GIS-502/DGIS-502/CGIS-502

M.A. /M.Sc. Geoinformatics/ DGIS/ CGIS

FUNDAMENTALS OF PHOTOGRAMMETRY AND REMOTE SENSING

DEPARTMENT OF REMOTE SENSING AND GIS
SCHOOL OF EARTH AND ENVIRONMENT SCIENCE
UTTARAKHAND OPEN UNIVERSITY
HALDWANI (NAINITAL)

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FUNDAMENTALS OF PHOTOGRAMMETRY AND REMOTE SENSING

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BLOCK 1: INTRODUCTION TO REMOTE SENSING

UNIT 1 - DEFINITION, SCOPE AND EVOLUTION OF REMOTE SENSING

1.1 OBJECTIVES

The objectives of this unit are to acquaint with and to introduce the fundamentals of remote sensing technology to you with respect to the following:

- Need, Scope and Importance of Remote Sensing.
- Concept and Definition
- Satellite Remote Sensing Versus Aerial Photography.
- Historical Overview.
- Evolution of Satellite Remote Sensing in India.

1.2 INTRODUCTION

Fundamentals of remote sensing are written to be primarily used as lecture note for introductory module under unit 1. This unit presents the basic principle of remote sensing data acquisition limiting the scope to the intersection of earth observation and remote sensing. The design of the lecture note was governed by the aim to cover the interests of wide user spectrum and the restriction that a student of Geoinformatics can learn the selected basics in a stipulated time frame. Being used in the beginning of the courses it tries to stimulate conceptual and abstract thinking without overloading it with formulae. It includes photogrammetric subjects and an introduction into techniques of data acquisition. It provides a frame to refer to when more detailed subjects are dealt with later in the programme.

Social well being, Sustainable economic development and environmental protection are the main issues which need adequate decisions. Availability of right information at right time and at right place will make sufficient progress in this particular context. Instrumental to achieving such progress is the availability of geospatial data, the more so the more drastically we exploit the planet earth. Fortunately, you can notice that the awareness increases worldwide of the importance of having access to reliable, detailed, timely and affordable geospatial data. Equally important, the technology of acquiring and providing geospatial data quickly develops stimulated by the rapid advances of information and communication technology.

Geospatial data acquisition is central to earth observation. Earth observation is gathering of information about physical, chemical, biological and geometrical properties of our planet; it helps us to assess the status and monitor changes of the natural and cultural environment. Thus, mapping, monitoring and also forecasting are the uses of earth observation. Earth observation gives us geospatial data. Geospatial data acquisition can be taken as starting point in our development cycle of observing-analysing-designing or planning-constructing or developing-observing etc. There are various tools and techniques for geospatial data acquisition. Which technique will be most suitable and satisfactory; this depends on the role of earth scientists, engineers, biologists, environmentalists and many of the other disciplines. However, the objectives of all those coincide at the collection of maximum amount of unbiased reliable data/information over a large area at less time, lower cost, lesser number of man power and with greater precision. Remote sensing e.g., Satellite remote sensing is the only scientific tool and technique to address the said issues.

The term Remote sensing was first coined by Ms Evelyn Pruitt in the mid-1950`s when she, geographer/oceanographer, was with the U.S. office of Naval Research (ONR) outside Washington, D.C. During 1960s and 1970s, the primary platform used to carry remotely sensed instruments shift from air planes to satellites. Satellite can cover much more land space than planes and can monitor areas on regular basis. Remote sensing is an instrument based technique used in the acquisition and measurement of spatially organized (distributed data/information on some properties (spectral, spatial and physical) of an array of target points (pixels) within the sensed scene that correspond to features, objects and materials. The recording devices not in contact in physical contact under surveillance are applied from the observed target, in which the spatial arrangement is preserved. The techniques involve amassing knowledge pertinent to sensed scene (target) by applying electromagnetic radiation, force fields or acoustic energy through employing cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, solar, thermal devices, seismographs, magnetometers, gravimeters and other sensing instruments.

While introducing and including this unit in your academic course curriculum, you might be very keen to know the objectives, queries like why remote sensing is needed, in which way it is useful to the society, what are its nature, principles, background, importance, merits and limitations. The texts, figures and tabular information of this unit reflect what all this you need.

1.3 DEFINITION, SCOPE AND EVOLUTION OF REMOTE SENSING

1.3.1 Need, scope and importance of remote sensing

There are certain factors responsible for socio-economic development of the Nation. Such factors are like man power, capital, natural resources, environmental conditions, planning, policies, devotion, dedication etc. Remote sensing, being an emerging and burning topic amidst the present day`s scientific and technological development, plays an important key role to evaluate directly or indirectly the said factors and subsequently the contribution towards speedy developmental procedures. For execution of any developmental work you need planning. For affective planning you need very quick, timely and reliable information. A map, either in analogue or digital form, showing the extent, location and spatial distribution of existing manmade and natural resources along with all other environmental/ecological conditions, is an essential tool for providing required information for planning and execution of all developmental work. Remote sensing plays a prominent role in preparing such maps as and when required in addition to all research activities in various disciplines and solving the problems. For evaluating the man power and capital requirement you need spatio-temporal information. The most crucial problems for affective planning are the timely and quick evaluation/assessment of natural resources with respect to their amount, extent, location, spatial distribution, prudent use and changing pattern. Similar is the case of findings of environmental conditions. Remote sensing is exceptionally a powerful tool to solve all such issues. The following examples primarily illustrate the diverse need and importance for remote sensing based information extraction:

Land Revenue department should have up-to-date property boundaries which are mostly coincide with observable terrain features.

A civil engineer has to design a highway. He needs information about the shape of the ground surface. Calculation of actual transportation costs of material can be based on re-surveying terrain relief after construction.

An urban planner may want to identify areas of informal settlement. The different types of houses and their configuration need to be determined. The municipality may furnish infrastructural improvement based on development plan for the identified areas. The urban planner will have to monitor the impact of provisions before proceeding to further planning.

An agronomist is interested in forecasting the overall agricultural production of a large area. He/she needs the size of fields per crop and data on biomass production to estimate the yield. Observing soil properties, sampling of crop types on the ground, monitoring soil degradation will improve the forecasts.

Forest officers need monitoring forest types, density, growing stock, carbon; forest degradation, depletion and desertification for evaluating the conditions of forest resources and its total impact on the surrounding environment and humanity.

An environment analyst is worried about pollutants of waste disposal sites. He/she has to detect dump composition and determine volumes.

A climatologist would like to understand the EL Nino phenomenon. To understand this end she/he needs data on spatial patterns of sea surface temperature at different times, data on sea levels and sea currents, the direction and velocity of surface winds, information about the processes of interaction between ocean and land surfaces, etc. In addition, the climatologists are interested to monitor and to know the overall vegetation cover and condition of the nationwide vegetation cover.

Geologists are interested to know the existing geological, geo-morphological, and hydrological and ground water condition and their impact.

In addition to above main scientific areas, there are many other fields of research and development where remote sensing based surveying is utmost essential. Following is one of the pertinent examples:

In the present context of climate change due to global warming, the role of remote sensing techniques has become a primary spatial indicator for forecasting their end results. Why remote sensing and why not the other techniques of Earth observation? Answer of these questions in view of said context is El Nino. Global warming and the rapid change of climate have an enormous impact on our well being. In early 1998 we observed particularly abnormal weather in many parts of world. There was very heavy rain in otherwise dry areas, causing landslides in Andes. There was drought and huge forest fires in Indonesia. The devastating weather coincided with a strong rise of sea water temperature in the eastern Pacific Ocean. Fishermen of Peru have named the phenomenon of water temperature change El Nino, because it happens around Christmas, not every year but in intervals of 4 to 9 years. The last El Nino event was 2015. The 1982 El Nino event caused an estimated economic loss of 8.2 billions$. The most direct impact of the observed cyclic temperature rise is the interruption of the fishing season in the Eastern Pacific. If we better understood the causes of El Nino and its effect on the climate, we would have a better starting position for taking preventive and mitigation actions. To develop and support this theory, we have to make the observations on sea water temperature and ascertain the changes in space and time. To find out we could place girders in the ocean and continuously measure the temperature there. But this task would have been a very tedious and time consuming keeping in view of vast areal extent of Pacific Ocean and the enormous amount of temperature variability therein. More over this conventional method reflect errors and biased information. However, the remote sensing based thermal scanners on board of the meteorological /environmental NOAA satellites, which can provide us can provide us with data at 1 Km spacing, can provide us the solution. In this technique we process the recording of scanner- which includes the correcting the atmospheric distortions of thermal emission of water to calculate surface temperature and derive sea surface temperature maps (Figure 1).

By comparing the temperature measurement at the girders with the recordings of the scanner we can calibrate the processing and thus obtain accurate temperature values for a network of much higher density than the one of the girders. This principle of “ground control” applies to most of remote sensing methods.

The thermal scanner gives us the temperature of the sea surface not temperature of subsurface currents, while the later is possible with girders. In general, the observations by remote sensing relate to thin layer of the Earth`s surface, which may be considered a limitation of optical remote sensing. Being interested in subsurface features we have to use additional information on how they manifest themselves in surface features.

The NOAA satellites do not only have a thermal scanner onboard (leveled AVHHR) but also other instruments, which provide us with data on atmospheric temperature, the concentration and distribution of ozone in the stratosphere, etc. To acquire data for studying a complex phenomenon like El Nino we have to rely on sensors on various platforms. NASA`s scatterometer aboard the Quick SCAT satellite provides us with information on speed and direction of ocean winds. NASA uses OrbView-2 data to study global warming; it can also provide us with ocean biomass estimates. We use space borne radar and laser altimeters to determine sea level changes.

A remote sensing approach is specifically suited for areas that are difficult to access. A related topic is that of acquiring global or continental data sets. Remote sensing allows data to be acquired globally using the same or similar sensor. This enables methods for monitoring and change detection. Remote sensing has become an important method of earth observation and for many applications it is the only suitable one-since an increasing number of issues are of global concern, such as clmate change, environmental degradation, natural disaster and population growth.

All the following preliminary topics under this chapter highlight the indications towards the contributions of remote sensing for the above issues:

1.3.2 Concepts

Remote sensing means sensing from the remote areas or observation or taking information from far off distance. In the simplest words, remote sensing is acquiring information about an object without touching it. With this concept, you will be able to understand that remote sensing deals with the observation and measurement of objects on the Earth's surface from a distance. The concept of remote sensing also encompasses both the fields of aerial photography and satellite imagery. Both these fields highlight the characteristics of objects of interest for their identification, measurement and analysis without any physical touch or direct contact. Remote sensing (RS), also called earth observation, refers to acquiring information about varieties of spatially distributed areas on the Earth's surface without being in direct contact with the object or area. Humans accomplish this task with aid of eyes or by the sense of smell or hearing; so, remote sensing is day-today business for people. Reading the newspaper, watching cars driving in front of you are all remote sensing activities. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces. Electro-magnetic radiation which is reflected or emitted from an object is the usual source of remote sensing data. However, the common remote sensing systems rely on variations in electromagnetic fields, force fields and acoustic wave fields.

Conventionally, however remote sensing has come to imply that the sensor and target are located remotely apart and the electromagnetic radiation serves as a link between sensor and the object, the Sun being the major source of energy illuminating the earth. The part of this energy is reflected, absorbed and transmitted by the surface. A sensor records the reflected energy.

Remote sensing systems based on electromagnetic field variations include Aerial Remote Sensing, satellite Remote Sensing, Multiband Aerial Photography, Microwave Remote sensing and Radar. Remote sensing systems based on force field variations include Gravity Meter, Magnetometer and Galvanometer. Remote sensing systems based on acoustic wave field variations include Ultrasound, Bat and Ultrasonic phenomena.

1.3.3 Definition

Remote sensing has been defined in many ways. It is the science, art and technique of obtaining information about an object or phenomena, through electromagnetic radiations, from a distance without any physical touch or contact. It can also be defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed without direct contact. Since remote sensing means acquiring information about a phenomenon object or surface while at a distance from it, this name is attributed to recent technology in which satellites and spacecrafts are used for collecting information about the earth surface. This was an outcome of developments in various technological fields from

1960 onward. The technical term "remote sensing" was first used in the United States in the 1960's, and encompassed photogrammetry, photo-interpretation, photo-geology etc. Since Landsat-1, the first earth observation satellite was launched in 1972; satellite remote sensing has become widely used.

According to Dr. Nicholas Short, Remote sensing is a technology for sampling electromagnetic radiation to acquire and interpret non-immediate geospatial data from which to extract information about features and objects on the Earth's land surface, oceans and atmosphere. As the land surface features are changing with the change of environmental conditions, remote sensing encompasses all such degree of dynamism under each satellite pass over the earth surface.

According to National Aeronautics and Space Administration (NASA) remote sensing is 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. This is rather a comprehensive definition highlighting the extensive fields, tools, techniques and scope of remote sensing.

Remote sensing is considered a primary means of acquiring spatial data. Remote sensing measures electromagnetic radiation that interacts with the atmosphere and objects. Interactions of electromagnetic radiation with the surface of the Earth can provide information not only on the distance between the sensor and the object but also on the direction, intensity, wavelength, and polarization of the electromagnetic radiation These measurements can offer positional information about the objects and clues as to the characteristics of the surface materials

In today's world of science, "remote sensing" means observing the Earth with electronically devised sensors from high above the Earth surface.

There are other short definitions of remote sensing which lacks its full understanding. Some of them are as under:

Remote sensing is the process of sensing and measuring objects from a distance without directly coming physically into contact with them.

John R Jensen has defined remote sensing as the acquiring data about an object without touching it. Canada Centre for Remote Sensing (CCRS) has defined remote sensing as 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, analysing and applying that information. It is simple definition but there is no mention about electromagnetic radiation as medium of sensing and the term “distance” from where the object is sensed otherwise the idea of `Remote` will disappear.

1.3.4 Satellite remote sensing versus aerial photography

The use of different and extended portions of the electromagnetic spectrum, development in sensor technology, different platforms for remote sensing (spacecraft, in addition to aircraft), emphasize on the use of spectral information as compared to spatial information, advancement in image processing and enhancement techniques, and automated image analysis in addition to manual interpretation are points for comparison of conventional aerial photography with modern remote sensing system.

During early half of twentieth century, aerial photos were used in military surveys and topographical mapping. Main advantage of aerial photos has been the high spatial resolution with fine details and therefore they are still used for mapping at large scale such as in route surveys, town planning, construction project surveying, cadastral mapping etc. But in the recent period the use of aerial photography has become limited up to a specific purpose because of the following reasons:

Aerial photographs cover very less areas of ground in comparison to satellite images and consequently take more time, money and man power for their interpretation, analysis, mapping and other applications.

Though the pair of aerial photographs provide 3D view of objects after their proper orientation under Mirror Stereoscope and facilitates to derive unbiased, accurate and reliable information but it requires an efficient and skilled personal having good stereoscopic vision.

Procurement of fresh aerial photographs needs more time in comparison to satellite images and it also needs defense clearance from the Ministry of defense.

The work of photo-interpretation is not amenable as the aerial photographs are not procured in digital format.

Following 3 survey companies/organizations are working for taking aerial photographs.

- CPRU, Air Force at Palam, Delhi.
- Air Survey Company at Kolkata.
- NRSC, at Hyderabad.

At present, National Remote Sensing Service Centre (NRSC), Hyderabad, a unit of ISRO, dept. of Space) is the only organization taking photography.

Modern remote sensing system provide satellite images suitable for medium scale mapping used in natural resources surveys and monitoring such as forestry, geology, watershed management etc. However the future generation satellites are going to provide much high-resolution images for more versatile applications.

1.3.5 Historical overview

1.3.5.1 Photography, space science / remote sensing in foreign countries

The concept of photography was developed by Greek mathematician Aristotle by using a pinhole camera in the 5th and 4th centuries. Photography was originally invented in the early

1800s. The world's first chemical photograph was taken in 1826 by Joseph Niépce of France using a process known as heliography. The word "photograph" was coined in 1839 by Sir John Herschel and is based on the Greek meaning "drawing, writing", together meaning "drawing with light". The first black and white aerial photograph was taken in the year 1860 by James Wallace Black from the height of 2,000 feet in Boston by using hot air balloon and during the year 1861 colour photographs were taken by James Clerk Maxwell. In 1897, Alfred Nobel became the first human being in the world to succeed in capturing an aerial photo with the help of a rocket mounted camera. In 1859 Gaspard Tournachon took an oblique photograph of a small village near Paris from a balloon. With this picture the era of earth observation and remote sensing had started. His example was soon followed by other people all over the world. During the period 1900-1914, continuous development with respect to film, mounting base of cameras, height from earth surface etc took place in the field of aerial photography for improving the quality of photographs and the ground coverage.

The first black-and-white photograph from space was taken by the V-2 rocket from an altitude of 65 miles on October, 24th of 1946. The first digital photograph was taken all the way back in 1957; that is almost 20 years before Kodak's engineer invented the first digital camera.

During the Civil War in the United States aerial photography from balloons played an important role to reveal the defense positions in Virginia (Colwell, 1983). Likewise other scientific and ethnical developments this Civil War time in the United States speeded up the development of photography, lenses and applied airborne use of this technology. Table 1 shows the important dates in the development of remote sensing.

The next period of fast development took place in Europe and not in the United States. The World War brought major improvements in the quality of cameras; photographs taken at 15,000 feet (4,572 meters) could be blown up to show footprints in the mud. It was during World War I that aero planes were used on a large scale for photoreconnaissance. Aircraft proved to be more reliable and more stable platforms for earth observation than balloons. But during World War I aerial photographs taken from planes were often highly distorted due to shutter speeds being too slow in relationship to the speed of the plane. Toward the end of the war, M. Fairchild developed a camera with the shutter located inside the lens. This design significantly reduced the distortion problem. In addition, the camera's magazine would prevent uneven spacing. Fairchild also designed an inter-valometer that allowed photos to be taken at any interval. Those developments made the Fairchild camera the best aerial camera system, with modifications, the Fairchild camera remained the desired aerial camera system for the next fifty years. Aerial photography had been taken for more than two-thirds of continental United States, most of which was taken in the later half of the thirties.

In the period between World War I and World War II a start was made with the civilian use of aerial photos. Application fields of airborne photos at that time included geology, forestry, agriculture and cartography. These developments lead to much improved cameras, films and interpretation equipment. The most important developments of aerial photography and photo interpretation took place during World War II. During this time span the development of other imaging systems such as near-infrared photography; thermal sensing and radar took place. Near-infrared photography and thermal-infrared proved very valuable to separate real vegetation from camouflage. The first successful airborne imaging radar was not used for civilian purposes but proved valuable for nighttime bombing. As such the system was called by the military 'plan position indicator' and was developed in Great Britain in 1941. During World War I aerial photographs taken from planes were often highly distorted due to shutter speeds being too slow in relationship to the speed of the plane. Toward the end of the war, M. Fairchild developed a camera with the shutter located inside the lens. This design significantly reduced the distortion problem. In addition, the camera's magazine would prevent uneven spacing. Fairchild also designed an inter-valometer that allowed photos to be taken at any interval. Those developments made the Fairchild camera the best aerial camera system, with modifications, the Fairchild camera remained the desired aerial camera system for the next fifty years.

During the 1950's, aerial photography continued to evolve from work started during World War II and the Korean War. Color-infrared became important in identifying different vegetation types and detecting diseased and damaged vegetation. Multispectral images taken at the same time but in different portions of the electromagnetic spectrum were tested for different uses. Radar technology moved along two paralleling paths, side-looking air-borne radar (SLAR) and synthetic aperture radar (SAR) The U-2 Plane (at 70,000 ft height) was used to take photography throughout the world for a wide variety of purposes, this event symbolizes the beginning of the use of satellites to look at conditions on the Earth's surface and the idea of the term, *"Remote Sensing."*

After the wars in the 1950s remote sensing systems continued to evolve from the systems developed for the war effort. Colour infrared (CIR) photography was found to be of great use for the plant sciences. In 1956 Colwell conducted experiments on the use of CIR for the classification and recognition of vegetation types and the detection of diseased and damaged or stressed vegetation. It was also in the 1950s that significant progress in radar technology was achieved. The term, "remote sensing," was first introduced in 1960 by Evelyn L. Pruitt of the U.S. Office of Naval Research. The period from 1960 to 2010 has experienced some major changes in the field of satellite remote sensing. The background for many of these changes occurred in the 1960 and 1970s. Some of these changes outlined below:

i) The term "remote sensing" was initially introduced in 1960. Before 1960 the term used was generally aerial photography. However, new methods and technologies for sensing of the Earth's surface were moving beyond the traditional black and white aerial photograph, requiring a new, more comprehensive term be established.

ii) The 1960s and 1970s saw the primary platform used to carry remotely sensed instruments shift from air planes to satellites. Satellites can cover much more land space than planes and can monitor areas on a regular basis.

iii) Imagery became digital in format rather than analog. The digital format made it possible to display and analyze imagery using computers, a technology that was also undergoing rapid change during this period. Computer technology was moving from large mainframe machines to small microcomputers and providing information more in graphic form rather than numerical output.

iv) Sensors were becoming available that recorded the Earth's surface simultaneously in several different portions of the electro-magnetic spectrum. One could now view an area by looking at several different images, some in portions of the spectrum beyond what the human eye could view. This technology made it possible to see things occurring on the Earth's surface that looking at a normal aerial photograph one could not detect.

v) Finally, the turbulent social movements of the 1960s and 1970s awakened a new and continuing concern about the changes in the Earth's physical environment. Remotely sensed imagery from satellites - analyzed and enhanced with computers - made it possible to detect and monitor these changes. Thus, societal support was and continues to remain strong for this technology, even though very few people are familiar with the term, remote sensing.

Today, many satellites, with various remote sensing instruments, monitor the Earth's surface. These satellites and their respective remote sensing programs can trace their origins back to the CORONA and Landsat programs. CORONA was a secretive military reconnaissance program that continues to the present time through the advanced Keyhole satellites and Landsat was an open Earth resources program that also continues through more advanced Landsats and other satellite resource monitoring programs. This unit centers on the development and growth of these two programs.

The CORONA Program occurred between 1959 and 1972 but the American public did not know about the project until 1995 when President Bill Clinton ordered the declassification of the imagery. Vice President Al Gore urged the declassification of the imagery in order to assist scientists in conducting various environmental studies.

Remote sensing by satellite began in 1960 with the CORONA project, a series of high-resolution satellites used for surveillance of the Soviet Union. These satellites operated at low orbits (150-450 km) and used cameras to obtain photographic images.13 Also in 1960, the United States launched the first weather satellite, TIROS-1. Its purpose was to provide early warning of major storms. In 1972, the first Earth monitoring satellite — Earth Resources Technology Satellite (ERTS-1) —was launched. The purpose of ERTS-1 was to gather information about agricultural and environmental conditions. This satellite was renamed Landsat 1 and was the first of three satellites that made up the first Landsat generation (Landsat 1-3). Landsat 1, 2 and 3 carried two scientific instruments: a return beam vidicon (RBV) camera and a multispectral scanner (MSS). On Landsat 1 and 2, the RBV camera had a resolution of 70-80 m; on Landsat 3 it was 26-40 m. The MSS on Landsat 1 and 2 scanned in four visible wavelengths; a fifth band for measuring thermal (infrared) radiation was added to Landsat 3. MSS resolution was 80 meters for the first four bands, and 240 m for the fifth band. In 1982, the first of a second generation Landsat series was launched— Landsat 4. An identical spacecraft, Landsat 5, was launched in 1984. These satellites each had 30 m Thematic Mappers and 80 m MSS's (described earlier). Landsat 6 was launched in 1993. but was lost when its launch vehicle failed. The most recent member of the series, Landsat 7, was launched in 1999. Landsat 5 and Landsat 7 are both currently operating.

1.3.5.2 Commercial Remote Sensing

Since the beginning of the space age, observation of the Earth (remote sensing) by satellite and human-occupied space vehicles has played an important role in U.S.and international space programs. The earliest remote sensing satellites were used for national security purposes. Later on , however, space policy makers and others recognized the potential importance of remote sensing for civilian purposes such as environmental and climate monitoring. Such satellites began appearing in the early 1960s. Furthermore, once these satellites were in operation, many in the space community began advocating transferring responsibility for developing and operating civilian remote sensing satellites to the private sector. This effort became the policy of the United States in 1979, and, since then, congressional and administrative action has attempted to implement that policy.

Since the late 1970s, NASA launched Landsat satellites and later by the success of the French SPOT satellite, NASA took steps to promote a commercial remote sensing industry in the United States. Commercialization Act of 1984 set out terms for transferring the government-owned Landsat satellite program to the private sector. The Land Remote Sensing Policy Act of 1992 repealed the previous Act, declared commercialization of land remote sensing to be a long-term policy goal of the United States, and established procedures for licensing private remote sensing operators. While a commercial satellite remote sensing industry has emerged in the United States in recent years, it has not been the success envisaged by its early proponents. Competition from aerial remote sensing (aircraft and balloons); the slow development of a market for remote sensing products outside local, state, and federal governments; competition from government-subsidized, foreign remote sensing satellites; and regulations resulting from national security concerns, among other factors, have slowed the development of a healthy commercial satellite remote sensing industry. A commercial remote sensing industry has been established, however, and by all accounts is growing. The images of the aftermath of the terrorist attack on the World Trade Center obtained by the Ikonos 2 satellite operated by Space Imaging gave particular prominence to the existence of the commercial remote sensing industry in this country. The U.S. Land Remote Sensing Act of 1992 gave new impetus to the industry by permitting commercial companies to launch high resolution (1 meter or less) remote sensing satellites. Competition from aerial remote sensing; the slow development of a market for remote sensing products outside local, state, and federal governments; competition from government-subsidized, foreign remote sensing satellites; and regulations resulting from national security concerns are among other factors that have slowed the development of the U. S. commercial satellite remote sensing industry. Federal support for the industry is concentrated in the Department of Defense's (DOD's) National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA). NIMA support, however, has been spotty because of funding limitations and DOD actions that are limiting the need for imagery by NIMA from commercial satellites. The industry is also creating national security benefits and challenges. The U.S. intelligence community is finding that commercial remote sensing images can supplement those of its own satellites. At the same time, the possibility that potential adversaries and terrorist groups may obtain access to sensitive images has resulted in federal regulations that restrict acquisition and publication of such images for national security and foreign policy reasons. This shutter control provision is controversial and is likely to result in a court challenge if and when it is invoked. In the current situation in Afghanistan, the U.S. government has avoided this possibility by contracting with Space Imaging, a private firm, for exclusive rights to all images covering the Operation Enduring Freedom area of operations. Future growth of the U.S. industry will likely depend on steady and broad-based federal support, development of new applications that result in an expanding market, and resolution of regulatory uncertainties, primarily the shutter control provisions.

Table 1.1 Milestones in the History of Photography and Satellite Remote Sensing

Year	Developments in the field of Remote Sensing
1800	Discovery of Infrared by Sir W. Herschel
1839	Beginning of Practice of Photography
1847	Infrared Spectrum Shown by J.B.L. Foucault
1859	Photography from Balloons
1873	Theory of Electromagnetic Spectrum by J.C. Maxwell
1909	Photography from Airplanes
]916	World War I: Aerial Reconnaissance
1935	Development of Radar in Germany
1940	WW II: Applications of Non-Visible Part of EMS
1950	Military Research and Development
1957	Earth Satellite `Sputnik 1` launched by Soviet Union.
1959	First Space Photograph of the Earth (Explorer-6)
1960	First TIROS Meteorological Satellite Launched
1962	The term ”Remote Sensing” first appeared
1970	Skylab Remote Sensing Observations from Space
1975	NOAA`s first geostationary earth orbiting satellite (GOES-1)
1972-78	Launch Landsat (ERTS) -1,2 and 3: MSS and RBV Sensors
1972	Advances in Digital Image Processing
1982	Launch of Landsat -4 : Second Generation of Landsat Sensor (Thematic Mapper;s:TM)
1984	Landsat-5, identical to Landsat-4
1993	Landsat -6 (failed lateron)
1994	Synthetic Aperture Radar (SAR), image mode –ERS-1 (European Remote Sensing)

1995	Synthetic Aperture Radar (SAR), image mode –ERS-2
1996	Synthetic Aperture Radar (SAR), image mode –RADARSAT
1996	Synthetic Aperture Radar (SAR), image mode –JERS
1999	Landsat -7, the most recent member of Landsat series (Sensor-ETM)
Commercial Developments in High resolution Remote Sensing Satellites	
1986	French Commercial Earth Observation Satellite SPOT 1
1986	Development of Hyper-spectral Sensors
1990	Development of High Resolution Space borne Systems
1990	French Commercial Earth Observation Satellite --SPOT 2
1993	French Commercial Earth Observation Satellite SPOT 3
1998	Towards Cheap One-Goal Satellite Missions
1999	Launch EOS : NASA Earth Observing Mission
1999, 2000	Launch of IKONOS 1&2 by Space Imaging.
1999, 2000	OrView 3&4 by ORBIMAGE, USA
2000, 2001	QuickBird 1&2 by Digital Glob,USA.
2000,2002, 2004	EROS- A&B by Imagesat International ,Israel

1.3.6 Photography, Remote Sensing/Space Science in India

1.3.6.1 Photography/Aerial photography (Aerial Remote Sensing)

Studies in scientific astronomy in India are known to date back at least to the 5th century. In the early part of 18th century, Maharaja Jai Singh (1686-1743) AD made significant contribution to Indian Astronomy by building a chain of five observatories at Delhi, Jaipur, Varanasi, Ujjain and Mathura With various kinds of instruments all built of masonry to great precision.

The existence of photography in India can be traced back as early as the 16th century. Later experiments started and the process of photography became more technologically advanced. The Photographic art arrived in India as early as 1850s under the Colonial Powers. Later on, in the 19th century, India had achieved the development of photographic art. Initially, Aerial Photography was carried out with the help of pigeons, kites rockets and balloons. The first recorded aerial photography in India was flown in 1927 on a scale of 4" mile. Since then, over the years, almost the entire country has been aerially photographed on various scales. The actual use of aerial photographs in India started w.e.f 1945 viz., after World War II for the preparation of topographical maps. Since that time Survey of India is continuously using Aerial photographs for the preparation of topographical of maps. Since 1965 Indian Institute of Remote Sensing, the then Indian Photo-interpretation Institute and Forest Survey of India the then Pre-investment Survey of Forest Resources have been using aerial photographs for the preparation of various types of maps and other research activities.

1.3.6.2India in Space Pioneers

The beginning of organized research in space science goes back to forties when the distinguished scientist Homi Bhabha and Vikram Sarabhai conducted research on Cosmic rays. In 1962, Sarabhai organized space research as chairman of Indian National Committee for Space Research (INCOSPAR). He set up of the Thumba Equatorial Rocket Launching Station and began manufacturing sounding rockets in India. He drew up plans to transmit education to remote villages across India with the Satellite Instructional Television Experiment (SITE). After Sarabhai died in 1971, the Vikram Sarabhai Space Center (VSSC) in Thiruvananthapuram is named for him. Another early developer of India's space program was Satish Dhawan. He was the longest serving director of the Indian Institute of Science. Following are the step by step developments in the field of space science and remote sensing programms.

- The establishment of Indian national committee for space research (INCOSPAR) at PRL, Ahmedabad in 1962 marked the beginning of Indian space programme. INCOSPAR works on establishing Thumba Equatorial Rocket Launching Station (TERLS).
- The first sounding rocket was launched on Nov. 21, 1963 from TERLS.
- Space Science & Technology Centre (SSTC) was established in Thumba during year1965. .
- During 1967 Satellite Telecommunication Earth Station was erected at Ahmedabad.
- TERLS dedicated to the United Nations on February 2, 1968.
- Indian Space Research Organisation (ISRO) was created on 15th August 1969 in the Department of Atomic Energy. Since then, ISRO has managed India's space research and the uses of space for peaceful purposes.
- The Indian space programme was institutionalized in November, 1969 with the formation of Indian Space Research Organization (ISRO).
- The government established the Space Commission and the Department of Space (DOS) in June, 1972.
- DOS conducted the nation's space activities for ISRO at four space centers across the country.
- The first Indian space satellite "ARYABHATA" was named after the name of an astronomer cum mathematician and was launched on 19th April, 1975.
- Bhaskara-I, an experimental satellite for earth observations, launched on June 7,1979.
- On August 10,1979 the first experimental launch of an SLV-3 rocket could not put its Rohini Technology Payload satellite in orbit.

- India successfully launched its own Rohini-1 satellite on July 18,1980 on SLV rocket from the Sriharikota Island launch site.
- First developmental launch of SLV-3. RS-D1 placed in orbit on May 31, 1981..
- APPLE, an experimental geostationary communication satellite successfully launched (June 19, 1981).
- Bhaskara-ll launched on November 20,1981.
- INSAT-1A launched on April 10, 1982 and deactivated on September 6,1982.
- Second developmental launch of SLV-3. RS-D2 placed in orbit on April 17, 1983.
- INSAT-1B,launched on August30,1983.
- Indo-Soviet manned space mission on April 1984.
- First developmental launch of ASLV with SROSS-1 satellite on board (March 24, 1987). Satellite could not be placed in orbit.
- Launch of first operational Indian Remote Sensing Satellite, IRS-1 A on March 17, 1988.
- Second developmental launch of ASLV with SROSS-2 on board (July 13,1988). Satellite could not be placed in orbit.
- INSAT-1 C launched on July 22, 1988. Abandoned in November 1989.
- INSAT-1 D launched on June 12, 1990. Identical to INSAT-1A. Still in service. A third stage motor landed from its launch, landed in Australia in 2008. It was launched by Delta 4925 vehicle.
- 3rd developmental launch of ASLV with SROSS-C on board (May 20, 1992). Satellite placed in orbit.
- INSAT-2A, the first satellite of the indigenously-built second-generation INSAT series, launched on July 10, 1992.
- INSAT-2B, the second satellite in INSAT-2 series, launched on July 23,1993.
- First developmental launch of PSLV with IRS-1 E on board (September 20, 1993). Satellite could not be placed in orbit.
- INSAT-2C, the third satellite in I NSAT-2 series, launched on December 7,1995.
- Launch of third operational Indian Remote Sensing Satellite, IRS-1 C on December 28, 1995.
- INSAT-2E, the last satellite in the multipurpose INSAT-2 series, launched by Ariane from Kourou Island, French Guiana (April 3, 1999).
- Indian Remote Sensing Satellite, IRS-P4 (OCEANSAT-1), launched by Polar Satellite Launch Vehicle (PSLV-C2) along with Korean KITSAT-3 and German DLR- TUBSAT from Sriharikota on May 26, 1999.

- Successful flight test of Geosynchronous Satellite Launch Vehicle (GSLV) on April 18, 2001 with an experimental satellite GSAT-1 on board.
- Successful launch of PSLV-C3 on October 22, 2001 placing three satellites - India's TES, Bangalore.
- PROBA and German BIRD, into Polar sun-synchronous orbit.
- Successful first operational flight of GSLV (GSLV-F01) from SDSC SHAR. EDUSAT placed in GTO (September 20, 2004).
- The Rohini-3 communications satellite, launched in August, 1983.
- By the end of 1985, Rohini -3 had extended nationwide television coverage from 20 to 70 percent of the population. Today it is about more than 90 %.
- Indian cosmonaut Rakesh Sharma spent eight days in 1984 aboard the USSR's space station Salyut 7 (138th man in space).
- The first developmental launch of a larger Augmented Satellite Launch Vehicle (ASLV) rocket, on March 24, 1987, did not place its SROSS-1 satellite in orbit. It could have lifted a 300-lb. satellite to an orbit 250 miles above Earth.
- The second developmental launch of an ASLV in July, 1988 also failed.
- Later, the third and fourth attempts had been successful.
- During the year1992 the Indian-built INSAT-2 geostationary communications and meteorological satellite superseded an American-built INSAT-1.
- The even larger Polar Satellite Launch Vehicle (PSLV) debuted in September, 1993 but failed to attain orbit. Its individual elements were successful. PSLV can lift a one-ton satellite to a Sun-synchronous polar orbit.
- The first launch of a still larger Geosynchronous Satellite Launch Vehicle (GSLV) rocket was successful on April 18, 2001. GSLV can boost a 2.5-ton satellite.
- On 16th September 2018 the Polar Satellite Launch Vehicle (PSLV-C42) successfully launched two satellites – Nova SAR and S1-4 from Satish Dhawan Space Centre (SDSC) SHAR, Sriharikota.
- In addition to Earth Observation, Communication and Research satellites, ISRO has launched 9 Navigation Satellites during the period 2013 to 2018 from the launch vehicles PSLV-C22, 24,26,27,31,32,33,39 and 41.
- In addition to placing large communications and weather satellites in high stationary orbits, India plans to use GSLV rockets to send probes away from Earth to explore the planets. Missions to Mercury, Venus and Mars are under consideration.
- From the last 5 decades, ISRO has launched more than 80 satellites for various scientific and technological applications like mobile communication, direct to home services, meteorological observations, telemedicine, telecommunication, disaster warning, radio networking, remote sensing etc.

1.3.7 Evolution of satellite remote sensing in India

Following the successful demonstration flights of Bhaskara-1 and Bhaskara-2 - experimental Earth observation satellites developed and built by ISRO (Indian Space Research Organization) - and launched in 1979 and 1981, respectively, India began the development of an indigenous IRS (Indian Remote Sensing Satellite) program. India realized quite early that sustaining its space program in the long run would depend on indigenous technological capabilities (in particular, US export restrictions made this clear). India under its different earth observation missions and programmes has launched varieties of satellites which have been proved to be an indispensable tool for natural resource mapping, monitoring, management and planning including environmental assessment at global, regional and local levels. The success of missions and developmental programmes has been based on its judicious scientific approach of selecting multi- space platform, multi-resolution, and synoptic viewing capabilities. Keeping this in mind, besides building satellites, India embarked as well on satellite launch vehicle development in the early 1970s. As a consequence, India has two very capable launch systems at the start of the 21st century, namely PSLV (Polar Satellite Launch Vehicle) and GSLV (Geosynchronous Satellite Launch Vehicle).

