique for modifying or enhancing an image.
- Filtering is a neighborhood operation, in which the value of any given pixel in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel.

Spatial Filtering

- Spatial filtering is the process of dividing the image into its constituent spatial frequencies, and selectively altering certain spatial frequencies to emphasize some image features.

Linear Filtering

- Linear filtering is filtering in which the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighborhood.

Convolution

- Linear filtering of an image is accomplished through an operation called *convolution*.
- Convolution is a neighborhood operation in which each output pixel is the weighted sum of neighboring input pixels.

Edge Enhancement

- Edge Enhancement is an image processing filter that enhances the edge contrast of an image or video in an attempt to improve its acutance (apparent sharpness). The Edge Enhancement feature is much like the "Sharpness"

Image Transformation

- Image transformation is a function or operator that takes an image as its input and produces an image as its output.
- Image transformations typically involve the manipulation of multiple bands of data, whether from a single multispectral image or from two or more images of the same area acquired at different times (i.e., multitemporal image data).
- Image transformations generate "new" images from two or more sources that highlight particular features or properties of interest, better than the original input images.

Characteristics of Filter and Spatial Filters

A common filtering procedure involves moving a 'window' of a few pixels in dimension (e.g., 3x3, 5x5, etc.) over each pixel in the image (Fig 10.1), applying a mathematical calculation using the pixel values under that window, and replacing the central pixel with the new value. The window is moved along in both the row and column dimensions one pixel at a time and the calculation is repeated until the entire image has been filtered and a "new" image has been generated. By varying the calculation performed and the weightings of the individual pixels in the filter window, filters can be designed to enhance or suppress different types of features. An image can be filtered either in the frequency or in the spatial domain.

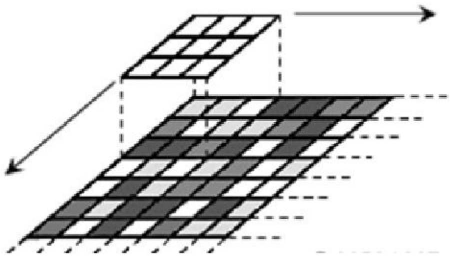


Fig. 10.1: Filtering by 3 x 3 pixels window.

Filtering in Frequency Domain

Filtering in the Frequency Domain involves transforming the image into the frequency domain, multiplying it with the frequency filter function, and re-transforming the result into the spatial domain. The filter function is shaped to attenuate some frequencies and enhance others. For example, a simple lowpass function represents frequencies smaller than the cut-off frequency and *0* for all others. The corresponding process in the spatial domain is to convolve the input image $f(i,j)$ with the filter function $h(i,j)$. This can be written as

$$g(i,j) = h(i,j) \odot f(i,j)$$

The mathematical operation is identical to the multiplication in the frequency space, but the results of the digital implementations vary since we have to approximate the filter function with a discrete and finite kernel. The discrete convolution can be defined as *a* `shift and multiply' operation, where we shift the kernel over the image and multiply its value with the corresponding pixel values of the image. For a square kernel with size $M \times M$, we can calculate the output image with the following formula:

$$g(i,j) = \sum_{m=-\frac{M}{2}}^{\frac{M}{2}} \sum_{n-=\frac{M}{2}}^{\frac{M}{2}} h(m,n)\, f(i-m, j-n)$$

Various standard kernels exist for specific applications, where the size and the form of the kernel determine the characteristics of the operation. The most important of them are discussed in this chapter. The kernels for two examples, the mean and the Laplacian operator, can be seen in Figure 10.2.

$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

Mean

0	-1	0
-1	4	-1
0	-1	0

Laplacian

Fig. 10.2: Convolution kernel for a mean filter and one form of the discrete Laplacian.

In contrast to the frequency domain, it is possible to implement non-linear filters in the spatial domain. In this case, the summations in the convolution function are replaced with some kind of non-linear operator:

$$g(i,j) = O_{m,n}[h(m,n)\ f(i-m,j-n)]$$

For most non-linear filters the elements of *h* (*i,j*) are all 1. A commonly used non-linear operator is the median, which returns the `middle' of the input values.

Filtering in the Spatial Domain

An image is filtered to emphasize certain features or remove other features. Image processing operations implemented with filtering include smoothing, sharpening, and edge enhancement. Filtering in the Spatial Domain refers to a neighborhood operation, in which the value of any given pixel in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel. A pixel's neighborhood is some set of pixels, defined by their locations relative to that pixel.

Spatial filters generally serve two purposes when applied to remotely sensed data: i) enhance imagery or ii) restore imagery. When it comes to enhancing imagery, spatial filters can help uncover patterns and processes. Spatial filters are useful for both manual image interpretation and automated feature extraction. Spatial filters can also help to restore imagery that has either gaps or artifacts.

A characteristic of remotely sensed images is a parameter called spatial frequency defined as a number of changes in Brighter Value per unit distance for any particular part of an image. If there are very few changes in Brighter Value once given areas in an image, this is referred to as a low-frequency area. Conversely, if the Brighter Value changes dramatically over short distances, this is an area of high frequency.

In Arc GIS Pro the most efficient way to apply spatial filters is to use the Raster Analysis Function - Convolution. From the Analysis menu i) select Raster Functions. ii) Choose the Convolution Raster Function. Within the Raster Functions pane iii) select the input raster iv) specify the type, and optionally v) modify the kernel. When you finish adjusting the parameters vi) click on Create a new layer.

Spatial Convolution Filtering

A linear spatial filter is a filter for which the brightness value (BV i. j) at location i, j in the output image is a function of some weighted average (linear combination) of brightness values located in a particular spatial pattern around the i, j location in the input image. This process of evaluating the weighted neighboring pixel values is called two-dimensional convolution filtering. The procedure is often used for the spatial frequency characteristics of an image. For example, a linear spatial filter that emphasizes high spatial frequencies may sharpen the edges within an image. A linear spatial filter that emphasizes low spatial frequencies may be used to reduce noise within an image.

Linear Filtering and Convolution

Linear filtering of an image is accomplished through an operation called *convolution*. Convolution is a neighborhood operation in which each output pixel is the weighted sum of neighboring input pixels. The matrix of weights is called the *convolution kernel*, also known as the *filter*. A convolution kernel is a correlation kernel that has been rotated 180 degrees.

For example, suppose the image is-

$$A = [17\ 24\ 1\ 8\ 15 \\ 23\ 5\ 7\ 14\ 16 \\ 4\ 6\ 13\ 20\ 22 \\ 10\ 12\ 19\ 21\ 3 \\ 11\ 18\ 25\ 2\ 9]$$

Fig. 10.3: Digital values (numbers) of an image being filtered.

and the correlation kernel is- h = [8 1 6

3 5 7

4 9 2]

You would use the following steps to compute the output pixel at position (2, 4):

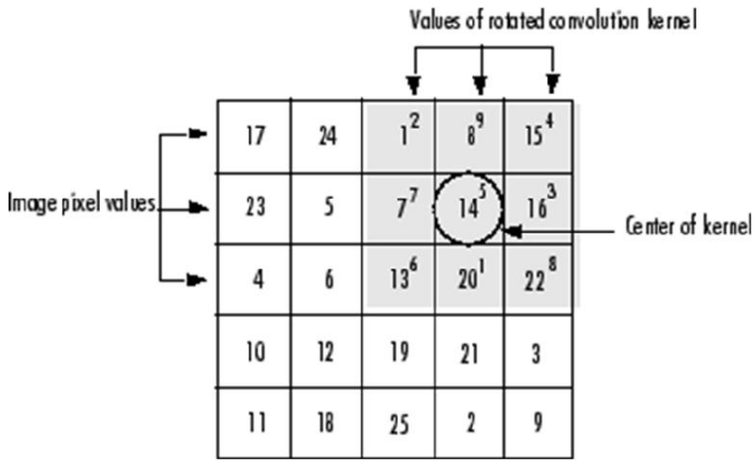
1. Rotate the correlation kernel 180 degrees about its center element to create a convolution kernel.
2. Slide the center element of the convolution kernel so that it lies on top of the (2,4) element of A.
3. Multiply each weight in the rotated convolution kernel by the pixel of A underneath.
4. Sum the individual products from step 3.

Hence the (2,4) output pixel is

$$1 \cdot 2 + 8 \cdot 9 + 15 \cdot 4 + 7 \cdot 7 + 14 \cdot 5 + 16 \cdot 3 + 13 \cdot 6 + 20 \cdot 1 + 22 \cdot 8 = 575$$

… shown in the following figure.

Computing the (2, 4) Output of Convolution



High Frequency Filtering in Spatial Domain

High-pass filtering is applied to imagery to remove the slowly varying components and enhance the high-frequency local variations. One high-frequency filter {HFF_5.out} is computed by subtracting the output of the low-frequency filter {LFF $_5$out} from twice the value of the original central pixel value, BV_5:

HFF_5 out = (2xBV_5} -(LFF_5.out}

Brightness values tend to be highly correlated in a nine-element window. Thus, the high-frequency filtered image will have a relatively narrow intensity histogram. This suggests that the output from most high-frequency filtered images must be contrast stretched before visual analysis.

Correlation

The operation called *correlation* is closely related to convolution. In correlation, the value of an output pixel is also computed as a weighted sum of neighboring pixels. The difference is that the matrix of weights, in this case called the *correlation kernel*, is not rotated during the computation. The Image Processing Toolbox filter design functions return correlation kernels.