IRS is the integrated LEO (Low Earth Orbit) element of India's NNRMS (National Natural Resources Management System) with the objective to provide a long-term space borne operational capability to India for the observation and management of the country's natural resources (applications in agriculture, hydrology, geology, drought and flood monitoring, marine studies, snow studies, and land use). The intend of the program is to create an environment of new perspectives for the Indian research community as a whole, to stimulate the development of new technologies and applications, and to utilize the Earth resources in more meaningful ways.
Note: The INSAT system is India's GEO (Geosynchronous Earth Orbit) element, providing for simultaneous domestic communications and earth observation functions.

1.4 SUMMARY

In this unit the fundamentals of remote sensing have been explained for your preliminary understanding of the topic. The need and scope, concepts, definitions, principles, historical overview, evolution, merits and demerits highlight the subject for gaining its knowledge in detail within the next successive topics/units.

The topic highlights why and what is remote sensing, its historical background, scope, evolution in foreign countries and India. How our country has progressed in this particular field of remote sensing and space science and subsequent developments in the fields of socio-economy, man -made and natural resources, infrastructure and overall environment. The conventional methods of doing surveys or any other kinds of manual work in the said fields are tedious and time consuming. The key advantages of using remote sensing tools and techniques are less time, lower cost, lesser number of man powers with greater precision, reliability and unbiased results.

Remote sensing technology has developed from balloon photography to aerial photography to multi-spectral satellite imaging. Satellite remote sensing is an outgrowth of aerial photography which has some merits and demerits. But the concept of photography and photo-interpretation was diluted keeping in view of fast developmental procedures of satellite remote sensing techniques. In addition to above said fields, the space science and remote sensing are advancing, with the passes of time, in various scientific, engineering, communication and information technology fields.

1.5 GLOSSARY

SLV: Satellite Launch Vehicle

ASL: Augmented Satellite Launch Vehicle

AVHHR: Advanced Very High Resolution Radiometer

PSLV: Polar Satellite Launch Vehicle

GSLV: Geostationary Launch Vehicle

EOS: Earth Observation Satellite

NASA: National Aeronautics and Space Administration

APPLE: Ariane (a launch vehicle of ESA) Passenger Payload Experiment

LANDSAT: Land Satellite (It is also renamed as ERTS)

INSAT: Indian National Satellite

SPOT: Satellite Pour I`Observation de la Terre (French satellite)

RESOURCESAT: It is an advanced remote sensing satellite built by ISRO, known as IRS-P6

CARTOSAT: The name cartosat is a combination of cartography and satellite (cartosat is a stereoscopic Earth observation satellite)

ERTS: Earth Resources Technology Satellite

TERLS: Thumba Equatorial Raucket Launching Station (Indian Spaceport)

RESAT: Radar Imaging Satellite

SARAL: Satellite with ARgos and ALtiKa is a cooperative altimetry technology mission of Indian Space Research Organization (ISRO)

1.6 ANSWER TO CHECK THE PROGRESS

Q1. What is Remote Sensing?

Q2. Why do we need of Remote Sensing?

Q3. Write the definitions of Remote Sensing?

Q4. Define Aerial photography?

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1.8 TERMINAL QUESTIONS

1- Define remote sensing and describe its concepts?

2- Highlight the need, scope and importance of satellite remote sensing.

3- Differentiate satellite remote sensing versus Aerial photography

4- Highlight the points of historical overview of satellite remote sensing both in India and Foreign countries.

5- Describe the history of photography and aerial photography in India and abroad.

6- Describe the contribution of India in space pioneers and space science.

7- List out the experimental and operational remote sensing satellites of India and the year of their launch.

UNIT 2 - ELECTROMAGNETIC RADIATION (EMR) AND ATMOSPHERIC WINDOWS

2.1 OBJECTIVES

After reading this unit you will be able to:

- Know about Electromagnetic Radiation and Electromagnetic Energy
- Know about Waves and Photons
- Gaining Knowledge about Sources of Electromagnetic Energy (EM)
- Understanding Sensing of Electromagnetic Energy (EM)
- Understand about Electromagnetic Waves
- Explain Electromagnetic Spectrum
- Explain Interaction of the EMR with earth surface matter
- Know Interactions of EMR with the Atmosphere

2.2 INTRODUCTION

Acquisition of Remote sensing data challenges you to make choices. Out of many sensors which of the sensor will be reliable and up to the mark for acquiring particular information. If the sensor producing several images, such as a multispectral scanner, which image or which combination of images to use for correct interpretation. When interpreting a multi coloured image, what causes the sensation `red, green, blue etc? For all this, you must have the understanding of physics of remote sensing including the basics of electromagnetic energy and electromagnetic radiation. It will help you in making more profound choices and enable you to deal with the types of sensors and data interpretation.

A standard photograph is an image of an object or scene, which very closely resembles direct sensing with your eyes. We see that the roof is red or black, tree is green, and sky is blue. The sensation of colour is caused by Electromagnetic radiation (EMR) and red, green, blue relate to forms of energy which we commonly refer to as light. Light is EMR that is visible to the human eye. As we are interested in earth observation through remote sensing our light source is Sun. The Sun emits light, the earth surface features reflect it, and the photosensitive cells (cones and rods) in our eyes detect it. When we look at a photograph/image, it is the light reflected from it, which lets us observe that a wall of the building is made of bricks. Light is not the only form of energy radiated from the Sun and other bodies. The sensation `warm` is caused by thermal emission. Sun tanning our body generating vitamin D is triggered by Ultraviolet (UV) radiation.

The foundation of remote sensing technology is based on the measurement and interpretation of the patterns of electromagnetic radiation. It is a dynamic form of energy, transmit cross space in the wave form and in the speed of light. The whole range of EMR is called spectrum. EMR is characterized by wavelength and frequency. Different wavelengths or frequencies indicates different portion of electromagnetic radiation. Electromagnetic radiation interact with atmosphere which causes significant absorption and/or scattering of the wavelength, such as Rayleigh (molecular) scattering, Mie (non-molecular) scattering, and non-selective scattering. Electromagnetic radiation also interacts with the surface materials in the form of absorption, reflection, and transmission. In this unit you focus your understanding and learn the concepts and characterization of electromagnetic radiation towards remote sensing for earth observation. It has been based on the following objectives:

2.3 ELECTROMAGNETIC RADIATION (EMR) AND ATMOSPHERIC WINDOWS

2.3.1Electromagnetic radiation and Electromagnetic energy

2.3.1.1 Physical basis of Electromagnetic Radiation (EMR)

There are waves of energy and light moving all around us in the form of TV and audio transmissions, gamma radiation from space, and heat in the atmosphere. Scientists call them all electromagnetic radiation. The waves of energy are called electromagnetic (EM) because they have oscillating electric and magnetic fields. Scientists classify them by their frequency or wavelength, going from high to low frequency (short to long wavelength). For a wave with a high frequency, it has a lot of energy, so it could be a gamma ray or x-ray. If it has low frequency, it has less energy and could be a TV or radio wave.

All EM energy waves travel at the speed of light. No matter what their frequency or wavelength, they always move at the same speed. Some properties of waves, such as diffraction and interference, are also seen in EM radiation. Scientists have figured out that there are tiny particles in these waves; they are called photons. The photons are specific units, or packets, of energy. Sometimes those particles interact with each other and change the way the light originally behaved.

All types of EM radiation are useful to the world of science. Look at radio waves as an example. Radio stations and ham radio operators of Earth work with radio waves every day. Radio waves are used to carry communications from one point to another. Radio waves are also extremely important to astronomers. Astronomers are constantly listening to the radio waves of other galaxies to learn more about their stars. Stars give off large amounts of EM radiation across the entire spectrum, and we can study that radiation to learn more about the universe.

An important idea you should always remember is that sometimes we use the word radiation. When you think of radiation, you probably think about nuclear power plants, bombs, and X-rays. Sure, those are all types of radiation. Nevertheless, more important to physics is the idea that all light is considered radiation. That means that everything from television and radio waves to gamma rays are all types of radiation. Think about the word *LASER*. The R stands for radiation, while a laser is just a souped-up flashlight. Think about heat. Most heat is actually infrared light being given off by an object. That heat is also radiation.

2.3.2 Basics of Electromagnetic radiation (EMR)

2.3.2.1 Electromagnetic Theory

Magnetism and electricity were once considered as separate forces. However in the year 1873, Clerk Maxwell, a Scottish physicist developed a unified theory of electromagnetism. Its study deals with how the electrically charged particles interact among themselves and with the magnetic field. The main electromagnetic interactions are provided in the points mentioned below.

- Magnetic poles come in pairs that repel and attract each other, just like electric charges do.
- The force of repulsion or attraction between two electric charges is inversely proportional to the square of the distance between the particles.
- An electric field in motion produces a magnetic field.
- A wire with electric current produces a magnetic field whose direction depends on the direction of the electric current.

2.3.2.2 Electromagnetic Radiation (EMR) Principles

EMR

- is radiated by atomic particles at the source (the Sun),
- propagates through the vacuum of space at the speed of light,
- interacts with the Earth's atmosphere,
- interacts with the Earth's surface,
- interacts with the Earth's atmosphere once again, and
- Finally reaches the remote sensors where it interacts with various optical systems and detectors.

2.3.2.3 Properties of Electromagnetic Radiation

When electromagnetic radiation occurs, the electron radiations are released as photons. These are bundles of light energy or quantized harmonic waves which travel at the speed of light. Then based on the wavelength of the electromagnetic spectrum, the energy is grouped into different categories. These magnetic and electric waves travel perpendicular to each other and have some characteristics like wavelength, amplitude, and frequency. They can travel through empty space. Waves other than electromagnetic waves have to travel through some substance. For example, sound waves will need either a solid, liquid or gas to pass through. Some basic properties of Electromagnetic Radiation are given in the points mentioned below:

- The speed of light is always constant.
- Wavelength is commonly characterized by the symbol 'λ'. It is the measure between the distance of either troughs or crest.

2.3.2.4 Electromagnetic Energy

Electromagnetic radiation can be modeled in two ways by waves and by radiant energy bearing particles called photons. The first publication on the wave theory date back to the 17th century. According to the wave theory light travels in straight line (unless there are outside influence) with energy levels changing in a wave fashion. Light has two oscillating components; the energy constantly changes between electrical energy and magnetic energy. We call it, therefore, electromagnetic energy. The two components interact; an instance of positive electrical energy coincides with a moment of negative magnetic energy. The wave behavior of light is common to all forms of EMR. All EM energy travels at the speed of light, which is approximately 300,000 km/s. or this is fast, but the distances in space are astronomical. It takes eight minutes for the Sun light to reach the earth, thus when we see

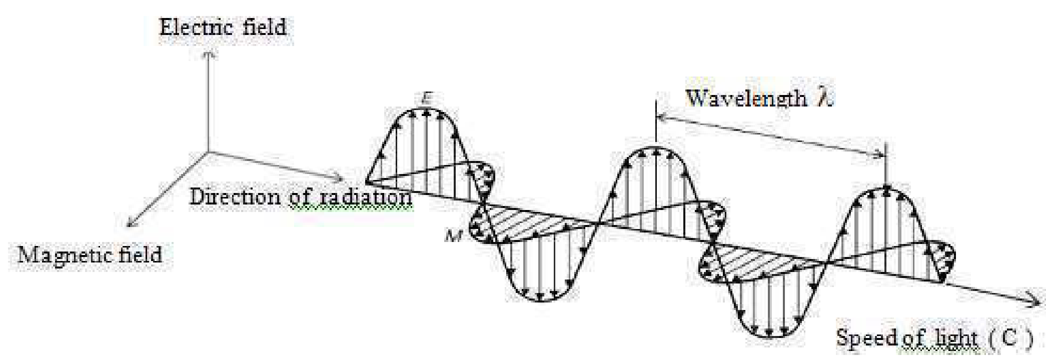
Sunrise, it actually occurred that much earlier. Because of the straight line travel we use the notion of light ray in optics.

2.3.3 Waves and Photons

Electromagnetic radiation is a dynamic form of energy that propagates as wave motion. It occurs when an atomic particle, like an electron, is accelerated by an electric field, causing it to accelerate. The waves have two components, Electric field E and Magnetic field M, both perpendicular to the direction of propagation of light//radiation direction. The wavelength λ is the differentiating property of the various types of EMR. It is the distance the energy travels from a moment of maximum electrical energy until reaching the maximum again (or any other two corresponding energy states; Figure 2.1.). Wavelength is the length of one cycle of oscillation. It is usually measured in micrometers. The amount of time needed by an EM wave to complete one cycle is called the period of wave. The reciprocal of period is called *frequency* of the wave. Thus, the frequency is the number of cycles of the wave that occur in one second. Usually the frequency is measured in hertz (Hz; 1Hz =1 cycle per second. This period corresponds to the wavelength of radiation. Thus, the parameters that characterize a wave motion are wavelength (λ), frequency (ν) and velocity (c). Since the speed of light is constant, the relationship between wavelength and frequency is:

Figure 2.1 Electromagnetic waves.

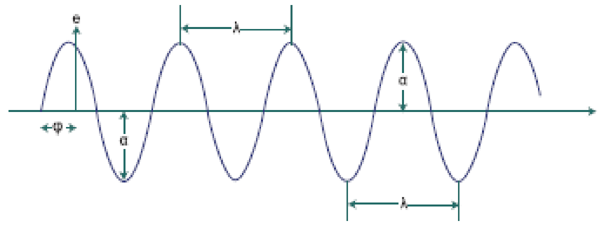
$$c = \lambda \times \nu.$$



Based on Einstein`s famous energy formula, the letter c is used commonly as symbol for the speed of light and v is the frequency.

The *amplitude*, a, is the peak value of the wave. The longer the amplitude the higher the energy of wave (you know this also from water waves). In imaging by active sensors (in the next unit), the amplitude of the detected signal is used as intensity measure and the *phase, Q,* (Figure 2.2) is an important quantity for precise ranging.

Figure 2.2: Characteristics of Electromagnetic waves



Since electromagnetic energy radiates in accordance with the basic wave theory. It describes as travelling in a harmonic sinusoidal fashion at the velocity of light (Figure 2.2). Although many characteristics of EM energy are easily described by wave theory, another theory known as particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that EMR is composed of many discrete units called photons/quanta. The relationship of energy of photon is as below:

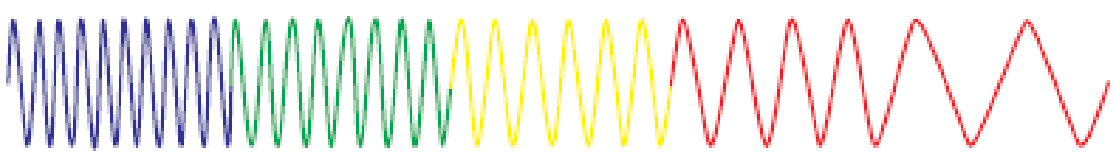
$$Q = hc / \lambda = h v \text{ --- (1)}$$

Where
Q is the energy of quantum,
h = Planck's constant

The energy carried by a single photon of light is just sufficient to excite a single molecule of photosensitive cell of the human eye, thus contributing to vision. It follows from Equation - (1) that long wavelength radiation has a low frequency level while short wavelength radiation is of high energy/frequency. Blue light is more energetic than red light (Figure 2.3). EM radiation beyond violet light is progressively dangerous to our body due to increasing frequency. UV radiation is already harmful to our eyes, so we wear sunglasses to protect them.

Figure 2.3 Relationship between wavelength, frequency and energy

Short wavelength **Long wavelength**



High frequency/ High energy **Low frequency/ Low energy**

2.3.4 Sources of electromagnetic energy (EM)

The Sun is the ultimate source of EM energy, but it is not the only one. All matter with an absolute temperature above zero emits EM energy because of molecular agitation. Absolute temperature is conventionally measured in kelvins (K) with Celsius-scaled increments. Absolute zero (0 K = -273.15^0 C) is the lowest possible temperature where nothing could be colder; at 0 K molecules do not move. The global mean temperature of the earth`s surface is

288 K and the temperature of objects on earth is rarely deviates very much from this mean over a finite period. Earth`s surface features, therefore, emit EM energy. Solar radiation constantly replenishes the energy that the earth loses into space. The Sun`s temperature is about 6000 K. The Sun emits 44% of its energy as light and 48% as infrared radiation.

The Sun is an approximate black- body and so are stars. The black-body is theoretical object with assumed extreme properties, which helps as in explaining EM radiation. A black body absorbs 100% of the radiation that hits it, it does not reflect any; thus, it appears perfectly black. A black- body has the capability of re-emitting all the energy it receives. You may say a black-body has the maximum emissivity of 1. A black- body emits energy at every wavelength (Figure 2.4). The energy emitted by a black body is called black- body radiation.

A black body can have different temperatures. The temperature of the black –body determines the most prominent wavelength of black-body radiation. At room temperature, black-bodies emit prominently infrared energy. When heating up a black-body beyond 127 K (1000^0 C) emission of light becomes dominant, from red, through orange, yellow and white (at 6000 K) before ending up at blue, beyond which the emission includes increasing amounts of ultraviolet radiation` White` is special , it is not colour but a perfect mixture of colours. At 6000 K a black-body emits radiant energy of all visible wavelengths equally. Higher temperature corresponds to a greater contribution of radiation with shorter wavelengths. Figure illustrates the physics of what you see when a blacksmith heats a piece of iron, or what we observe when looking at candle. The flame appears light- blue at the outer core; there the flame is the hottest with a temperature of 1670 K. The centre appears orange, with a temperature of 1070 K. Generally flames, flames show different colours (depending on the burning material, the temperature of surrounding and the amount of oxygen) and have accordingly had different temperatures (in the range of 600^0C to 1400 ^{0}C). Colours tell you about temperature. You can use colour to estimate, eg, temperature of a lava flow- from a safe distance. More general, if you could build sensors, which allow you to detect and quantify EM energy of different wavelengths (outside the visible range), you could use Remote Sensing recordings to estimate object temperature. You also notice from the black-body radiation curves (Figure) that the intensity increases with increasing temperature; the total radiant emittance at a certain temperature is the area under a curve.

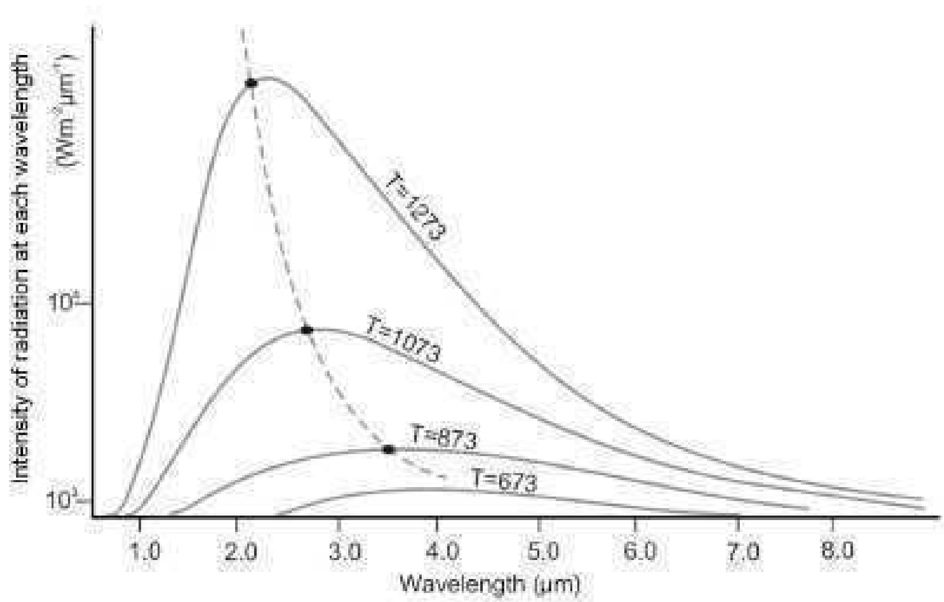
When quantifying energy you can use different measures. The amount of energy is commonly expressed in joule. You may be interested, however, in the radiant energy per unit time, called the radiant power. We measure the power in watt (W; 1W=1 joule per second). Radiant emittance is the power emitted from a surface; it is measured in watt per square meter (Wm^{-2}). The spectral radiant emittance characterizes the radiant emittance per wavelength; it is measured in $Wm^{-2}\mu m^{-1}$. (This is the unit used in the Figure 4.) Radiance is the frequency used in Remote Sensing. It is the radiometric measure, which describes the amount of energy being emitted or reflected from a particular area per unit solid angle and per unit solid time. Radiance (observed intensity) is usually expressed in $Wm^{-2}sr^{-1}$. Irradiance is the amount of incident energy on a surface per unit area and per unit time. Irradiance is usually expressed in Wm^{-2}.

Real objects can only approximate black-bodies; they can re-emit some 80 98% of the received energy. The emitting ability of real material is expressed as dimensionless ratio called emissivity (with value between 0 and 1). The emissivity of a material specifies how well a real body emits energy as compared with a black-body. A surface`s spectral emissivity depends on several factors, such as temperature,, emission angle and wavelength. Observing the material`s emissivity help us, among others, in modeling global warming.

2.3.5 Sensing of Electromagnetic energy (EM)

Electromagnetic radiation is produced whenever a charged particle, such as an electron, changes its velocity. The energy of the electromagnetic radiation thus produced comes from the charged particle and it's therefore lost by it. A common example of this phenomenon is the oscillating charge or current in a radio antenna. The antenna of a radio transmitter is part of an electric resonance circuit in which the charge is made to oscillate at a desired frequency. An electromagnetic wave so generated can be received by a similar antenna connected to an

Figure 2.4 Black-body radiation curves (with temperatures, T, in K)



Oscillating electric circuit in the tuner that is tuned to that same frequency. The electromagnetic wave in turn produces an oscillating motion of charge in the receiving antenna. In general, one can say that any system which emits electromagnetic radiation of a given frequency can absorb radiation of the same frequency.

When the electromagnetic radiation wave hits the moving object, it "bounces" back toward the source, which also contains a receiver as well as the original transmitter. However, since the wave reflected off of the moving object, the wave is shifted as outlined by the relativistic Doppler effect.

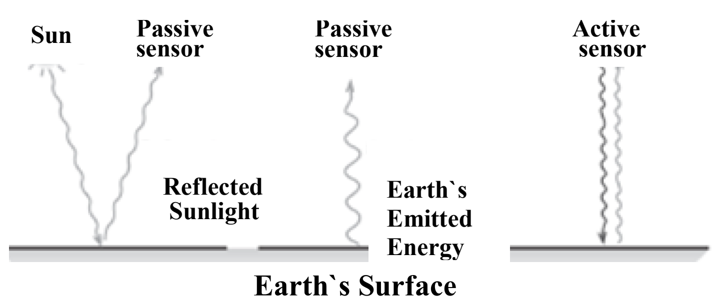
Since the electromagnetic radiation was at a precise frequency when sent out and is at a new frequency upon its return, this can be used to calculate the velocity, v, of the target (which acts as a intermediary source).

2.3.5.1 Sensing Properties

A remote sensor is a device that detects EM energy, quantifies it and usually records it, in an analogue or digital form. It may also transmit the recorded data (to a receiving station on the ground). Many sensors used in earth observation detect solar energy. Others detect the energy emitted by the earth itself. However, there are some bottlenecks. The Sun is not always shining brightly and there are regions on globe almost permanently under cloud cover. There are regions with seasons of very low Sun elevation, so that objects cast long shadows over long periods. There is night time with only "atmospheric night- glow" and perhaps moonlight. Sensors detecting reflected solar energy are useless at night time and face problems under unfavorable season and weather conditions. Sensors detecting emitted terrestrial energy do not directly depend on the Sun as source of illumination; they can be operated any time. The Earth`s emission, we have learned, is only at longer wavelengths because of the relatively low surface temperature and long EM waves are not very energetic, thus more difficult to sense.

Above facts highlight that we should not rely solar and terrestrial radiation only. We must build instruments, which emit EM energy and then detect the energy returning from the target objects or surface. Such instruments are called active sensors as opposed to passive once, which measure solar or terrestrial energy (Figure 2. 5). An example of active sensor is laser range finder. Camera is also an active sensor in which flash light is used particularly during night time. But if we use the same camera without flash light it will be called as passive sensor. The main advantages of active sensors are that they can be operated day and night, are less weather dependent and have a controlled illuminating signal, which is less affected by the atmosphere. Laser and radar instruments are the most prominent active sensor.

Figure 2.5 Passive and Active Sensors (own source of energy)



Most remote sensing sensors measure either an intensity change or a phase change of EM radiation. Some - like a simple laser range finder – only measure the elapse time between sending out an energy signal and receiving it back. Radar sensor may measure both intensity and phase. Phase measuring sensors are used for precise ranging (distance measurement), eg, by GPS `phase receiver` or continuous wave laser scanners. The intensity of radiation can be measured via the photon energy striking the sensor`s sensitive surface. When sensing reflected light the radiance at the detector is the radiance at the Earth`s surface attenuated by atmospheric absorption plus the radiance of scattered light:

$$L = \rho E \tau / \pi + \text{skyradiance}$$

Where L is the total radiance at the detector, E is the irradiance at the Earth`s surface, ρ is the terrain reflectance , and ↄ is the atmospheric transmittance. The radiance at the Earth`s surface depends on the irradiance (the intensity of the incidenr solar radiation) and the terrain surface reflectance. The irradiance in turn stems from direct sunlight and diffuse light, the later caused by atmospheric scattering and more so on a hazy day (Figur 2.6) . This indicates why you should study radiometric correction (on the coming units) to better infer on surface features.

The radiance is observed for a `spectral band`, not for a single wavelength. A spectral band or wavelength band is an interval of the EM spectrum for which the average radiance is measured. Sensors like pachroma camera, a nadir sensor, or a laser scanner only measure in one specific band while a multispectral scanner or a digital camera measures in several spectral bands at the same time. Multispectral sensors have several ` channels`, one for each spectral band. Sensing in several spectral bands simultaneously allows us to relate properties that show up well in specific spectral bands. For example reflectance characteristics in the specral band2 to 2.4μm as recorded by Landsat -5 TM -5, channel 7 tell us some thing about the mineral composition of the soil. The combined reflectance characteristics in the red and NIR bands from Landsat -5 TM channels 3 and 4 can tell us some thing about biomass and plant health.

2.3.5.2 Classification of sensors

We may classify sensors in the following categories:

2.3.5.2.1 Aerial film cameras: Aerial film cameras find their prime use today in large scale topographic mapping, cadastral mapping, orthophoto production for urban planning etc. Photographic recording is a multustage process that involves film exposure and chemical processing (development). It is followed by printing. It has two main types of film: black and white (B & W) film and color film. B &W or panchromatic film has one emulsion layer (silver halide crystals) whereas colour films have three emulsion layers of blue, green and red. The film emilsion type applied determine the spectral and radiometric characteristics of the photograph.

2.3.5.2.2 Digital aerial cameras: Digital cameras are more popular on the consumer market in comparison to their use as aerial camera. They use CCD arrays instead of film and are treated together with optical scanners. A digital camers is an electro-optical sensor. It consists of the camera body, a lens, a focal plane array CCD`s and a storage device but no machanical component. The CCD array can either be an assembly of linear arrays or matrix array. Each CCD has its colour filter right on top to only let the wanted band of incident light pass and each colour has three channels.

2.3.5.2.3 Digital Video Camers: Those are not only used to record every day motion pictures. They are also used in aerial earth observation to provide low cost and low resolution images for mainly qualitative purposees.

2.3.5.2.4 Multispectral Scanners: Multispectral scanners are mostly operated from satellites and other space vehicles. The essential difference with satellite line cameras is in the imaging/optical system; they use a moving mirror to `scan ` a line (ie, a narrow strip on the ground) and a single detector instead of recording intensity value of an entire line at ne instance by an array of detectors. Figure 6 shows an image obtained by combiming the images of the Landsat TM channels 4,5 and 7, which are displaced in red, green and blue respectively. How to produce such `false colour image` is explained in the next unit.

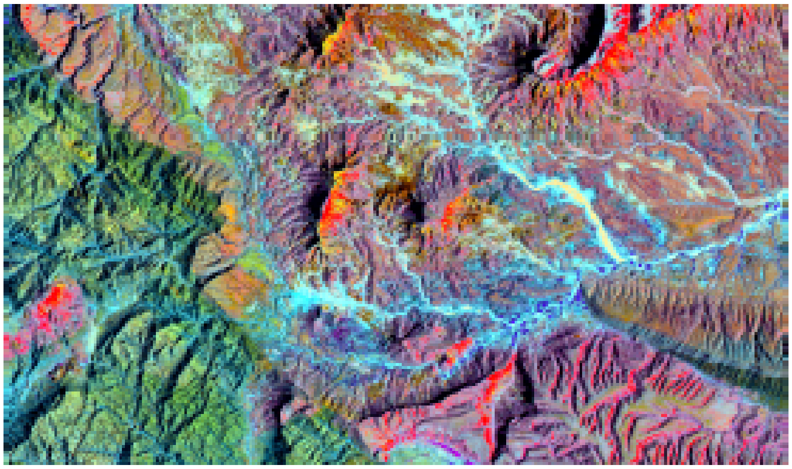
An optical scanner is an electro-optical remote sensor with a scanning device, which is in most cases a machanical component. In its simplest form, it consists of sensor rack, a single detector with electronics, a mirror,optics for focusing and storage device. A detector has a very narrow field of view, called the` instantaneous field of view`(IFOV), of 25 milliradians or less. In order to image a large area we have to scan the ground across the track while the aircraft or spacecraft is moving. The most commonly used scanning device is a moving mirror, which can be an oscillating mirror or rotating mirror.

Scanners are used for sensing in a broad spectral range, from light to TIR and beyond to microwave radiation. Photodiodes made of silicon are used for the visible and NIR bands. Coded photon detectors (eg,using mercury cadmium telluride semicondoctor material) are used for thermal scanners.

2.3.5.2.5 Yperspectral Scanners: These are imaging spectrometers with scanning mirror. These are touched in the coming units.

2.3.5.2.6 Thermal Scanners: These scanners are placed here in the optical domain for the sake of convenience. They exist as special instruments and as component of multispectral radiometers Thermal scanners provide us with data, which can directly be related to object temperature..

Figure 2.6 False colour composite of Landsat 5 TM, area 30Km by 17 Km



2.3.6 Electromagnetic waves

The electromagnetic spectrum describes a wide range of different electromagnetic waves. Also called EM waves, these are a special type of wave that can travel without a medium. Unlike sound waves and water waves, electromagnetic waves don't need a fluid, or a solid, or even air to help them travel from one place to another. EM waves can travel across the great vacuum of space, which is why we see light from distant stars and planets.

Electromagnetic waves are named for the fact that they have both an electric and a magnetic component. They begin when charged particles, like electrons, vibrate due to the various forces acting on them. The vibration of charged particles results in an emission of energy known as electromagnetic radiation. EM waves propagate outward from the source. Just like regular transverse waves, the oscillations of EM waves are perpendicular to the direction of the wave's travel. But, EM waves are more complicated; the electric component oscillates in one plane, while the magnetic component oscillates in a different plane. In a vacuum, EM waves always travel at the same speed - the speed of light, which is roughly 300 million meters per second. We call this value the speed of light, but really, it counts as the normal speed for all of the EM waves.

So, what are the other EM waves besides light? Electromagnetic waves include infrared, ultraviolet, radio waves, and microwaves. They also include X-rays and gamma rays. You've probably heard of all these waves before, but you may not have seen how they relate to visible light. Let's take a look at how these seven groups of waves fit together on the electromagnetic spectrum.

2.3.7 Electromagnetic spectrum and remote sensing

Sensors collect and store data about the spectral reflectance and emission of natural features and objects, both of which reflect radiation (Figure 2.7). This radiation can be quantified on an Electromagnetic Spectrum (EMS). One of the major characteristics of a remotely sensed image is the wavelength region it represents in the EMS. Electromagnetic Spectrum is very useful for identifying and characterizing earth and atmospheric feature. It describes energy in a specific region of the spectrum. These are visible light, Infrared, Thermal infrared, Microwaves, Radio waves, UV rays, X-rays, Gamma and Cosmic rays. This spectrum is an overview of the continuum of electromagnetic energy from extremely short wavelengths (cosmic and gamma rays) to extremely long wavelengths (radio and television waves). These divisions are not absolute and definite as overlapping may occur. The energy of EM spectrum is measured in micrometers (mμ; 1 mμ= 10^{-6}m), angstrom (1 angstrom = 10^{-9}m]. Millimeters may be used for longer wavelengths.

Some earth's surface material primarily rocks and minerals emit visible UV radiation. This region is beyond the violet portion of the visible wavelength, and hence its name. However UV radiation is largely scattered by earth's atmosphere and hence not used in field of remote sensing. 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 color. Blue Green and Red are the three primary colors of the visible spectrum. They are defined as such because no single primary color can be created from the other two, but all other colors 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. Blue light has the wavelength of around 0.45 µm. Red light at the other end of the colour spectrum of a rainbow as a wavelength of around 0.65 µm. EMR outside the range of o.38 to0.76 µm is not visible.

Figure 2.7 Data collection by sensor

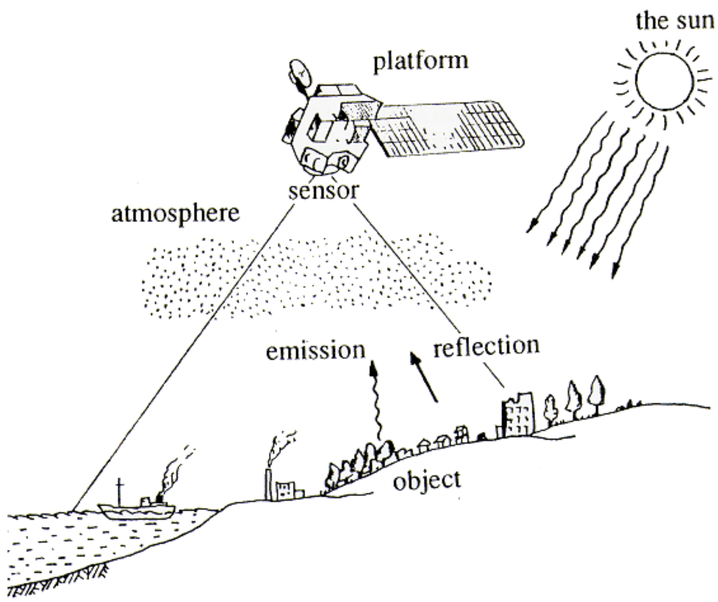


Figure 2.8 Electromagnetic Spectrum of visible wavelength

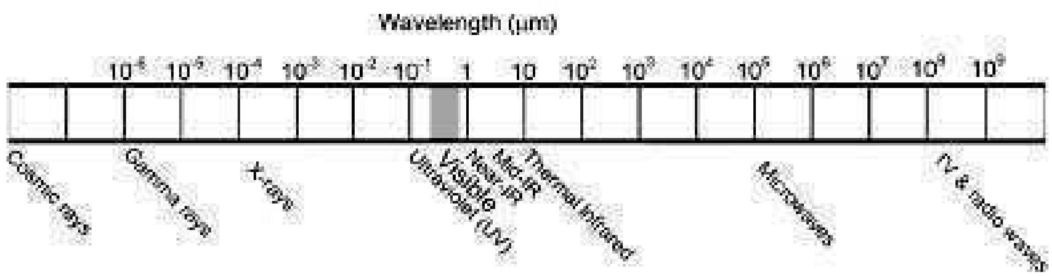


Figure 2.9 Electromagnetic Spectrum of all Specific wavelength Regions

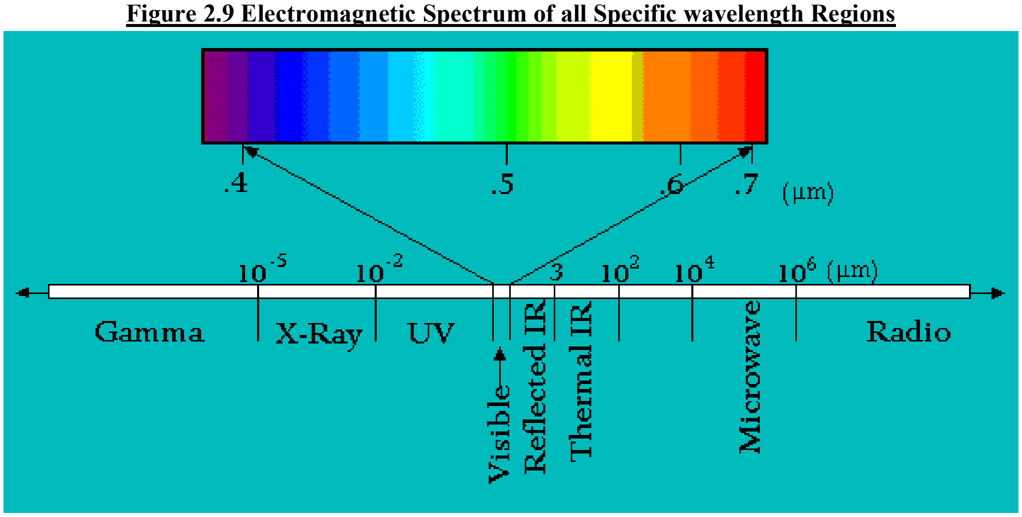


Table 2.1 Principal Divisions of the Electromagnetic Spectrum

Regions of Electromagnetic Spectrum		
1.	Gamma Ray	<0.03 nanometers
2.	X - Ray	0.03 - 3.0 nanometers
3.	Ultraviolet	3.0 nanometers - 0.4 micrometers
4.	Visible	0.4 - 0.7 micrometers
5.	Near Infrared	0.7 - 1.3 micrometers
6.	Mid-Infrared	1.3 - 3.0 micrometers
7.	Thermal Infrared	3.0 - 5.0 mm + 8.0 - 14.0 mm
8.	Microwave	0.3 - 300.0 cm

Wavelengths longer than the red portion of the visible spectrum are designated as the infrared spectrum. British Astronomer William Herschel discovered this in 1800. The infrared region can be divided into two categories based on their radiation properties. Reflected IR (0.7 μm - 3.0 μm) is used for remote sensing. Thermal IR (3 -5.5 μm and 8-12 μm) is the radiation emitted from earth's surface in the form of heat and used for remote sensing. This is the longest wavelength used in optical remote sensing.