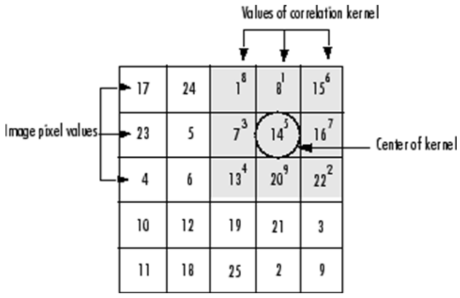
The following figure shows how to compute the output pixel of the correlation of A, assuming h is a correlation kernel instead of a convolution kernel, using these steps:

1. Slide the center element of the correlation kernel so that lies on top of the (2, 4) element of A.
2. Multiply each weight in the correlation kernel by the pixel of A underneath.
3. Sum the individual products.

The (2, 4) output pixel from the correlation is

$$1 \cdot 8 + 8 \cdot 1 + 15 \cdot 6 + 7 \cdot 3 + 14 \cdot 5 + 16 \cdot 7 + 13 \cdot 4 + 20 \cdot 9 + 22 \cdot 2 = 585$$

Computing the (2, 4) Output of Correlation



Types and Uses of Spatial Filtering

The three types of spatial filters used in remotely sensed data processing are Low-pass filters, Bandpass filters, and High-pass filters.

Low Pass Filter

The filter type LOW employs a low pass or averaging, filter over the input raster and essentially smoothens the data. A low pass filter smoothes the data by reducing local variation and removing noise. It calculates the average (mean) value for each 3 x 3 neighborhood. It is essentially equivalent to the Focal Statistics tool with the Mean statistic option. The effect is that the high and low values within each neighborhood will be averaged out, reducing the extreme values in the data. Following is an example of the input neighborhood values for one processing cell, the center cell with the value 8.

7	5	2
4	8	3
3	1	5

The calculation for the processing cell (the center input cell with the value 8) is to find the average of the input cells. This is the sum of all the values in the input contained by the neighborhood, divided by the number of cells in the neighborhood (3 x 3 = 9).

Value = ((7 + 5 + 2) + (4 + 8 + 3) + (3 + 1 + 5)) / 9 = 38 / 9 = 4.222

The output value for the processing cell location will be 4.22.

Since the mean is calculated from all the input values, the highest value in the list, which is the value 8 of the processing cell, is averaged out. In the following example, the input raster has an anomalous data point caused by a data collection error. The averaging characteristics of the LOW option have smoothed the anomalous data point.

Fig. 10.4: Example of Filter output with LOW option filter.

A low-pass filter is designed to emphasize larger, homogeneous areas of similar tone and reduce the smaller detail in an image. Thus, low-pass filters generally serve to smooth the appearance of an image. Average and median filters, often used for radar imagery (and described in Chapter 3), are examples of low-pass filters. High-pass filters do the opposite and serve to sharpen the appearance of fine detail in an image. One implementation of a high-pass filter first applies a low-pass filter to an image and then subtracts the result from the original, leaving behind only the high spatial frequency information. Directional, or edge detection filters are designed to highlight linear features, such as roads or field boundaries. These filters can also be designed to enhance features which are oriented in specific directions. These filters are useful in applications such as geology, for the detection of linear geologic structures.

High Pass Filter

The high pass filter accentuates the comparative difference between a cell's values and its neighbors. It has the effect of highlighting boundaries between features (for example, where a water body meets the forest), thus sharpening edges between objects. It is generally referred to as an edge-enhancement filter. With the HIGH option, the nine-input z-values are weighted in such a way that removes low frequency variations and highlights the boundary between different regions.

The 3 x 3 filter for the HIGH option is:

-0.7	-1.0	-0.7
-1.0	6.8	-1.0
-0.7	-1.0	-0.7

Note that the values in the kernel sum to 0, since they are normalized. The High Pass filter is essentially equivalent to using the Focal Statistics tool with the Sum statistic option, and a specific weighted kernel.

The output z-values are an indication of the smoothness of the surface, but they have no relation to the original z-values. Z-values are distributed about zero with positive values on the upper side of an edge and negative values on the lower side. Areas, where the z-values are close to zero, are regions with nearly constant slope. Areas with values near z-min and z-max are regions where the slope is changing rapidly.

Following is a simple example of the calculations for one processing cell (the center cell with the value 8):

7	5	2
4	8	3
3	1	5

The calculation for the processing cell (the center cell with the value 8) is as follows:

Value = ((7*-0.7) + (5*-1.0) + (2*-0.7) + (4*-1.0) + (8*6.8) + (3*-1.0) + (3*-0.7) + (1*-1.0) + (5*-0.7)) = ((-4.9 + -5.0 + -1.4) + (-4.0 + 54.4 + -3.0) + (-2.1 + -1.0 + -3.5) = -11.3 + 47.4 + -6.6 = 29.5

The output value for the processing cell will be 29.5.

By giving negative weights to its neighbors, the filter accentuates the local detail by pulling out the differences or the boundaries between objects.

In the example below, the input raster has a sharp edge along the region where the values change from 5.0 to 9.0. The edge enhancement characteristic of the HIGH option has detected the edge.

5.0	5.0	5.0	9.0	9.0	9.0
5.0	5.0	5.0	9.0	9.0	9.0
5.0	5.0	5.0	9.0	9.0	9.0
5.0	5.0	5.0	5.0	5.0	5.0
5.0	5.0	5.0	5.0	5.0	5.0
5.0	5.0	5.0	5.0	5.0	5.0

Input with edge where cell values change from 5.0 to 9.0

0.0	0.0	-9.6	9.6	0.0	0.0
0.0	0.0	-9.6	9.6	0.0	0.0
0.0	0.0	-6.8	16.4	9.6	9.6
0.0	0.0	-2.8	-6.8	-9.6	-9.6
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

The HIGH option has detected the edge.

Note that the output values have no relation to the input values.

Fig. 10.5: Example of Filter output with HIGH option filter (Edge Enhancement).

Processing cells of No Data

The Ignore NoData in calculations option controls how NoData cells within the neighborhood window are handled. When this option is checked (the DATA option), any cells in the neighborhood that are NoData will be ignored in the calculation of the output cell value. When unchecked (the NODATA option), if any cell in the neighborhood is NoData, the output cell will be NoData.

If the processing cell itself is NoData, with the Ignore NoData option selected, the output value for the cell will be calculated based on the other cells in the neighborhood that have a valid value. Of course, if all of the cells in the neighborhood are NoData, the output will be NoData, regardless of the setting for this parameter.

Edge Enhancement Filters

Edge enhancement filters, enhance the local discontinuities at the boundaries of different objects (edges) in the image. An edge in a signal is normally defined as the transition in the intensity or amplitude of that signal. Most of the edge enhancement filters are thus based on first and second-order derivatives and different gradient filters are also common to use.

The edge enhancement filters are divided into the following groups:

- Gradient
- Laplacian

Gradient edge enhancement

The gradient of an image I (x,y) is defined along two orthogonal directions. This operator is approximated in the discrete case. The output of such filters consists of positive and negative intensities and emphasizes the high-frequency details of the image. When the sensitivity for noise is too high larger kernels should be considered to approximate the derivative operators.

Roberts edge enhancement kernel:

This kernel focuses on the diagonal pixel differentials, which emphasize corners more clearly but can blur together small horizontal or vertical features.

Sobel edge enhancement kernel

Provides a more uniform edge enhancement, although it still gives increased weight to the orthogonal pixels over the diagonal pixels.

Pixel Difference

The Pixel difference edge enhancement filter is very similar to the Roberts edge enhancement filter and the output will be alike, but in opposite directions. For many remote sensing Earth science applications, the most valuable information that may be derived from an image is contained in the edges surrounding various objects of interest. Edge enhancement delineates these edges and makes the shapes and details comprising the image more conspicuous and perhaps easier to analyze. Generally, what the eyes see as pictorial edges are simply sharp changes in brightness value between two adjacent pixels. The edges may be enhanced using either linear or nonlinear edge enhancement techniques.

Laplacian Filter

The Laplacian is a 2-D isotropic measure of the 2nd spatial derivative of an image. The Laplacian of an image highlights regions of rapid intensity change and is therefore often used for edge detection. The Laplacian is often applied to an image that has first been smoothed with something approximating a Gaussian smoothing filter in order to reduce its sensitivity to noise, and hence the two variants will be described together here. The operator normally takes a single gray level image as input and produces another gray level image as output.

How It Works

The Laplacian *L(x,y)* of an image with pixel intensity values *I(x,y)* is given by:

$$L(x,y) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}$$

This can be calculated using a convolution filter.

Since the input image is represented as a set of discrete pixels, we have to find a discrete convolution kernel that can approximate the second derivatives in the definition of the Laplacian. Two commonly used small kernels are shown in Figure 1.

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

Fig. 10.6: Two commonly used discrete approximations to the Laplacian filter. (Note, we have defined the Laplacian using a negative peak because this is more common; however, it is equally valid to use the opposite sign convention).

Linear Edge Enhancement

A straightforward, method of extracting edges in remotely sensed imagery is the application of a directional first-difference algorithm and approximates the first derivative between two adjacent pixels. The algorithm produces the first difference of the image input in the horizontal, vertical, and diagonal directions. The algorithms for enhancing horizontal, vertical, and diagonal edges are respectively are shown in Table 10.1.

Table 10.1 Algorithms for enhancing horizontal, vertical, and diagonal edges.

Vertical	BViJ = BViJ -BViJ+l + K (7-16)
Horizontal	BViJ = BViJ -BVi-1J + K (7 -17)
NE Diagonal	BViJ = BViJ -BVi+1J+l +K (7-18)
SE Diagonal	BViJ = BViJ -BVi-1J+l'+K (7-19)

Non-linear Edge Enhancement

Nonlinear edge enhancements are performed using nonlinear combinations of pixels. Many algorithms are applied using either 2x2 or 3x3 kernels. The Sobel edge detector is based on the notation of the 3x3 window previously described and is computed according to the relationship:

$Sobek1_{5.out} = -.\sqrt{X^2 + y^2}$

where

$X = (BV_3 = 2BV_6 + BV_9) - (BV_1 + 2BV_4 + BV_7)$

and$Y = (BV_1 = 2BV_2 + BV_3) - (BV_7 + 2BV_8 + BV_9)$

The Sobel operator may also be computed by simultaneously applying the following 3x3 templates across the image.

$$X = \begin{matrix} -1 & 0 & 1 \\ 1 & 2 & 1 \\ -2 & 0 & 2 \end{matrix}, \quad y = \begin{matrix} 0 & 0 & 0 \\ -1 & 0 & 1 \\ -1 & -2 & -1 \end{matrix}$$

Likewise, there are Robert's edge detector Kirsch non-linear edge enhancement techniques.

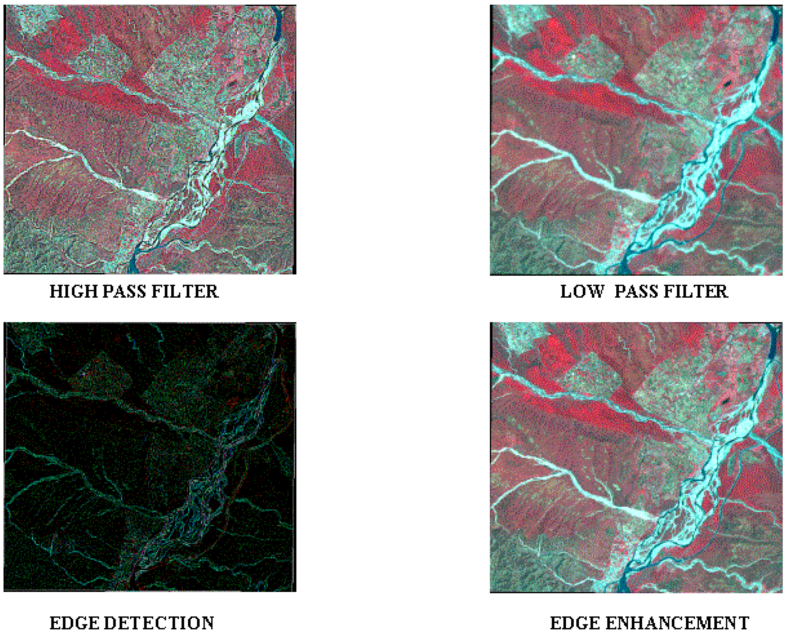


Fig. 10.7: Filtering of images.

Image Transformation Types, Characteristics and Uses

In image transformation, depending on the transform chosen, the input and output images may appear entirely different and have different interpretations. Fourier transforms, principal component analysis (also called Karhunen- Loeve analysis), and various spatial filters, are examples of frequently used image transformation procedures. In Image Transformation [*image*,*f*], the value of every pixel at position $\{x, y\}$ in the output image is obtained from the position $f[\{x, y\}]$ in the input *image*. This is known as a backward transformation.

Image Subtraction

Basic image transformations apply simple arithmetic operations to the image data. Image subtraction is often used to identify changes that have occurred between images collected on different dates. Typically, two images that have been geometrically registered are used with the pixel (brightness) values in one image (1) being subtracted from the pixel values in the other (2). Scaling the resultant image (3) by adding a constant (127 in this case) to the output values will result in a suitable 'difference' image. In such an image, areas where there has been little or no change (A) between the original images, will have resultant brightness values around 127 (midgrey tones), while those areas where significant change has occurred (B) will have values higher or lower than 127 - brighter or darker depending on the 'direction' of change in reflectance between the two images. This type of image transformation can be useful for mapping changes in urban development around cities and for identifying areas where deforestation is occurring, as in this example.

Image Division or Spectral Rationing

Image division or spectral rationing is one of the most common transforms applied to image data. Image rationing serves to highlight subtle variations in the spectral responses of various surface covers. By rationing the data from two different spectral bands, the resultant image enhances variations in the slopes of the spectral reflectance curves between the two different spectral ranges that may otherwise be masked by the pixel brightness variations in each of the bands. The following example illustrates the concept of spectral rationing. Healthy vegetation reflects strongly in the near-infrared portion of the spectrum while absorbing strongly in the visible red. Other surface types, such as soil and water, show near-equal reflectances in both the near-infrared and red portions. Thus, a ratio image of Landsat MSS Band 7 (Near-Infrared - 0.8 to 1.1 mm) divided by Band 5 (Red - 0.6 to 0.7 mm) would result in ratios much greater than 1.0 for vegetation, and ratios around 1.0 for soil and water. Thus, the discrimination of vegetation from other surface cover types is significantly enhanced. Also, we may be better able to identify areas of unhealthy or stressed vegetation, which show low near-infrared reflectance, as the ratios would be lower than for healthy green vegetation.

Another benefit of spectral ratioing is that, because we are looking at relative values (i.e. ratios) instead of absolute brightness values, variations in scene illumination as a result of topographic effects are reduced. Thus, although the absolute reflectances for forest-covered slopes may vary depending on their orientation relative to the sun's illumination, the ratio of their reflectances between the two bands should always be very similar. More complex ratios involving the sums of and differences between spectral bands for various sensors have been developed for monitoring vegetation conditions. One widely used image transform is the Normalized Difference Vegetation Index (NDVI) which has been used to monitor vegetation conditions on continental and global scales using the Advanced Very High-Resolution Radiometer (AVHRR) sensor onboard the NOAA series of satellites.

Principal Components Analysis

Different bands of multispectral data are often highly correlated and thus contain similar information. For example, Landsat MSS Bands 4 and 5 (green and red, respectively) typically have similar visual appearances since reflectances for the same surface cover types are almost equal. Image transformation techniques based on complex processing of the statistical characteristics of multi-band data sets can be used to reduce this data redundancy and correlation between bands. One such transformation is called principal components analysis**.** The objective of this transformation is to reduce the dimensionality (i.e. the number of bands) in the data and compress as much of the information in the original bands into fewer bands. The "new" bands that result from this statistical procedure are called components. This process attempts to maximize (statistically) the amount of information (or variance) from the original data into the least number of new components. As an example of the use of principal components analysis, a seven-band Thematic Mapper (TM) data set may be transformed such that the first three principal components contain over 90 percent of the information in the original seven bands. Interpretation and analysis of these three bands of data, combining them either visually or digitally, is simpler and more efficient than trying to use all of the original seven bands. Principal components analysis, and other complex transforms, can be used either as an enhancement technique to improve visual interpretation or to reduce the number of bands to be used as input to digital classification procedures, discussed in the next section.

This is the most widely used and popular technique among digital image enhancement techniques. The technique is nothing but deriving eigenvalues and associated eigen vectors PCA output is produced using the eigen vectors in linear combination with original data. The ultimate effect is the reorientation of the coordinate system with respect to the original system.

PCA, a factor of Karhumem-Loeve analysis has proven to be of significant value in the analysis of remotely sensed digital data (Jensen, 1986). PCA images often result in better interpretable images compared to the original data and is also used as a data compression technique. For example, if four multispectral bands are used as input to derive PCA images then the first PCA (PC1) contains maximum information, compiled from all spectral channels, and the rest will have lesser information in decreasing order. The technique involves reducing the correlation between PCs and increasing variance within each spectral channel, which is directly proportional to the information content in the image.

Band Rationing

Sometimes differences in brightness values from identical surface materials are caused by topographic slope and aspect, shadows, or seasonal changes in sunlight illumination angle and intensity. These conditions may hamper the ability of an interpreter or classification algorithm to identify correctly surface materials or land use in a remotely sensed image.

Fortunately, ratio transformations of the remotely sensed data can, in certain instances, be applied to reduce the effects of such environmental conditions. In addition to minimizing the effects of environmental factors, ratios may also provide unique information not available in any single band that is useful for discriminating between soils and vegetation. The mathematical expression of the ratio function is

$$BV_{I\,j,\,r} = BV_{I\,j\,k} / BV_{I\,j\,l}$$

To represent the range of the function linearly and to encode the ratio values in a standard 8-bit format (values from 0 to 255), normalizing functions are applied. Using this normalizing function, the ratio value 1 is assigned the brightness value 128. Ratio values within the range 1/255 to 1 are assigned values between 1 and 128 by the function

$$BV_{ij,n} = \text{Int}\,[(BV_{ij,r} \text{ X } 127) + 1]$$

Ratio values from 1 to 255 are assigned values within the range 128 to 255 by the function

$$BV_{ij,n} = \text{Int}\,(128 + BV_{ij,r}) \quad (2)$$

The simple ratios between bands, only negate multiplicative extraneous effects. When additive effects are present, we must ratio between band differences. ratio techniques compensate only for those factors that act equally on the various bands under analysis. In the individual bands, the reflectance values are lower in the shadowed area and it would be difficult to match this outcrop with the sunlit outcrop. The ratio values, however, are nearly identical in the shadowed and sunlit areas and the sandstone outcrops would have similar signatures on ratio images. This removal of illumination differences also eliminates the dependence of topography on ratio images.

Ratio images can be meaningfully interpreted because they can be directly related to the spectral properties of materials. Rationing can be thought of as a method of enhancing minor differences between materials by defining the slope of the spectral curve between two bands.