Depending on the wavelength and the nominal spectral location, principal applications can be matched with suitable satellite bands for classification. Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount and kind of energy in different bands of the electromagnetic spectrum. It depends on the property of material (structural, chemical and physical), surface roughness, angle of incidence, intensity and wavelength of radiant energy.

2.3.8 Interaction of the EMR with earth surface matter

Radiation from the sun, when incident upon the earth's surface, is either reflected by the surface, transmitted into the surface or absorbed and emitted by the surface (Figure 2.10). The EMR, on interaction, experiences a number of changes in magnitude, direction, wavelength, polarization and phase. These changes are detected by the remote sensor and enable the interpreter to obtain useful information about the object of interest. The remotely sensed data contain both spatial information (size, shape and orientation) and spectral information (tone, colour and spectral signature). When the EMR strikes the matter following phenomenon takes place:

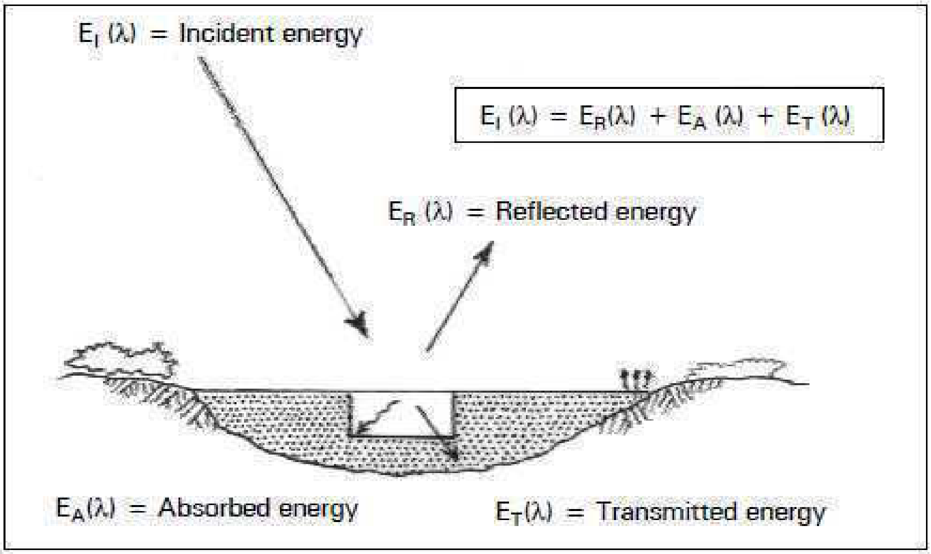
- A part of the incoming energy is brought back in the space containing the source, which is known as reflection - $E_R(\lambda)$.
- Second part enters the matter and disappears therein; which is known as absorption- $E_A(\lambda)$.
- Third and last part having passed through the matter is transmitted beyond it, which is known as transmission- $E_T(\lambda)$.

If EI (λ) is the value of the incident radiation the budget of this interaction between the EMR and the matter may be written as:

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda).$$

The above equation conveys the conservative property of the energy.

Figure 2.10 Interaction of Energy with the earth's surface



(source: Liliesand & Kiefer, 1993)

From the viewpoint of interaction mechanisms with the object-visible and infrared wavelengths from 0.3 µm to 16 µm can be divided into three regions. The spectral band from 0.3 µm to 3 µm is known as the reflective region. In this band, the radiation sensed by the sensor is that due to the sun, reflected by the earth's surface. The band corresponding to the atmospheric window between 8 µm and 14µm is known as the thermal infrared band. The energy available in this band for remote sensing is due to thermal emission from the earth's surface. Both reflection and self-emission are important in the intermediate band from 3 µm to 5.5 µm. In the microwave region of the spectrum, the sensor is radar, which is an active sensor, as it provides its own source of EMR. The EMR produced by the radar is transmitted to the earth's surface and the EMR reflected (back scattered) from the surface is recorded and analyzed. The microwave region can also be monitored with passive sensors, called microwave radiometers, which record the radiation emitted by the terrain in the microwave region. Under interaction mechanism the following reflection phenomenon is dealt in detail.

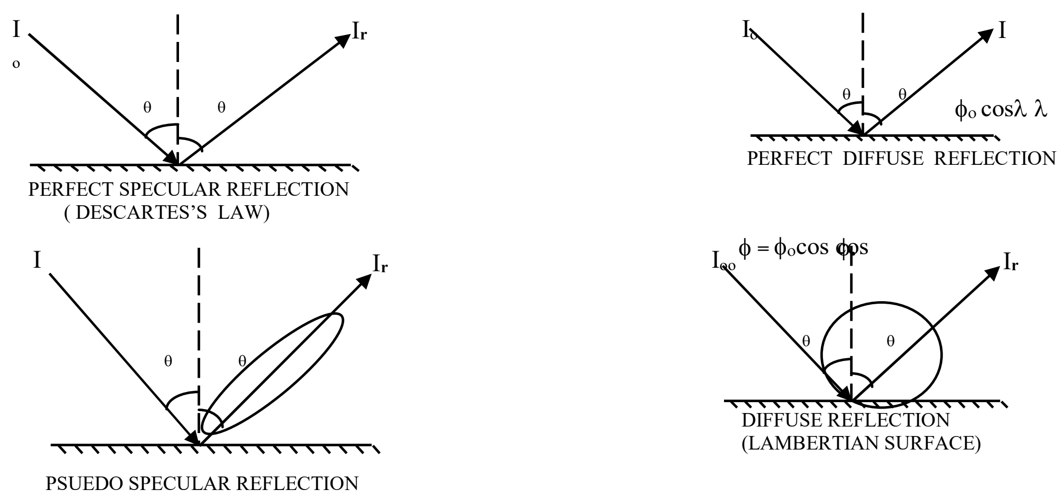
2.3.8.1 Reflection

Of all the interactions in the reflective region, surface reflections are the most useful and revealing in remote sensing applications. Reflection occurs when a ray of light is redirected as it strikes a non-transparent surface. The reflection intensity depends on the surface refractive index, absorption coefficient and the angles of incidence and reflection. The phenomenon is complex with respect to natural surfaces. There are basically two main types of reflections:

- The specular reflection; which occurs with perfectly smooth (polished) surfaces. This type of reflection is described through the ′Laws of Des Cartes′.
- The diffuse reflection occurring with perfectly rough surfaces known as diffusing surfaces) the perfect case is described by the ′Lambert's Law ′(Lambertian surface).

In common situation, the actual reflection is always between these two sheer cases of reflection (Figure 2.11) which gives the value of the energy measured in each direction θ as reflected by surface when lighted by an incident flux I.

Figure 2.11 Types of reflection



Normally, the reflection is considered the "surface property" of the matter but thorough analysis has revealed that the radiation always "penetrates" the matter and the EMR interaction with the material media takes place in a layer. The thickness of which mainly depends on:

- the wavelength of the EMR
- the electrical properties of the matter
- the diffraction which occurs, when the surface is affected by periodical structure (such as a grating)
- the spontaneous after-glow of the matter such as the fluorescence which occurs after the excitation by the incident radiation is over.

Finally, the reflection phenomena are due to the interaction of EMR with the matter and that this interaction finds expression in alteration of the incident radiation in:

- direction
- intensity lowering (absorption or extinction coefficient)
- spectral composition (colour or spectral signature of the matter)
- polarization (increase or decrease)

There are two classes of variables to describe the reflection:

i) relative variable also called "coefficient" which are mostly employed (albedo and reflectance).

ii) absolute variables defined with energy units (radiance)

Relative variable comes from the ratio of two variables of the same nature thus relating in a dimensionless coefficient, which is often turned into a percentage.

The ALBEDO or "whiteness coefficient":

$$\frac{\text{All the light reflected by the surface}}{\text{All the light incident on the surface}}$$

It is noteworthy here that this variable is improperly used to characterize spectral reflection due to the angular dependence of reflection phenomenon. The evaluation of such a coefficient implies that the sensor is able to measure, first the whole spectrum of the incident radiation with even sensitivity and second the whole radiation reflection in all direction by the irradiated surface. The last condition is neither met in airborne nor in space-borne remote sensing.

The reflectance coefficient ρ (θ) is the ratio of the reflected radiation in specified direction θ to the incident radiation. As the reflection is a function of the wavelength the spectral reflectance coefficient ρ ($\lambda\theta$) is the value of this ratio given wavelength (λ). The value of this ratio is often given for a small interval.

$$\Delta\lambda = 1\mu m$$

Unless any special specification is made, the reflectance coefficient will be understood for "global" i.e., including both specular and diffuse components in the measured reflected energy. When the value of each of specular reflectance coefficient and diffuse reflectance coefficient is known separately; Hemispherical (spectral) reflectance coefficient is:

$$\int^{2\pi \text{ ster}} \rho\ (\lambda\theta)\ d\theta$$

When the reflected radiation is considered in all directions, O of the source space (2 π steradian). It is obvious that integrating new for λ (spectrum of the source) leads to the albedo value.

2.3.9. Interactions of EMR with the atmosphere

The sun is the source of radiation, and electromagnetic radiation (EMR) from the sun that is reflected by the earth and detected by the satellite or aircraft-borne sensor must pass through the atmosphere twice, once on its journey from the sun to the earth and second after being reflected by the surface of the earth back to the sensor. Interactions of the direct solar radiation and reflected radiation from the target with the atmospheric constituents interfere with the process of remote sensing and are called as **"Atmospheric Effects".** Figure 9 represent the whole process of interaction of EMR with the atmosphere and earth surface.

The interaction of EMR with the atmosphere is important to remote sensing for two main reasons. First, information carried by EMR reflected/ emitted by the earth's surface is modified while traversing through the atmosphere. Second, the interaction of EMR with the atmosphere can be used to obtain useful information about the atmosphere itself. The atmospheric constituents scatter and absorb the radiation, modulating the radiation reflected from the target by attenuating it, changing its spatial distribution and introducing into field of view Radiation from sunlight scattered in the atmosphere and some of the energy reflected from nearby ground area. Both scattering and absorption vary in their effect from one part of the spectrum to the other.

The solar energy is subjected to modification by several physical processes as it passes the atmosphere, viz.1) Scattering; 2) Absorption, and 3) Refraction

2.3.9.1 Atmospheric Scattering

Scattering is the redirection of EMR by particles suspended in the atmosphere or by large molecules of atmospheric gases. Scattering not only reduces the image contrast but also changes the spectral signature of ground objects as seen by the sensor. The amount of scattering depends upon the size of the particles, their abundance, the wavelength of radiation, depth of the atmosphere through which the energy is traveling and the concentration of the particles. The concentration of particulate matter varies both in time and over season. Thus the effects of scattering will be uneven spatially and will vary from time to time. Theoretically scattering can be divided into three categories depending upon the wavelength of radiation being scattered and the size of the particles causing the scattering. The three different types of scattering from particles of different sizes are summarized below:

Figure: 2.12 Energy interactions in the atmosphere and earth surface

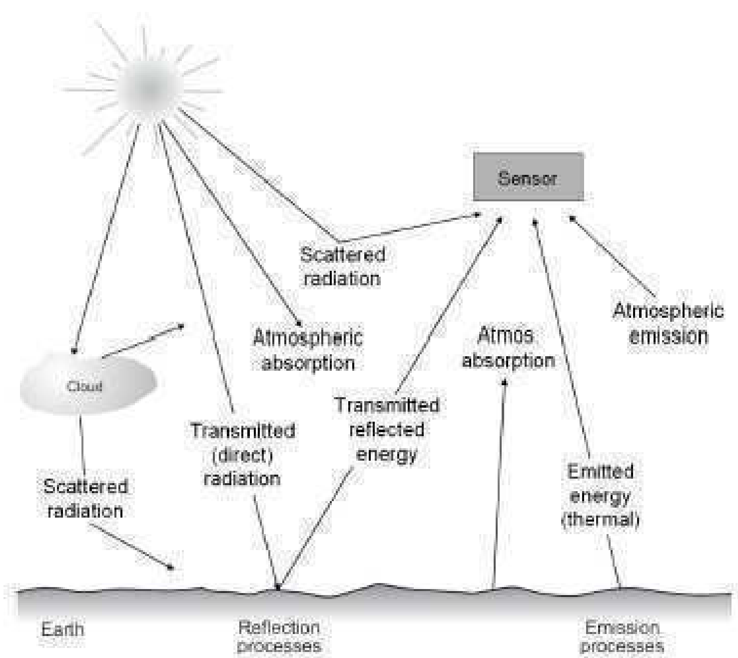


Table 2.2 Atmospheric scattering from three different particle size

Scattering process	**Wavelength**	**Approximate dependence particle size**	**Kinds of particles**
Selective			
Rayleigh	λ^{-4}	< 1µm	Air molecules
Mie	λ^{o} to λ^{-4}	0.1 to 10 µm	Smoke, haze
Non-selective	λ^{o}	>10 µm	Dust, fog, clouds

2.3.9.1 A Rayleigh scattering

Rayleigh scattering predominates where electromagnetic radiation interacts with particles that are smaller than the wavelength of the incoming light. The effect of the Rayleigh scattering is inversely proportional to the fourth power of the wavelength. Shorter wavelengths are scattered more than longer wavelengths. In the absence of these particles and scattering the sky would appear black. In the context of remote sensing, the Rayleigh scattering is the most important type of scattering. It causes a distortion of spectral characteristics of the reflected light when compared to measurements taken
on the ground.

2.3.9.1 B Mie Scattering

Mie scattering occurs when the wavelength of the incoming radiation is similar in size to the atmospheric particles. These are caused by aerosols: a mixture of gases, water vapor and dust. It is generally restricted to the lower atmosphere where the larger particles are abundant and dominates under overcast cloud conditions. It influences the entire spectral region from ultra violet to near infrared regions.

2.3.9.1 C Non-selective Scattering

This type of scattering occurs when the particle size is much larger than the wavelength of the incoming radiation. Particles responsible for this effect are water droplets and larger dust particles. The scattering is independent of the wavelength, all the wavelength are scattered equally. The most common example of non-selective scattering is the appearance of clouds as white. As cloud consist of water droplet particles and the wavelengths are scattered in equal amount, the cloud appears as white.

Occurrence of this scattering mechanism gives a clue to the existence of large particulate matter in the atmosphere above the scene of interest which itself is a useful data. Using minus blue filters can eliminate the effects of the Rayleigh component of scattering. However, the effect of heavy haze i.e. when all the wavelengths are scattered uniformly, cannot be eliminated using haze filters. The effects of haze are less pronounced in the thermal infrared region. Microwave radiation is completely immune to haze and can even penetrate clouds.

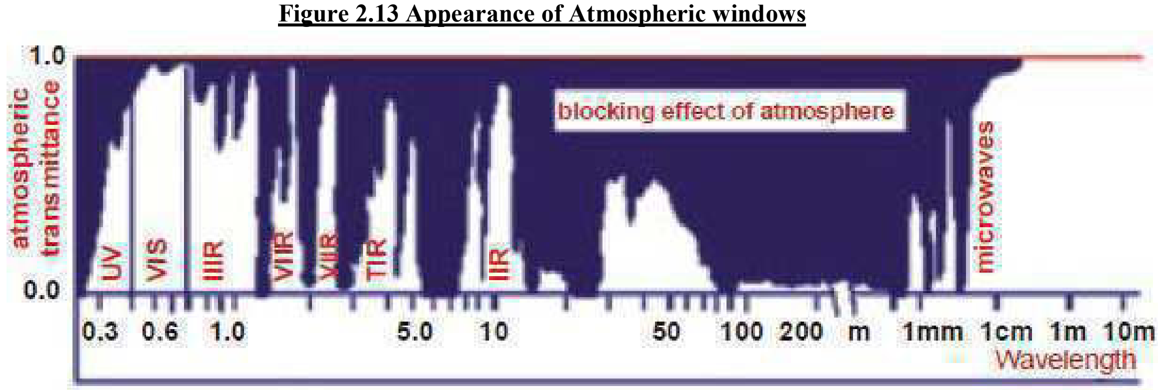
2.3.9.1D Atmospheric Absorption

The gas molecules present in the atmosphere strongly absorb the EMR passing through the atmosphere in certain spectral bands. Mainly three gases are responsible for most of absorption of solar radiation, viz. ozone, carbon dioxide and water vapour. Ozone absorbs the high energy, short wavelength portions of the ultraviolet spectrum (λ < 0.24 µm) thereby preventing the transmission of this radiation to the lower atmosphere. Carbon dioxide is important in remote sensing as it effectively absorbs the radiation in mid and far infrared regions of the spectrum. It strongly absorbs in the region from about 13-17.5 µm, whereas two most important regions of water vapour absorption are in bands 5.5 - 7.0 µm and above 27 µm. Absorption relatively reduces the amount of light that reaches our eye making the scene look relatively duller.

2.3.9.1 E Atmospheric Windows

The general atmospheric transmittance across the whole spectrum of wavelengths is shown in Figure 2.13. The atmosphere selectively transmits energy of certain wavelengths. The spectral bands for which the atmosphere is relatively transparent are known as atmospheric windows. As explained above, the gas molecules present in the atmosphere strongly absorb the EMR passing through the atmosphere in certain spectral bands. These atmospheric windows appear due to the combination of both transparence and absorption of certain parts of Electromagnetic Spectrum. Atmospheric windows are present in the visible and infrared regions (.4 µm – 1.3 µm) of the EM spectrum. In the visible part transmission is mainly effected by ozone absorption and by molecular scattering. The band corresponding to the atmospheric window between 8 µm and 14 µm is known as the thermal infrared band. The energy available in this band for remote sensing is due to thermal emission from the earth's surface. Both reflection and self-emission are important in the intermediate band from 3 µm to 5.5 µm. In the microwave region of the spectrum, the sensor is radar, which is an active sensor, as it provides its own source of EMR. The EMR produced by the radar is transmitted to the earth's surface and the EMR reflected back scattered) from the surface is recorded and analyzed. The microwave region can also be monitored with passive sensors, called microwave radiometers, which record the radiation emitted by the terrain in the microwave region. The atmosphere is transparent again beyond about λ= 1mm, the region used for microwave remote sensing (Figure 2.13).

Figure 2.13 Appearance of Atmospheric windows



2.3.10 Refraction

The phenomenon of refraction that is bending of light at the contact between two media also occurs in the atmosphere as the light passes through the atmospheric layers of varied clarity, humidity and temperature. These variations influence the density of atmospheric layers, which in turn, causes the bending of light rays as they pass from one layer to another. The most common phenomena are the mirage like apparitions sometimes visible in the distance on hot summer days.

2.4 SUMMARY

Electromagnetic (EM) Energy travels through space in the form of sinusoidal fashion of waves including interacting electrical and magnetic oscillation. Electromagnetic radiation (EMR) can be modeled either by waves or by a stream of energy bearing particles called photons. One property of EM waves that is particularly important for understanding remote sensing is the wavelength (λ), defined as the distance between successive wave crests measured in micrometers.

All Matters with a temperature above absolute zero (0 k) emits EM energy due to molecular oscillation. Matter that is capable of absorbing and re-emitting all EM energy received is known as a black-body. All matter with a certain temperature emits radiant energy of various wavelengths depending on its temperature. The total range of wavelengths is commonly referred to as the electromagnetic spectrum. It extends from cosmic/gamma rays to TV/radio waves. The amount of energy detected by a remote sensor is a function of interactions at the earth`s surface and energy interactions in the atmosphere.

The interactions of the Sun`s energy with physical materials, both in atmosphere and at the earth`s surface, cause this to be absorbed, scattered, transmitted and reflected. The most efficient absorbers of solar energy in the atmosphere are ozone molecules, water vapour, water molecules and carbon dioxide. Atmospheric scattering occurs when the particles and gaseous molecules present in the atmosphere interact with electromagnetic radiation and cause it to be redirected from its original path. All types of scattering are disturbing to remote sensing of land and water surface.

When solar energy reaches the earth`s surface, three fundamental energy interactions are possible: absorption, transmission and reflectance. Specular reflection occurs when a surface is smooth and the incident energy is directed away from the surface in a single direction. Diffuse reflection occurs when a surface is rough and the energy is reflected almost uniformly in all directions.

Remotely sensed radiation of wavelength up to 3 µm is predominately reflected solar energy while infrared radiation above 3 µm can be mainly attributed to emitted energy, namely, terrestrial heat. Because reflected EM energy follows the law of optics (reflection, refraction, transmission and focusing of rays by lenses or mirrors, etc.), sensors operating in this range are often referred to as optical remote sensors.

2.5 GLOSSARY

1. Electro-magnetic energy

It is a form of energy that can be reflected or emitted from objects through electrical or magnetic waves travelling through space. Gamma rays, X-rays, ultraviolet radiation, visible light, microwaves, radio waves and infra-red radiation are the examples of EMR.

2. Electro-magnetic waves

Electro-magnetic waves are the combination of electric and magnetic field waves produced by oscillations or acceleration of charged particle. The magnetic and electrical waves oscillate in perpendicular planes with respect to each other, due to the oscillating electric and magnetic fields. Once in motion, the electric and magnetic fields become self perpetuating and time- dependent.

3. Electromagnetic Spectrum

The electromagnetic spectrum covers a wide range of wavelengths and photon energies.

4. Wavelength

Wavelength (λ) is the distance between successive crests of a wave, especially points in an electromagnetic wave or sound wave. It can be simply defined as the distance of one full cycle of the oscillation. If 'λ' is the wavelength, 'c' is the speed of light and '*v*'is frequency. Then we can derive the relation given below.

$c = \lambda v$

The shorter the wavelength, greater the frequency and greater the frequency, higher the energy.

5. Amplitude

It is the distance from the middle of the wave to the maximum vertical displacement of the wave. Larger the amplitude, higher the energy and lower the amplitude, lower the energy. Amplitude tells us about the brightness or intensity of a wave compared to other waves.

6 Frequency

The number of cycles per second is defined as Frequency. It is defined as Hertz (Hz) or sec^{-1}. If 'E' is the energy, 'h' is Planck's constant which is equal to 6.62607×10^{-34} and '*v*'is the frequency we can derive the relation given below.

$E = hv$

Thus we can see that frequency is directly proportional to energy.

7. Period

Period is commonly characterized by the symbol 'T'. It is the total time which a wave takes to travel one wavelength.

8. Velocity

In relation with electromagnetic radiation, the velocity is normally expressed as:

Velocity = λv

*[where, **v** = frequency]*

2.6 ANSWER TO CHECK THE PROGRESS

Q1- What is Electromagnetic Radiation?
Q2- What is Electromagnetic energy?
Q3- What are Waves and Photons
Q4- What are the Sources of Electromagnetic Energy (EM)?
Q5- What is Reflection?
Q6- What is Rayleigh scattering?
Q7 What is Mie Scattering?
Q8 What is Non-selective Scattering?
Q9- What is Atmospheric Absorption?
Q10- What is Atmospheric Windows?

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2.8 TERMINAL QUESTIONS

1-Describe the Physical basis of Electromagnetic Radiation (EMR).
2-Diagrammatically, explain the concepts of waves and photons.
3-What are the sources of electromagnetic radiation? Explain the concepts of black body temperature radiation.
4-How an electromagnetic radiation is produced? Elaborate its full concept.
5-Explain the functions of different types of sensors.
6-Explain electromagnetic waves and spectrum and write the wavelength of their principal divisions.
7-Describe the interaction mechanism of EMR with earth surface matter with special reference to reflectance.
8-What are the different types of atmospheric scattering, explain each one.
9-What is the role of atmospheric windows in the field of remote sensing? Write their wavelength range and absorption criterion.

UNIT 3 - PLATFORMS AND SENSORS

3.1 OBJECTIVES

After reading this unit you will be able to understand that:

- Definition of platform and sensors
- Remote sensing missions
- Platform types and their characteristics
- Sensor types and their characteristics
- Features of platforms and sensors

3.2 INTRODUCTION

In the previous two chapters you have learnt about the full overview of remote sensing indicating its need, scope, importance, historical background, advantages and limitations followed by the characteristics of electromagnetic radiation and its parameters. In this unit you will be learning about various types of remote sensing platforms and sensors and their characteristics. These platforms and sensors types are determined under different missions of remote sensing programmes for earth observation and the objectives under those missions. Data from space-borne sensors are widely available through data providers. The sensor–platform combination determines the characteristics of the resulting data. Various aircrafts, space shuttles, space stations and satellites are used to carry one or more sensors for earth observation. Optical scanners are covering multispectral, hyper-spectral and thermal scanners. Based on your information need and on time and budgetary criteria, you can determine which data source is most appropriate.

A remote sensing system comprises two basic components: a sensor and a platform. The sensor is the instrument used to record data; a platform is the vehicle used to deploy the sensor. Every sensor is designed with a unique field of view which defines the size of the area instantaneously imaged on the ground. The sensor field of view combined with the height of the sensor platform above the ground determines the *sensor footprint*. A sensor with a very wide field of view on a high-altitude platform may have an instantaneous footprint of hundreds of square kilometers; a sensor with a narrow field of view at a lower altitude may have an instantaneous footprint of ten of square kilometers.

Using the broadest definition of remote sensing, there are innumerable types of platforms upon which to deploy an instrument. Satellites and aircraft collect the majority of base data and imagery; the sensors typically deployed on these platforms include film and digital cameras, light-detection and ranging (lidar) systems, synthetic aperture radar (SAR) systems, multispectral and hyperspectral scanners. Many of these instruments can also be mounted on land-based platforms, such as vans, trucks, tractors, and tanks. In the future, it is likely that a significant percentage of GIS and mapping data will originate from land-based sources; however, due to time constraints, we will only cover satellite and aircraft platforms in this course.

The design of a sensor destined for a satellite platform begins many years before launch and cannot be easily changed to reflect advances in technology that may evolve during the interim period. While all systems are rigorously tested before launch, there is always the possibility that one or more will fail after the spacecraft reaches orbit. The sensor could be working perfectly, but a component of the spacecraft bus (attitude determination system, power subsystem, temperature control system, or communications system) could fail, rendering a very expensive sensor effectively useless. The financial risk involved in building and operating a satellite sensor and platform is considerable, presenting a significant obstacle to the commercialization of space-based remote sensing.

Due to ever advancing technologies, the remote sensing field is experiencing unprecedented developments recently, fueled by sensor advancements and continuously increasing information infrastructure. The scope and performance potential of sensors in terms of spatial, spectral and temporal sensing abilities have expanded far beyond the traditional boundaries of remote sensing, resulting in significantly better observation capabilities. First, platform developments are reviewed with the main focus on emerging new remote sensing satellite constellations and UAS (Unmanned Aerial System) platforms. Next, sensor georeferencing and supporting navigation infrastructure, an enabling technology for remote sensing, are discussed. Finally, we group sensors based on their spatial, spectral and temporal characteristics, and classify them by their platform deployment competencies. In addition, we identify current trends, including the convergence between the remote sensing and navigation field, and the emergence of cooperative sensing, and the potential of crowd sensing.

Typical platforms are satellites and aircraft, but they can also include radio-controlled aero-planes, balloons kits for low altitude remote sensing, as well as ladder trucks or 'cherry pickers' for ground investigations. The key factor for the selection of a platform is the altitude that determines the ground resolution and which is also dependent on the instantaneous field of view (IFOV) of the sensor on board the platform. Keeping in view of the types of content to be described in this chapter it has been aimed at the following objectives:

3.3 PLATFORMS AND SENSORS

3.3.1 Platform

In general we may define platform **as** a horizontal surface or structure with a horizontal surface raised above the level of the surrounding area or a flat, elevated piece of ground. We may define platforms in different ways as stated below:

The vehicle or carrier for a remote sensor to collect and record energy reflected or emitted from a target or surface is called a platform. The sensor must reside on a stable platform removed from the target or surface being observed. Platforms for remote sensors may be situated on the ground, on an aircraft or balloon (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere.

Platforms refer to the structures or vehicles on which remote sensing instruments are mounted. The platform on which a particular sensor is housed determines a number of attributes, which may dictate the use of particular sensors. These attributes include: at which distance the sensor is placed from the object of interest, periodicity of image acquisition, timing of image acquisition, location and extent of coverage. There are three broad categories of remote sensing platforms: ground based, airborne, and satellite.

3.3.2 Sensor

Like platform, a sensor can be defined in many ways.

- Sensor is a mechanical device sensitive to light, temperature, radiation level, or the like, that transmits a signal to a measuring or control instrument.
- Sensor is endowed with sensation having perception through the senses.
- Sensor is readily or excessively affected by external agencies or influences.
- Any instrument such as a radar device or camera , that scans the earth or another planet from space in order to collect data about some aspect of it is called sensor.
- A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be a light, heat, motion, moisture, pressure.
- We may also define sensor as the sophisticated device that is frequently used to detect or respond to electrical or optical signals. A sensor converts the physical parameter into a signal which can be measured electrically.
- Chemical based sensor of cameras used in ground and aerial photography and electronic sensors used in the satellite remote sensing are mostly used for collecting object oriented data from ground and their analysis. There are many other sensors used for different purposes, as per this definition.
- Remote Sensing Sensors is a device to detect the electro-magnetic radiation reflected or emitted from an object is called a "remote sensor" or "sensor". Cameras or scanners are examples of remote sensors. Based on wavelength, remote sensing sensors can be categorized under optical and microwave. Optical remote sensing function is confined within 0.4 to 12.5µm whereas microwave functions under 1mm to 1m range.

3.3.3 Remote sensing missions

Mission planning and execution is usually done by commercial survey companies or otherwise by large national mapping agencies or the military. Companies use professional software for flight planning and most likely one of the two integrated aircraft guidance and sensor management systems during mission. Pioneer work for computer controlled navigation and camera management is done in many aerial photographic departments.

3.3.3.1 Satellite Missions

The monitoring capability of a satellite sensor are to a large extent determined the parameters satellite`s orbit, An orbit is a circular elliptical path described by the satellite in its movement round the Earth. Different types of orbits are required to achieve continuous monitoring, global mapping or selective imaging. For earth observation purposes, the following orbit characteristics are relevant:

- **Orbit altitude:** It is the distance from the satellite to the surface of Earth. It influences to a large extent the area (spatial coverage) that can be viewed and the details that can be observed (spatial resolution). In general, the higher the altitude the larger is the spatial coverage but lower the spatial resolution.

- **Orbital inclination angle:** It is the angle (in degree) between the orbital plane and equatorial plane. The inclination angle of the orbit determines, together with field of view (FOV) of sensor, the latitude up to which the Earth can be observed. If the inclination is 60^0then the satellite flies over the Earth between the latitudes 60^0 north and 60^0 south. If the satellite is in a low –earth orbit with an inclination of 60^0, then it cannot observe the parts of the Earth at latitude above 60^0 north and below 60^0 south which means it cannot be used for observations of the polar regions of the Earth.

- **Orbital period:** It is the time (in minutes) required to complete one full orbit. For instance, if a polar satellite orbits at 810 Km mean altitude, then it has an orbital period of 101 minutes. The Moon has an orbital period 27. 3 days. The speed of the platform has implications on the type of images that can be acquired. A camera on a lower -earth orbit satellite would need very short exposure time to avoid motion blur due to high speed. Short exposure time, however, requires high intensity of incident radiation, which is a problem in space because of atmospheric absorption. It may be obvious that the contradicting demands on high spatial resolution, no motion blur, high temporal resolution, long satellite lifetime and thus lower cost represent a serious challenge to satellite –sensor designers.

- **Repeat cycle:** It is the time (in days) between two successive identical orbits. The revisit time (time between two subsequent images of the same area) is determined by the repeat cycle together with the pointing capability of the sensor. Pointing capability refers to the possibility of the sensor-platform combination to look to the side, or forward, or backward, not only vertically down. Many of the modern satellites have such a capability. We can make use of the pointing capability to reduce the time between successive observations of the same area, to image an area that is not covered by clouds at that moment, and to produce stereo images.

The following orbit types are most common for remote sensing missions:
j) Polar Orbit: Polar orbit is an orbit with an inclination angle between 80^0 and 100^0. An orbit having an inclination larger than 90^0 means that the satellite `s motion is in the westward direction. Launching a satellite in eastward direction requires less energy, because of eastward rotation of the Earth. Such a polar orbit enables observation of the whole globe, also near the pole. The satellite is typically placed in orbit at 600 Km to 100 Km altitude.

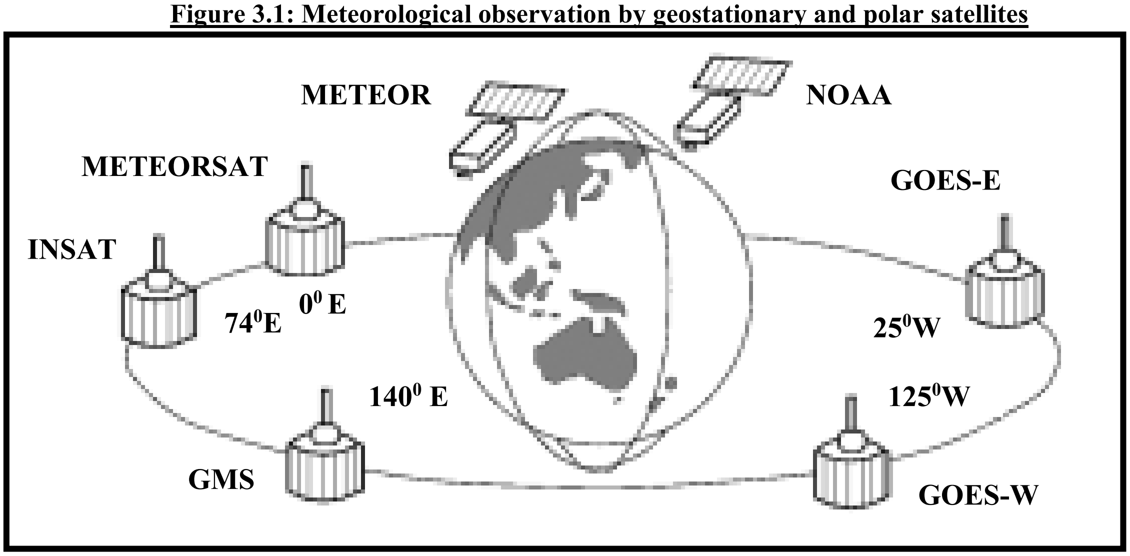
ii) Sun-synchronous Orbit: Sun-synchronous orbit can place a satellite in constant sunlight, which allows the solar panels to work continually. This is a near –polar orbit chosen in such a way that the satellite always passes overhead at the same time. This orbit is also useful for imaging, spy, and weather satellites, because every time that the satellite is overhead, the surface illumination angle on the planet underneath it will be nearly the same. This consistent lighting is a useful characteristic for satellites that image the Earth's surface in visible or infrared wavelengths, such as weather and spy satellites; and for other remote-sensing satellites, such as those carrying ocean and atmospheric remote-sensing instruments that require sunlight. For example, a satellite in Sun-synchronous orbit might ascend across the equator twelve times a day each time at approximately 15:00 mean local time.

Most sun–synchronous orbits cross the equator at mid-morning at around 10.30 hour local solar time. At that moment the Sun angle is low and the resultant shadow reveal terrain relief. In addition to day- time images, a sun-synchronous orbit also allows the satellite to record night time images (thermal or radar) during the ascending phase of the orbit at the dark side of the earth. Examples of polar orbiting, sun-synchronous satellites are Landsat, SPOT and IRS.

iii) Geostationary orbit: This refers to orbits where the satellites are placed above the equator (inclination angle 00) at an altitude of approximately 36000 Km. At this height, the orbital period of satellite is equal to the rotational period of the Earth, exactly one side real day. The result is that the satellite is at a fixed position relative to the Earth. Geostationary orbits are used for meteorological and telecommunication satellites as those are useful for communications and weather monitoring platforms.

Today`s meteorological weather satellite systems use a combination of geostationary satellites and polar orbits (Figure 3.1). The Geostationary satellite offers a continuous hemispherical view of almost half the Earth (45%), while the polar orbits offer a higher spatial resolution.

Figure 3.1: Meteorological observation by geostationary and polar satellites



Remote sensing images from satellites come with data on orbital parameters and other parameter values to facilitate georeferencing of the images. High resolution sensor systems such as Ikonos or QuickBird use GPS receivers and star trackers as POS.