Apart from the simple ratio of the form A/B, other ratios like A/(A+B), (A- B) /(A+B), (A+B)/(A-B) are also used in some investigations. However, a systematic study of their use for different applications is not available in the literature. It is important that the analyst be cognizant of the general types of materials found in the scene and their spectral properties in order to select the best ratio images for interpretation. Ratio images have been successfully used in many geological investigations to recognize and map areas of mineral alteration and for lithologic mapping.

Colour Ratio Composite Images

We can combine several ratio images to form a colour ratio composite image. Colour ratio composite images are most effective for discriminating between the altered and unaltered sedimentary rocks, and in some cases, for distinguishing subtle differences among the altered and unaltered rocks. In some studies, it has been noticed that the ratios 4/5, 5/6, and 6/7 composite provide the greatest amount of information for discriminating between hypo-thermally altered and unaltered rocks, as well as separating various types of igneous rocks. Density slicing can also be used after band rationing to enhance subtle tonal differences.

Tasseled Cap Transformation

Tasseled cap (Kauth-Thomas) transformation is another transformation, which helps in deriving ‘brightness’, ‘greenness’, ‘yellowness’, and ‘non-such’ indices by using multispectral satellite data. These images are derived using a linear band combination of already derived coefficients and input band data. The justification for this operation is that the areas will provide a consistent, physically-based coordinate system for interpretation of images of an agricultural area obtained at different stages of the growth cycle of the crop (Mather, 1987). This is a means by which it is possible to highlight the most important (spectrally observable) phenomena of crop development in a way that allows discrimination of specific crops, and crops from other vegetative cover, in Landsat multi-temporal image.

Three major orthogonal directions of significance in vegetation can be identified. The first is the principal diagonal along which soils are distributed. This was chosen by Kauth and Thomas as the first axis in the tasseled cap transformation and is known as brightness. The development of vegetation moves towards maturity appears to occur orthogonal to the soil major axis. This direction was then chosen as the second axis, with the intention of providing a greenness indicator. Senescence takes place in a different plane to maturity. The third axis orthogonal to the soil line and greenness axis will give a yellowness measure. Finally, a fourth axis is required to account for data variance not substantially associated with differences in soil brightness or vegetative greenness or yellowness. Again, this needs to be orthogonal to the previous three. It was called 'non-such' by Kauth and Thomas in contrast to the names 'soil brightness', 'green-stuff', and 'yellow-stuff' they applied to the previous three.

De-correlation Techniques

Multispectral digital data normally exhibit a high degree of correlation among the spectral channels. Due to this, the separation of certain features becomes extremely difficult. Contrast stretching of the data does not produce improved results as the data tend to concentrate along the diagonal in the three-dimensional axis. Hence, to improve the interpretability and data quality it is required to reduce the correlation between the spectral channels so that the data gets spread in the three-dimensional axis to all corners. Principal Component Analysis and Hue, Saturation, Intensity (HIS) transformation are some of the commonly used tools.

HSI Technique

This is yet another decorrelation technique which words in a three-dimensional axis to produce an output which has similar characteristics as a PC image. The Red, Green, and Blue (RGB) input can be manipulated by a three-dimensional transformation to obtain Hue: which explains the perceived colours, Saturation: which explains the degree of purity in colours and intensity explains the brightness or dullness of colours. This enhancement is particularly useful in deriving better perceptible and interpretable images. HSI images after stretching can be transformed back to RGB space to work in the normal colour composite mode for better differentiation of objects.

10.4 SUMMARY

Spatial filtering types, techniques, and methods are used to enhance the appearance of an image which facilitates the clarity for visual as well as digital image processing and interpretation. Such tools and techniques certainly provide the extraction of huge amounts of information based on the objectives of users. Spatial filters are designed to highlight or suppress specific features in an image based on their spatial frequency. Spatial frequency is related to the concept of image texture which refers to the frequency of the variations in tone that appear in an image. "Rough" textured areas of an image, where the changes in tone are abrupt over a small area, have high spatial frequencies, while "smooth" areas with little variation in tone over several pixels, have low spatial frequencies. Similarly in image transformation, the multispectral character of remote sensing data renders it amenable to spectral transformations that generate new sets of image components or bands which highlights the clarity of ground features in different shades/tones, texture etc. The transformed image makes evident features not discernable in the original data. The techniques show the significance of displaying data in the three dimensions available on a colour monitor or in colour hardcopy and for transmission and storage of data.

10.5 GLOSSARY

Absorption factor The ratio of the total absorbed radiant or luminous flux to the incident flux.

Field Angle The Field Angle is the angle between the two directions opposed to each other over the beam axis for which the luminous intensity is 10% that of the maximum luminous intensity. In some cases, it is also called a beam angle.

Radiance Radiance is the radiant intensity per unit surface area.

Scattering Albedo The ratio between the scattering coefficient and the absorption coefficient for a participating medium. An albedo of 0 means that the particles do not scatter light. An albedo of 1 means that the particles do not absorb light.

Standard unit of radiance Watts per steradian and square meter ($W/sr\ m^2$).

Transmission coefficient The ratio of the directly transmitted light after passing through one unit of a participating medium (atmosphere, dust, fog) to the amount of light that would have passed the same distance through a vacuum. It is the amount of light that remains after the absorption coefficient and the scattering coefficient (together the extinction coefficient) are accounted for.

Transmittance Transmittance is the ratio of the total radiant or luminous flux transmitted by a transparent object to the incident flux, usually given for normal incidence.

10.6 ANSWER TO CHECK YOUR PROGRESS

1. Spatial filtering in GIS involves the manipulation of pixel values within an image.
2. Image transformation techniques are used to enhance or modify the visual representation of geographic data.
3. Spatial filtering can be applied to both raster and vector data.
4. Convolution is a common technique used in spatial filtering to apply masks or kernels to an image.
5. Image smoothing is a spatial filtering operation that reduces noise in an image.
6. Sharpening is a spatial filtering operation that enhances edges and details in an image.
7. Image classification is an example of image transformation where pixels are assigned to specific categories.
8. Histogram equalization is a technique used for enhancing the contrast in an image.

9. Geometric transformation involves changing the spatial orientation or scale of an image.
10. Spatial filtering is essential for preprocessing remote sensing data.
11. Edge detection is a spatial filtering technique used to identify abrupt changes in pixel values.
12. Multispectral images can be transformed into false-color composites for better visualization.
13. Image transformation and spatial filtering are fundamental processes in GIS for extracting meaningful information from imagery.

10.7 REFERENCES

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14.8 TERMINAL QUESTIONS

Long Questions

1. Why filtering for digital images is needed? Define filter, filtering, spatial, and linear filtering.
2. What type of filter you will use if you want to highlight regions of rapid intensity change and use edge enhancement? Describe it in detail.
3. Highlight the techniques of Tasseled Cap Transformation, De-correlation and HSI to improve the interpretability and data quality.
4. What is the utility of principal components analysis in digital image enhancement techniques?

Short Questions

1. What is filtering in geoinformatics?
2. What is spatial and linear filtering?
3. Write a short note on image transformation.
4. Discuss the different types of image transformation.
5. Describe the characteristics of spatial filtering.
6. What is spatial Convolution filtering?
7. Describe filtering in frequency and spatial domain.
8. What are the types and uses of spatial filtering?
9. Explain image subtraction and division.
10. Discuss linear and non-linear edge enhancement.
11. Highlight the importance of spectral band rationing.

Multiple Choice Questions

1. What is the primary purpose of spatial filtering?

a) Creating vector polygons

b) Enhancing or modifying image pixel values

c) Calculating distances between points

d) Measuring elevation changes

2. Which type of data can spatial filtering be applied to?

a) Raster data only

b) Vector data only

c) Both raster and vector data

d) Tabular data only

3. Which technique in spatial filtering involves the use of masks or kernels?

a) Histogram equalization

b) Image classification

c) Convolution

d) Geometric transformation

4. What is the primary purpose of image smoothing in spatial filtering?

a) Enhancing image edges

b) Reducing image noise

c) Changing image colors

d) Increasing image contrast

5. Which spatial filtering operation is used to enhance edges and details in an image?

a) Image smoothing

b) Sharpening

c) Image classification

d) Geometric transformation

6. Image classification is an example of:

a) Image smoothing

b) Histogram equalization

c) Geometric transformation

d) Image transformation

7. What does histogram equalization primarily aim to improve in an image?

a) Image noise

b) Color balance

c) Image contrast

d) Geometric accuracy

8. Geometric transformation in GIS involves:

a) Changing pixel values

b) Changing the spatial orientation or scale of an image

c) Assigning pixels to categories

d) Filtering image data

9. What does the process of warping typically involve?

a) Enhancing image details

b) Changing image colors

c) Changing the spatial projection of an image

d) Calculating distances between points

10. Affine transformations in image processing include operations like:

a) Rotation and translation

b) Histogram equalization and smoothing

c) Image classification and convolution

d) Geometric transformations and warping

11. Edge detection is a spatial filtering technique used to identify:

a) Noise in the image

b) Smooth areas in the image

c) Abrupt changes in pixel values

d) Geometric distortions in the image

12. What can multispectral images be transformed into for better visualization?

a) Vector data

b) Raster data

c) False-color composites

d) Contour maps

13. In GIS, spatial filtering and image transformation are crucial for:

a) Creating text-based reports

b) Calculating demographic statistics

c) Extracting meaningful information from imagery

d) Drawing geometric shapes

14. Which type of data is commonly preprocessed using spatial filtering techniques in remote sensing?

a) Weather data

b) Social media data

c) Satellite imagery

d) Traffic data

15. What is the fundamental purpose of image transformation and spatial filtering?

a) Enhancing image aesthetics

b) Simplifying data visualization

c) Extracting meaningful information from spatial data

d) Converting raster data to vector data

Answers: 1-b, 2-c, 3-c, 4-b, 5-b, 6-d, 7-c, 8-b, 9-c, 10-a, 11-c, 12-c, 13-c, 14-c, 15-c.