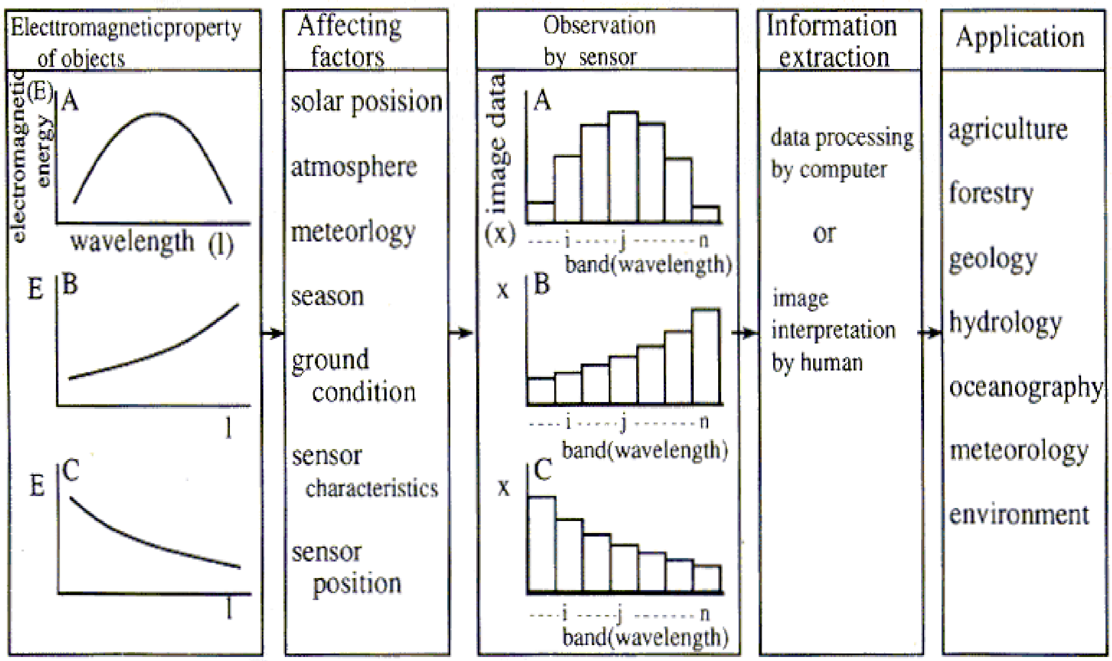
The data of space- borne sensor need to be sent to the ground. Russia`s SPIN -2 satellite with the KVR camera used film cartridges, which were dropped to a designated area on the Earth.. Today the Earth observing satellites `downlink` the data. The acquired data are sent directly to a receiving station on the ground or via a geostationary communication satellite. One of the current trends is that small receiving units, consisting of small dish with a PC, are being developed for local reception of remote sensing data.

3.3.3.2 India`s Earth Observation Missions

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 resolutions to cater to different user requirements in the country and for global usage. 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.

In general, Remote sensing missions are ascertained on the basis of aims and objectives and thereby determining the platform and sensor types. For such planning one must first clarify the available budget under each flow of remote sensing mission. However, it needs the understanding of Electromagnetic Property of object, affecting factors, observation by sensor, and information extraction for the Applications as shown in figure 3.2. In addition, you should have the understanding of the characteristics of an application in relation to reflected or emitted electro-magnetic radiation under the mission. That is, "each object has unique and different characteristics of reflection or emission if the type of object or the environmental condition is different."Remote sensing is a technology to identify and understand the object or the environmental condition through the uniqueness of the reflection or emission.

Figure 3. 2 Flow of remote sensing



3.3.4 Platforms types and their characteristics

3.3.4.1 Ground based Platforms

A wide variety of ground based platforms are used in remote sensing. Some of the more common ones are hand held devices, tripods, towers and cranes. Instruments that are ground-based are often used to measure the quantity and quality of light coming from the sun or for close range characterization of objects. For example, to study properties of a single plant or a small patch of grass, it would make sense to use a ground based instrument.

Laboratory instruments are used almost exclusively for research, sensor calibration, and quality control. Much of what is learned from laboratory work is used to understand how remote sensing can be better utilized to identify different materials. This contributes to the development of new sensors that improve on existing technologies.

Field instruments are also largely used for research purposes. This type of remote sensing instrument is often hand-held or mounted on a tripod or other similar support. Pictures several field instruments. The term "sky shed" refers to indirect (also known as diffuse) illumination from the sky (as opposed to direct sunlight).

Permanent ground platforms are typically used for monitoring atmospheric phenomenon although they are also used for long-term monitoring of terrestrial features. Towers and cranes are often used to support research projects where a reasonably stable, long-term platform is necessary. Towers can be built on site and can be tall enough to project through a forest canopy so that a range of measurements can be taken from the forest floor, through the canopy and from above the canopy.

3.3.4.2 Airborne Platforms

Airborne or Aerial platforms are primarily stable wing aircraft, although helicopters are occasionally used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

Airborne platforms are the sole non-ground-based platforms for early remote sensing work. The first aerial images were acquired with a camera carried aloft by a balloon in 1859. Balloons are rarely used today because they are not very stable and the course of flight is not always predictable, although small balloons carrying expendable probes are still used for some meteorological research.

At present, airplanes are the most common airborne platform. Nearly the whole spectrum of civilian and military aircraft is used for remote sensing applications. When altitude and stability requirements for a sensor are not too demanding, simple, low-cost aircraft can be used as platforms. However, as requirements for greater instrument stability or higher altitudes become necessary, more sophisticated aircraft must be used.

Analog aerial photography, videography, and digital photography are commonly used in airborne remote sensing. Synthetic Aperture Radar imaging is also carried out on airborne platforms.

3.3.4.3 Satellite Platforms

In space, remote sensing is sometimes conducted from the space shuttle or, more commonly, from satellites. Satellites are objects which revolve around another object - in this case, the Earth. For example, the moon is a natural satellite, whereas man-made satellites include those platforms launched for remote sensing, communication, and telemetry (location and navigation) purposes.

The most stable platform aloft is a satellite, which is space-borne. The first remote sensing satellite was launched in 1960 for meteorology purposes. Now, over a hundred remote sensing satellites have been launched and more are being launched every year. The Space Shuttle is a unique spacecraft that functions as a remote sensing satellite and can be reused for a number of missions.

Satellites can be classified by their orbital geometry and timing. Three orbits commonly used for remote sensing satellites are geostationary, equatorial and Sun synchronous. A geostationary satellite has a period of rotation equal to that of Earth (24 hours) so the satellite always stays over the same location on Earth. Communications and weather satellites often use geostationary orbits with many of them located over the equator. In an equatorial orbit, a satellite circles Earth at a low inclination (the angle between the orbital plane and the equatorial plane). The Space Shuttle uses an equatorial orbit with an inclination of 57 degrees.

Sun synchronous satellites have orbits with high inclination angles, passing nearly over the poles. Orbits are timed so that the satellite always passes over the equator at the same local sun time. In this way the satellites maintain the same relative position with the sun for all of its orbits. Many remote sensing satellites are Sun synchronous which ensures repeatable sun illumination conditions during specific seasons. Because a Sun synchronous orbit does not pass directly over the poles, it is not always possible to acquire data for the extreme polar regions. The frequency at which a satellite sensor can acquire data of the entire Earth depends on sensor and orbital characteristics. For most remote sensing satellites the total coverage frequency ranges from twice a day to once every 16 days.

Another orbital characteristic is altitude. The Space Shuttle has a low orbital altitude of 300 km whereas other common remote sensing satellites typically maintain higher orbits ranging from 600 to 1000 km.

Most remote sensing satellites have been designed to transmit data to ground receiving stations located throughout the world. To receive data directly from a satellite, the receiving station must have a line of sight to the satellite. If there are not sufficient designated receiving stations around the world, any given satellite may not readily get a direct view to a station, leading to potential problems of data discontinuity. To work around this problem, data can be temporarily stored onboard the satellite and then later downloaded upon acquiring contact with the receiving station. Another alternative is to relay data through TDRSS (Tracking and Data Relay Satellite System), a network of geosynchronous (geostationary) communications satellites deployed to relay data from satellites to ground stations.

The payload for remote sensing satellites can include photographic systems, electro-optical sensors, microwave or lidar systems. For applications benefiting from simultaneous coverage by different sensors, more than one sensing system can be mounted on a single satellite. In addition to sensor systems, there are often devices for recording, preprocessing and transmitting the data.

Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. Cost is often a significant factor in choosing among the various platform options.

5.3.5 Sensors

There are several broad categories of basic sensor system types such as passive vs. active, and imaging vs. non-imaging. Passive vs. active refers to the illumination source of the system; imaging vs. non-imaging refers to the form of the data. A variety of different sensors fit in these categories, which are not mutually exclusive. Prior to the classification of sensor into the said types we may first categorize them under the following classes:

5.3.5.1 Ground Based Sensors

Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors. In some cases, this can be used to better characterize the target which is being imaged by these other sensors, making it possible to better understand the information in the imagery. Ground based sensors may be placed on a ladder, scaffolding, tall building, cherry-picker, crane, etc.

Table 3.1 Important Satellite Platforms

Salient feature of some important satellite platforms.					
Features	**Landsat 1,2,3**	**Landsat 4,5**	**SPOT**	**IRS-IA**	**IRS-IC**
Nature	Sun Syn	Sun Syn	Sun Syn	Sun Syn	Sun Syn
Altitude (km)	919	705	832	904	817
Orbital period (minutes)	103.3	99	101	103.2	101.35
inclination (degrees	99	98.2	98.7	99	98.69
Temporal resolution (days)	18	16	26	22	24
Revolutions	251	233	369	307	341
Equatorial crossing (AM)	09.30	09.30	10.30	10.00	10.30
Sensors	RBV, MSS	MSS, TM	HRV	LISS-I, LISS-II	LISS-III, PAN, WIFS

5.3.5.2 Photographic/ Aerial Photographic/ Airborne Sensor

A photo sensor reacts to light by creating an electrical charge. The brighter the light, the greater the charge. If you measure the value of this charge, you can determine the brightness of the light that created it. With this information, you can reproduce the effect of this light on a computer screen or a sheet of paper.

If there was only one large photo sensor, all the light from the scene would be averaged to a single tone and the image would be a uniform grey. Double the number of sensors and you capture double the amount of information - your picture would be two grey blocks, though probably of slightly different tones.

As you increase the number of sensors, you increase the amount of picture information. Eventually, you get to a point where there is enough information for a recognizable image to appear.

It is very much like creating a mosaic with small tiles that vary in tone from white to black through a range of greys. Each tile has only one tone, but by laying tiles of different tones next to each other you can build up a picture.

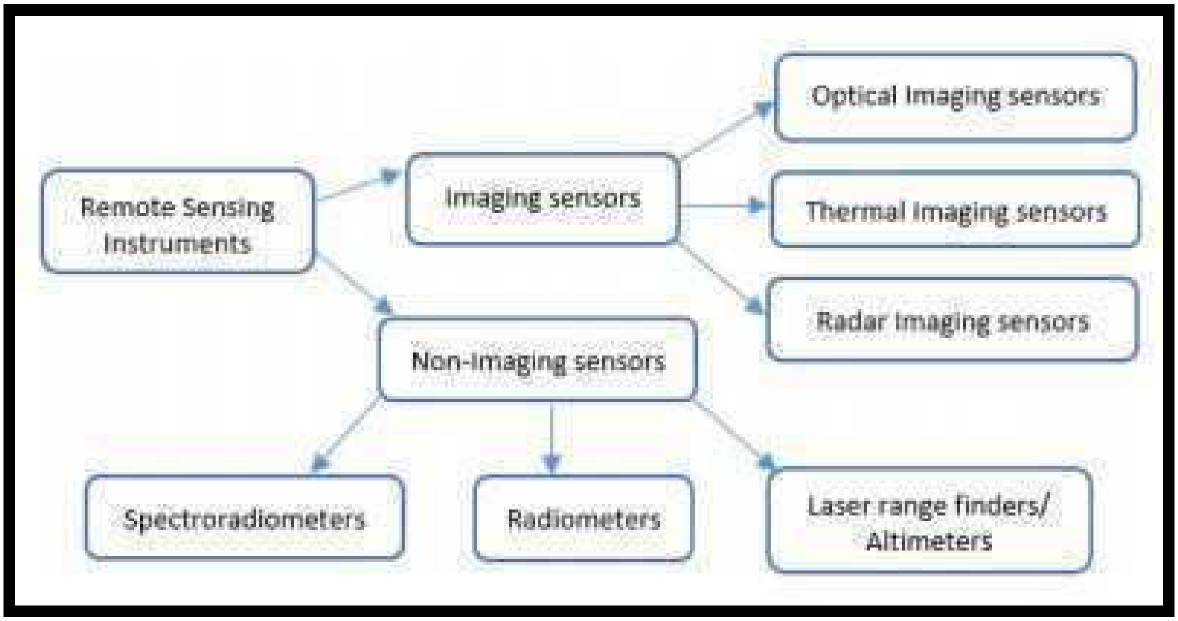
Early digital cameras used sensor arrays based on a grid of 640 columns by 480 rows, giving just over 0.3 million sensors packed together on the array. This sounds a lot, but while the images produced look good as small prints, the lack of detail quickly becomes apparent when the images are enlarged.

The first EOS digital camera - the DCS 3 - offered 1.3 million sensors (or megapixels). This was in 1995. However, it was the 6.3 megapixel EOS D60 (2002) that really started to compete with film cameras.

5.3.5.3 Space borne sensors

Space borne sensors have been developed for over 40 years. Currently, approximately 50 countries are operating remote sensing satellites. There are more than 1000 remote sensing satellites available in space, and among these, approximately 593 are from the USA, over 135 are from Russia, and approximately 192 are from China. Conventionally, remote sensors are divided into two groups: passive sensors and active sensors,. However, as sensor technology has advanced, nothing has been absolute. For example, an imaging camera is usually regarded as a passive sensor. However, in 2013, a new approach that integrates active and passive infrared imaging capability into a single chip was developed. This sensor enables lighter, simpler dual-mode active/passive cameras with lower power dissipation. Alternatively, remote sensing sensors can be classified into imaging sensors and non-imaging sensors. In terms of their spectral characteristics, the imaging sensors include optical imaging sensors, thermal imaging sensors, and radar imaging sensors. Figure 3 illustrates the category in terms of imaging sensors and non-imaging sensors. Optical imaging sensors Optical imaging sensors operate in the visible and reflective IR ranges. Typical optical imaging systems on space platform include panchromatic systems, multispectral systems, and hyper-spectral systems. In a panchromatic system, the sensor is a mono-spectral channel detector that is sensitive to radiation within a broad wavelength range. The image is black and white or gray scale. A multispectral sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image that contains both the brightness and spectral (color) information of the targets being observed. A hyper-spectral sensor collects and processes information from 10 to 100 of spectral bands. A hyper-spectral image consists of a set of images. Each narrow spectral band forms an image. The resulting images can be utilized to recognize objects, identify materials, and detect elemental components. Table 2 gives a more detailed description of these optical imaging systems. It can be seen that when a light is split into multiple spectrums, the greater the number of spectrums is, the lower the imaging resolution will be. That is, a panchromatic image usually presents a higher resolution than a multispectral/hyper-spectral image. Pan-sharpening technique was introduced by Padwick et al. in 2010 for improving the quality of multispectral images. This method combines the visual information of the multispectral data with the spatial information of the panchromatic data, resulting in a higher resolution color product equal to the panchromatic resolution.

Figure 3.3 Flow chart showing spaceborne remote sensing sensors



The sensors on the above said platforms are further classified under the following categories:

5.3.5.4.1 Passive sensors

Record radiation reflected from the earth's surface. The source of this radiation must come from *outside* the sensor; in most cases, this is solar energy. Because of this energy requirement, passive solar sensors can only capture data during daylight hours.

Passive sensors measure light reflected or emitted naturally from surfaces and objects. Such instruments merely observe, and depend primarily on solar energy as the ultimate radiation source illuminating surfaces and objects. Use of data collected by passive sensors often requires accurate measurements of solar radiation reaching the surface at the time the observations were made. This information allows for the correction of "atmospheric effects" and results in data or images that are more representative of actual surface characteristics.

Passive sensors are the most common sensor type for vegetation and other Earth surface features related remote sensing. This is not only because passive sensor systems are generally simpler in design (built only to receive energy) but also because portions of the solar spectrum provide very useful information for monitoring plant and canopy properties.

A major limitation of passive systems is that in most cases they require sunlight in order for valid and useful data to be acquired. Consequently, deployment of or data acquisition by passive sensors is very dependent on lighting (time of day, time of year, latitude) and weather conditions, since cloud cover can interfere with the path of solar radiation from the sun to the surface and then to the sensor.

The signals detected by passive sensors can be greatly altered due to atmospheric effects, especially in the shorter wavelengths of the solar spectrum that are strongly scattered by the atmosphere. These effects can be minimized (but not eliminated) by collecting data only under very clear and dry atmospheric conditions. Sophisticated atmospheric correction routines now exist to remove atmospheric effects from data acquired by passive sensors.

5.3.5.4.2 Active sensors

They are different from passive sensors. Active sensors (such as radar and lidar systems) first emit energy (supplied by their own energy source) and then measure the return of that energy after it has interacted with a surface. Unlike passive sensors, active sensors require the energy source to come from *within* the sensor. For example, a laser-beam remote sensing system is an active sensor that sends out a beam of light with a known wavelength and frequency. This beam of light hits the earth and is reflected back to the sensor, which records the time it took for the beam of light to return. Topographic LIDAR laser beach mapping data included on this CD-ROM were collected with an active sensor.

Active systems supply their own illumination energy which can be controlled. Some advantages active systems have over passive sensors are they do not require solar illumination of surfaces or perfect weather conditions to collect useful data. Consequently they can be deployed at night or in conditions of haze, clouds, or light rain (depending on the wavelength of the system).

5.3.5.4.2.1 Radar Active Microwave Sensor

Radar (radio detection and ranging) systems use microwaves (wavelengths ranging from 1 millimeter to 1 meter). Microwave pulses are transmitted at a target or surface, and the timing and intensity of the return signal is recorded.

Transmission characteristics of radar depend on the wavelength and polarization of the energy pulse. Common wavelength bands used in pulse transmission are K-band (11-16.7 mm), X-band (24-37.5 mm), and L-band (150-300 mm). The use of letter codes to designate the wavelength range for various radar systems originated when radar was being developed during World War II. The random letter designations were assigned arbitrarily to ensure military security, however their use has persisted. Distinct from wavelength is the polarization of the transmitted energy. Pulses can be transmitted or received in either an H (horizontal) or V (vertical) plane of polarization.

Factors determining the strength of a radar return signal are complex and varied, however the most important are geometric and electrical properties of the surface or object that reflects the signal. Information about the structure and composition of objects and surfaces can be detected with radar. Radar has been used in a number of fields, including geology, snow and ice studies, oceanography, agriculture, and vegetation studies. Radar has been especially useful in areas with nearly constant cloud cover.

5.3.5.4.2.1 Lidar active optical Sensor

Lidar (light detecting and ranging) systems use laser light as an illumination source. A short pulse of light is emitted from a laser and a detector receives the light energy (photons) after it has been reflected, or absorbed and remitted, by an object or surface. Lidar systems emit pulses at specific, narrow wavelengths that depend on the type of laser transmitter used. The possible wavelengths range from about 0.3 to 1.5 micrometers, which covers the ultraviolet through near-infrared spectral range.

The simplest lidar systems measure the round trip travel time of a laser pulse, which is directly related to the distance between the sensor and the target. Basic distance measuring lidars are often referred to as rangefinders or as laser altimeters if deployed on an aircraft or spacecraft. These systems typically measure elevation, slope, and roughness of land, ice, or water surfaces.

More advanced lidars measure the received intensity of the backscattered light as a function of travel time. The intensity of the signal provides information about the material that reflected the photons. Such backscatter lidar systems are often used for atmospheric monitoring applications concerned with the detection and characterization of various gases, aerosols and particulates. Lidar methods have recently been adapted to measure tree heights and the vertical distribution of canopy layers with great accuracy and precision. Lidar instruments have flown on the Space Shuttle, and Vegetation Canopy Lidar (VCL) and Ice, Cloud, and land Elevation Satellite (ICESat) lidar missions are planned for the near future.

Lidar systems can also make fluorescence measurements. Fluorescence refers to the process where a material absorbs radiant energy at one wavelength and then emits it at a different wavelength without first converting the absorbed energy into thermal energy. The wavelengths at which absorption and emission occur are specific to particular molecules. Fluorescence data can identify and quantify the amount of plankton and pollutants in the marine environment. Leaf fluorescence can also help to identify plant species. The classification of sensors particularly being used in aerial and satellite remote sensing has been described in unit 2. Sensor types in the field of remote sensing are given in table-3.2 and 3.3.

Table 3.2 Categorization of Important Sensor Types

TYPES OF REMOTE SENSORS	
Active sensors	**Passive Sensors**
Non-Scanning • Non-Imaging. (They are a type of profile recorder, ex. Microwave Radiometer. Magnetic sensor. Gravimeter. Fourier Spectrometer. • Imaging. (Example of this is the cameras which can be: Monochrome, Natural Colour, Infrared etc.) **Scanning** • Imaging. Image Plane scanning. Ex. TV Camera, Solid scanner. Object Plane scanning. Ex. Optical Mechanical Scanner, Microwave radiometer.	**Non-Scanning** • Non-Imaging. (They are a type of profile recorder, ex. Microwave Radiometer. Microwave Altimeter. Laser Water Depth Meter. Laser Distance Meter. **Scanning** • Imaging. Object Plane scanning: Real Aperture Radar. Synthetic Aperture Radar. Image Plane Scanning: Passive Phased Array Radar.

Table 3.3 Indian Remote Sensing Satellites with Special reference to sensor types

Satellite	**Launching date**	**Launch Vehicle**	**Sensors**	**Completion of mission**
SARAL	May 25, 2013	PSLV-C20	Ka band Altimeter, ALTIKA ARGOS Data Collection System Solid State C-band Transponder (SCBT)	Since Mar 13, 2013
RISAT-1	April 26, 2012	PSLV-C19	SAR	Since Jul 1, 2012
Megha-Tropiques	Oct 12, 2011	PSLV-C18	MADRAS, SAPHIR, ScaRaB and ROSA	-
RESOURCESAT-2	Apr 20, 2011	PSLV-C16	LISS III,LISS IV Mx,AWiFS	Since May 8, 2011
Oceansat-2	23.09.2009	PSLV-C14	OCM,SCAT	OCM Since Jan 1, 2010 SCAT from Jan 1, 2010-Jan 30, 2014.
RISAT-2	20.04.2009	PSLV-C12	SAR	Since Apr 22, 2009
IMS-1	28.04.2008	PSLV-C9	IMS-1 Mx, HySI	Apr 30, 2008 to Sep 20, 2012
CARTOSAT-2A	Apr 28, 2008	PSLV-C9	PAN	-
CARTOSAT - 2	10.01.2007	PSLV-C7	PAN	Since Apr 14, 2007
CARTOSAT-1	05.05.2005	PSLV-C6	PAN	Since May 8, 2005
Resourcesat-1(IRS-P6)	17.10.2003	PSLV-C5	LISS III ,LISS IV Mx, AWiFS	Since Dec 7, 2003
Tech. Exp. Satellite (TES)	22.10.2001	PSLV-C3	PAN	Nov 1, 2001 to Dec 12, 2011

DECOMMISSIONED SATELLITES				
Oceansat -1 (IRS-P4)	26.05.1999	PSLV-C2	OCM, MSMR	Jul 1, 1999 to Aug 05, 2010
IRS-1D	29.09.1997	PSLV-C1	PAN,LISS III WiFS	Jan 1, 1998 to Dec 31, 2009
IRS-P3	21.03.1996	PSLV-D3	WiFS,MOS	Apr 1, 1996-Jan 25, 2004
IRS-1C	28.12.1995	Molniya	PAN,LISS III WiFS	Nov 14, 1996 to Sep 20, 2007
IRS-P2	15.10.1994	PSLV-D2	LISS-2A,LISS-2B	-
IRS-1B	29.08.1991	Vostok	LISS-1,LISS-2A,LISS-2B	Oct 2, 1991 to Sep 9, 2001 Archival policy implemented (4 cycles per year
SROSS-2	July 13, 1988	ASLV	Gamma Ray Burst (GRB) payload and Mono Payload Ocular Electro-Optic Stereo Scanner (MEOSS) built by DLR, Germany	-
IRS-1A	17.03.1988	Vostok	LISS-1,LISS-2A,LISS-2B	Apr 4, 1988 to May 28, 1991 Archival policy implemented (4 cycles per year
RS-D2	Apr 17, 1983	SLV-3	LISS-1,LISS-2A,LISS-2B	-
Bhaskara-II	Nov 20, 1981	C-1 Intercosmos	TV cameras, three band Microwave Radiometer (SAMIR)	-
RD-D1	May 31, 1981	SLV-3	Landmark Tracker (remote sensing payload)	-
Bhaskara-I	Jun 07, 1979	C-1Intercosmos	TVcameras, three band Microwave Radiometer (SAMIR)	-

3.4 SUMMARY

This unit has provided an introduction to platforms and sensors. The two prime platforms are aircrafts and satellites. Satellites can provide repeated and large area coverage. Most earth observation satellites circle in a `sun – synchronous` orbit so that they pass overhead at the same time. The sensor – platform combination determine the characteristics of the obtained RS data in particular the temporal resolution, the spatial resolution and the spatial coverage.

Under space-borne sensors, active and passive sensors have been described. An imaging camera is usually regarded as a passive sensor. In the modern times, a new approach that integrates active and passive infrared imaging capability into a single chip is developed. This sensor enables lighter, simpler dual-mode active/passive cameras with lower power dissipation. Alternatively, remote sensing sensors can be classified into imaging sensors and non-imaging sensors. In terms of their spectral characteristics, the imaging sensors include optical imaging sensors, thermal imaging sensors, and radar imaging sensors. Optical imaging sensors operate in the visible and reflective IR ranges. Typical optical imaging systems on space platform include panchromatic systems, multispectral systems, and hyper-spectral systems. In a panchromatic system, the sensor is a mono-spectral channel detector that is sensitive to radiation within a broad wavelength range. The image is black and white or gray scale. A multispectral sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image that contains both the brightness and spectral (color) information of the targets being observed. A hyper-spectral sensor collects and processes information from 10 to 100 of spectral bands. A hyper-spectral image consists of a set of images. Each narrow spectral band forms an image. The resulting images can be utilized to recognize objects, identify materials, and detect elemental components.

Radar (radio detection and ranging) systems use microwaves (wavelengths ranging from 1 millimeter to 1 meter). Microwave pulses are transmitted at a target or surface, and the timing and intensity of the return signal is recorded. Factors determining the strength of a radar return signal are complex and varied, however the most important are geometric and electrical properties of the surface or object that reflects the signal. Information about the structure and composition of objects and surfaces can be detected with radar.

Lidar active optical Sensor systems use laser light as an illumination source. A short pulse of light is emitted from a laser and a detector receives the light energy (photons) after it has been reflected, or absorbed and remitted, by an object or surface. Lidar systems emit pulses at specific, narrow wavelengths that depend on the type of laser transmitter used. The possible wavelengths range from about 0.3 to 1.5 micrometers, which covers the ultraviolet through near-infrared spectral range. The simplest lidar systems measure the round trip travel time of a laser pulse, which is directly related to the distance between the sensor and the target. Basic distance measuring lidars are often referred to as rangefinders or as laser altimeters if deployed on an aircraft or spacecraft. These systems typically measure elevation, slope, and roughness of land, ice, or water surfaces.

3.5 GLOSSARY

- **IMU**-Inertial Measuring Unit
- **RMSE**-Root Mean Square Error
- **GPS-** Global Positioning System
- **POS-**Positioning and Orientation System
- **FOV** –Field of View
- **LEO-** Low-earth Orbit (LEO)
- **Yohkoh-** Yohkoh Mission is a Japanese Solar mission with US and UK collaborators. It was launched into Earth orbit in August of 1991.
- **TRACE** - NASA's Transition Region And Coronal Explorer (TRACE) is the first US solar research satellite
- **Hinode** - Hinode (Solar-B) is a Japanese-led mission with ESA participation to study the mechanisms which power the solar atmosphere and look for the causes of violent solar eruptions.
- **UAS-** Unmanned aerial system
- **VCL** -Vegetation Canopy Lidar,
- **SPIN-** Space Placements in Industry scheme

3.6 ANSWER TO CHECK THE PROGRESS

Q1- Define platform?
Q2- Define sensors?
Q3- Define Remote sensing missions?
Q4- Write a short note on types of Platform?
Q5- Define characteristics of platform?
Q6- Define types of Sensors?
Q7- Define characteristics of sensors?

3.7 REFERENCES

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3. Manual of Remote Sensing. IIIrd Edition. American Society of Photogrammtery and Remote Sensing.
4. Sabins, F.F. 1997. Remote Sensing and Principles and Image Interpretation. WH Freeman, New York.
5. http://www.ccpo.odu.edu/SEES/veget

3.8 TERMINAL UESTIONS

1-Define remote sensing platform and sensor. What are the different platform types?
2-Explain the characteristics of different platforms.
3-Describe the orbital missions of remote sensing.
4-What are the different types of sensors? Compare the characteristics of passive and active sensors.
5-Describe the characteristics of Lidar and Radar sensors.

BLOCK 2: AERIAL PHOTOGRAPHY

UNIT 4: AERIAL PHOTOGRAPH

4.1 OBJECTIVES

After reading this unit, you should be able to:

- know how aerial photography is done;
- acquire skill how to study data and apply aerial photography data;
- discuss about different types of aerial photo graphs used for remote sensing ;
- describe the aerial camera , lenses and films used in aerial photography;
- explain about planning and processes of aerial photography;

4.2 INTRODUCTION

In Block 1, you learned that remote sensing is concerned with obtaining information about a target by recording the interaction of incident electromagnetic radiation (EMR) with the target. The platforms are in different orbits in space, either close to or far from the Earth. The majority of remote sensing is done from orbital or suborbital platforms, with devices (sensors) measuring EMR reflected or emitted from the target. A sensor is an instrument that receives and records energy reflected or emitted from a target and is situated on a stable platform away from the Earth. In this unit we shall discuss about the concepts of aerial photography and aerial photos.

4.3 AERIAL PHOTOGRAPH

History of Aerial Photography

Aerial photography is the practice of shooting photographs from a plane or other flying object (or airborne imaging). Aerial photography is done with fixed-wing aircraft, helicopters, unmanned aerial vehicles (UAVs or "drones"), balloons, blimps, and dirigibles, as well as rockets, pigeons, kites, parachutes, and stand-alone telescopic and vehicle-mounted poles. Mounted cameras can be actuated remotely or automatically, and a photographer can take hand-held images. Aerial photography is mostly used for pictorial representation, such as mosaics, photo interpretation, and photogrammetric surveys.

In 1858, Gaspar Felix Tournachon, a French photographer and balloonist known as "Nadar," took the first documented aerial photograph. In 1855, he patents the idea of using aerial photographs in mapmaking and surveying, but it takes him three years of trial and error to produce the first aerial photograph. It was an aerial photograph of Petit-Becetre, France, taken from an 80-meter-high tethered hot-air balloon.

Given the complexity of the early collodion photographic process, which necessitated the transportation of a complete darkroom in the balloon's basket, this was no small feat! Unfortunately, none of Nadar's early photographs have survived, and the earliest aerial photograph known to exist is James Wallace Black's view of Boston from a hot-air balloon in 1860. Triboulet carried out the first free flight balloon picture expedition above Paris in 1879, thanks to the invention of the dry-plate process, which eliminated the need for as much equipment. It got easier to take cameras into the air as photographic technology evolved. In addition to hot air balloons, early pioneers used kites, birds, and rockets to carry their cameras above the ground.

E. D. Archibald, an English meteorologist, was one of the first to successfully fire a kite shot in 1882. He used a line of kites, with the last one being connected to the camera. In 1889, Arthur Batut used a kite to take aerial photographs at Labruguiere, France. He suspended his still-large camera with a single kite and set an automatically timed exposure. A slow-burning fuse, detonated by a rubber band-driven gadget, actuated the shutter just a few moments after the kite was released. Batut took his first aerial shot in May 1888.

During the 1906 earthquake and fire, George R. Lawrence photographed the ruins of San Francisco using a camera mounted on a line of kites far above the city. His large-format camera had a curved film plate, which allowed him to create panoramic photos that are now regarded as some of the greatest aerial exposures ever taken. It took 17 kites to lift the camera 2,000 feet into the air, which was massive and heavy. Lawrence also took "aerial" images from a lower level using ladders and high towers.

Pigeons were used by the Bavarian Pigeon Corps to transport messages and conduct aerial reconnaissance. In 1903, Julius Neubranner invented a breast-mounted camera for carrier pigeons. The camera may be set to take automated exposures at 30-second intervals as the pigeon flew by. The flight route, on the other hand, was not always accurate! The birds were first seen at the 1909 Dresden International Photographic Exhibition, where postcards of aerial photos made during the event were extremely popular among the general public.

In 1897, a Swedish inventor named Alfred Nobel snapped the first successful aerial photograph with a rocket-mounted camera. He is well known in today's world for earning the Nobel Prize. In 1906, Albert Maul of Germany invented a more reliable method by using compressed air to propel a rocket. His camera captured an aerial shot from a height of 2,600 feet before he was removed and parachuted back to Earth. He invented the idea of using powder rockets in 1903, and by 1904, he was experimenting with parachute-recoverable gyroscopically stabilised cameras launched by rockets. In 1909, Wilbur Wright became the first person to take aerial photographs from an aeroplane. He was in Italy selling jets to the Italian government when he picked up a passenger filming at Centocelli, a military base near Rome.

Aerial photography swiftly replaced aerial observers' sketching and drawing during World War I. Both sides used aerial photographs to generate battle maps, and towards the end of the war, both sides were recording the whole front at least twice a day. Thermal infrared detectors were being developed, as well as cameras designed expressly for use in planes. Stability and shutter speed were difficulties, so near the end of the war, Sherman M. Fairchild devised a camera with the shutter incorporated inside the lens. This concept improved image quality substantially over the next 50 years and became the industry standard for aerial camera systems. After the conflict, the aerial camera was employed for non-military purposes. Using a series of overlapping photographs, Sherman Fairchild built an aerial map of Manhattan Island. This aerial map was a commercial success, and it was used by a variety of New York City departments and businesses. Other cities followed suit, realising that his airborne inspections were significantly more efficient and cost-effective than ground assessments. Aerial photography has been demonstrated to have civilian applications and might be a lucrative business venture.

In addition to his successful aerial camera, Fairchild also developed and manufactured aero planes with high-wings and enclosed cabins as a more safe and stable platform from which to shoot photos. Aerial photography has becoming more widely used as a result of his inventiveness and dedication to the industry. Fairchild's cameras were carried on Apollo 15, 16, and 17 before he died in 1971, and his cameras mapped the moon while astronauts examined the lunar surface. Most aerial photographers use gyro-stabilizers to correct for aircraft movement as their cameras become more digital. The images that result are high-resolution aerial views of excellent quality that may be delivered to the client's desktop the same day as the shoot. Aerial photography is employed by a diverse spectrum of clients, including commercial, industrial, agricultural, government, and private individuals.

Aerial photography in India:

In 1920, the first large-scale aerial photographs of Agra, India, were taken. The Air Study Party of the Survey of India then commenced an aerial survey of the Irrawaddy Delta forests, which was completed in 1923–24. Following that, countless further surveys were carried out, using improved mapping techniques based on aerial photographs. Under the direction of the Directorate of Air Survey (Survey of India) in New Delhi, aerial photography is presently carried out over India. The Indian Air Force, Kolkata's Air Survey Company, and Hyderabad's National Remote Sensing Centre have all been granted formal clearance to take aerial photographs across the country. The method for indenting aerial photographs for educational purposes can be assisted by APFPS Party No. 73, Directorate of Air Survey, Survey of India, West Block IV, R. K. Puram, New Delhi.

Characteristics of Aerial Photographs:

Synoptic view: When you record or take aerial photographs geographically over a large area, it's like having a birds eye perspective from the top. The detection and discrimination of micro scale traits, as well as spatial interactions between them, are possible with these technologies.

Time freezing ability: They're described as "basically permanent records of present conditions on the Earth's surface at one point in time" that can also be used as a historical document.

Capability to stop action: Flooding, migrating wildlife, traffic, oil spills, forest fires, shifting dynamics in natural phenomena, and so on are all examples of variable/dynamic events.

Three Dimensional perspectives: Aerial photographs provide a stereoscopic depiction of the Earth's surface, allowing both horizontal and vertical measurements.

Spectral and spatial resolution: Electromagnetic radiation with wavelengths (0.3 m to 0.9 m) that are outside the spectral sensitivity of the human eye are sensitive to aerial films (0.4 m to 0.7 m).

Availability: To produce a permanent record of any location, airborne photographs can be acquired at a user-defined time and scale.

Applications of Aerial Photography

Photography Mapping

The use of aerial photography in photogrammetric mapping is a well-known practice around the world. It has been discovered to be fast, accurate, indispensable in inaccessible areas, and cost effective in the long run, despite the fact that establishing a photogrammetric survey/mapping unit initially requires capital expenditure due to the cost of photogrammetric instruments and other ancillary equipment.

Interpretation

In a variety of fields, photo interpretation has revolutionized data collection methods. It drastically minimizes fieldwork and, as a result, costs. For most research, such as geology, water resources, geomorphology, hydrogeology, forestry and ecology, soil surveys, and urban and regional planning, the data is reliable and accepted.

Map Substitute

Aerial images can be used as map substitutes in the form of photomaps when there aren't enough large-scale maps accessible. These photomaps can be created via rectification to remove the effects of tilt distortion and scale correction in the case of relatively flat terrain. This method was discovered to be three to four times faster than traditional photogrammetric mapping methods. Such photomaps (orthophoto maps) can be created on steep terrain using the orthophoto approach, which has also proven to be faster than traditional mapping. Simple mosaics made from aerial pictures can be used to replace maps in some emergency scenarios.

Methods of aerial photography:

There are two types of methods of aerial photography

Pin Point Photography:

Taking a vertical or oblique photograph of a particular object on the ground with an aircraft is called pin point photography. This object can be a building, factory, bridge, airport, railway station or any other place, for which one or two photographs are captured.

Block photography :

Block photography method is used instead of pin point photography for aerial survey of large areas. In this method the given area is divided into parallel strips. After that, overlapping photographs of each strip are taken while flying the aircraft in serpentine pattern over these strips .

Check Your Progress

Q.1 What is aerial photography?

Q.2 Write three basic applications of aerial photography.

Q.3 Fill in the blank-

a) Gaspar Felix Tournachon, a French photographer and balloonist known as "Nadar," took the first documented aerial photograph in the year ----.
b) Taking a vertical or oblique photograph of a particular object on the ground with an aircraft is called ----------- photography.