UNIT 11 - IMAGE CLASSIFICATION

11.1 OBJECTIVES

After reading this unit learner will be able to understand:

- Importance of digital image classification
- Spectral signature
- Classification training and types of classification
- Classification accuracy assessment
- Classification error matrix

11.2 INTRODUCTION

In the previous units you have studied basics of digital image processing, preprocessing, image registration and different types of digital enhancement techniques for bringing clarity, interpretability and maximizing the reliable information extraction. The sequence of these study topics becomes progressive for your full understanding towards digital image processing tools and techniques. But your ultimate goal of digital image classification and analysis is still to be learnt and the same is being described in this unit. Before learning digital image classification, you should have the curiosity in its historical background as mentioned in the following paragraph:

Considerable amount of work has been done for mapping, monitoring and analysis of various resources along with different ecosystems and environmental parameters at various levels. Stereoscopic interpretation of aerial photographs and visual interpretation of coarse resolution of satellite images were most common methods during 1960-70s. Initially, in the 1960s, with the emergence of the space program, cosmonauts and astronauts started taking photographs out of the window of their spacecraft in which they were orbiting the earth. During 1970s 1:1 million scale satellite images were used for interpretation and mapping for broad land use and land cover categories. With the passage of time the choice of visual interpretation method on paper print was changed into onscreen visual interpretation of data visible in the computer monitor. Today, remote sensing is carried out using airborne and satellite technology, not only utilizing film photography, but also digital camera, scanner and video, as well as radar and thermal sensors. Unlike in the past, when remote sensing was restricted to only the visual part of the electromagnetic spectrum i.e., what could be seen with naked eye, today through the use of special filters, photographic films and other types of sensors, the parts of the spectrum which cannot be seen with the naked human eye can also be utilized. Now the digital image processing techniques, by using specific sophisticated computer hardware and software's, are quite common for detailed data analysis. There are various methods by which the raw data available from satellite are rectified and enhanced so as to get clarity with high degree of contrast. By applying different mathematical algorithms during the processing and classification one can achieve the results of his own choice. Thus, today remote sensing is largely utilized in environmental management, which frequently requires rapid, accurate, and up-to-date data collection and its digital image processing.

Digital image classification of satellite remote sensing operations is used to digitally identify and classify pixels in the data. Classification is usually performed on multi-channel data sets and this process assigns each pixel in an image to a particular class or theme based on statistical characteristics of the pixel brightness values. There are a variety of approaches taken to perform digital classification. The two generic approaches which are used most often, namely supervised and unsupervised classification.

The objective of these operations is to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This involves the analysis of multi-spectral image data and the application of statistically based decision rules for determining the land cover ideality of each pixel in an image. The intent of classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This classified data may be used to produce thematic maps of the land cover present in an image. Based on the contents and sub topics to be described under this unit, the study is aimed at the following objectives:

11.3 IMAGE CLASSIFICATION

Definitions

Classification and Digital Image Classification

- Classification is a process related to categorization, the process in which ideas and objects are recognized, differentiated, and understood.

- Digital Image Classification classifies each individual pixel by using the spectral signature/ information represented by the digital numbers in one or more spectral bands.
- Image classification refers to the task of extracting information classes from multiband raster image.

Spectral signature

- Spectral signature is the variation of reflectance or emittance of a material with respect to wavelengths (i.e., reflectance/emittance as a function of wavelength).
- The spectral signature of an object is a function of the incidental EM wavelength and material interaction with that section of the electromagnetic spectrum.

Supervised classification

- Supervised classification uses the spectral signatures obtained from training samples to classify an image.

Unsupervised classification

- Unsupervised classification finds spectral classes (or clusters) in a multiband image without the analyst's intervention.

Accuracy and Classification Accuracy

- Accuracy is one metric for evaluating classification models.
- Informally, accuracy is the fraction of predictions our model got right.
- Formally, Accuracy=Number of correct predictions/Total number of predictions.
- Classification accuracy is defined as "percentage of correct predictions"..

Confusion Matrix

- Confusion matrix describes the performance of a classifier so that one can see what types of errors the classifier is making.

Importance of Digital Image Classification

Digital image processing techniques assist the analyst in the qualitative (i.e., visual) interpretation of images. Multi-spectral classification is emphasized because it is, at the present times; the most common approach to computer assisted mapping from remote sensing images. It is important at this point, however, to make a few appropriate comments about multi-spectral classification. First, it is fundamental that we are attempting to objectively map areas on the ground that has similar spectral reflectance characteristics. The resulting labels assigned to the image pixels, therefore, represent spectral classes that may or may not correspond to the classes of ground objects that we are ultimately interested in mapping. Second, manually produced maps are the result of a long, often complex process that utilizes many sources of information. The conventional tools used to produce a map range from the strictly quantitative techniques of photogrammetry and geodesy, to the less quantitative techniques of photo-interpretation and field class descriptions, to the subjective and artistic techniques of map "generalization" and visual exploration of discrete spatial data points.

The final output of the classification process is a type of digital image, specifically a map of the classified pixels. For display, the class at each pixel may be coded by character or graphic symbols or by color. The classification process compresses the image data by reducing the large number of gray levels in each of several spectral bands into a few numbers of classes in a single Image.

Spectral Signatures

Relying on the assumption that different surface materials have different Spectral reflectance (in visible and microwave regions) or thermal emission characteristics, multi spectral classification logically partitions the large spectral measurement space (256k possible pixel vectors for an image with 8 bits / pixel / band and k bands) into relatively few regions, each representing a. different type of surface material. The set of discrete spectral radiance measurements provided by the broad spectral bands of the sensor define the spectral signature of each class, as modified by the atmosphere between the sensor and the ground. The spectral signature is a k- dimensional vector whose coordinates is the measured radiance in each spectral band.

Concept of Spectral Signature in Image Classification

Features on the Earth reflect, absorb, transmit, and emit electromagnetic energy from the sun. Special digital sensors have been developed to measure all types of electromagnetic energy as it interacts with objects in all of the ways listed above. The ability of sensors to measure these interactions allows us to use remote sensing to measure features and changes on the Earth and in our atmosphere. A measurement of energy commonly used in remote sensing of the Earth is reflected energy (e.g., visible light, near-infrared, etc.) coming from land and water surfaces. The amount of energy reflected from these surfaces is usually expressed as a percentage of the amount of energy striking the objects. Reflectance is 100% if all of the light striking and object bounces off and is detected by the sensor. If none of the light returns from the surface, reflectance is said to be 0%. In most cases, the reflectance value of each object for each area of the electromagnetic spectrum is somewhere between these two extremes. Across any range of wavelengths, the percent reflectance values for landscape features such as water, sand, roads, forests, etc. can be plotted and compared. Such plots are called "spectral response curves" or "spectral signatures." Differences among spectral signatures are used to help classify remotely sensed images into classes of landscape features since the spectral signatures of like features have similar shapes. The figure no 10.1 below shows differences in the spectral response curves for healthy versus stressed sugar beet plants.

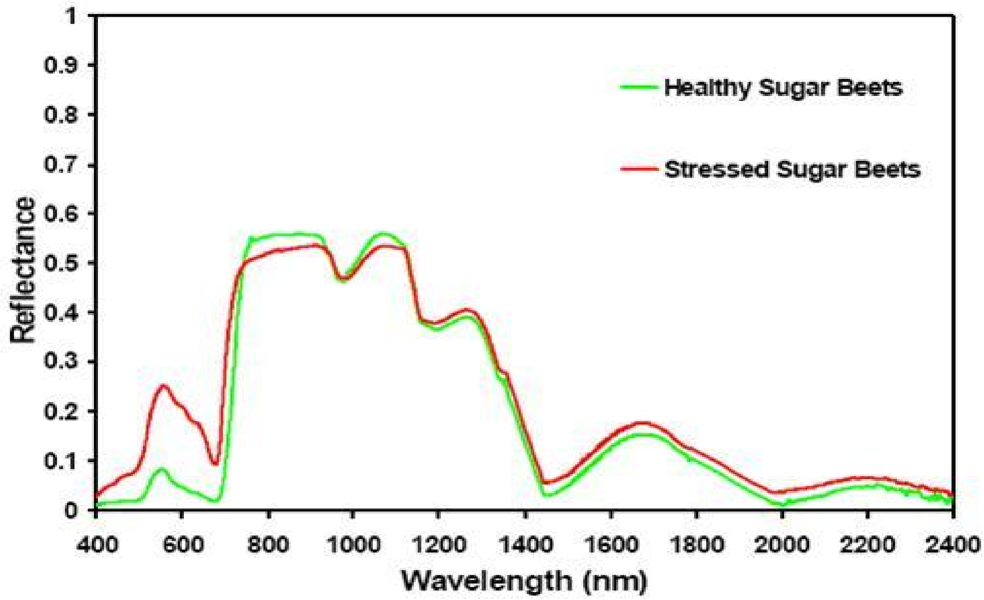

Fig. 11.1: Spectral curve of healthy and stressed Sugar beets

The more detailed the spectral information recorded by a sensor, the more information that can be extracted from the spectral signatures. Hyperspectral sensors have much more detailed signatures than multispectral sensors and thus provide the ability to detect more subtle differences in aquatic and terrestrial features.

Importance of Spectral Signatures in Digital Image Classification

Spectral signature is one of the important tools in the analysis of digital data as it forms the basis of identification and discrimination between various features on the Earth. Spectral signatures of various cover types at two different seasons must be studied with the objective to find out their role in analysis of multispectral digital data using a Multispectral Data Analysis System (M-DAS). Multispectral data in in different bands of two different seasons are generally plotted with respect to their mean grey scale values. These values become very helpful in identification of various land use/land covers/features and to understand their spectral separability which in turn highlights a clue for final grouping of different classes during computer aided digital classification.

Spectral Signature Generalization and Expansion Can Improve the Accuracy of Satellite Image Classification

Conventional supervised classification of satellite images uses a single multi-band image and coincident ground observations to construct spectral signatures of land cover classes. The approach is compared with the following three alternatives that derive signatures from multiple images and time periods:

i) **Signature Generalization**: Spectral signatures are derived from multiple images within one season, but perhaps from different years;

ii) S**ignature Expansion**: Spectral signatures are created with data from images acquired during different seasons of the same year; and

iii) **Combinations of Expansion and Generalization**:The quality of these different signatures was assessed to (a) classify the images used to derive the signature, and (b) for use in temporal signature extension, i.e., applying a signature obtained from data of one or several years to images from other years. When applying signatures to the images they were derived from, signature expansion improved accuracy relative to the conventional method, and variability in accuracy declined markedly. In contrast, signature generalization did not improve classification. When applying signatures to images of other years (temporal extension), the conventional method, using a signature derived from a single image, resulted in very low classification accuracy. Signature expansion also performed poorly but multi-year signature generalization performed much better and this appears to be a promising approach in the temporal extension of spectral signatures for satellite image classification.

Classification Training

The first step of any classification procedure is the training of the computer program to recognize the class signatures of interest. To train the computer program, we must supply a sample of pixels from which class signatures, for example, mean vectors and covariance matrices can be developed. There are basically two ways to develop signatures:

- Supervised training
- Unsupervised training

Supervised Classification:

For supervised training, the analyst uses prior knowledge derived from field surveys, photo-interpretation, and other sources, about small regions of the image to be classified to identify those pixels that belong to the classes of interest. The feature signatures of this analyst --identified pixels are then calculated and used to recognize pixels with similar signatures throughout the image.

In a supervised classification, the identify and the location of some of the land cover types, such as urban, agriculture, wetland, and forest, are known a priori though a combination of field work, analysis of aerial photography, maps, and personal experience.

These areas are commonly referred to as training sites because the spectral characteristics of these known areas are used to "train" the classification algorithm for eventual land cover mapping of the remainder of the image. Multi-variate statistical parameters (means, standard deviations, covariance matrices, correlation matrices, etc.) are calculated for each training site. Every pixel both within and outside these training sites is then evaluated and assigned to the class of which it has be highest likelihood of being a member. The following are important aspects of conducting a rigorous and hopefully useful supervised classification of remote sensor data:

- An appropriate classification scheme must be adopted.
- Representative training sites must be selected, including an

- Appreciation for signature extension factors, if possible.
- Statistics must be extracted from the training site spectral data.
- The statistics are analyzed to select the appropriate features (bands) to be used in the classification process.
- Select the appropriate classification algorithm.
- Classify the imagery into the required classes.
- Statistically evaluate the classification accuracy.

The classification performance depends on using suitable algorithms to label the pixels in an image as representing particular ground cover types, or classes. A wide variety of algorithms are available for supervised classification.

Maximum Likelihood Classification- This is the most common method used with remote sensing image data interpretation/ classification. The decision rules are based on Baye's principle. To derive the a priori probabilities sufficient amount of training data should be available in the form of ground referenced data for various cover types. From this information training set spectral statistics and a priori probabilities are calculated for each pixel before categorizing to respective likelihood class (Fig. 11.2).

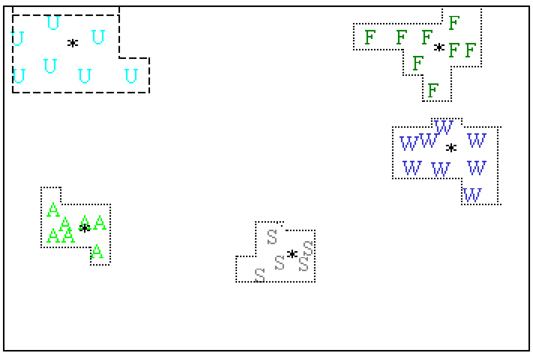

Fig. 11.2: Maximum likelihood classification.

Minimum Distance Classification: It is an automatic option for classification when sufficient ground truth data is not available for different cover types in a given area. This is a classifier, which does not make use of variance-covariance matrices while classifying different cover types.

With this classifier, training data is used only to determine class means; classification is then performed by placing the pixel in the class of the nearest mean (Figure 11.3).

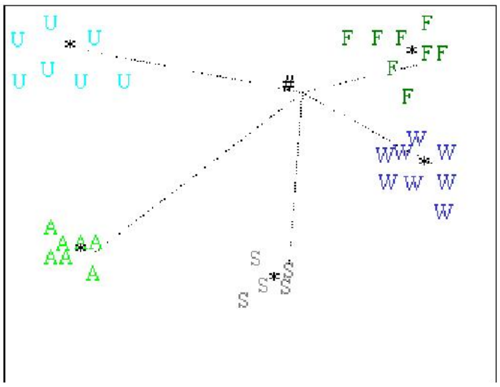

Fig. 11.3: Minimum distance classification.

Parallelepiped Classification- This is a very simple supervised classifier that is, in principle, trained by inspecting histograms of the individual spectral components of the available training data. The Upper and lower significant bounds on the histograms are identified and used to describe the brightness value range for each component characteristic of that class. Together, the range in all components describes a multidimensional box or parallelepiped (Figure 11.4). A two dimensional pattern space might therefore be segmented. If there is a considerable gap between two parallel piped; pixels in those regions will not be classified. Whereas in the case of maximum likelihood and minimum distance algorithms the pixels are labeled as belonging to one of the available classes depending on the pre-set threshold.

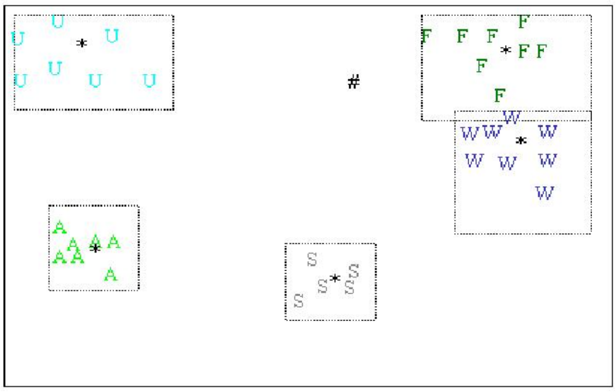

Fig. 11.4: Parallelepiped classification.

Unsupervised Classification - For unsupervised training, the analyst employs a computer algorithm that locates naturally occurring concentrations of feature vectors from a heterogeneous sample of pixels. These computer- specified clusters are then assumed to represent feature classes in the image and are used to calculate class signatures. Unsupervised classification requires only a minimal amount of input from the analyst. It is a process whereby numerical operations are performed that search for "natural" groupings of the spectral properties of pixels, as examined in multi-spectral feature space. The user allows the computer to select the class means and covariance matrices to be used in the classification. Once the data are classified, the analyst attempts, a posterior (after the fact) to assign these "natural" or spectral classes to the information classes of interest. This may not be easy. Some of the clusters may be meaningless because they represent mixed classes of earth surface materials.

Hundreds of clustering methods has been developed for a wide variety of purposes apart from pattern recognition in remote sensing. The clustering algorithm operates in a two -pass mode (i.e. it passes through the registered multi-spectral data set two times). In the first pass, the program reads through the data set and sequentially builds clusters (groups of points in space). There is a mean vector associated with each cluster. In the second pass, a minimum -distance classification to means algorithm similar to the one described previously is applied to the whole data set on a pixel -by -pixel basis, where each pixel is assigned to one of the mean vectors created in pass one. The first pass, therefore, automatically creates the cluster signatures to be used by the classifier:

PASS 1: Cluster Building:

During the first pass, the analyst may be required to supply four types of Information:

- R, a radius in spectral space used to determine when a new cluster should be formed.
- C, a spectral space distance parameter used when merging clusters
- .N, the number of pixels to be evaluated between each merging of the clusters
- .C_{max}, the maximum number of clusters to be identified by the algorithm.

PASS 2: Assignment of Pixels to one of the C_{max} Clusters using minimum distance classification logic:

The final cluster mean data vectors are used in a minimum -distance to means classification algorithm to classify all the pixels in the image into one of the C_{max} clusters. The analyst usually produces a display depicting to which cluster each pixel was assigned. It is then necessary to evaluate the location of the clusters in the image, label them, if possible, and see if any should be combined. It is usually necessary to combine some clusters. This is where an intimate knowledge of the terrain is critical.

Cluster Labeling:

It is usually performed by interactively displaying all the pixels assigned to an individual cluster on a CRT screen. In this manner, it is possible to identify their location, and spatial association with the other clusters. This interactive visual analysis, in conjunction with the information provided in the scatter plot, allows the analyst to group the clusters into information classes.