Q.4 True false against the following-

a) Aerial photography is mostly used for pictorial representation, such as mosaics, photo interpretation, and photogrammetric surveys.
b) Pin point photography method is used instead of pin point photography for aerial survey of large areas.

Factors that influence Aerial Photography

Scale

The scale of an aerial photograph is the ratio of distances between two photographs and the actual distance between the same two points/objects on the ground, also known as the f/H ratio (where f is the focal length of the camera lens and H is the flying height above the mean terrain). The scales of different images may differ due to differences in flying height. Because of the effects of tilt and relief displacements, the scale may vary. Combinations of camera, film, and filter The image must be of the best quality in order to get the most information from an aerial photograph. Modern distortion-free cameras are utilized to assure good image quality. Image motion correction mechanisms are included in some of the more recent versions to eliminate or decrease the impacts of forward motion. Different lens/focal length/film/filter combinations can be utilized according on the requirements.

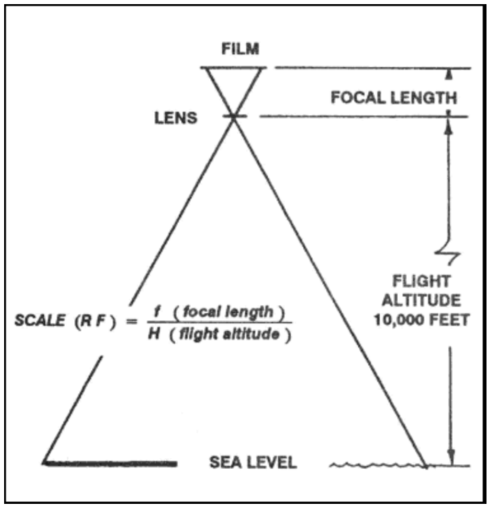

Fig 4.1. Scale of photograph
Source- http://www.globalsecurity.org/military/library/policy/army/fm/3-25-26/ch8.htm

Aerial Camera and lenses

Aerial cameras are special cameras designed for mapping with great geometric and radiometric precision. Airborne cameras are precision-engineered to expose a large number of films/photographs in rapid succession while maintaining the highest geometric fidelity and quality. Aerial cameras have a medium to large format, a big film magazine, a mount to hold the lens, the camera in a vertical position, and a motor drive. Aerial mapping cameras (single lens), reconnaissance cameras, strip cameras, panoramic cameras, multilens cameras, multiband aerial cameras, and digital cameras are all examples of aerial cameras. In order to extract maximum information for aerial photographs, the image quality should be highest possible quality. Twins your good image quality, modern distortion free and higher resolving power aerial cameras such as WILD RC-20,LMK,KA series,WILD RC -10,WILD RC 10 A , or R are MK 15/23 or ZEI SS RMK are 30/23 should be used and should, therefore, be specified by the the indentor. The lenses available in India are the focal length of 8.8 cm (super Wide Angle),15 cm (wide Angle)21 cm (normal angle) and 30cm (narrow angle) which should preferably the specified by the indentor, which asking for aerial photography.

Aerial Films

Aerial film is a multi-layer emulsion that is laid down on a non-halation basis. Aerial films are typically sold on rolls with a cross section of about 10 inches wide and a length of 200 to 500 feet. A number of films are available that are utilised depending on their usefulness for various purposes and particular scenarios. The two most widely used films are panchromatic and natural colour. These two films, as well as infrared and false colour, are the most used aerial photography media. As shown below in fig.4.2.

Fig 4.2. Types of film photographs
Source- http://www.globalsecurity.org/military/library/policy/army/fm/3-25-26/ch8.htm

- **Panchromatic**: Panchromatic film, sometimes known as black and white film, is the most frequent type used in photogrammetry. Silver salt crystals (bromide, chloride, and halide) are suspended in a pure gelatine coating that lies atop a plastic base sheet in the sensitive layer. The visible (0.4- to 0.7-m) region of the electromagnetic spectrum is sensitive to the emulsion.
- **Colour:** True colour film is also known as natural colour film. The visible part of the electromagnetic spectrum is sensitive to the multilayer emulsion. Three layers of gelatine with sensitised dyes, one for blue (0.4–0.5 m), green (0.5–0.6 m), and red (0.6–0.7 m) light, are used. Blue wavelengths are also sensitive to the green and red layers. Visible light waves travel through the blue layer first, reacting with it, and then passing through a filter layer that prevents the blue rays from passing through any further. Green and red waves penetrate past this barrier and sensitise the dyes in their respective colours, generating a chemical reaction that completes the exposure and creates a true colour image.
- **Infrared**: There are two varieties of aerial infrared film now available: black and white infrared and colour infrared. The emulsion sensitive to green (0.54–0.6 m), red (0.6–0.7 m), and part of the near infrared (0.7–1.0 m) sections of the spectrum creates a gray-scale image in Black and White Infrared. (Fig.3)
- **Colour Infrared**: Colour false colour is a word used to describe infrared film. Green (0.5–0.6 m), red (0.6–0.7 m), and part of the near infrared (0.7–1.0 m) regions of the spectrum are responsive to the multilayer emulsion. In vegetative environments, a false colour image comprises red/pink hues, with the colour varying depending on how active the photosynthetic process is.

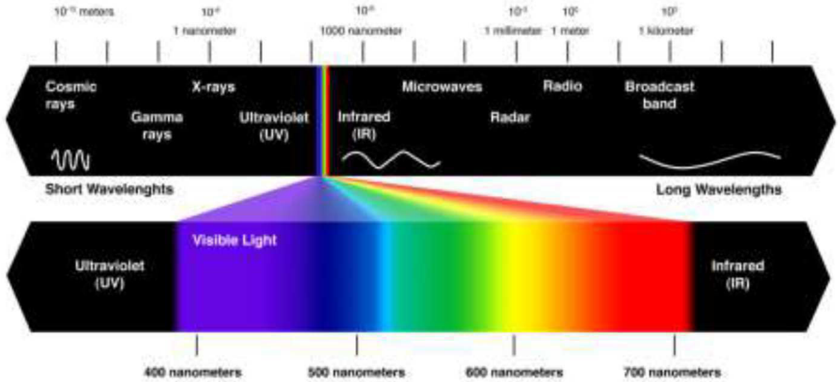

Fig 4.3. Visible Spectrum
Source:http://www.harrisgeospatial.com/Learn/WhitepapersDetail/TabId/802/ArtMID/2627/ArticleID/13742/Vegetation-Analysis-Using-Vegetation-Indicesin-ENVI.aspx

Flight Direction

Aerial photography should be flown in tiles to cover the desired region in the defined flight line (shown in fig 4.4). It's best to keep the number of tiles to a bare minimum for ease of handling. The strips/tiles' flight direction is therefore maintained along the length of the region. This direction can be any appropriate direction along a natural or man-made feature, and it should be defined clearly. Figure 4.5depicts the data collecting and transmission process.

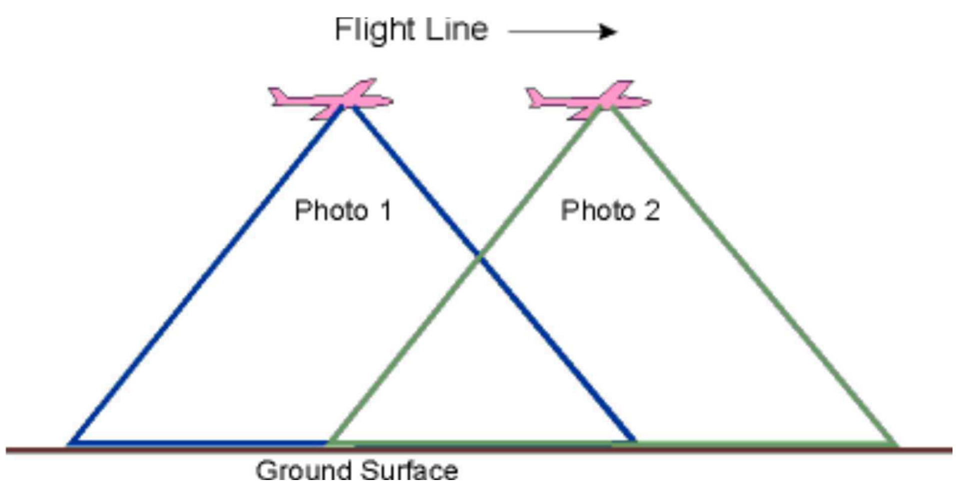

Fig 4.4. Flight Line
Source:http://www.sonoma.edu/users/f/freidel/techniques/exer/rem_sens/RemSen_a.html

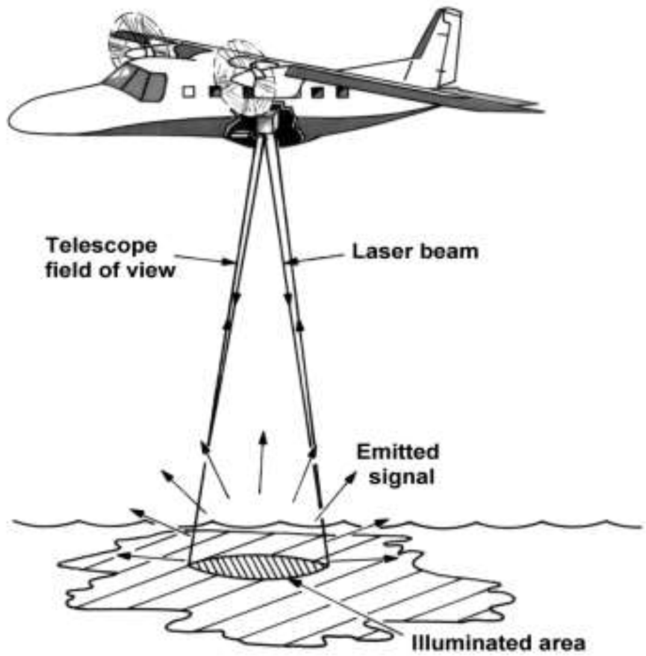

Fig 4.5. Flight direction and signal receiving process
Source-http://www.seos-project.eu/modules/laser-rs/laser-rs-c07-p01.html

Time/Season of Photography

Aerial photography time is critical since long, deep shadows obscure features, yet short shadows effectively outline specific aspects and are generally beneficial in boosting the interpretive values of a shot. Aerial photography should be flown while the sun is 30 degrees above the horizon, or three hours before and after local noontime, according to experience.

Seasonal differences in light reflectance, seasonal changes in vegetation cover, and seasonal changes in climatological parameters all influence the most appropriate season. The season is also determined by the aim of aerial photography. The ground, for example, should be as visible as feasible for photogrammetric mapping, geological, or soil survey purposes.

Atmospheric Conditions

As previously said, the presence of particles (smoke or dust) and molecules of gases in the atmosphere tends to lessen contrast due to scattering, particularly by larger particles; thus, the optimum time for photography is when the sky is clear, which is typically from November to February in India. Aerial photography is prohibited during the pre-monsoon summer months due to the presence of dust and smoke, and during the monsoon months due to the presence of clouds.

Stereoscopic Coverage

Aerial photography is generally flown with a 60 percent forward overlap and a 25% side lap to provide full coverage of the region in order to investigate the earth's surface in three dimensions. From the standpoint of photogrammetric mapping, this is a prerequisite in order to acquire data on planimetry and heights utilizing the stereoscopic concept of observation in 3-D and measurement techniques using stereo plotting devices. Because the model is viewed in three dimensions, stereoscopic viewing aids interpretation (Fig. 4.6a and 4.6b).

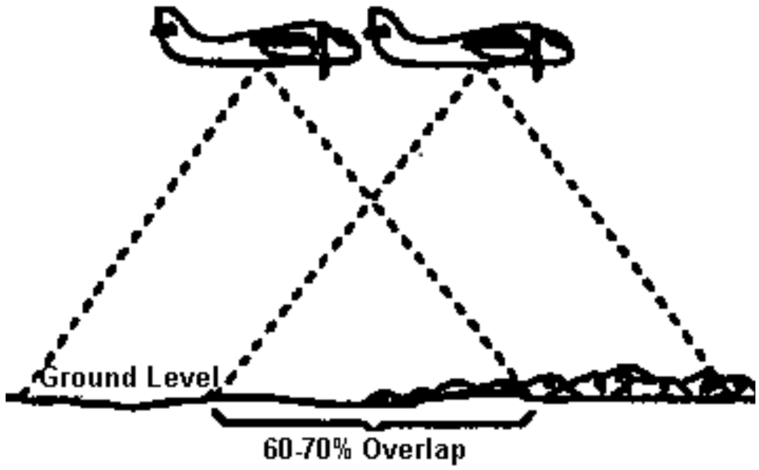

Fig 4.6(a) Overlap required to get the full coverage of area
Source- http://hosting.soonet.ca/eliris/remotesensing/bl130lec4.html.

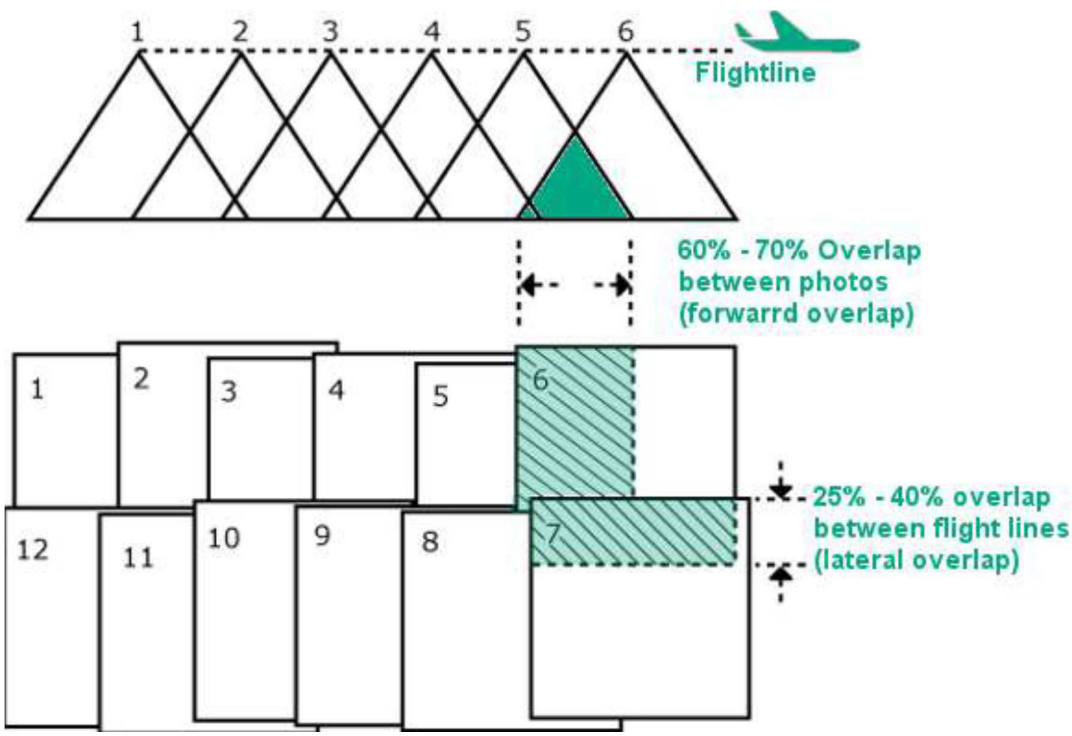

Fig 4.6(b) Overlap required to get the full coverage of area
Source- http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-airphotos/air-photos/about-aerial-photography/9687

Check Your Progress

Q.5 What is infrared film used in aerial photography?
Q.6 What is over lapping in aerial photography?

Q.7 Fill in the blank-

a) ------------- sometimes known as black and white film, is the most frequent type used in photogrammetry.
b) Aerial photography should be flown while the sun is ----- degrees above the horizon, according to experience.

Q.8 True false against the following-

a) The two most widely used films are panchromatic and natural colour.
b) Aerial photography is generally flown with a 40 percent forward overlap and a 60% side lap to provide full coverage of the region in order to investigate the earth's surface in three dimensions.

Classification of Aerial Photograph

Aerial pictures are classified using a variety of criteria. Scale, tilt angle, angular coverage, film type, and spectral bands are all different requirements. Aerial pictures can be categorised into the following categories based on these parameters (fig 4.7a, 4.7b):

Scale

- Large scale: RF 1:5,000 to 1:20,000
- Medium scale: RF 1:20,000 to 1:50,000
- Small scale: smaller than RF 1:50,000

Fig 4.7(a) Small scale and large scale difference
Source- http://www.physicalgeography.net/fundamentals/2a.html

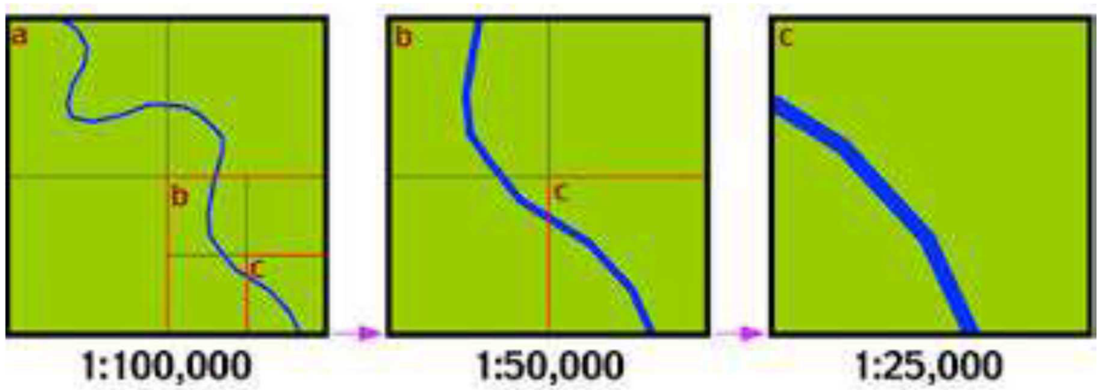

Fig 4.7(b) Difference in levels of scale
Source- http://giscommons.org/chapter-2-input

Camera Orientation

Vertical: When the vertical photograph is taken it evident that optical axis of camera should be vertical or nearly vertical. (Tilt is within 3°) (Fig 4.8 a,b,c)

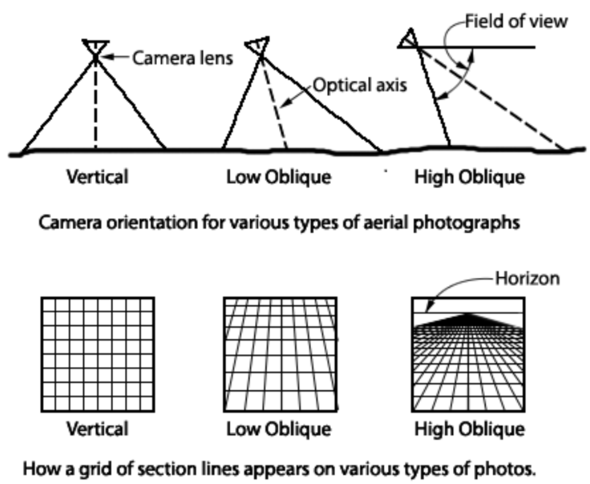

Fig 4.8(a) Camera orientation for various types of photograph
Source- https://www.e-education.psu.edu/geog480/node/444

- **Oblique:**

a) Low oblique: Photograph is taken with strongly tilted optical axis but not to the extent that horizon appears in the photograph (horizon does not appear but tilt is more than 3°).

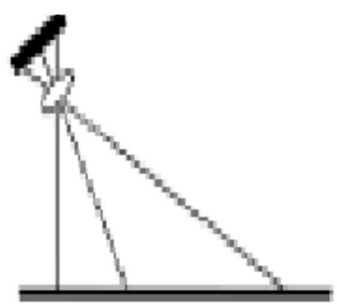

Fig.4.8(b)Low oblique

Source- Sourcettp:// www.engr.usask.ca/classes/GEOE/218/notes/airphoto_reading/ apg.htm

b) High oblique: Photograph is taken with deliberately tilted optical axis enough from the vertical to show the Earth's horizon (horizon appears in the photograph).

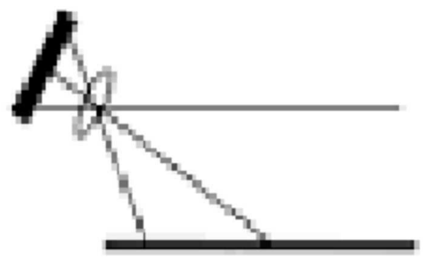

Fig. 4.8(c) High oblique

Source:http://www.engr.usask.ca/classes/GEOE/218/notes/airphoto_reading/ apg.htm

- Horizontal or terrestrial: Photograph is taken with camera axis horizontal.
- Convergent Photography: It is a sequential pair of low oblique in which the optical axes converse towards one another. In this kind of photography both the photographs cover the same area but from different locations.

Angular Coverage: Angular coverage is a function of focal length and format size. Narrow Angle: Angle of Coverage Less than 200 (Large Focal length) Used for General interpretation, intelligence and mosaics.

- Normal angle: Angle of coverage between 50^0 - 75^0 used for general interpretation, mapping, ortho-photography, and mosaics.
- Wide angle: angle of coverage 85^0 - 95^0 used for general interpretation, general purpose photography for normal terrain, resource mapping and mosaics.
- Super-wide angle: angle of coverage more than 110^0 Used for General purpose mapping of flat areas

Film

- Black and white panchromatic: This is most broadly used type of film for photogrammetric, mapping and interpretation.
- Black and white infrared: This is used interpretation and intelligence and in hazy environment as IR can penetrate through haze.
- Colour: This is used for interpretation and mapping.
- Colour infrared/ false colour: This is used for vegetation studies, water pollution, and crop studies

Spectral Coverage/Response

- Multispectral: Depending upon the number of spectral bands.

Photographic Products

All aerial photography assignments are captured on film negatives, which are rarely used for mapping or interpretation. For photogrammetric mapping and interpretation work, positive prints or transparencies/diapositives prepared from film negatives are employed. The criteria for successful positive prints are that they should accurately depict the actual response and duplicate all of the information in the negative in a way that allows for easy identification.

Paper, film, and glass plates are used as positive materials. Positive transparencies, also known as diapositives, are preferable because they capture all of the features found in negatives. When high precision and quality are required, dipositives are employed. Paper printouts, on the other hand, are so much easier to work with that they're always utilised for picture interpretation and field testing. Below is a list of the various sorts of photographic data products.

- Negatives on film (polyester based): previously on glass plates also.
- Diapositives/transparencies on film
- Contact prints on various grades and types of photographic paper. These photographic papers come in soft, medium, and hard grades, and they're used to make contact prints with the best contrast from the original film negative. If the original negative has a lot of contrast, for example, the contact prints are made on a soft paper. Likewise, photographic paper comes in a variety of thicknesses and surface characteristics (matte or glossy) for usage at various phases of mapping and interpretation. Enlargements obtained on film or photographic paper for specific uses.

- Colour/false colour prints. Positive prints from original colour negative films can also be made on colour films/paper/transparencies for use in interpretation. Similarly, such prints/transparencies can be made from colour infrared/false colour infrared/false colour infrared/false colour infrared/false colour infrared/false
- colour films. However, the processing of such films requires special processing facilities.
- Multispectral photographs on film or photographic paper. Color composites or false colour composites can be made from multispectral photos taken with an I2S camera by combining or superimposing different spectral bands: for example, true colour composites can be made by combining the blue, green, and red bands in a specific projection equipment. Color/false colour composites can be obtained using special instruments such as the Mini Addcol Viewer if all you want to do is look at them.

Obtaining Aerial Photography

According to Indian government policy, all forms of aerial images are categorised as secret or restricted documents, depending on their location and strategic relevance. All activities connected to the performance of aerial photography duties for all civilian needs are coordinated by the Surveyor General of India. The following are the responsibilities of the coordinating authority:

- Design and issue of the specifications for photographic tasks.
- Layout and priorities, clearance from various agencies and distribution of tasks among the three flying agencies.
- Flight planning and evaluation for suitability of the executed tasks.
- Distribution of photographs to the indenter.
- Accounting for the above.

Flying Agencies

The Indian Air Force, the Air Survey Company, Dum Dum, Calcutta, and the National Remote Sensing Agency (NRSA), Hyderabad, perform the aerial photography missions because the coordinating agency lacks its own flying resources.

Cost of Aerial Photography

The cost of aerial photography in India is determined by the flying agency that performs the job, the scope of the job, and the area covered. The cost also varies depending on whether the prints are made from new or old photographs.

The cost of the Indian Air Force is determined by the number of actual flying hours and the type of aircraft deployed, and so cannot be calculated in advance.

For 1:40,000 scale, the cost is Rs. 75.20 per square mile (Rs. 29/- per square km) in the case of Air Survey Company (1990 price - the cost is now under revision). A linear conversion can be done for various scales; for example, the cost of a 1:5,000 scale is (40/5) X 75.2 = Rs. 601.60 per square mile, while the cost of a 1:60,000 scale is (40/60) X 75.20 = Rs. 50.15 per square mile.
In the case of the NRSA, the price varies depending on the scale and distance from their headquarters. As a result, each task's cost must be calculated independently.

Check Your Progress

Q.9 What is vertical photograph?
Q.10 What are the two basic uses of infrared colour aerial photograp?

Q.11 Fill in the blank-

a) -----------photograph is taken with deliberately tilted optical axis enough from the vertical to show the Earth's horizon.

b) ---------------------,--------------------- and ------------------------, perform the aerial photography missions.

Q.12 True false against the following-

a) All activities connected to the performance of aerial photography duties for all civilian needs are coordinated by the Surveyor General of India.
b) Black and white infrared: This is used interpretation and intelligence and in hazy environment as IR can penetrate through haze.

Handling of Aerial Negatives

Humidity and thermal expansion/contraction are the most common causes of dimensional change in aerial negatives. Negatives should be stored at the same temperature and relative humidity as they were when they were exposed. Temperatures should be 70 degrees Fahrenheit with a +/-3 degree Fahrenheit tolerance, and relative humidity should be 50 to 60 percent. It is recommended that the temperature of the aerial camera be kept near to normal room temperature while in operation to ensure dimensional stability.
Negative rolls should also be preserved for future use in the above-mentioned controlled temperature and humidity conditions. Negatives should be maintained clean and free of dust, grease, scratches, and fingerprints while being worked on. These safeguards will aid in the generation of high-quality data products when they are needed.

Specifications of Aerial Photography

The goal of the picture and scale are the most important concerns while planning new photographs. However, the following aspects should be considered when creating these specifications. Unless otherwise stated, overlaps should be preserved at 60% in the forward direction and 25% in the lateral direction, unless otherwise specified. In steep mountainous areas and metropolitan centers with high-rise buildings, the overlaps can be increased to 80 percent in the forward direction and 50 to 60 percent in the lateral direction for unique duties and terrains.

- Camera lens : depending on the type of photography required.
- Film/filter combination : depending on the type of photography required.
- Shutter speed : depending on the scale, type of aircraft, its speed and film speed/aperture (between 1/100 to 1/1,000 seconds).
- Image motion : to be kept within tolerable limits(i.e. 20 um on the negative scale) by the proper combination of shutter speed/aperture and speed of aircraft
- Camera frame : stable mounts
- Platforms : ceiling height, stability in flying and speed limits.
- Auxiliary data : as required
- Processing : depending on the film type and the requirements of the data products.

4.4SUMMARY

In this unit we have discussed various aspects related to aerial photography along with introduction. We know how photography is done and what are the factors affecting it. We learned about aerial photography and types of aerial photographic images and their various uses. Along with this, there was a discussion about the aerial camera, lens, film history used in aerial photography.

4.5 GLOSSARY

Aerial photograph: a photograph taken with a precise camera from an airborne platform.
Aerial photography: is the art, science, and technology of photographing the sky from an aircraft.
Aerial camera: a high-resolution camera developed for use in aircraft.
Aerial film: is a roll film with high sensitivity, inherent resolution, and dimensionally robust emulsion support.
Flight line: the path taken by an aeroplane while photographing during a sortie.

Flying height: the altitude at which the aircraft was flying at the time the images were shot; this has a direct impact on the scale of the photographs.

Infrared film: Infrared film has an emulsion that is particularly sensitive to infrared and blue light. Because of the penetrating capacity of infrared light, it is utilised to picture through haze and in camouflage detection to distinguish between living vegetation with chlorophyll and dead vegetation or artificial pigment.

Vertical photograph: is one shot from the bottom of an aircraft with a camera looking straight down. The snapshot depicts the ground in plan view, making it simple to compare to a map.

Oblique photograph: An aerial photograph taken with the camera pointing in a slanting direction towards the ground is known as an oblique photograph.

Oblique photograph - high: an oblique photograph in which the horizon is shown.

Oblique photograph - low: an oblique photograph in which the horizon is not shown.

Overlap: The amount of overlap between two adjacent aerial images is referred to as overlap in aerial photography. The amount of overlap required to view in stereo is described by established standards. This is usually 60 percent forward and 15% laterally (i.e. side-to-side and top-to-bottom).

4.6 ANSWER TO CHECK YOUR PROGRESS

Ans .1 Aerial photography: Are the art, science, and technology of photographing the sky from an aircraft.

Ans.2 Aerial photography is mostly used for pictorial representation, such as mosaics, photo interpretation, and photogrammetric surveys

Ans.3 Fill in the blank-

a) 1858
b) Pin point photography.

Ans .4 True false against the following-

a) True
b) False

Ans .5 infrared films has an emulsion that is particularly sensitive to infrared and blue light.

Ans.6 The amount of overlap between two adjacent aerial images is referred to as overlapping in aerial photography.

Ans .7 Fill in the blank-

a) panchromatic
b) 30^0

Ans.8 True false against the following-

a) True
b) False

Ans.9 Vertical photograph is one shot from the bottom of an aircraft with a camera looking straight down. The snapshot depicts the ground in plan view, making it simple to compare to a map**.**

Ans .10 vegetation studies, water pollution

Ans .11 Fill in the blank-

a) high oblique
b) The Indian Air Force, the Air Survey Company, Dum Dum, Calcutta, and the National Remote Sensing Agency (NRSA), Hyderabad

Ans .12 True false against the following-

a) True
b) True

4.7 REFERENCES

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4.8TERMINAL QUESTIONS

Q.1 Write a short note on history of aerial photography in India.
Q.2 Discuss on the applications of aerial photographs.
Q.3 What is block photography?
Q.4 Discuss on aerial camera and lenses used in aerial photography.
Q.5 What is vertical photography?
Q.6 Write a note on aerial films used in aerial photography.

UNIT 5: STEREOSCOPIC AREA PHOTOGRAPH

5.1 OBJECTIVES

After reading this unit, you should be able to:

- know the concepts of stereoscopy in photogrammetry ;
- acquire skill of stereoscopic viewing in analog photogrammetry;
- develop stereo models for determining ground elevations and features heights.
- discuss about stereoscopic measurement sand parallax;

5.2 INTRODUCTION

Photographs are usually studied stereoscopically to get the most out of them. A stereoscopic pair is made up of two images taken from two camera stations but covering the same common area. When examined in a certain way, it appears as if a three-dimensional representation of the common area is being seen. This unit concludes with a discussion of the reason behind this subjective impression. The basics of stereoscopy in aerial photography will be discussed in this unit, as well as the usage of aerial photographs to investigate stereoscopically to extract important information.

A stereoscope is a device for viewing a stereoscopic pair of distinct images as a single three-dimensional image, exhibiting left-eye and right-eye perspectives of the same scene. A stereoscope's purpose is to divert typically converging lines of sight, allowing each eye to see a separate image. Lens stereoscopes and reflecting or mirror stereoscopes are the two types of instruments currently in use for three-dimensional analysis of aerial photos. Stereoscopic vision, also known as space vision or plastic vision is a feature that most people with normal eyesight have. It is vital for imagining objects in three dimensions and judging distances. For photogrammetry and photo interpretation, stereoscopic vision is required. Stereoscopy is described as the science or art of dealing with stereoscopic or other three-dimensional effects and the methods used to create them. Humans have a natural ability to recognize depth. However, there are numerous assistances to depth perception, such as closer things partially covering distant objects or distant objects appearing smaller than nearby identical objects.

5.3STEREOSCOPIC AREA PHOTOGRAPH

Stereoscopic Vision

Stereoscopic vision, also known as space vision or plastic vision is a feature that most people with normal eyesight have. It is vital for imagining objects in three dimensions and judging distances. For photogrammetry and photo interpretation, stereoscopic vision is required. Stereoscopy is described as a science or art that deals with stereoscopic or other three-dimensional effects and the methods used to create them. Close objects are larger, brighter, and more detailed than distant objects, and close objects obscure far object's perspective. Monocular vision refers to the ability to see with only one eye. Binocular vision refers to seeing with both eyes open at the same time. "Stereoscopic acuity" refers to the degree of depth perception. Normal when pictures on the retina have particular qualities, stereoscopic acuity is feasible. Two eyes are required to see two images that differ just slightly in angle of view, orientation, colour, brightness, shape, and size. (Fig.5.1) The two points of observation required for parallax are provided by human eyes fixed on the same object. When viewed with the left and right eyes alternately, a finger held with the arm stretched appears to move sideways. The horizontal parallax is hence movement or displacement.

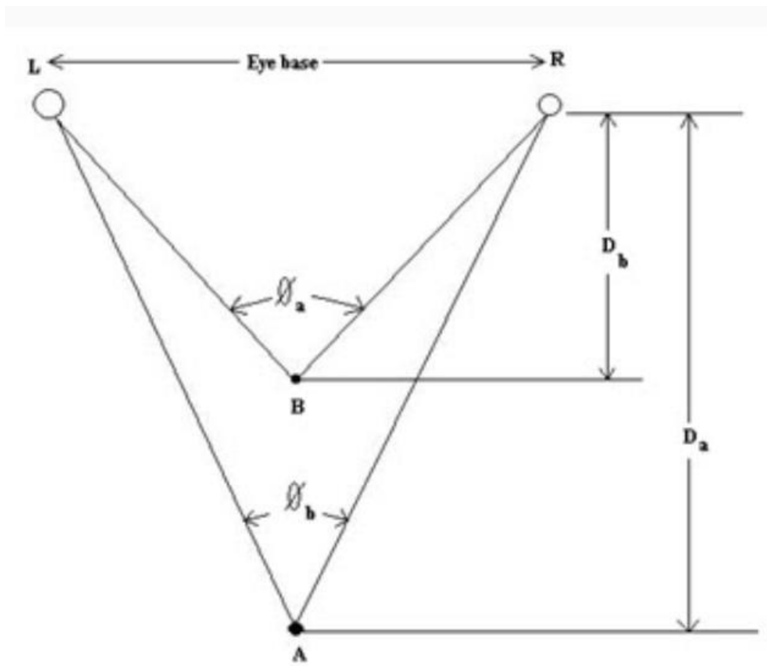


Fig.5.1 Human stereoscopic vision
(resourceonline.isri.res.in)

Depth Perception

Humans have a natural ability to recognize depth. However, there is a variety of assistance to depth perception, such as closer things partially covering distant objects or distant objects appearing smaller than nearby identical ones. These are monocular vision aids. Binocular vision is more important for short distances and is of interest to photogrammetrists since it allows us to receive a spatial sense of a model formed by two photographs of an object (or objects) taken from different view positions.

Our eyes normally provide us two slightly distinct images, which are biologically combined by the brain and result in the experience of seeing a three-dimensional model. However, the three-dimensional effect created by binocular vision is quite limited, drastically diminishing beyond a viewing distance of one meter. As a result, it's reasonable to argue that binocular vision serves primarily as a tool for controlling and guiding limb movements. A small percentage of the population lacks binocular vision, and no amount of training can help them acquire it.

Unfortunately, there is no known physical intervention that can produce stereoscopic vision to someone who does not have it natively, but individuals with weak fusion can benefit from training.

Types of Stereoscopic Vision

Stereoscopic vision can be of two types: i. Natural Stereoscopic Vision; ii. Artificial Stereoscopic Vision

i. **Natural Stereoscopic vision** is achievable due to Monocular Vision, which is possible due to relative object sizes, overcutting convergence and accommodation of the eyes, atmospheric haze, and other factors. Binocular Vision is also responsible for depth perception. The brain fuses two slightly distinct images perceived by two eyes at the same time into one, creating the impression of a three-dimensional model. Beyond a one-meter viewing distance, the three-dimensional impression is lost. The distance between two eyes, known as the 'Eye base,' also has an impact on stereoscopic vision. The better the three-dimensional illusion, the wider the eye base.

ii. Certain aids can be used to create **artificial stereoscopic vision**, and a two-dimensional photograph can be used to create a three-dimensional illusion. This image is comparable to the image obtained when two eyes are placed at two places on a flight line for exposure stations. The 'airbase' is the distance between two exposure stations in this case.

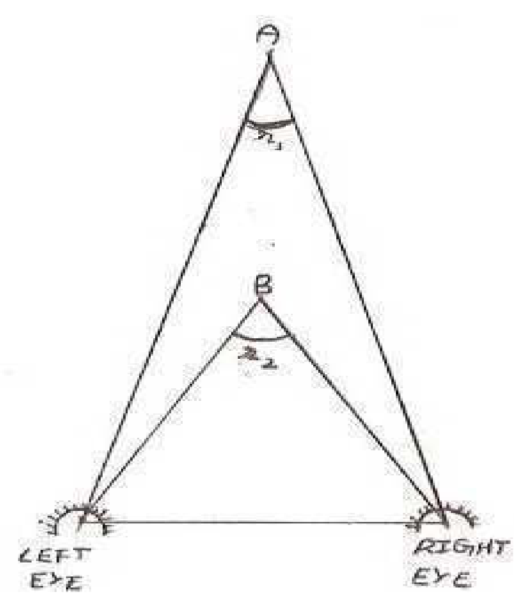


Fig 5.2 Converging Angle in viewing object at different distance (Devi sunita, 2012)

It's crucial to understand the relationship between accommodation, or shifts in focus, and convergence (Fig.5.2) or divergence of visual axis. The eyes turn when they focus on an item, causing lines of sight to meet at the object. The angle of convergence of a closer item is greater than the angle of convergence of a farther object. For efficient eye function, there must be a proper connection between accommodation and convergence. By using your eyes incorrectly, you might weaken or disrupt this connection. Important elements impacting photo interpretation include visual illusion, colour vision, focus flaws, coordination errors in depth perception, and so on. The ability of the observer to resolve parallax variations between far and near pictures is referred to as stereoscopic vision. The ability to discern small but considerable quantities of parallax is required for stereoscopic acuity. The ability of the brain to transform parallax variations into accurate depth perception is dependent on the ability of the right eye to perceive objects from the right side and the left eye to see the same thing from the left side. Closer objects appear closer when this order is reserved, as when the relative position of an aerial shot is reserved, and this effect is known as 'pseudo' stereo vision.

Requirements of Stereoscopic Photography

If we look at images of the same subject taken from two different views instead of gazing at the original scene, we can get a three-dimensional impression from the two-dimensional photos under the right conditions. This perception may be quite similar to the original scene's impression; however this is rarely the case in practice.

The two pictures of a scene must meet specific conditions in order to build a spatial model:

- Both photos must cover the same scene and have a 60% overlap.
- Both images must have the same exposure time.
- The two images should be roughly the same size. It is possible to handle a difference of up to 15%. Differences of more than 5% may be problematic for continuous observation and measurements.
- Both images should have a similar level of brightness.
- A suitable value for the base height ratio is required.
- The 'B/Z' or base height ratio is usually around 2.0. The ideal value is unknown; however, it is most likely about 0.25. If this ratio is too low, say 0.02, the stereoscopic vision will not convey a better sense of depth than viewing a single shot.

In the base height ratio- B/Z

Where - B = is the distance between two exposure stations
Z = is the distance between an object and the line joining two exposure stations.

When overlap diminishes, the base height ratio rises, and a larger viewing angle correlates to a higher base height ratio. Cameras with a short focal length and wide-angle lens provide a superior base height ratio, which is useful in natural resource surveys.

Base height ratio B/Z is also = b/c

Where b = photo base is the distance between two principal points of consecutive photographs.
c = principal distance of camera.

The depth perception is accentuated when the picture base is greater than the eye base and the image is viewed stereoscopically without enlargement. When aerial photographs are positioned in such a way that the shadows of the objects fall towards the observer, enlargement of images by binoculars, telescopes, and other means enhance parallaxes as well, increasing depth perception.

Types of stereoscopes

A stereoscope's purpose is to divert typically converging lines of sight, allowing each eye to see a separate image. Lens stereoscopes and reflecting or mirror stereoscopes are the two types of instruments currently in use for three-dimensional analysis of aerial photos. There are two types of stereoscopes:

1. pocket or Lens stereoscope
2. Mirror stereoscope

Pocket Stereoscope

The lens stereoscope, sometimes known as a pocket stereoscope, is by far the most popular. The lens of a pocket stereoscope is commonly plane-convex, with a flat upper surface and a focal length of 100 mm. The rays entering the eyes have been accommodated (focused) at a distance of 100 mm and are now parallel and converge at infinity (Fig. 5.3). A closer view, i.e. at 100 mm, results in amplification because the typical viewing distance is 250 mm. As a result, the magnification is 250/100 = 2.5. A replaceable eye base is available on more expensive models. Operators with an average eye-base range of 60 to 68 mm do not require this modification. The pocket stereoscope is inexpensive, lightweight, and has a huge field of vision. It has two significant drawbacks:

a) Magnification is restricted. Because of the considerable rise in lens aberrations, basic plane-convex lenses cannot be used in pocket stereoscopes with magnifications greater than three times. Furthermore, the distance between the head and the photographs is too short to provide appropriate illumination without causing unnecessary problems.
b) On the images, the distance between related locations must be equal to or less than the eye base. Without bending or folding the photos, this becomes difficult or impossible with typical size photographs.

It should be noted, however, that the image quality of the pocket stereoscope is excellent thanks to the basic optical system.

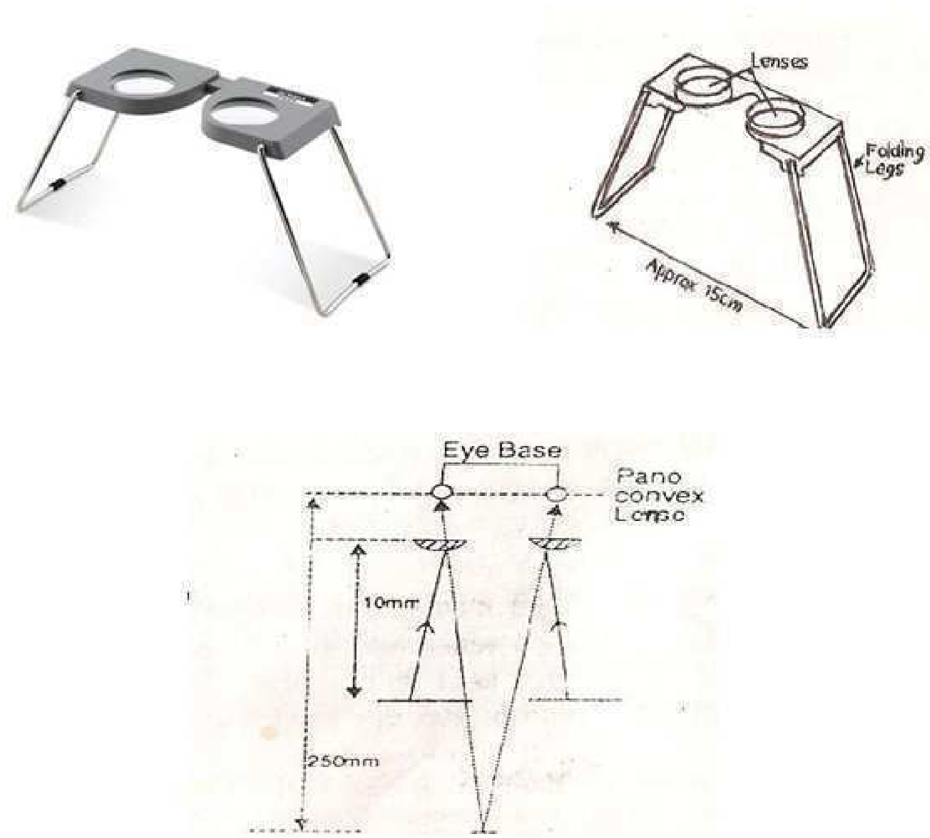
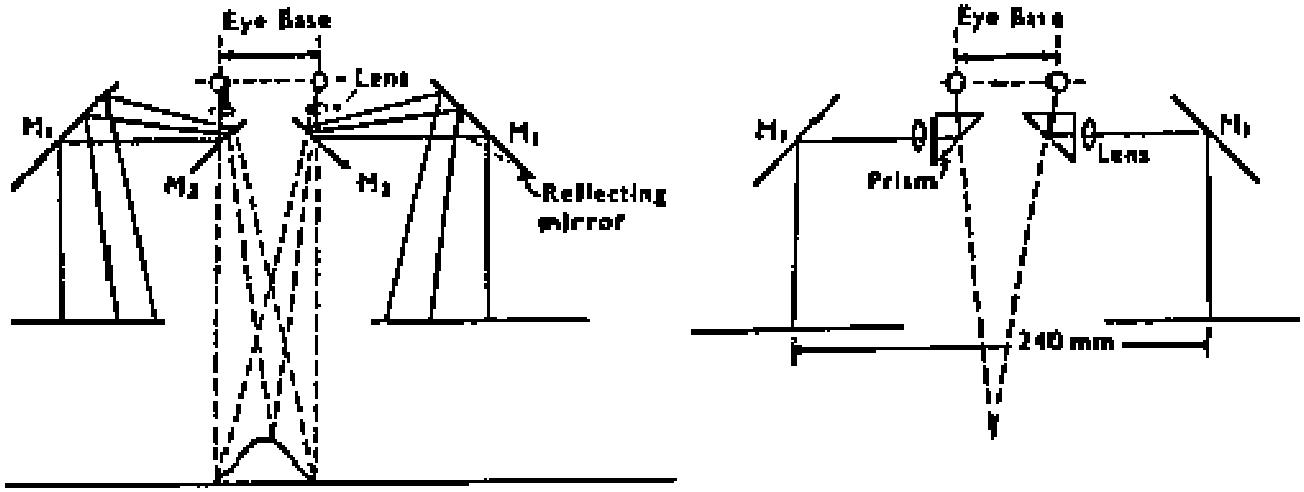


Fig.5.3pocket or Lens stereoscope (Source: Girard, 2003)

Mirror Stereoscope

The mirror stereoscope was created as a result of the two disadvantages described above. The standard-size photographs (23 cm × 23 cm) may be split and viewed via the stereoscope without having to fold them. The bundle of rays has been deflected and brought to the eyeballs at a distance of 65 mm. This is accomplished by the use of reflecting mirrors. The distance between corresponding spots is usually preserved at 240 mm to allow for independent placement of photos, essentially increasing the eye base from 65 mm to 240 mm. To achieve convergence at infinity, the image must be at the focal plane of the lenses, much like with a pocket stereoscope. The small mirrors M2 (typically prisms) are positioned in such a way that the picture distance becomes equal to the focal length of the lens, which is normally 300 mm (Fig. 5.4). (a). This results in a magnification of about 250/300 = 0.8, or a decrease of the image shown. Additional oculars with magnifications of 3x to 8x can be placed over the prisms to magnify the image, or a lens can be placed in front of each prism (see Fig. 5.4(b) for a magnification of roughly 1.8x).



(a) (b)

Fig. 5.4 a and b
(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

Check Your Progress

Q.1 What stereoscopy in aerial photography?
Q.2 Write the basic concept of stereo vision.
Q.3 Fill in the blank-
   a) A ---------------- is a device for viewing a stereoscopic pair of distinct images as a single three-dimensional image.
   b) The lens of a pocket stereoscope is commonly plane-convex, with a flat upper surface and a focal length of --------- mm.

Q.4 True false against the following-
   a) Stereoscopy is described as the science or art of dealing with stereoscopic or other three-dimensional effects and the methods used to create them.
   b) The distance between corresponding spots is usually preserved at 100 mm to allow for independent placement of photos, essentially increasing the eye base from 55 mm to 100 mm.

Binocular Observation of Stereoscopic Photographs

We can witness epipolar lines in many ways if we have a pair of stereoscopic images in front of us, on paper, glass plates, or projected using projectors, and they are aligned in the way mentioned above.We must utilise the words accommodation and convergence to analyse the various modes of observation.Accommodation is the process of adjusting the focus of one's eye lens in order to see objects clearly at different distances. The focus of an unaccommodated eye is said to be infinity. The directing of the two eyes' lines of sight (i.e., the optical axis) to the same place is referred to as convergence. The optical axis of the eye can be rotated in its socket to change its direction. Angle of convergence or parallactic angle refers to the angle formed by the ocular base at the location. The standard reading distance is 250 mm, which means that we adapt and converge our eyes at this distance while reading. Because the human eye's base is on average 65 mm (2.5 inches), the angle of convergence is around 16 degrees. (The eye-base, also known as the interocular or interpupillary distance, is a line that connects the nodes of the eyes) (Fig. 5.6).The angle of convergence (in radians) is proportional to the accommodation distance (d).

$$= \frac{E}{d}$$

The interpupillary distance is denoted by the letter E.

In most cases, accommodation and convergence are inextricably related. Accommodation and convergence are set for a certain distance when we stare at a point at a given distance. We can break this link, but it will put a lot of strain on our eyes. Accommodation at a distance other than the convergence distance necessitates a lot of practice.

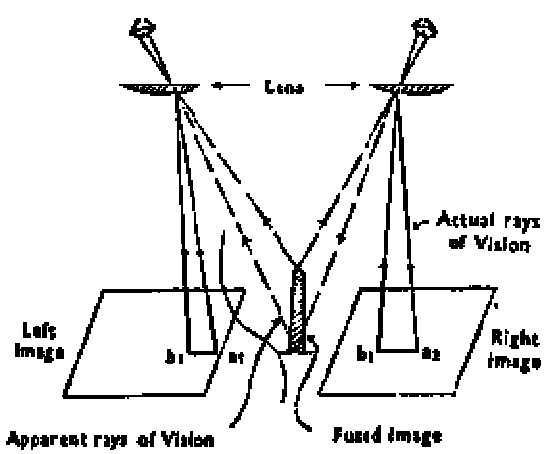


Fig.5.5

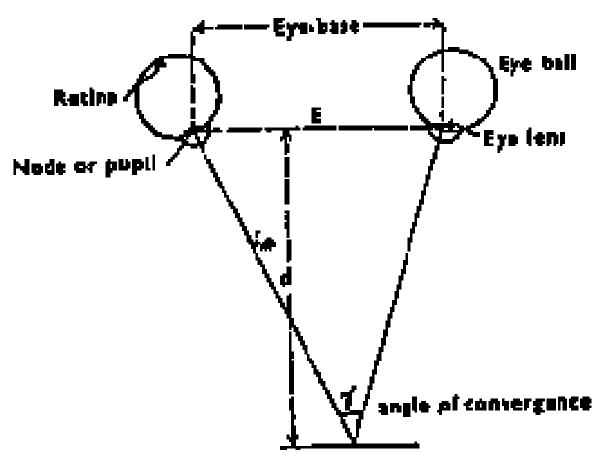


Fig.5.6

Source-(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

There are three different ways to look at stereoscopic photographs:

a) Crossed eye axes observation

This entails gazing at the left photograph with the right eye and the right photograph with the left eye (Fig.5.7 a). Because convergence and accommodation are at such a great distance apart, this form of observation is quite exhausting. This method works well with large photographs, although it is rarely utilized in practice due to the strain on the eyes.

b) Parallel eye axes observation

This procedure can be done without any optical assistance, but it is exhausting because the eyes are concentrated on infinity, although accommodative at around 250 mm(Fig.5.7 b). Positive lenses are placed between the eyes and the photographs so that the photos are placed at the focal length of the lenses, which makes it less tiring. After then, the accommodation matches to the convergence, and the eyes are gazing normally. On this basis, the'pocket-stereoscope' was created.

c) Convergent eye-axes observation

The seeing is the least taxing when the accommodation and convergence are at the same distance, and this is the standard mode of viewing (Fig.5.7 c). However, in order to view the photographs in stereoscopic mode, they must be stacked so that point A on one shot and point A' on the other lie at the point of convergence.

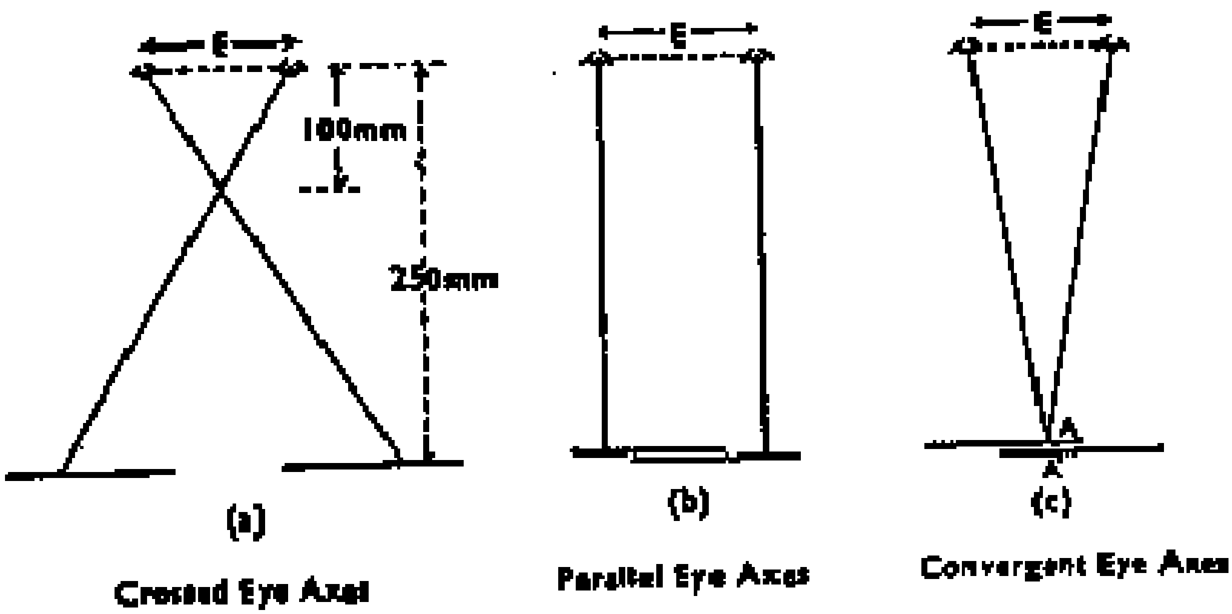


Fig.5.7Three ways of looking at stereoscopic photographs

Source-
(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

The images must be divided so that the left eye only sees the photographs on the left-hand side and the right eye only sees the photographs on the right-hand side. The stereoscopic perception that results is comparable to that of regular three-dimensional perception. Color filters or polarised filters can be used to accomplish separation.

In the field of stereoscopy, there is a fascinating phenomenon. The eyes can sometimes achieve a reversal of the relief while seeing landscape through aerial photography. Pseudoscopy, or pseudoscopic illusion, is the name given to this phenomenon. Viewing the photographs with crossed eye axis can give you this impression. Pseudoscopy can also occur while seeing with the shadows away from the observer in the case of significant relief. To avoid the pseudoscopic perspective, it is preferable to view the images with shadows of objects falling towards the viewer in the early phases.

Separation by colour filters

In two different colours, the photographs are projected or printed. By placing a filter of the same colour over each eye, only one eye sees the associated picture. In practice, it is difficult to tackle this problem fully. The human eye can detect light with wavelengths ranging from 400 to 720 millimetres (mm). The vertex is located at 560 mm.

Filters that take off all wave lengths exceeding 560 mm (its colour would be blue-green) and all wave lengths under 560 mm might be used to separate the two superimposed images (orange-red).With an orange-red glass in front of the eye, the picture projected in orange-red can be seen. It's the polar opposite with the blue-green image. This means we have a bluish image from one projector on one retina and a red image from the other projector on the other. We appear to have succeeded in fusing these disparate images into a single stereoscopic white-black image. The situation differs from that stated above in the case of anaglyphs printed on paper. Red and blue are used to print the two images. The red picture is imperceptible to the eye wearing the red filter, and only the blue image is seen as changing hues of grey. Similarly, the blue-filtered eye appears to be a red image only. When the spectacles are reversed, the right eye sees the LH photograph and vice versa. The result will be a pseudoscopic image.

Separation by polarized filters

Light has wave-like properties, with waves vibrating in all possible planes perpendicular to the direction of prorogation. Transverse waves are what they're called. Filters can be used to divide transverse waves into different components along two axes perpendicular to each other and to the propagation direction.

The filters are set in stereoscopic vision so that the polarised light rays forming the left picture are at right angles to the light rays forming the right image. Using polarised light has a number of advantages:

- light loss is about 50% only in both projections,
- there is not colour contrast between the two pictures, and
- it is possible to use colour photography on this principle.

However, there is one major drawback to employing the technology, which has kept it from being used in photogrammetry thus far. With the type of plotting device that uses this approach, it is critical that the image be projected on a diffuse screen so that it may be viewed equally well from all angles. However, a diffuse surface works as a depolarizer, so no stereoscopic image is visible.

Subjective spatial model

Stereo-model is the subjective spatial model perceived using a stereoscope when photos with overlap are viewed. A spatial model is not visible when looking down from an aeroplane at the ground. The eye base is so small (65 mm on average) in comparison to the plane's flying height that the two-retine image is nearly identical. As a result, there is no meaningful comparison between a model's normal view and its stereoscopic perspective.

If we witness an object with a normal base-height ratio, we can presume that we are seeing natural relief. In view of what has already been stated, namely that binocular vision was primarily used to aid in limb movement control; we can estimate that a normal base-height ratio is around 65/250, or approximately 1/4 to 1:1 or even 1:0. 6. This may lead to the conclusion that the stereoscopic image created by aerial images is always different and distorted. Other elements, however, have an impact on the subjective model.

a) Assume that the images were shot with a vertical optical axis and that they were seen flat on a table with the epipolar rays aligned.

b) The first difference is that the eye-base has been reduced from 800 to 65 millimetres. This alteration solely affects the model's scale; otherwise, the two perspectives are identical.

c) The second distinction is that the images are viewed from a distance that differs from the principal distance. This not only changes the model's magnification, but it also changes the ratio of the x, y, and z scales to the z scale. If this distance is smaller than the principal distance, we obtain an affine flattened model; if it is more than the principal distance, we get an inflated model. This is consistent with what one observes in practice.

d) Our eyes are moved away from the vertical through the major points, which is the third difference. Deformations are difficult to construct or visualize in a diagram as a result of this.

e) The fourth distinction is that during observation, one of the images is relocated, causing the associated points to appear vertically. The rays from the associated sites to the relevant observation are shifted by the same amount as the stereoscopic parallax (P). However, because this parallelism implies that the spatial model should be generated at infinity, the building of the spatial image is impossible. In practice, the image appears at an undetermined distance ranging from 250 mm to 1 metre, depending on the operator's own quirks.

f) Finally, the object's shape, shadows, natural association of observed data, and relative distance all influence the depth perception process.

Measurement of height at aerial photos

Parallax

The most essential attribute of pictures is the ability to discover height disparities between items using measurements on photographs of the region in question. This is done by calculating parallaxes on the photos. So, what exactly is parallax? The term parallax refers to the apparent shift in the position of an item induced by a shift in the observer's position. The term is widely used in optics, astronomy, and other sciences, and each application has a different meaning. We are mostly concerned in stereoscopic parallax in photogrammetry. The aerial camera does not take continuous aerial photos, but rather at predetermined exposure intervals. If, instead of negative film, there were a ground glass on which ground images could be seen, it would be visible as the camera frame changed.

Consider that the aero plane is at 01, vertically above a point P, at any given time. On the ground-glass, the picture of P will appear at p. (Fig.5.8). When the plane is at 02, it will emerge at p' after a while. The parallax of P is the shift pp' in the position of the image of P on the ground glass. Similarly, Q will be qq' for any other point.

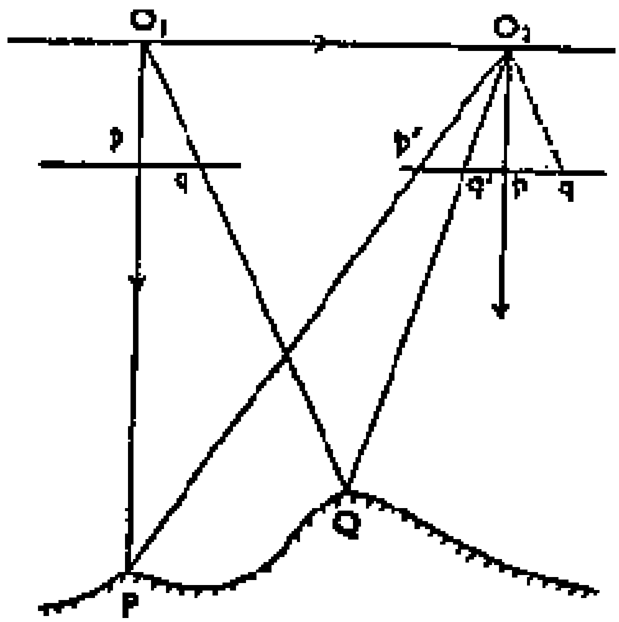


Fig. 5.8

Source-(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

Photos of higher points in the terrain will move across the ground glass faster than images of lower spots in the valley, as may be seen again. As a result, the separation (parallax) of images from a higher point is greater than the separation (parallax) of images from lower places (during the same interval of time). This means that points at higher elevations have more parallax than points at lower elevations.

X- and Y- Parallaxes

P1, p2', and p2 p1' are the photo bases of the left and right pictures, respectively, in Fig. 5.9. The equivalent images of an object point are a1 and a2. A p1 a1 and a p2 a2 can be resolved into two mutually perpendicular directions, one parallel to the X-direction and the other perpendicular to it (Y-direction). If X1, Y1 and X2, Y2 are the resolved sections of p1 a1 and p2 a2 in the two directions, respectively.

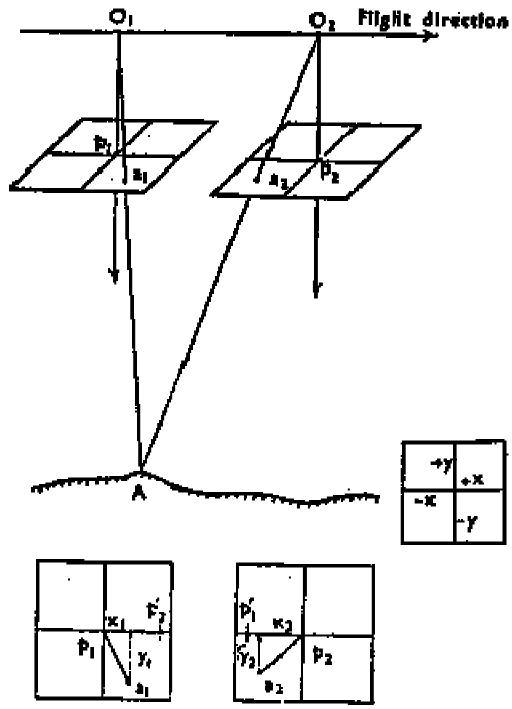


Fig. 5.9: Parallax of principal points
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(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

The X- parallax, also known as absolute stereoscopic parallax or horizontal parallax, is defined as the algebraic difference in the distances of the two pictures of an object from their respective principal points in the direction of the air base.

(Note: X2 is given a minus sign since the distance from the principal point is measured in the negative X-direction, i.e., in the opposite direction of flight.)

Y-Parallax or Vertical Parallax is sometimes known as (Y1 - Y2). The Y-Parallax is absent if the paired photos are considered to be vertical and taken from the same altitude above the datum.

Parallax of principal points

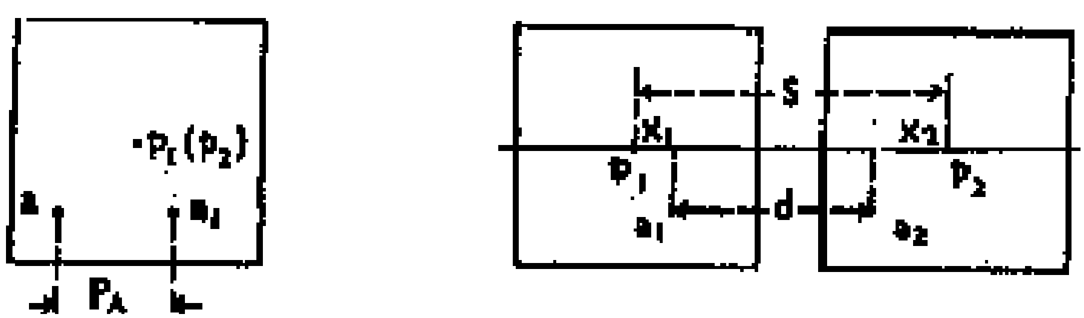
If we transfer the main point P1 of a stereo pair's left-hand photograph to the right-hand photograph at p1' (Fig. 5.9), then p2 p1' is the parallax of the left image's principal point and is the distance between the exposure stations (air-base) on the right-hand photograph's scale. Similarly, p1 p2' denotes the air-base on the scale of the left-hand snapshot and is the parallax of the principal point of the right-hand photograph. If the terrain is flat, the flight is level, and the altitude of the aircraft is constant, the scale of the two images will be identical, and the two photo-bases will be identical.
It is so simple to determine the parallax of either of the major points using measurements on the photos, assuming that the assumptions do not depart much from the ideal scenario, namely.

i) In both circumstances, the focal length is the same, which is always the case.
ii) the height of flight is the same
iii) vertical optical axis

In reality, we tolerate 3-degree tilts; of course, flying heights must be within reasonable bounds.

Parallax Difference

Two images are taken with the image of an item point A a1 and a2 on them, assuming that there is no tilt and that the flight is level. By definition, a2 a1 is the absolute stereoscopic parallax if the two photos are placed on top of each other with their main points p1 and p2 and flight direction coincident (Fig. 5.10 a).



(a) (b)

Fig.5.10 Parallax Difference

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(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

If we now place the two images under a stereoscope for fusion, they must be separated at a convenient distance p1p2, say a distance denoted by 'S' (Fig. 5.10 b).

The parallax of A, PA = p1 p2 - a1 a2

= S -a1 a2

Similarly, parallax of another point Q,

PQ = S - q1 q2

Considering `A' as the reference point, the parallax difference between `A' and `Q' is

$$\Delta p = PQ - PA$$
$$= a1\ a2 - q1\ q2$$

In practice, we rarely measure parallax directly; instead, we use a parallax bar or a parallax wedge to calculate the parallax difference (Δp).

Graduations on parallax bars are typically marked in such a way that as the separation between corresponding images decreases (i.e. 'd' decreasing - Fig. 5.10 b), the reading on the parallax bar increases - the point with larger parallax gives a higher reading, and corresponds to a higher elevation point. In this situation, the parallax difference is significant.

Δp = (Parallax bar reading for Q - Parallax bar reading for A)

= q1 q2 - a1 a2

Check Your Progress

Q.5 What is Pseudoscopy?
Q.6 What is parallax?

Q.7 Fill in the blank-

a) The angle of convergence (in radians) is proportional to the ------------------.
b) The term -------- refers to the apparent shift in the position of an item induced by a shift in the observer's position

Q.8 True false against the following-

a) The X- parallax, also known as absolute stereoscopic parallax or horizontal parallax.
b) The points at higher elevations have low parallax than points at higher elevations.

Parallax Formula

Starting with the premise that:

i. the images are tilt-free,
ii. the flight height above the datum is constant,
iii. the photographs are central projections, with the centre of projection at the perspective centre, i.e. no lens distortion, and
iv. the photographic material is distortion-free.

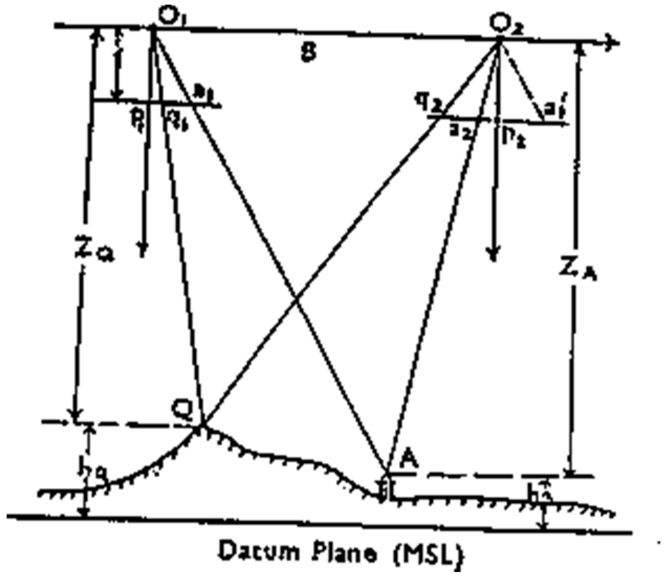

Fig. 5.11
Source-(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

Figure 5.11 shows the air-bases O1 and O2 at a vertical distance of ZA and ZQ above terrain points A and Q, respectively; a1 and a2 are the equivalent pictures of around locations A on the photograph. The aerial camera lens has a focal length of f.

From O_2 draw a line O_2 a1' parallel to O_1 a1. Then, by definition parallax of A is -

PA = a2 a1'

From similar triangles O_2 a2 a1' and A O_2 O_1

ZA/f = B/a2a1’ =B/PA

$$\frac{ZA}{f} = \frac{B}{a2a1'} = \frac{B}{PA}$$

$$ZA = \frac{B.f}{PA} \quad ....(1)$$

Similarly for a point Q, ZQ = B.f/ PQ ------------------(2)

Fromequations (1) and(2)

$$ZA - ZQ = B.f\left(\frac{1}{PA} - \frac{1}{PQ}\right)$$

$$= B.f \frac{PQ - PA}{PA.PQ}$$

$$= \frac{B.f}{PA} \,.\, X \, \frac{PQ - PA}{PQ}$$

$$= ZA \,.\, \frac{PQ - PA}{PQ}$$ .... by substituting for $\frac{B.f}{PA}$ fromequation(1)

$$= ZA. \frac{\Delta p}{PA + Dp} \quad ....(3)$$

where p = PQ - PA

Let hA and hQ be the mean sea-level heights of object points A and Q respectively. Then

ZA + hA = Flying height of the aircraft above datum plane (MSL)

= ZQ + hQ

ZA - ZQ = hQ - hA

= differences of heights between terrain points Q and A

= h.

Equation (3) now can be written as

$$h = \frac{ZA . \Delta p}{PA + p} \quad \ldots\ldots (4)$$

Relation (4) is the fundamental parallax equation.

Equation (4) can be put in the form (by cross-multiplying and rearranging)

$$\Delta p = \frac{PA . h}{ZA} \quad (5)$$

These parallax equations (equations (4) and (5)) have been assumed to be true only when the photography is vertical and the aircraft is level. It can, however, be used for minor deviations from these ideal conditions. If the h values are minor (for example, tree height or embankment height), the simplified equations are used.

$$Dph = \frac{ZA}{PA}$$

can be used and similarly

$$\Delta p = \frac{PA . h}{ZA}$$

The length of the photo-base on the right hand photograph is usually measured and substituted in the solution of parallax equations for the absolute parallax of the principal point of the left hand photograph (PA). The use of the stereo-average pair's photo-base produces reasonably accurate results for near vertical pictures or relatively flat terrain. Then the formulas become

$$h = \frac{Z . \Delta p}{bm + p} \text{ and } \Delta p = \frac{bm . h}{Z - h}$$

and the approximate formulae can be writtenas

$$h = \frac{Z}{bm} . p \quad \text{and} \quad \Delta p = \frac{bm}{Z} . h$$

Where Z is the average flying height above the terrain and bm the average photo-base.

False parallax across the overlap is caused by image displacement caused by the tilt of one of the two photos. The parallaxes are also affected by the slope of the air base. As a result, the parallaxes seen in such images are riddled with flaws. If the two places between which the height difference is required are not far apart, the effect on parallax caused by tilt and inclination of the air base is almost identical and cancels out.

Floating Marks

Because floating marks are utilised for exact measuring on stereo pictures, they are also known as Measuring marks. When viewed stereoscopically with a photographic overlap, these are characterised as pairs of identical reference marks that merge to form a single floating image. When two dots, A1, A2 (Fig. 5.11), of approximately a millimetre in diameter are placed at a distance of about 65 mm on a piece of paper and viewed through a pocket stereoscope (the eye base held parallel to the line uniting the dots), they would merge into one dot. Now, if we place another set of dots B1, B2 close to them, with the line connecting them parallel to the eye base and spaced closer than the first set, we observe that this set fuses into one mark as well, but it is floating, i.e. higher above the first. Stereoscopic depth is defined as the vertical distance 'AB'. That is, if the parallax of the mark differs from the parallax of its surrounds, it will appear higher or lower. The fused dot appears in contact with the fused image if there is no parallax between the dots and the object images. At present time, the distance between these reference points may be measured with great precision.

Measurement of Parallax Difference

The difference in parallax can be measured using a regular ruler, but the findings will not be accurate or precise. The notion of floating marks is applied in parallax bar or parallax wedge for accurate results. The purpose of these stereo metres is to measure parallax changes that are too small to be measured with standard rulers.

Parallax bar

A parallax bar is made up of two glass plates, A and B, that are joined by a bar and have identical measuring marks engraved on them (Fig. 5.11). A micrometre screw can be used to adjust the separation S between the markers. M, graded for readings of up to 0.01 mm. Glass A can be moved up and down the rod and clamped by screw C. The bar's graduations are arbitrary and do not correspond to the actual spacing S of the measuring markers. As the distance between corresponding locations, i.e., the separation S, decreases, the graduations on the micrometre and the bar are normally numbered in ascending order.

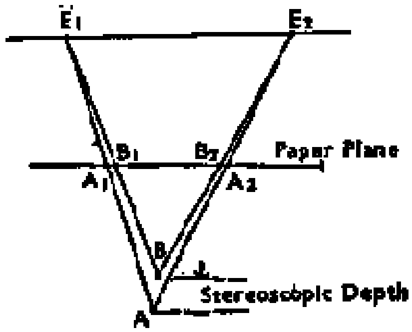

Fig. 5.11

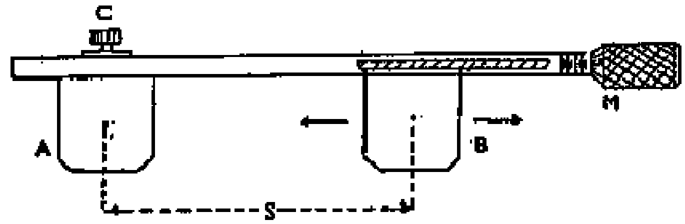

Fig. 5.12

Source-(https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004021910157039ajay_misra_geo_STEREO_MODEL.pdf)

Parallax wedge

There are no converging rows of dots on this clear sheet. The wedge is pushed back and forth in a 'Y' motion until two dots on the ground fuse into one, and the reading is taken. The dots are numbered according to the parallax values they correspond to. (Fig.5.13).