Combination of Supervised and Unsupervised Training:

Because supervised training does not necessarily result in class signatures that are numerically separable in feature space, and because unsupervised training does not necessarily result in classes that are meaningful to the analyst, a combined approach has the potential to meet both requirements. If time and financial resources permit, this is undoubtedly the best procedure to follow.

Pre-classification Processing and Feature Extraction:

Those aspects of remote sensing imagery that are used to define mapping classes are known as features. The simplest features, the pixel grey levels in each band of a multispectral image, are not necessarily the best features for accurate classification. They are influenced by such factors as atmospheric scattering and topographic relief, and are more often highly correlated between spectral bands, resulting in the inefficient analysis of redundant data.

Incorporating Ancillary and Contextual Data in the Classification Process:

Ancillary data is any type information used in the classification process that is not directly obtainable from either the spatial or spectral characteristics of the remote sensor data itself. For example, the amount and the type of agricultural land use in the previous year should be of value in this year's agricultural crop -type inventory. Similarly, certain types of forest species are spatially distributed based solely on aspect and/ or topographic characteristics.

Ideally, land cover classifications based on the analysis of remote sensor data should incorporate such valuable ancillary information.

Contextual Classification:

The classifiers so far discussed are point or pixel specific in which the pixels in an image are classified independently of the classifications of their neighbors. Procedures are available for classifying pixels in the context of their neighbors. These require information from a spatial model of the region under consideration and tend to develop thematic map that is consistent both spectrally and spatially.

Statistical classification techniques commonly achieve accuracies above 80%. The main limitation of many classification techniques is that they perform classification on a pixel-by-pixel basis. It is obvious that the classification is based on the spectral characteristics of the object in consideration. If two independent objects possess similar spectral properties, statistical classification methodology fails to recognize the object as a different class. Hence, the probability of misclassification, even though can be minimized, is very much scene dependent. Scenes having lot of variability in the spectral responses will require too many training sets for satisfactory classification. Many analysts adopt post-classification smoothing to minimize unclassified pixels. But this procedure results in exclusion of other small areas, which are of interest. So, smoothing is more restricted to visual purpose only. The pixel process does not emulate human abilities, which are clearly distinguished by their use of texture and context in addition to tone to aid interpretation decisions. Here the role of digital spatial contextual analysis is of great interest in order to improve a multispectral classification.

In order to improve the classification one form of context analysis is, viz., This is also known as type I pixel-based re-classifier, as it combines local information surrounding pixels to assist the reclassification of each pixel. The most important requirement in contextual algorithms is it should maintain homogenous areas of irregular shape, but identify and correct those isolated pixels, which are misclassified. The probabilistic relaxation model provides an appropriate examination of the technique. Rosenfeld et al. (1976) define three models of relaxation: a discrete model, a fuzzy model and a probabilistic model. Probabilistic models are the most generally used methodology and has wide literature coverage. The probabilistic relaxation model attempts to reduce the uncertainty in a twofold manner by.

- Examining the local neighborhood of each pixel to produce locally consistent labels.
- Using statistical information on the label interrelationships present in the whole image.

The core of the model is the probability updating rule. The neighborhood operator provides spatial context information over n-local pixels.

Temporal Classification:

Temporal classification exploits the usefulness of time related features as another element for interpretation. Temporal analysis uses two basic time interpretive functions in forestry application:

- Time related phonological features as additional discriminate.
- Time related change in forest cover features.

Suitability of specific index for the estimation of biomass production is initially assessed through pilot study using ground radiometers and aerial scanner data as complements to the satellite data. Indices have become more efficient estimation of vegetation amount as compared with the performance of different bands independently. The selection of remote sensing data and acquisition is based on the required spatial resolution. A balance between spatial, spectral and temporal resolution is usually made depending upon the scale of study. For detailed digital image classification techniques of remote sensing data, students may consult the concerned books.

Classification Accuracy Assessment

Quantitatively assessing classification accuracy requires the collection of some *in situ* data or a priori knowledge about some parts of the terrain, which can then be compared with the remote sensing derived classification map. Thus to assess classification accuracy it is necessary to compare two classification maps 1) the remote sensing derived map, and 2) the assumed true map (in fact it may contain some error). The assumed true map may be derived from in situ investigation or quite often from the interpretation of remotely sensed data obtained at a larger scale or higher resolution.

Overall Classification Map Accuracy Assessment

To determine the overall accuracy of a remotely sensed classified map it is necessary to ascertain whether the map meets or exceeds some predetermined classification accuracy criteria.

Overall accuracy assessment evaluates the agreement between the two maps in total area or each category. They usually do not evaluate construction errors that occur in the various categories

Site-Specific Classification Map Accuracy Assessment

This type of error analysis compares the accuracy of the remote sensing derived classification map pixel by pixel with the assumed true land use map. First, it is possible to conduct a site-specific error evaluation based only on the training pixels used to train the classifier in a supervised classification. This simply means that those pixel locations i, j used to train the classifier are carefully evaluated on both the classified map from remote sensing data products and the assumed true map. If training samples are distributed randomly throughout the study area, this evaluation may be considered representative of the study area. If they act biased by the analyst a prior knowledge of where certain land cover types exist in the scene. Because of it is bias, the classification accuracy for pixels found within the training sites is generally higher than for the remainder of the map because these are the data locations that were used to train the classifier. Conversely, if other test locations in the study area are identified and correctly labeled prior to classification and if these are not used in the training of the classification algorithm, they can be used to evaluate the accuracy of the classification map. This procedure generally yields a more credible classification accuracy assessment. However additional ground truth is required for these test sites coupled with the problem of determining how many pixels are necessary in each test site class. Also, the method of identifying the location of the test sites prior to classification is important since many statistical tests require that locations be randomly selected (e.g., using a random number generator for the identification of unbiased row and column coordinates) so that the analyst does not bias their selection.

Once the Criterion for objectively identifying the location of specific pixels to be compared is determined, it is necessary to identify the class assigned to each pixel in both the remote sensing derived map and the assumed true map. These data are tabulated and reported in a contingency table (error matrix), where overall classification accuracy and misclassification between categories are identified. It takes the form of an m x m matrix, where m is the number of classes under investigation. The rows in the matrix represent the assumed true classes, while the columns are associated with the remote sensing derived land use. The entries in the contingency table represent the raw number of pixels encountered in each condition; however, they may be expressed as percentages, if the number becomes too large. One of the most important characteristics of such matrices is their ability to summarize errors of omission and commission. These procedures allow quantitative evaluation of the classification accuracy. Their proper use enhances the credibility, of using remote sensing derived land use information.

Classification Error Matrix:

One of the most common means of expressing classification accuracy is the preparation of classification error matrix sometimes called confusion or a contingency table. Error matrices compare on a category-by-category basis, the relationship between known reference data (ground truth) and the corresponding results of an automated classification. Such matrices are square, with the number of rows and columns equal to the number of categories whose classification accuracy is being assessed. Table 11.1 is an error matrix that an image analyst has prepared to determine how well a Classification has categorized a representative subset of pixels used in the training process of a supervised classification. This matrix stems from classifying the sampled training set pixels and listing the known cover types used for training (columns) versus the Pixels actually classified into each land cover category by the classifier (rows).

Table 11.1 Error Matrix resulting from classifying training Set pixel training set data (Known cover types) Classification data

	W	*S*	*F*	*U*	*C*	*H*	*Row Total*
W	480	0	5	0	0	0	**485**
S	0	52	0	20	0	0	**72**
F	0	0	313	40	0	0	**353**
U	0	16	0	126	0	0	**142**
C	0	0	0	38	342	79	**459**
H	0	0	38	24	60	359	**481**
Column Total	**480**	**68**	**356**	**248**	**402**	**438**	**1992**

Producer's Accuracy	Users Accuracy
W= 480/480 = 100%	W= 480/485 =99%
S = 052/068 = 16%	S = 052/072 = 72%
F = 313/356 = 88%	F = 313/352 = 87%
U = 126,2411 = 51%	U = 126/147 = 99%
C = 342/402 = 85%	C = 342/459 = 74%
H = 359/438 = 82%	H =359/481= 75%

Overall accuracy = (480 + 52 + 313+ 126+ 342 +359)/1992= 84%

(W, water; S, sand, F, forest; U Urban; C, corn; H, hay)

An error matrix expresses several characteristics about classification performance. For example, one can study the various classification errors of omission (exclusion) and commission (inclusion). Note in Table 1 the training set pixels that are classified into the proper land cover categories are located along the major diagonal of the error matrix (running from upper left to lower right). All non-diagonal elements of the matrix represent errors of omission or commission. 'Omission errors correspond to non-diagonal column elements' (e.g. 16 pixels that should have been classified as "sand" were omitted from that category). 'Commission errors are represented by non-diagonal row element' (e.g. 38 urban pixels plus 79 hay pixels were improperly included in the corn category). Several other ensures for e.g. the overall accuracy of classification can be computed from the error matrix. It is determined by dividing the total number of correctly classified pixels (sum of elements along the major diagonal) by the total number of reference pixels. Likewise, the accuracy of individual categories can be calculated by dividing the number of correctly classified pixels in each category by the total number of pixels in the corresponding rows or column. Producer accuracy which indicates how well the training sets pixels of a given cover type are classified can be determined by dividing the number of correctly classified pixels in each category by the number of training sets used for that category (column total). Whereas the user's accuracy is computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category (row total). This figure is a measure of commission error and indicates the probability that a pixel classified into a given category actually represents that category on the ground. Note the error matrix in the table indicates an overall accuracy of 84%. However, producer's accuracy range from just 51 %(urban) to 100% (water), and users' accuracy range from 72%(sand) to 99% (water). This error matrix is based on training data. If the results are good it indicates that the training samples are spectrally separable and the classification works well in the training areas. This aids in the training set refinement process but indicates little about classifier performance elsewhere in the scene.