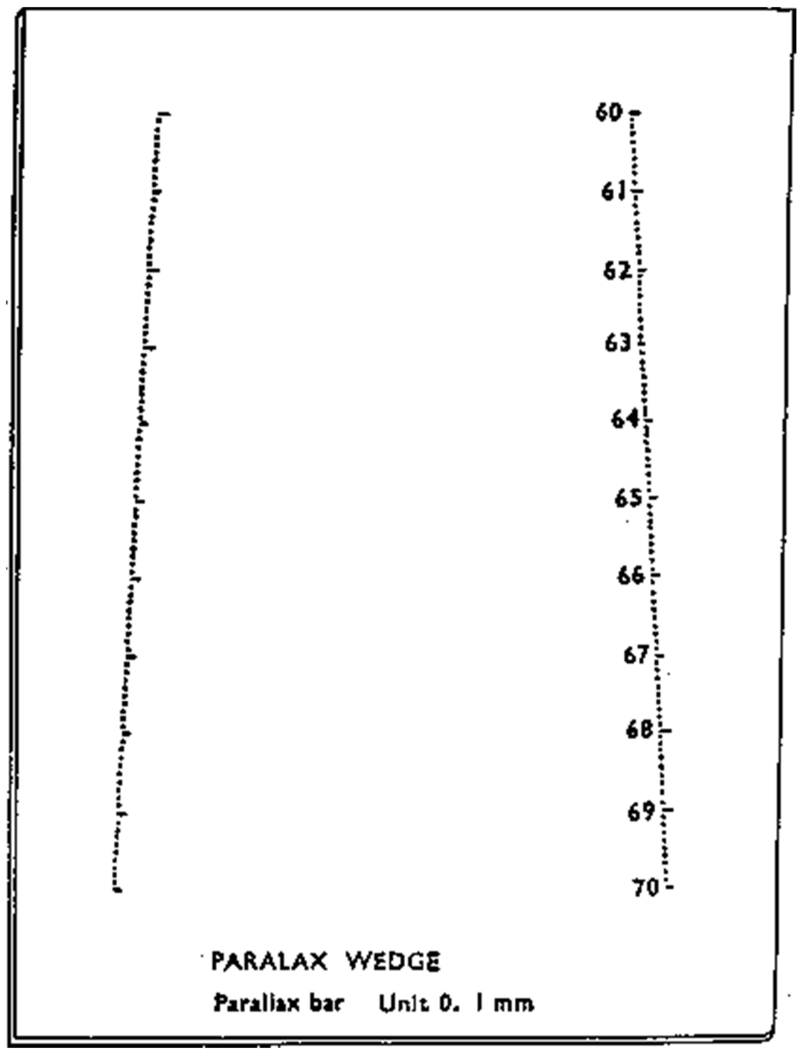

Fig. 5.13

Source-
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5.4SUMMARY

In this unit we have discussed various aspects related to stereoscopic aerial photography along with the concepts of stereo vision, stereo model, and stereoscopes. We know how stereoscopic photography is usedfor interpretation. We learned about height measurement at aerial photographs and the concept of parallax.

5.5 GLOSSARY

Floating Mark-A reference mark in inspecting or measuring the stereoscopic model that is viewed as occupying a place in the three-dimensional space generated by the stereoscopic fusion of a pair of pictures.

Index Mark:A genuine mark, such as a cross or a dot, situated in the plane or object space of an image and used single as a reference mark in certain types of monocular instruments or singly or as one of two to form a floating mark as in certain types of stereoscopes.

Reticle: A mark on the image plane of a viewing equipment, such as a cross or a system of lines, used single as a reference mark in certain types of monocular instruments or as one of a pair to form a floating mark in stereoscopes.

Overlapping Pair: Two images shot at various exposure stations with a section of one photograph showing the same terrain as the other. This word refers to a wide range of situations and does not indicate that the images were taken for stereoscopic analysis.

Parallax- A shift in the point of observation causes an apparent displacement of the position of a body with regard to a reference point or system.

Absolute Stereoscopic Parallax-Photogrammetry: The absolute stereoscopic parallax of a point is the algebraic difference, parallel to the air base, of the distances of the two images from their respective principal points in a pair of truly vertical photographs of equal principal distances taken from equal flight heights, or a pair of rectified photographs.

Parallax Difference- The difference between two points depicted on a set of photos in terms of absolute stereoscopic parallaxes. Traditionally used to determine the difference in elevations between two objects.

Y-Parallax-Photogrammetry: The difference between the perpendicular distances of a point's two pictures from the vertical plane containing the air base is its y-parallax. The presence of y-parallax is a sign of tilt in one or both photos, as well as a variation in flying height, which makes stereoscopic inspection of the pair difficult. Vertical parallax is another name for it, however the latter is not favoured.

Angular Parallax- The angle formed by the observer's eye base in relation to the item being observed. Also known as the Parallactic Angle or Convergence Angle.

Stereoscopy- The science and art that deals with stereoscopic effects and the methods used to create them.

Stereoscope- An optical aid for enabling the spectator in obtaining the mental impression of a three-dimensional model by viewing two correctly prepared photographs or pictures.

Binocular Vision-Simultaneous vision with both eyes.

Stereoscopic Vision- That particular application of binocular vision that allows the observer to perceive an object or two different viewpoints of an object (like two images taken from different camera stations) and derive a mental impression of a three-dimensional model from them.

Stereoscopic Fusion-That mental process in which two perspective images on the retinas of the eyes are combined in such a way that a mental impression of a three-dimensional model is formed. The mental impression of a three-dimensional model that arises through statoscopic fusion is known as a stereoscopic image.

Stereoscopic Pair-Photogrammetry: Two images of the same scene, taken from different camera positions in such a way that stereoscopic viewing is possible. A stereogram is another name for a stereogram.

5.6 ANSWER TO CHECK YOUR PROGRESS

Ans .1stereoscopyis the science and art which deal with stereoscopic effects and the methods by which they are produced

Ans.2 That particular application of binocular vision which enables the observer to view an object or two different perspectives of an object to obtain therefrom the mental impression of a three-dimensional model.

Ans.3 Fill in the blank-

a) stereoscope
b) 100mm

Ans .4 True false against the following-

a) True
b) False

Ans .5 In the field of stereoscopy, there is a fascinating phenomenon. The eyes can sometimes achieve a reversal of the relief while seeing landscape through aerial photography. Pseudoscopy, or pseudoscopic illusion, is the name given to this phenomenon.

Ans.6 Parallax is the apparent displacement of the position of a body with respect to a reference point or system caused by a shift in the point of observation.

Ans .7 Fill in the blank-

a) accommodation distance
b) parallax

Ans.8 True false against the following-

a) True
b) False

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5.8TERMINAL QUESTIONS

Q.1 Write a short note on stereoscopic aerial photograph.
Q.2 Discuss on the uses of stereoscopic aerial photographs.
Q.3 What is stereoscope?
Q.4 Discuss on various types of stereoscopes.
Q.5 What is parallax in aerial photography?
Q.6 Write a note on measurement of height at aerial photography.

UNIT 6: RELIEF DISPLACEMENT IN AERIAL PHOTOGRAPH

6.1 OBJECTIVES

After reading this unit, you should be able to:

- know the concepts of image distortion/ displacement;
- discuss about relief displacement in photogrammetry;
- measure relief displacement in aerial photographs.

6.2 INTRODUCTION

On a planimetric map, all features/details are depicted in their proper horizontal position at a given scale. Due to image, displacement, or distortion, this is not so in the case with of aerial images. Displacement/distortion is a disturbance of the geometric principle. There are three main causes of displacement/distortion: optical or photographic flaws, such as lens distortion and aberration; relief fluctuation of the shot object; and tilt of the camera axis at the time of exposure.

(a) Lens distortion

Small distortions are caused by faults in the optical components (i.e. lens) of camera systems. The most well-known examples of this effect are vehicle windows/windshields and carnival mirrors. These effects are radial from the principal point (making objects appear closer or farther away than they are), and they can be adjusted via calibration curves .Instead of being pictured at its actual position I on the image plane, object point O is imaged at I'. In this situation, d represents the image displacement. This form of distortion is almost non-existent in current aerial camera lenses (Fig.6.1).

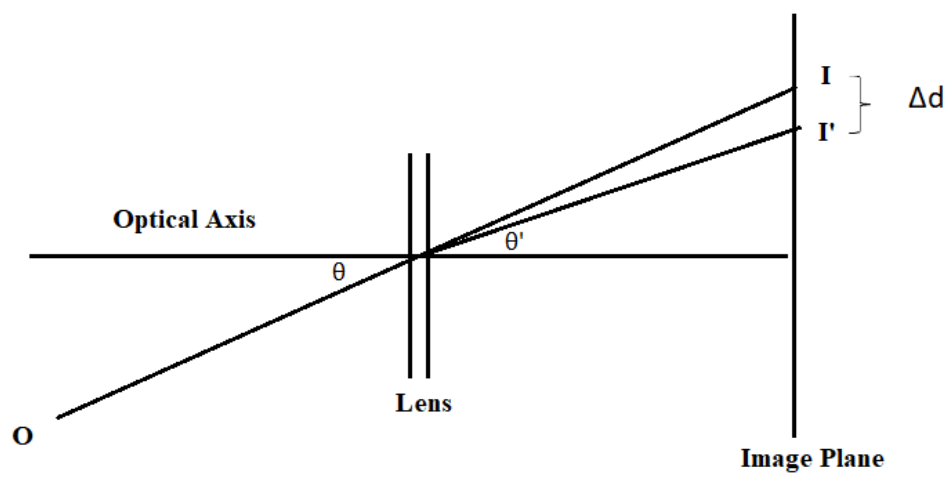


Fig. 6.1 Lens distortion

(b) Tilt distortion

Instead of a true vertical record, a slanted snapshot gives a slightly angled view. All of the photographs are skewed in some way. Like the perfect lens, the perfect gyro stabilisation mechanism has yet to be created. Tilt is created by the platform being rotated away from vertical. The axis of the wings or the flight line is the most common locations for this type of displacement. Tilt displacement radiates from the photo's isocenter, causing objects to be displaced radially inward on the tilted photo's upper side and radially outward on the bottom side. The photo can be corrected if the quantity and direction of tilt are known. Some landscape feature (a) is exhibited on a photograph (point a) that is radially inward by the amount d from the proper location on the photograph c (Fig.6.2).

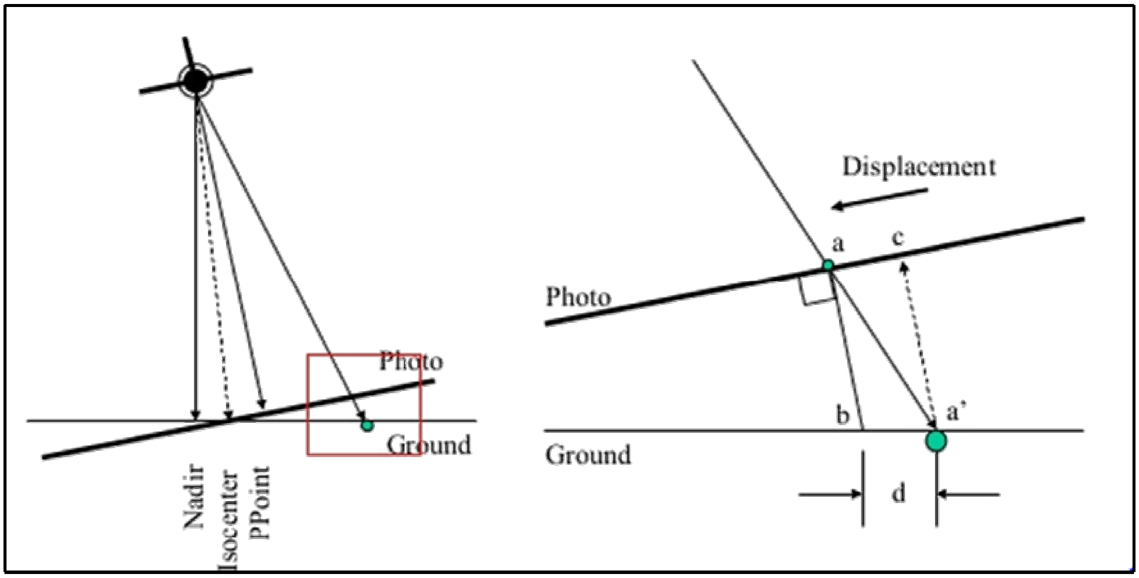


Fig.6.2 Tilt distortion

(Source- nestopgis.com/Aerial-Photography/Principles-of-Photogrammetry/Displacements-and-Distortions/1-Distortion-in-Air-Photos-Lens-Tilt-Radial-Relief.html)

(c) Relief displacement

The radial distance between where an object appears in an image and where it should be in a Planimetric coordinate system is known as relief displacement. The images of ground placements in the central projection of an aerial shot are changed or displaced due to terrain relief. If a photograph is actually vertical, the images are displaced in a radial direction from the centre. The radial displacement owing to relief is the name given to this displacement. Scale discrepancies within a single shot are also caused by radial displacement owing to relief, therefore a photograph is not an accurate map.

Differences in relative height of objects photographed produce relief displacement. The photographic images of any objects that extend above or below a datum plane are shifted to some degree. The term "radial line displacement" refers to the displacement that happens along the line connecting the photo point and the nadir. Alternatively, this displacement is always radial in relation to the principal point. It rises in proportion to the height of the feature and the distance from the nadir. The geometric distortion, known as relief displacement, that is present on all vertical aerial images taken with the camera focused directly down is depicted in Fig. 6.3. The tops of objects like buildings appear to "lean" away from the photograph's main point, or optical centre. At higher radial distances from the centre, the amount of displacement increases and reaches a maximum at the photograph’s corners (Fig.6.4)

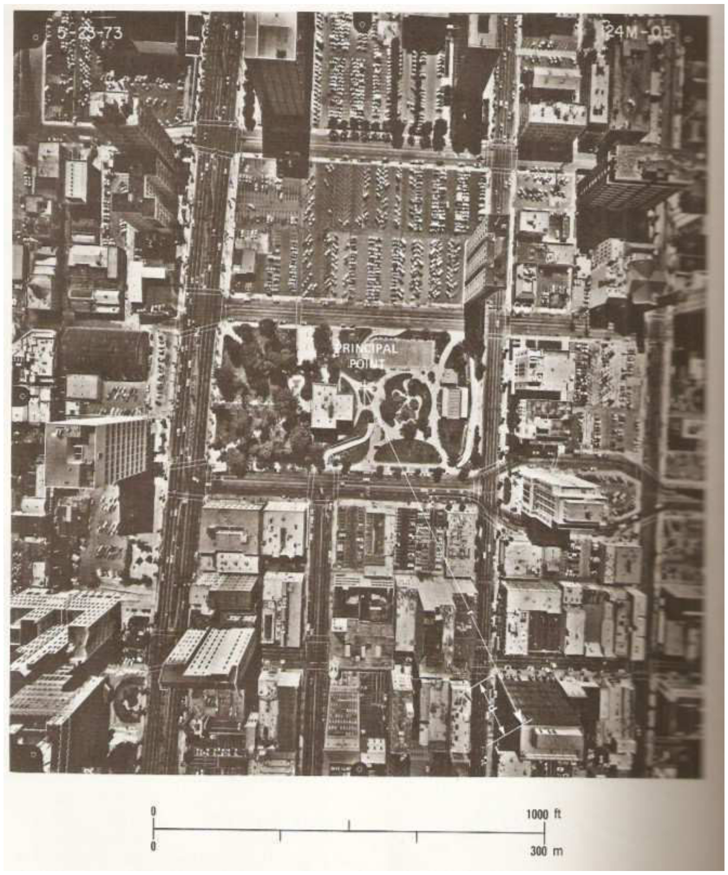


Fig.6.3: Vertical aerial photograph of Long Beach, California, showing relief displacement. Courtesy J. Van Eden.

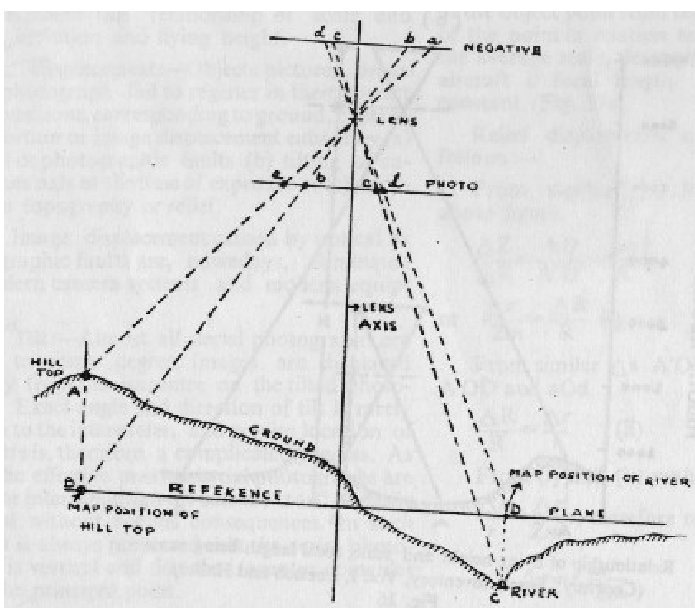


Fig. 6.4: Geometry of displacement due to topographic relief

(Source: http://www.edc.uri.edu/nrs/classes/nrs409509/RS/Papers/ReliefDisplacement.pdf

The geometry of image displacement is depicted in Fig. 6.5A, in which light rays are tracked from the terrain via the camera lens and onto the film. Prints made from the film appear to be in the location depicted in Fig. 6.5 A by the plane of photographic print.
The vertical arrows on the terrain represent things of varying heights and distances from the central point. The ray reflected from the base of item A intersects the plane of the photographic print at location A, while the ray reflected from the top (or tip of the arrow) intersects the print at position A'. The relief displacement (d) depicted in the plan view of Fig. 6.5 B is the distance A-A'.

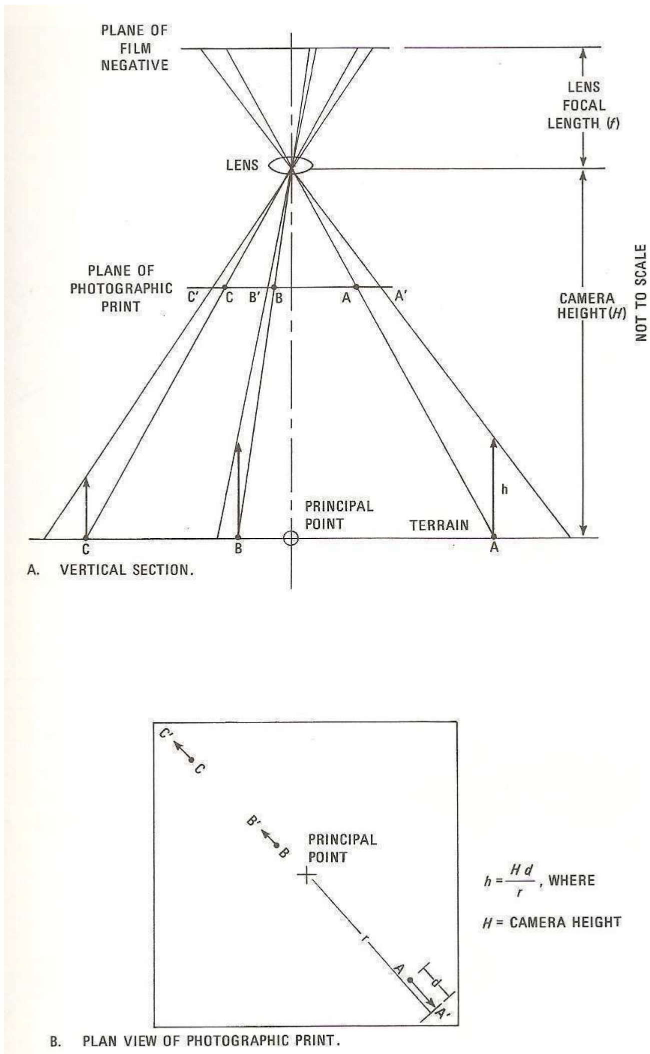
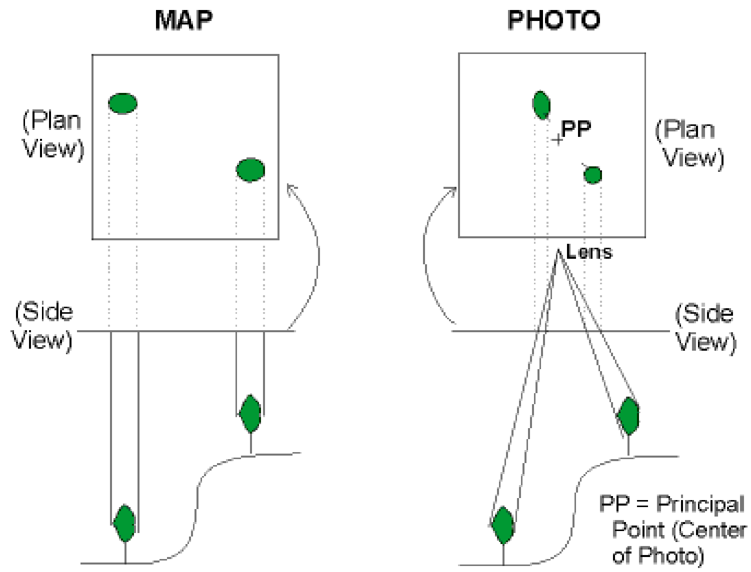


Fig.6.5 Geometry of relief displacement on a vertical aerial photograph

On a shot taken over a variety of terrain, the effect of relief displacement is visible. In essence, increasing the elevation of a feature causes it to be shifted significantly outward from the focal point of the shot. As a result, when a vertical feature is photographed, relief displacement causes the feature's top to be farther away from the photo centre than the base.

As a result, vertical features appear to be leaning away from the photograph's centre. (Fig. 6.6).



(a) Map (orthographic projection) Constant Scale, No relief displacement

(b) Photo (perspective projection) varied scale relief displacement

Fig. 6.6 Comparative geometry of (a) map and (b) a vertical photograph, differences in shape, size and location of the two trees.

(http://web.sonoma.edu/users/f/freidel/techniques/exer/rem_sens/RemSen_c.html)

The scale of an aerial photograph is determined by the height at which it was taken. As a result, changes in elevation affect the scale of aerial pictures. The higher an object's elevation, the more it is displaced from its true position away from the photograph's focal point. An object will be shifted towards the principal point as its elevation decreases.

1. Arrangement of vertically stretched objects within a photograph. (Fig.6.7)

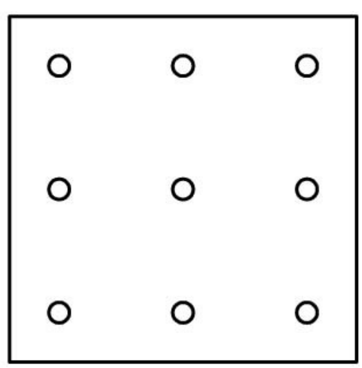


Fig.6.7

2. Relief displacement seen in frame photography, when the complete image is taken at the same time and relief displacement is always radial in relation to the nadir point. (Fig.6.8)

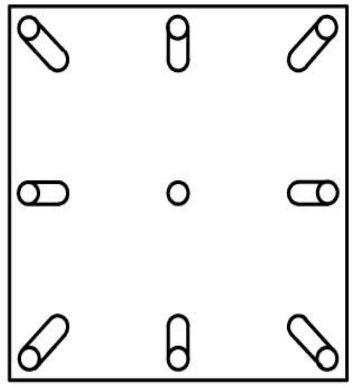


Fig.6.8
(https://seos-project.eu/3d-models/3d-models-c02-p02.html)

3. The image is built up over time by the platform motion; relief displacement only exists within a line, as shown in push broom imaging. It's still radial in relation to the nadir point, but each line has a different nadir point. As a result, cross-track displacement is the only component of relief displacement; there is no along-track component. (The platform moves up and down.) (Fig.6.9)

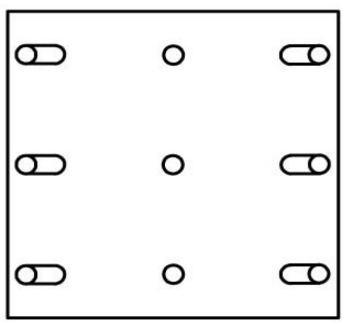


Fig. 6.9

Generalcharacteristicsofrelief displacement

Relief displacement reveals the presence of several significant general correlations. Topographic displacement is another name for relief displacement. These connections can be expressed as follows:

1. At Nadir, there is no topographic displacement. If r is 0, then d is also zero.
2. Assuming that the datum elevation is at Nadir, points above the datum are radially displaced away from Nadir, while points below the datum are radially displaced towards Nadir.
3. Topographic displacement is proportional to the radial distance between the item and the Nadir. The displacement of an elevation two inches from the Nadir is half that of an elevation four inches from the Nadir.
4. Topographic displacement is proportional to an object's height. A 100-foot tree would be displaced twice as far from Nadir as a 50-foot tree at the same distance.
5. Topographic displacement is inversely proportional to the flying height of the object's base. As a result, topography displacement is barely visible in space imagery.

The rationale for the minor relief displacement from space is that a shorter focal length lens requires flying at a lower altitude to reach a given scale. In stereoscopic images, utilising short focal length lenses causes topographic displacement, distortion, and perceived depth of the third dimension (vertical exaggeration). (See Figure 6.10)

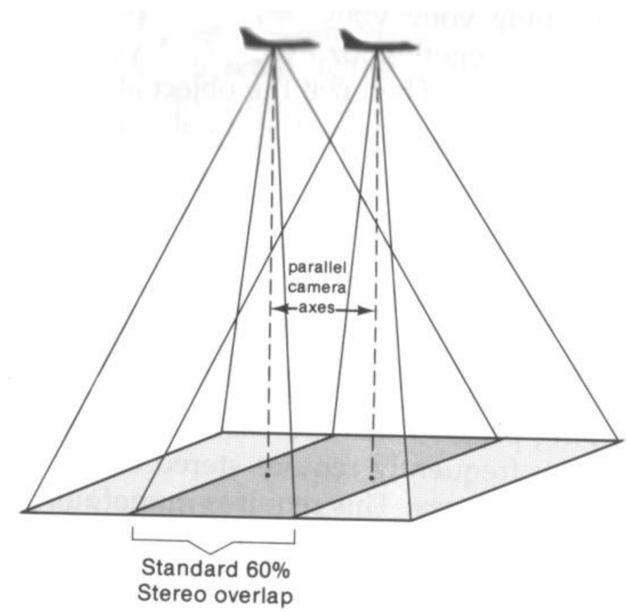


Fig. 6.10
(http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

Causes of reliefdisplacement

The height of the object, the distance of objects from the nadir point, focal length, flying height or altitude, the height of objects in relation to the datum plane, and the effect of the field of view are the main factors of relief displacement. The amount of relief displacement is determined by the following factors:

A. Height of theobject

When the distance between objects and the nadir point is constant. The object's height, on the other hand, grew or declined. The higher the thing, the more it is displaced. (Fig.9)

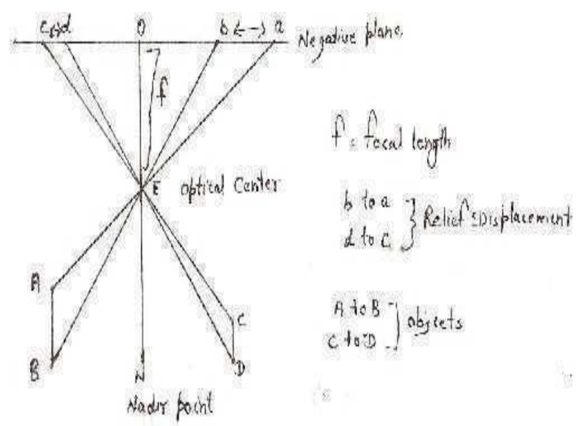


Fig. 6.11 Change in height of objects
http://www.edc.uri.edu/nrs/classes/nrs409509/RS/Papers/ReliefDisplacement.pdf

B. The distance of the objects from nadirpoint.

The relief displacement increases as the object's distance from the nadir point increases. The relief displacement will be smaller if the object is closer to the nadir point. (Fig. 6.12)

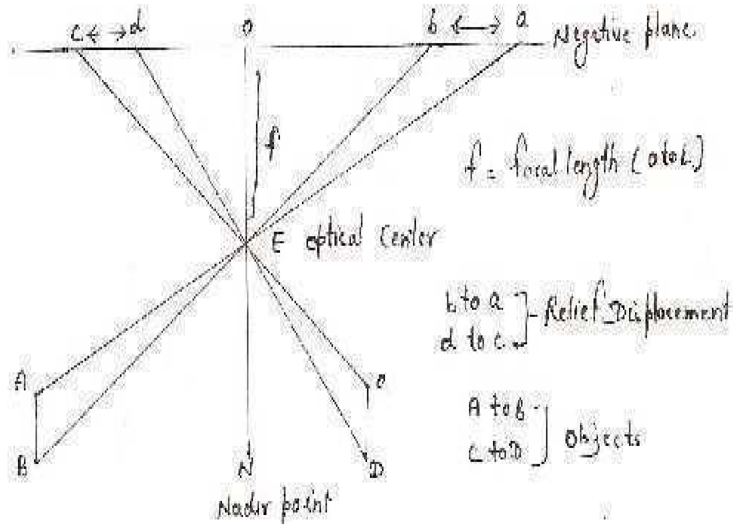


Fig. 6.12 Distance of object from nadir point
(http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

C. FocalLength

The relief displacement increases as the focal length of the camera lens is raised. When the focal length of the camera lens is reduced, however, the relief displacement is reduced. (Fig. 6.13)

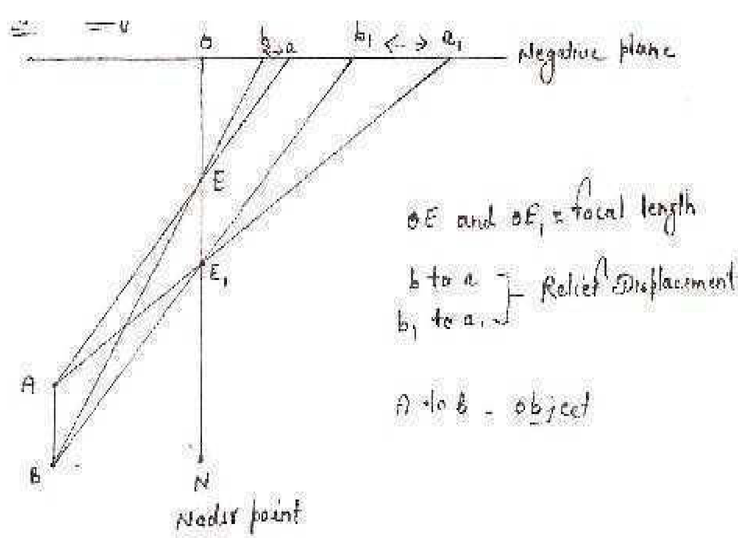


Fig. 6.13 Change in focal length
(http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

D. Flying height oraltitude

The average scale is determined by the aircraft's altitude. If the camera lens' focal length remains constant. The relief displacement will rise as the flying height is raised.. (Fig. 6.14)

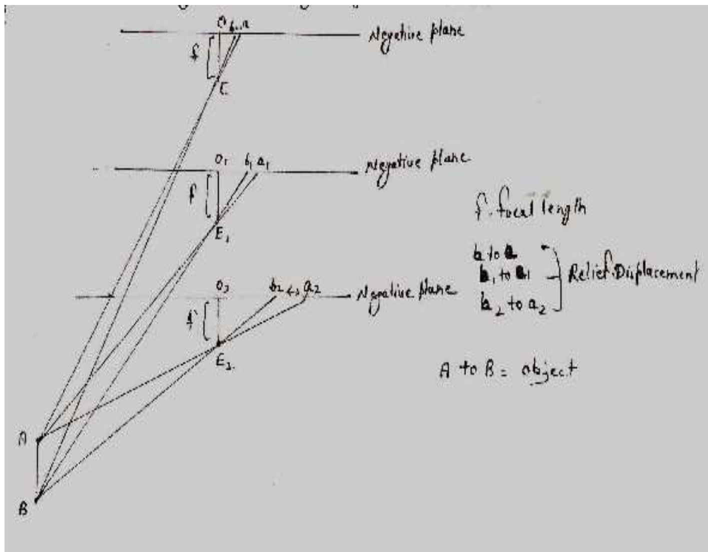


Fig. 6.14 Change in flying height or altitude
(http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

E. The object's height in reference to the datum plane. (Fig.6.15)

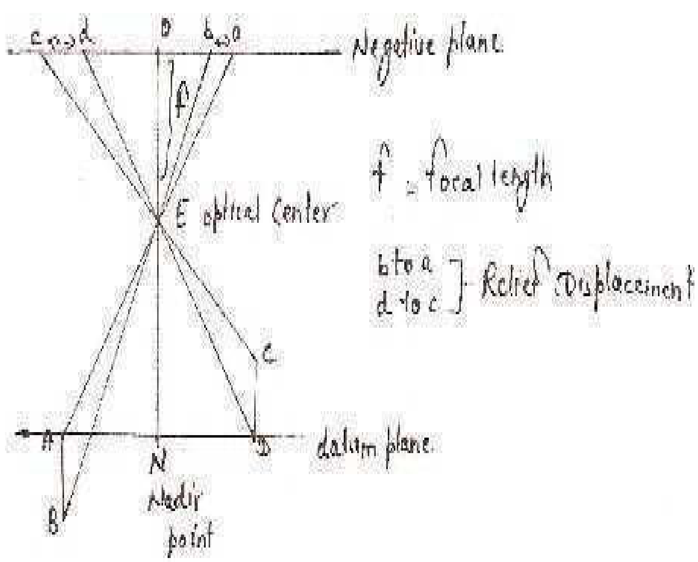


Fig. 6.15 Height of object in relation to datum plane
(http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

F. Effect of the field of view

Relief displacement (shift on an image of a point due to relief) will be smaller with a normal angle of view (height). (Fig.6.16)

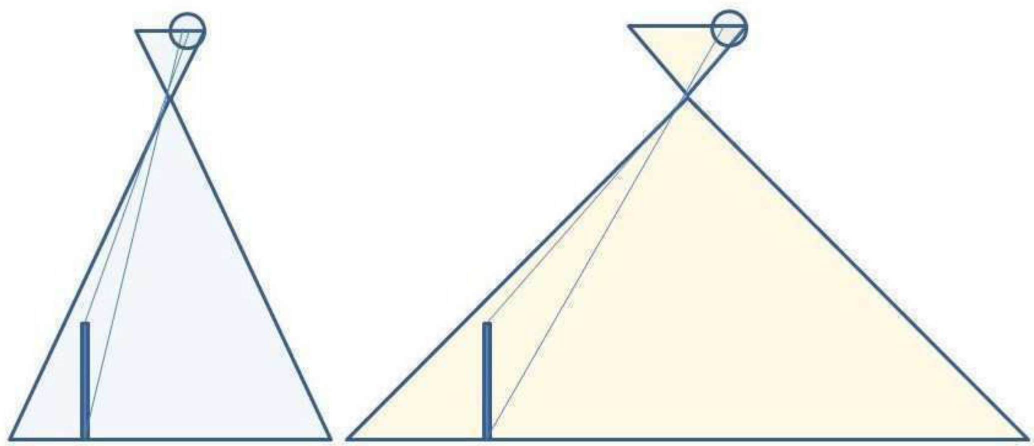


Fig. 6.16 Effect of the field of view

Check Your Progress

Q.1 What relief displacement in aerial photography?

Q.2 What is tilt distortion?

Q.3 Fill in the blank-

a) If a photograph is actually vertical, the images are displaced in a ---------- direction from the centre.
b) An object will be shifted towards the principal point as its elevation ----------.

Q.4 True false against the following-

a) The relief displacement will rise as the flying height is decreased.
b) Relief displacement will be smaller with a normal angle of view .

Measurement of relief displacement

The measurement of relief displacement depends upon:-

A. The amount of relief displacement d on a vertical photograph is proportional to the difference in elevation h between the object whose image is displaced on the datum and the object whose image is displaced on the datum..