Kappa coefficient

'Discrete multivariate' techniques have been used to statistically evaluate the accuracy of remote sensing derived maps and error matrices since 1983 and are widely adopted. These techniques are appropriate as the remotely sensed data are discrete rather than continuous and are also binomial or multinomial distributed rather than normally distributed. Kappa analysis is a discrete multivariate technique for accuracy assessment. Kappa analysis yields a Khat statistic that is the measure of agreement of accuracy.

The techniques of image processing so far deal with deriving results in the form of classified maps or enhanced images and associated statistics, which can be correlated with available conventionally generated thematic maps. There are many procedures in satellite image processing which have already been automated, especially under pattern recognition techniques. However, efforts are in progress to find newer techniques which consume a lesser amount of time, does better integrate of data from various sources, has better automation capabilities and simple to use. Some of the techniques, which have made a big impact in present-day data processing, are:

- Expert Systems/Artificial Intelligence
- Contextual classification

The spectral classification of remotely sensed data, in the parametric approach, depends more on the spectral statistics and related signatures. The spectral knowledge is a limiting factor with respect to the given image. Generation of scene independent spectral knowledge is a critical element in the development of Expert systems. Expert systems generally require, knowledge base, a rules interpreter (or rule base) and a working memory. The spectral knowledge-based computer systems are designed to avoid the need for scene-based parameter optimization. It is to make classification decisions based on the knowledge of spectral relationships within and between classes to be categorized given that the relationships are stable over a period of time.

Context based classification algorithms are gaining moment in the present-day image processing. Contextual classification is mainly based on categorization of the image data with respect to the context of the particular pixel in consideration. The rules used to accept or reject the classification decision at a given level depend upon the local contextual interpretation associated with the pixel under consideration.

There are hybrid methods by which useful results are obtained in image processing. Temporal images are classified using parametric methods over difference seasons. Specific knowledge base is used to refine parametric classification with respect to the behavior of the features in the particular phenological stage respectively. Different knowledge base is used to compare two time parametric classification (already refined) to show constant and changing areas over the period. In addition to this stratification information is superimposed from available thematic maps (e.g. Forest boundaries are extracted and classified on the final product). This kind of hybrid methods not only improve upon the classification performance but also go a long way in deriving newer techniques of images processing to achieve better end results.

Future trends of the remote sensing and image processing are generation of data base and national network for information exchange which finally will lead to the operationalisation of National Resources Information System (NRIS) in India.

11.4 SUMMARY

Digital image processing techniques are quite common for detailed data analysis and data out puts for obtaining the desired results. There are various methods by which the raw data available from satellite are rectified and enhanced so as to get clarity with a high degree of contrast. By applying different mathematical algorithms during the processing and classification one can achieve the results of his own choice. Thus, today remote sensing is largely utilized in environmental management, which frequently requires rapid, accurate, and up-to-date data collection and digital image processing.

Digital image processing and classification techniques of satellite remote sensing data are used to obtain clarity of features to identify and classify pixels in the data. Classification is usually performed on multi-channel data sets and this process assigns each pixel in an image to a particular class or theme based on statistical characteristics of the pixel brightness values. There are a variety of approaches taken to perform digital classification. The two generic approaches which are used most often, namely supervised and unsupervised classification.

The objective of digital image classification is to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. The digital image classification provides a detailed data output results based on the user`s requirement. This involves the analysis of multi-spectral image data and the application of statistically based decision rules for determining the land cover ideality of each pixel in an image. The intent of classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This classified data may be used to produce thematic maps of the land cover present in an image. The topic defines and describes the sub-topics consisting of importance of digital image classification, spectral Signature, classification training and types of classification, classification accuracy and assessment of Classification Error Matrix.

Spectral signature, concept and importance of spectral signature in digital image classification have been explained. The theme and importance of supervised and unsupervised classification under classification training are described. Under supervised classification, the maximum likelihood classification algorithm, minimum distance classifier and box classification schemes have their own role of bringing classification accuracy based on the distribution pattern of spectral signatures for each of the assigned classes. Other classification schemes like contextual classification, temporal classification etc. have also been described along with the classification accuracy and error matrix.

In addition to pattern recognition techniques, efforts are in progress to find new techniques which consumes lesser amount of time, does better integration of data from various sources, has better automation capabilities and simple to use. Some of the techniques, which have made a big impact in the present day data processing are i) Expert Systems/Artificial Intelligenceii)Contextual classification.

11.5 GLOSSARY

CRT (Cathode Rays Tube) screen:	A CRT monitor or computer screen contains millions of tiny red, green, and blue phosphor dots that glow when struck by an electron beam that travels across the screen to create a visible image.
Map Accuracy	The accuracy of any map is equal to the error inherent in it as due to the curvature and changing elevations contained in each map from which the map was made, added to or corrected by the map preparation techniques used in joining the individual maps.
Relative map accuracy	It is a measure of the accuracy of individual features on a map when compared to other features on the same map.
Absolute map accuracy	Absolute map accuracy is a measure of the location of features on a map compared to their true position on the face of the Earth.
Mapping accuracy	Mapping accuracy standards generally are stated as acceptable error and the proportion of measured features that must meet the criteria. In the case of some plotting and display devices, accuracy refers to tolerance in the display of graphic features relative to the original coordinate file.
The level of allowable error of maps	As applied by National Map Accuracy Standards, it is determined by comparing the positions of well-defined points whose locations or elevations are shown on the map with corresponding positions as determined by surveys of a higher accuracy.

11.6 ANSWER TO CHECK YOUR PROGRESS

1. Image classification in GIS involves categorizing pixels or features in remote sensing images.
2. Supervised classification requires labeled training data to teach the algorithm.
3. Unsupervised classification groups pixels based on statistical similarities.
4. Feature extraction is a critical step to identify relevant information within an image.

5. Accuracy assessment measures how well a classification model performs.
6. Confusion matrices are used to evaluate the performance of classification algorithms.
7. Spectral bands are crucial for distinguishing various land cover types.
8. Remote sensing platforms like satellites and drones capture imagery for classification.
9. Land use and land cover mapping is a common application of image classification in GIS.
10. Object-based image analysis (OBIA) groups pixels into meaningful objects.
11. Machine learning algorithms like Random Forest and Support Vector Machines are often used for image classification.
12. Multi-temporal analysis involves classifying images acquired at different time points.
13. Preprocessing tasks like atmospheric correction can enhance classification accuracy.
14. Data fusion combines different types of remote sensing data for better classification results.
15. Remote sensing software like Arc GIS and QGIS provide tools for image classification.

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11.8 TERMINAL QUESTIONS

Long Questions

1. What is supervised classification, list out the aspects for extracting useful information/results out of supervised classification?
2. In which condition the digital image classification using maximum likelihood algorithm becomes useful? Draw the related diagram to explain this statement.

Short Questions

1. What is supervised classification, list out the aspects for extracting useful information/results out of supervised classification?
2. In which condition the digital image classification using maximum likelihood algorithm becomes useful? Draw the related diagram to explain this statement.
3. Explain diagrammatically the difference between minimum distance and box or Parallelepiped Classification.
4. Describe the concept of contextual classification.
5. The combination of both supervised and unsupervised classification techniques improves the accuracy limit of digital classification. Elaborate this statement.
6. Describe site specific classification map accuracy assessment
7. What do you mean by Kappa coefficient? Highlight the newer tools and techniques for digital image classification to reduce the classification and mapping errors.
8. Set an example of preparation of classification error matrix /confusion matrix.

Multiple Choice Questions

1. What is the primary goal of image classification?

a) Data visualization

b) Data storage

c) Data categorization

d) Data interpolation

2. Which type of image classification relies on training data with known labels?

a) Supervised classification

b) Unsupervised classification

c) Object-based classification

d) Clustering

3. Which classification method groups pixels based on their statistical similarities?

a) K-Means clustering

b) Random Forest

c) Principal Component Analysis (PCA)

d) Support Vector Machine (SVM)

4. In GIS, what are spectral bands used for in image classification?

a) Capturing metadata

b) Enhancing image resolution

c) Distinguishing different land cover types

d) Georeferencing images

5. Which remote sensing platforms can be used for image acquisition?

a) GIS software

b) Drones

c) Printers

d) Scanners

6. Which of the following is an application of image classification?

a) Web development

b) Video editing

c) Land use and land cover mapping

d) Social media management

7. What is the purpose of an accuracy assessment in image classification?

a) To correct image distortion

b) To measure the quality of training data

c) To evaluate how well a classification model performs

d) To classify satellite images

8. What does multi-temporal analysis involve in image classification?

a) Classifying images acquired at different times

b) Converting images to grayscale

c) Combining images into a mosaic

d) Applying different filters to images

9. Which preprocessing task can improve image classification accuracy by removing atmospheric effects?

a) Data fusion

b) Data interpolation

c) Atmospheric correction

d) Georeferencing

10. What is data fusion in the context of image classification?

a) Combining different types of remote sensing data for better results

b) Removing unwanted data from an image

c) Compressing image files for storage

d) Merging two images into one

11. In image classification, what is the primary purpose of a confusion matrix?

a) To confuse the classification algorithm

b) To visualize image data

c) To evaluate the performance of a classification model

d) To classify land cover types

Answers: 1-c, 2-a, 3-a, 4-c, 5-b, 6-c, 7-c, 8-a, 9-c, 10-a, 11-c.

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