B. It is proportional to the radial distance between the displaced image and the primary point, which is r.

C. It is inversely proportional to the camera's altitude H above the datum.Fig.6.17)

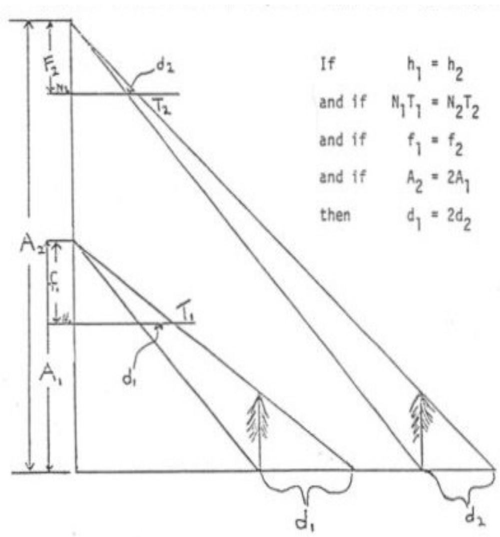


Fig. 6.17 Inversely proportional to flight altitude above the datum. (http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

D. Relief displacement is outward from places with elevations higher than datum and inward from points with elevations lower than datum.(Fig.6.18)

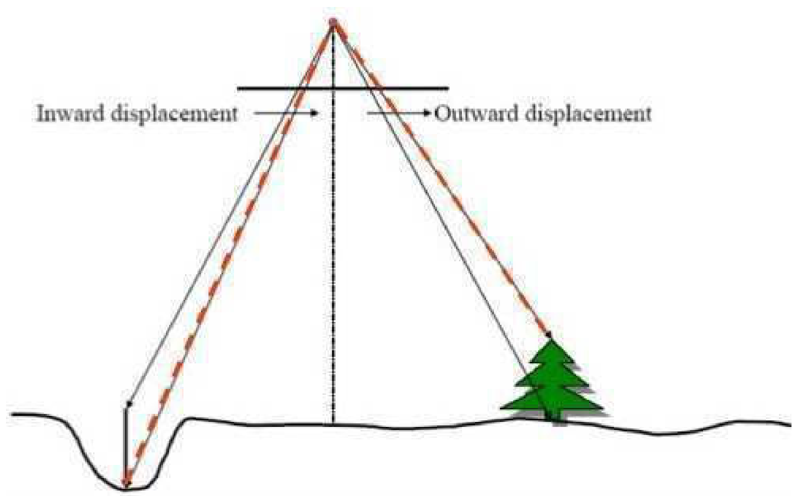


Fig.6.18 Inward and Outward displacement
(http://www.edc.uri.edu/nrs/classes/nrs409509/RS/Papers/ReliefDisplacement.pdf)

E. The relief displacement is radial in direction from the photograph's nadir point. (Fig.6.19)

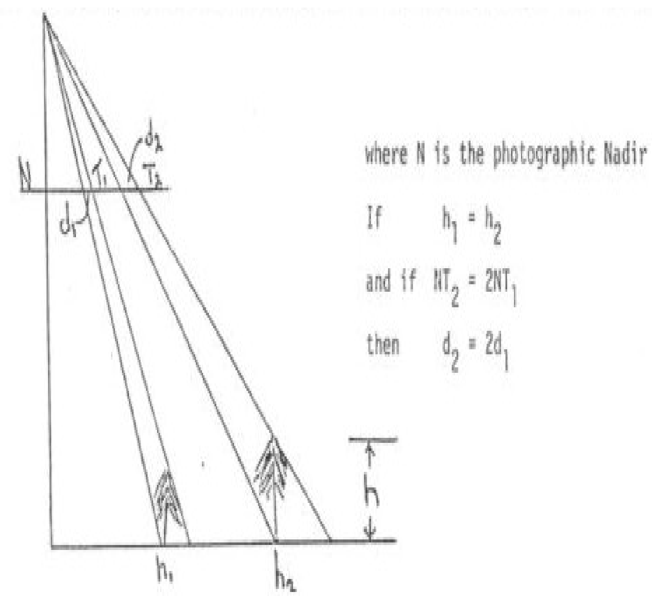


Fig.6.19 Directly proportional to the distance of the displaced image from the photo nadir(http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf)

Relief displacement can becalculated

Relief displacement is expressed mathematically as:

$d = hr/H$
d = Relief Displacement h = Height of the object
r = Radial distance from nadir point
H = Total altitude of the camera or flying height

Example

An aircraft was flying at a height of 25000 feet above the ground when it took a vertical aerial photograph of a 30 metre tall item. The object's picture is around 6 inches away from the nadir point.

Solution

H = 25000 feet or 25000 x 30 = 750000cms h = 30 meters or 30x100 = 3000cms
r = 6 inches or 6 x 2.5 = 15.0cms
$d = hr/H$
$d = 3000 \times 15.0 / 750000$
d = 0.06cms

Check Your Progress

Q.5 What are the causes of relief displacement?

Q.6 how to calculate the relief displacement at an aerial photograph?

Q.7 Fill in the blank-

a) Relief displacement is inversely proportional to the camera's ------ above the datum.
b) Relief displacement is expressed mathematically as--------------.

Q.8 True false against the following-

a) The relief displacement is radial in direction from the photograph's nadir point.
b) Relief displacement is outward from places with elevations higher than datum and inward from points with elevations lower than datum.

The earth's surface is not smooth and level. As a result, a natural phenomena occurs that causes real orthogonality of photo image characteristics to be disrupted. An orthogonal image is one in which the displacement has been removed and all of the visual features are aligned horizontally. Any alteration in the position of an image on a photograph that does not change the perspective properties of the photograph is referred to as displacement. Displacement is caused primarily by the camera's perspective view, which results in a perspective or central projection on the shot. The shift or displacement in the photographic location of an image induced by relief or topography is known as relief displacement. The images of ground placements in the central projection of an aerial shot are changed or displaced due to terrain relief. If a photograph is actually vertical, the images are displaced in a radial direction from the centre. The radial displacement owing to relief is another name for this displacement. At higher radial distances from the centre, the amount of displacement increases and reaches a maximum at the photograph's corners. The amount of relief displacement is determined by the object's height, distance from the nadir point, focal length, flying height or altitude, object height in reference to the datum plane, and the field of vision effect. The rationale for the minor relief displacement from space is that a shorter focal length lens requires flying at a lower altitude to reach a given scale. In stereoscopic images, utilising short focal length lenses causes topographic displacement, distortion, and perceived depth of the third dimension (vertical exaggeration).

6.4SUMMARY

This unit examined the concepts of image distortions/ displacement in photogrammetry, as well as lens and tilt distortion. The reasons of relief displacement were also explored, as well as how to calculate relief displacement.

6.5 GLOSSARY

Distortion-A shift in the placement of an object that alters the photo's perspective properties.
Displacement-The fiducial distance between an object's picture and its true plan position, which is induced by change in elevation.) shift in the location of an object in a photo that does not modify the perspective properties of the shot.
Principal Point-The principal point is the intersection of the photo image and the perpendicular projected via the lens's centre.
Nadir-At the time of exposure, the Nadir is the point vertically underneath the camera centre.
Isocenter - On the snapshot, the point that is half-way between the primary point and the Nadir point.
Lens distortion-Small distortions are caused by faults in the optical components (i.e. lens) of camera systems (which are typically more serious at the edges of photos). The most well-known examples of this effect are vehicle windows/windshields and carnival mirrors. These effects are radial from the principal point (making objects appear closer or farther away than they actually are), and they can be rectified via calibration curves.
Tilt Displacement-Instead of a true vertical record, a slanted snapshot gives a slightly angled view. All of the photographs are skewed in some way. Like the perfect lens, the perfect gyro stabilisation mechanism has yet to be created. Tilt is created by the platform being rotated away from vertical. The axis of the wings or the flight line is the most common locations for

this type of displacement. Tilt displacement radiates from the photo's isocenter, causing objects to be displaced radially inward on the tilted photo's upper side and radially outward on the bottom side. The photo can be corrected if the quantity and direction of tilt are known.

Topographic Displacement-The most serious sort of displacement is usually this one. From Nadir, this displacement radiates outward. The perspective geometry of the camera and the terrain at various heights generate topographic displacement.

6.6 ANSWER TO CHECK YOUR PROGRESS

Ans .1 The radial distance between where an object appears in an image and where it should be in a Planimetric coordinate system is known as relief displacement. The images of ground placements in the central projection of an aerial shot are changed or displaced due to terrain relief. If a photograph is actually vertical, the images are displaced in a radial direction from the centre.

Ans.2 Instead of a true vertical record, a slanted snapshot gives a slightly angled view. All of the photographs are skewed in some way. Like the perfect lens, the perfect gyro stabilisation mechanism has yet to be created. Tilt is created by the platform being rotated away from vertical. The axis of the wings or the flight line is the most common locations for this type of displacement. Tilt displacement radiates from the photo's isocenter, causing objects to be displaced radially inward on the tilted photo's upper side and radially outward on the bottom side.

Ans.3 Fill in the blank-

a) Radial
b) increases.

Ans .4 True false against the following-

a) False
b) True

Ans.5 Height of theobject, distance of the objects from nadirpoint, FocalLength, Flying height oraltitude, object’s height in reference to the datum plane, Effect of the field ofview

Ans.6 Relief displacement is expressed mathematically as:

d = hr/H

d = Relief Displacement h = Height of the object

r = Radial distance from nadir point

H = Total altitude of the camera or flying height

For example, An aircraft was flying at a height of 25000 feet above the ground when it took a vertical aerial photograph of a 30 metre tall item. The object's picture is around 6 inches away from the nadir point.

Solution

H = 25000 feet or 25000 x 30 = 750000cms h = 30 meters or 30x100 = 3000cms

r = 6 inches or 6 x 2.5 = 15.0cms

d =hr/H

d = 3000 x 15.0/ 750000

d = 0.06cms

Ans .7 Fill in the blank-

a) altitude H
b) d = hr/H

Ans.8 True false against the following-

a) True
b) True

6.7 REFERENCES

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11. https://seos-project.eu/3d-models/3d-models-c02-p02.html
12. http://geography.middlebury.edu/data/gg1002/Readings/Week2/AirPhotoGeometry.pdf
13. http://www.edc.uri.edu/nrs/classes/nrs409509/RS/Papers/ReliefDisplacement.pdf

6.8TERMINAL QUESTIONS

Q.1 Write a short note on **Lens distortion in** aerial photograph.
Q.2 what is tilt distortion?
Q.3 Write a short note on general characteristics of relief displacement.
Q.4Whatis relief displacement?
Q.5 Discuss on the causes of relief displacement.
Q.6 How to measure the relief displacement at the aerial photograph?

BLOCK 3: INTRODUCTION TO IMAGE INTERPRETATION

UNIT 7: CONCEPT OF PHOTOGRAPHY

7.1 OBJECTIVES

After reading this unit, you should be able to:

- know the geometry of an aerial photograph;
- explain the methods of computing scale of aerial photo;
- define aerial photo interpretation;
- discuss aerial photo interpretation;
- describe elements of photo interpretation;

7.2 INTRODUCTION

In Units 5 and 6, we looked at stereoscopic area photographs and relief displacement, respectively. We all learnt aspects of surface relief and height measurement while making 3D models from aerial photograph in the units. The different components of aerial photography that affect the interpretation of the photograph and the information obtained from it, as well as the utilisation of aerial photographs, will be explained in this section. The approaches of interpretation of aerial photographs will be discussed as well.

7.3 CONCEPT OF PHOTOGRAPH

Geometry of an aerial photograph

1- Projection

Projection It is vital to grasp what projection means in terms of geometry in order to comprehend the geometric properties of a photograph. The triangle ABC and the line LL' on which the projection is produced are in the same plane in the cases given.

a) **Parallel Projection**- The projecting rays are parallel in this projection. On the LL', the triangle ABC is projected. The triangle's projection is 'abc'. In this scenario, the projection beams Aa, Bb, and Cc are all parallel.

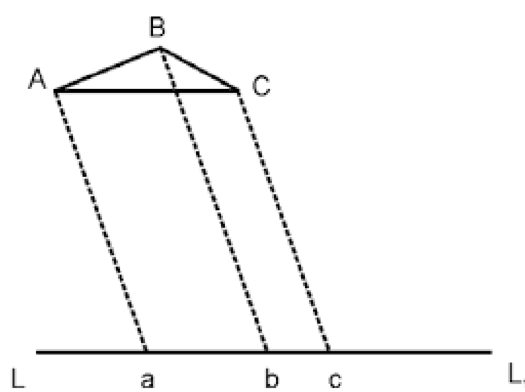

Fig.7.1 Parallel Projection
https://ncert.nic.in/textbook/pdf/kegy306.pdf

b) **Orthogonal Projection**- The projecting rays are all perpendicular to the line LL' in this scenario. This is an example of parallel projection in action. A map is a scaled-down orthogonal projection of the ground. The distances, angles, and areas in the plane are independent of the objects' elevation differences, which is a benefit of this projection.

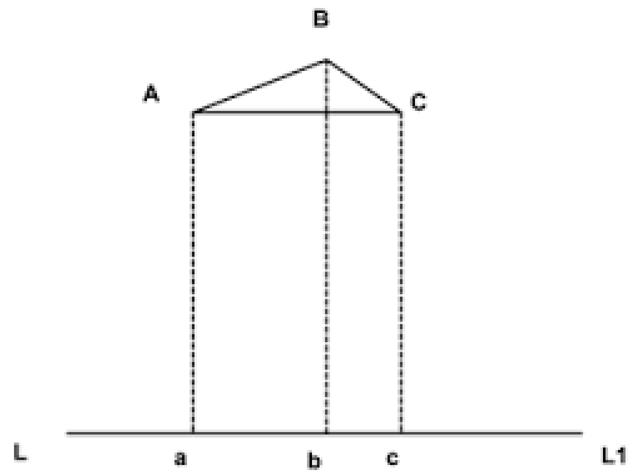

Fig.7.2Orthogonal Projection
https://ncert.nic.in/textbook/pdf/kegy306.pdf

c) **Central Projection-** The projecting rays Aa, Bb, and Cc pass via the Projection Centre, also known as the Perspective Centre. A central projection is applied to the image projected by a lens system (though stringly it is not, as the lens is not a single point).

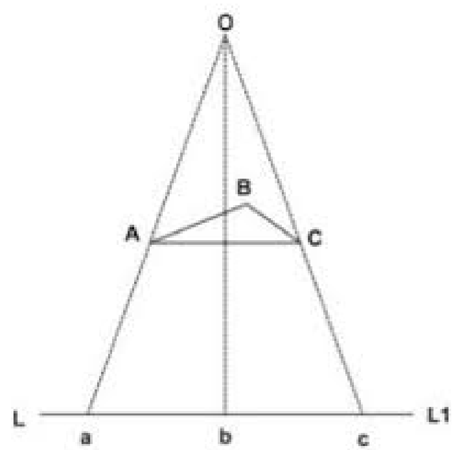

Fig.7.3Central Projection
https://ncert.nic.in/textbook/pdf/kegy306.pdf

2-Printed Information/Annotation on aerial photograph

We can locate the following information along the top border of the aerial photo: Date of Flight - always top left. On top right of images are always the camera focal length in mm (often 152.598 mm = 6"), Nominal scale (RF), Vendor/Job #, Roll #, Flight line, and Exposure #. Orientation of Photograph Labels and annotations are usually placed along the photo's northern edge, however the eastern edge is occasionally utilised as well.
According to the photo's roll and frame, each aerial photo is issued a unique index number. Photo A23822-35, for example, is the 35th annotated photo on film A23822. This number can be used to locate a photo in NAPL's database, as well as details such as the date it was taken, the plane's height (above sea level), the camera's focal length, and the weather conditions.

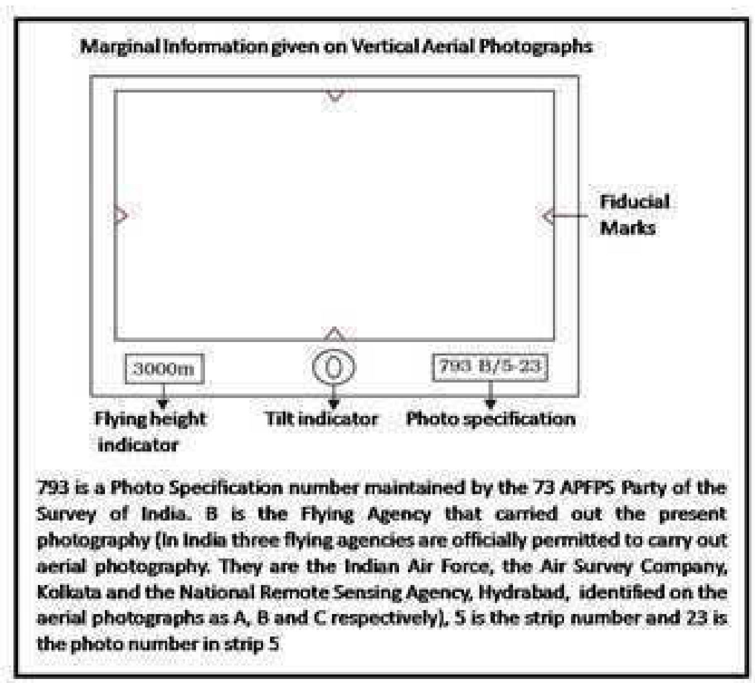

Fig.7.4 Marginal Information/Annotation on aerial photograph
https://www.researchgate.net/publication/326988868_Aerial_Photography_and_Photogramm etary

3-Flight Lines and Index Maps:

At the conclusion of a photo mission, the aerial survey contractor maps the location of the first, last, and fifth photo centres on a National Topographic System (NTS) map, together with the roll and frame numbers. Small circles symbolise photo centres, and straight lines connect the circles to illustrate photos flying in the same direction.

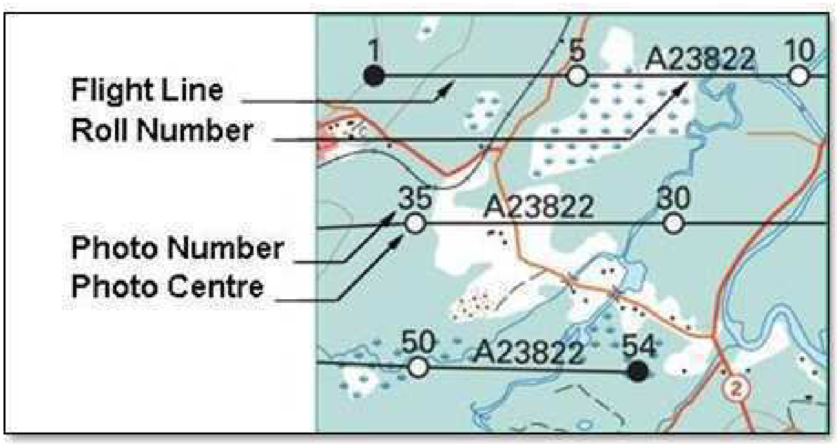

Fig.7.5Flight line and index map
https://www.researchgate.net/publication/326988868_Aerial_Photography_and_Photogrammetary

An air photo index map is a graphical representation that allows you to tie photos to their geographical position. Small-scale images are indexed on NTS map sheets with a scale of 1:250 000, while larger-scale photographs are indexed on NTS maps with a scale of 1:50 000.

3-Fiducial marks

Geometric figures that are optically projected at the four corners or four sides of an image. A single aerial photograph's coordinate axes and geometric centre are defined by them. The x-axis is the closest to defining flight direction. The y-axis comes the closest to defining the flying path. The "principal point" of the photograph is the junction of the fiducial markers.These markers are used to define the frame of reference for spatial measurements on aerial images and are exposed onto the original film within the camera. At about the image centre or central point of the aerial photograph, two opposing fiducial markings are joined. The geometric centre of the shot is the focal point. Figure 7.5 depicts typical fiducial mark positions in an aerial photograph, whereas Figure 7.6 depicts different examples of fiducial mark shapes.

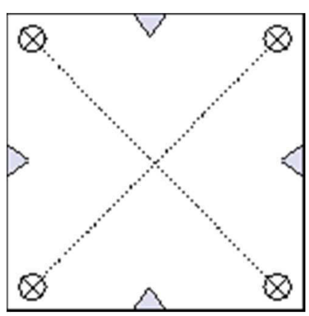

Fig.7.6 Location of the fiducial marks and principal point for an aerial photo image. The intersection of the dotted line indicates the principle point.
https://vision-cdc.csiro.au/changs/fiducial/node1.html#fgshapes

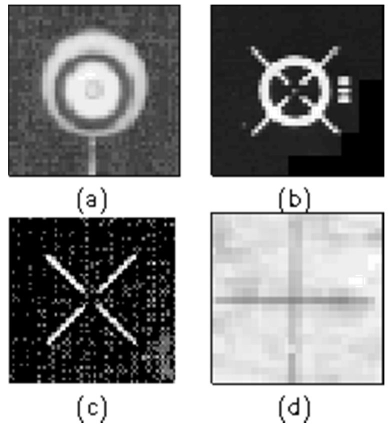

Fig.-7.7Several typical shapes of fiducial mark in an aerial photo image.
https://vision-cdc.csiro.au/changs/fiducial/node1.html#fgshapes

4- **Principal Point**

It is the geometric centre of the photograph, as well as the point where the X and Y axes connect.The principle point is the spot on the ground directly beneath the camera lens as seen from above. The look of objects at the principle point is identical to how they appear on the ground if the plane carrying the camera maintains a straight-and-level flight path. Due to air turbulence, the aircraft occasionally deviates from a straight-and-level flight path. In this instance, the camera lens will tilt slightly, resulting in a somewhat slanted view of the items in the shot. The effect of slanting is explained further down (see "Center Point Projection"). Ordinary cameras can now compensate for the slanting effect automatically, resulting in images that show objects exactly as they look, without the slanting effect. The intersection point of two diagonal lines between principal point indicating markers on the outer frame of an aerial image is known as the principal point.

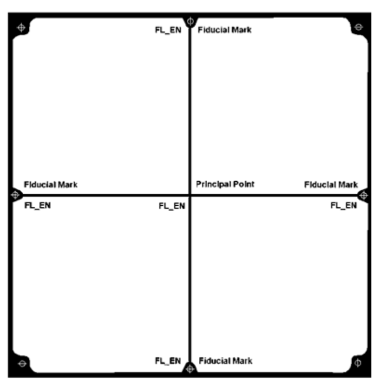

Fig.7.8Principal Point on the aerial photograph

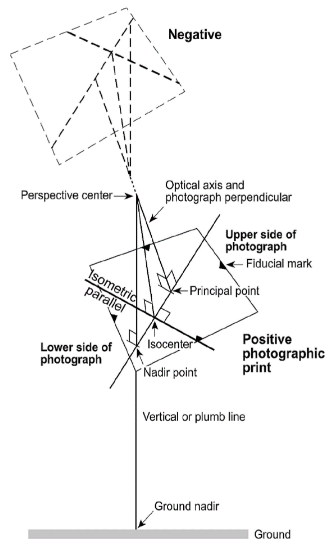

Fig.7.9 Plumb point or nadir point , Isocentre and principal point

4-Plumb Point or Nadir

The point at which the vertical line passing through the center of the camera lens touches the film is called the plumb point. Like the principal point, the plumb point also has a homologous point on the surface. It is worth noting here that the principal point and the plumb point are one in the true vertical bio photo picture. It is also called nadir point. The effects of topographic displacement frequently increase as you move farther from the plumb point . During the collection process, it is a means of computing location and height.

6. Isocentre

On the aerial photo , the point that is half-way between the principal point and the Nadir point. All three of them would be at the same place on a true vertical aerial image. A true vertical aerial photograph does not exist. Every air photo has a slight tilt or tip to it (Fig.7.9).

7-Camera axis

The projection centre C and the main point PP define it. The optical axis is represented by the camera axis. It's parallel to the image plane.

8-Tilt angle:

It is angle between vertical and cameraaxis.

9-Overlap:

It is the proportion of one photograph's area that is covered by another photograph, represented as a percentage. The picture survey aims for a 60 percent forward overlap (between photos taken along the same flight line) and a 30% lateral overlap (between photos on adjacent flight lines).

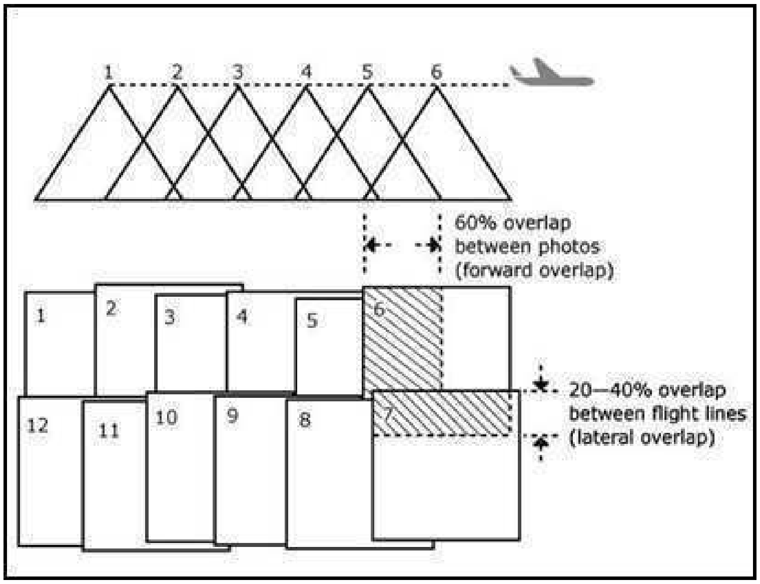

Fig.7.10 Forward and lateral overlapping
https://www.researchgate.net/publication/326988868_Aerial_Photography_and_Photogrammetary

10-**Stereoscopic Coverage**

When two overlapping photographs (called a stereo pair) are seen via a stereoscope, the result is a three-dimensional view. Each of the stereo pair's photographs depicts a slightly different picture of the same location, which the brain mixes and interprets as a three-dimensional image. By crossing two lines of sight, stereoscopic vision estimates the distance to an object. The following equipment can be used to create stereoscopic vision:

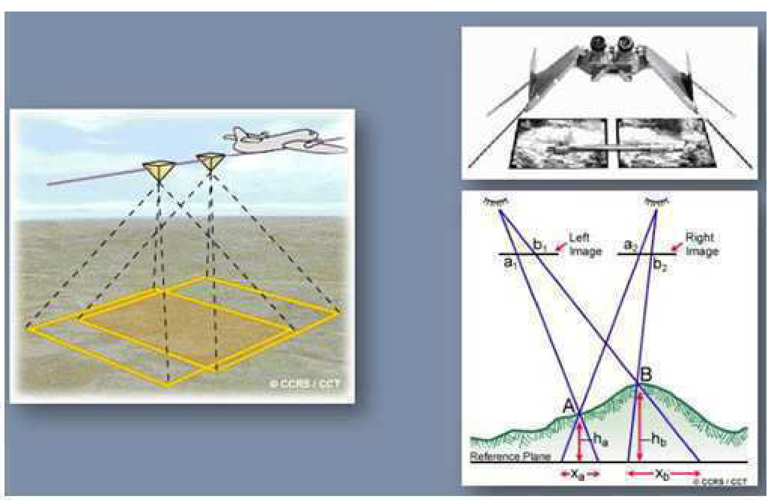

Fig.7.11 Stereo pair photograph
https://www.researchgate.net/publication/326988868_Aerial_Photography_and_Photogrammetary

Pocket Stereoscope:A lens or pocket stereoscope is a low-cost tool that can be used in both the field and the office. It has a fixed magnification, which is usually 2.5X.
Mirror Stereoscope:A mirror stereoscope can perform the same functions as a lens, but it is not suitable for usage in the field. At the nominal magnification ratio, the mirror stereoscope has a larger field of view. The equipment is useful for simple stereoscopic measurements since images may be held stationary for stereo viewing under a mirror stereoscope. Binocular eyepieces with magnifications of 6X and 9X can be added to mirror stereoscopes. The high magnification aids in the identification, interpretation, and measurement of photographic details.

Scale of the Aerial photograph

The concept of scale in aerial photography is similar to that of a map. In the actual world, scale is the ratio of a distance on an aerial photograph to the distance between the same two points on the ground. It can be stated as a representative fraction or in unit equivalents such as 1 cm = 1,000 kilometres (or 12,000 inches) (1:100,000).What objects will be visible, the accuracy of estimates, and how specific aspects will seem are all determined by scale. When doing an analysis using air pictures, it may be essential to make estimations about the number of items, the area covered by a specific amount of material, or whether certain features may be identified based on their length. To determine this dimension during air photo interpretation, estimates of lengths and areas will be required, which will necessitate knowledge of the photo scale. There are three approaches to compute the scale of an aerial shot utilising distinct sets of information.

Method 1: By establishing the relationship between photo and ground distances:

It is quite simple to calculate the scale of a vertical photograph if additional information such as ground distances of two recognisable spots in an aerial shot is given. Assuming that the ground distances (Dg) for which the distances on an aerial photograph (Dp) are measured are known. In such instances, an aerial photograph's scale will be calculated as a ratio of the two, i.e. Dp/ Dg.
Example- 1
Two centimetres is the distance between two points on an aerial image. One kilometre is the recognised distance between two places on the earth. Calculate the aerial photograph's scale (Sp).

Solution
Sp = Dp : Dg
= 2 cm : 1 km
= 2cm : 1 × 100,000 cm
= 1 : 100,000/2
= 50,000 cm
= 1 unit represents 50,000 units Therefore,
Sp = 1 : 50,000

Method 2: By establishing a relationship between photo and map distances:

The distances between different sites on the ground are not always known, as we all know. 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 \sus to compute the scale of the aerial photograph (Sp). The following is the relationship between the two distances:

(Photo scale : Map scale) = (Photo distance : Map distance)
We can derive Photo scale (Sp) = Photo distance (Dp) : Map distance (Dm) × Map scale factor (msf)
Example- 2Two centimetres is the distance between two locations on a map. On an aerial photograph, the equivalent distance is 10 cm. Calculate the photograph's scale when the map's scale is 1: 50,000.
Sp = Dp : Dm × msf
Or = 10 cm : 2 cm × 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: By Establishing a Relationship Between the Focal Length (f) and the Aircraft's Flying Height (H):

If no further information about the relative distances on the photograph and the ground/map is available, we can determine the photo-scale if the focal length of the camera (f) and the aircraft's flying height (H) are known (Fig. 7.12) If the given aerial photograph is genuinely vertical or nearly vertical, and the region photographed is flat, the photo scale obtained could be more trustworthy. Most vertical images provide minimal information such as the camera's focal length (f) and the aircraft's flying height (H) . The photo-scale formula can be derived in the following method using Fig7.12:

Focal Length (f) : Flying Height(H) = Photo distance (Dp) : Ground distance (Dg)
Example 3 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 × 100 cm
Or Sp = 1 : 750,000/15
Therefore, Sp = 1 : 50,000

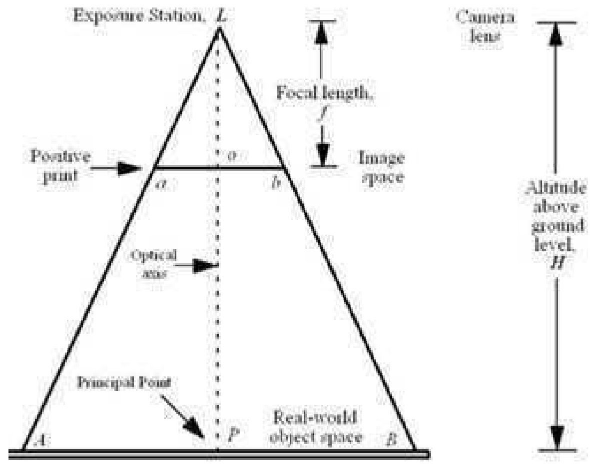

Fig.7.12 Relationship Between the Focal Length (f) and the Aircraft's Flying Height (H):

Relief Displacement:

The movement in an object's image location caused by its elevation above a specific datum is known as relief displacement. A vertical item (such as a structure or tree) will appear to be lying along a line radial to the nadir point of the image. Relief displacement is the term for this type of deformation.

Here,
r = distance on the photo from the nadir to the displaced landscape feature
r' = actual place on the photo where the landscape feature should be located .
d = relief (topographic) displacement.
f = focal length.
h = height of the landscape feature.
A = altitude of the aircraft above sea level.
E = elevation of the landscape feature.
H = Flying height above the base of the landscape feature at nadir.
R = distance from the nadir to the landscape feature.

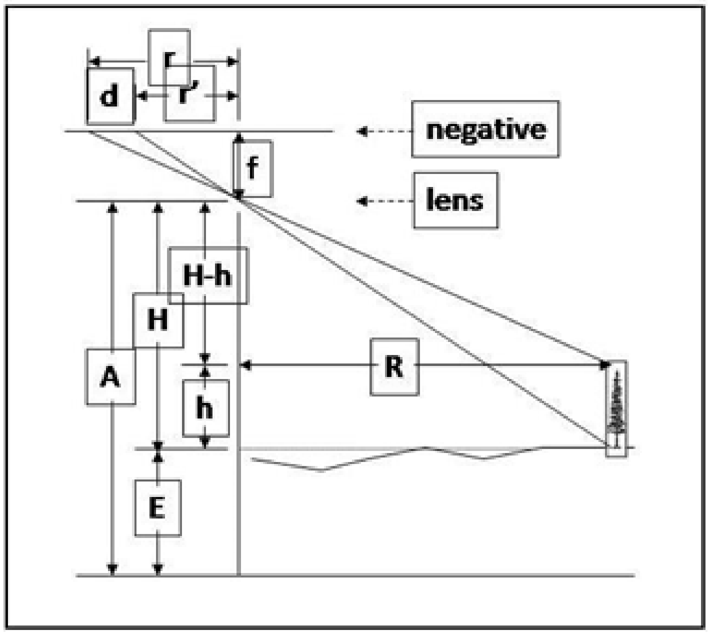

Fig.7.13 Relief Displacement
https://www.researchgate.net/publication/326988868_Aerial_Photography_and_Photogrammetary

Check Your Progress

Q.1 What is principal point ?

Q.2 What is plumb point ?

Q.3 Fill in the blank-

a) The -------------- is the spot on the ground directly beneath the camera lens as seen from above.

b) Photo scale (Sp) = Photo distance (Dp) : ------------------- × Map scale factor (msf)

Q.4 True false against the following-

a) Scale is the ratio of a distance on an aerial photograph to the distance between the same two points on the ground.

b) The movement in an object's image location caused by its elevation above a specific datum is known as relief displacement.

Aerial Photo Interpretation

Photo interpretation is the process of identifying and extracting the meaning of items from a photograph. Photos can be used for topographic mapping and as a mapping layer with map data overlain on top once they've been rectified and georeferenced. Air photographs can be a useful source of spatial data for researching the Earth's environment if they are properly interpreted.

Photogrammetric workstation: A photogrammetric workstation is a system that combines hardware and software to capture, manipulate, analyse, store, display, and produce softcopy photographs. These systems include analytical stereo plotters, automated DEM production, digital ortophoto computation, perspective view preparation, and data acquisition in @D and 3D for usage in a GIS.

Elements of aerial photo interpretation

Color and tone

In the blue, green, red, and infrared regions of the electromagnetic spectrum, real-world elements such as vegetation, water, and bare earth reflect various proportions of energy. To develop a spectral signature, an interpreter can document the quantity of energy reflected from each at specific wavelengths. These signatures can help explain why particular items appear in black and white or colour images the way they do. Tone refers to the several colours of grey. The less light a thing reflects, the darker it seems. Humans can distinguish thousands of various hues, unlike shades of grey, hence colour imagery is frequently favoured. The process of photo interpretation is aided by colour.

Fig.7.14 Tone
http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

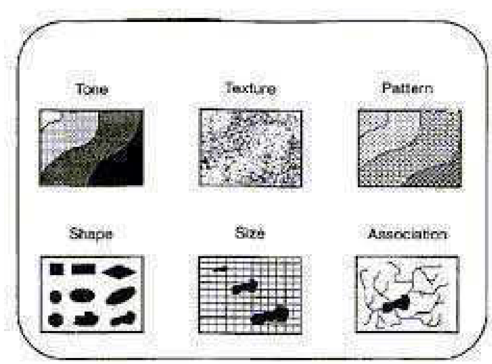

Fig.7.15Object Signature Characteristics
http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Shape

There are an unlimited amount of naturally and artificially formed items in the world. The triangular shape of modern jet aircraft and the design of a typical single-family home are two instances of shape. Humans have altered the terrain in fascinating ways, giving form to a variety of objects, but nature also modifies the landscape in its own unique way. Straight, recti-linear elements in the environment are almost often human-made. Natural forms are more delicate.

Fig.7.16Shape
http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Size

One of the most identifying aspects of an object, as well as one of the most crucial factors of interpretation, is its size. The most typical measurements are length, breadth, and perimeter. To be able to do this correctly, you must first understand the photo's scale. The interpreter can rule out plausible options by measuring the size of an unknown object. Measuring the size of a few well-known objects to compare to the unknown-object has proven to be useful. Major sports like soccer, football, and baseball, for example, have uniform field measurements over the world. If things like this are visible in the photograph, the size of the unknown object can be determined by simply comparing the two.

Fig.7.17Size
http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Texture

Texture is defined as the "distinctive placement and arrangement of tone or colour repetitions in a picture." The adjectives smooth (uniform, homogeneous), intermediate, and rough are frequently used to describe texture (coarse, heterogeneous). It's vital to note that texture is a scale-dependent phenomenon. Objects depicted at a big scale may appear to have an intermediate texture. However, when the scale shrinks, the texture may appear more uniform or smooth. The "smoothness" of a paved road or the "coarseness" of a pine forest are two examples of texture.

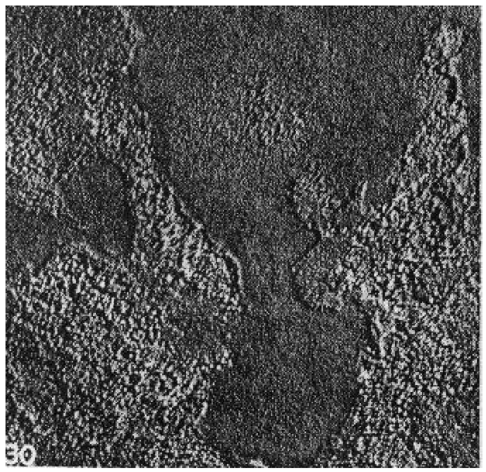

Fig.7.18texture

http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Pattern

The spatial arrangement of objects in the landscape is known as pattern. The objects can be placed in a systematic or random manner. They can be natural, such as a river's drainage pattern, or man-made, such as the squares created by the US Public Land Survey System. Random, systematic, round, oval, linear, rectangular, and curvilinear are some of the adjectives commonly used to describe pattern.

Fig.7.19Pattern

http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Shadow

The height, shape, and direction of an object are all revealed by its shadow (e.g. tree species).

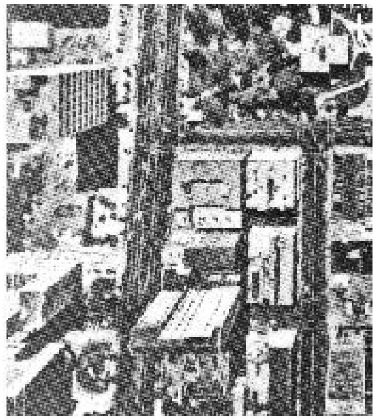

Fig.7.20Shadow
http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Association

The elevation, slope, and kind of surface cover of a site are all unique physical characteristics (e.g., grass, forest, water, bare soil). Sites might also have socioeconomic factors like land value or proximity to water. The "situation" of the objects in a photograph or image refers to how they are structured and "situated" in relation to one another. The materials and structures associated with most power plants are reasonably predictable. When you identify a specific activity in a photograph or image, you will almost always come across related or "associated" characteristics or activities. When interpreting an image, site, circumstance, and association are rarely utilised in isolation. A large shopping mall is an example of this. Multiple huge buildings, massive parking lots, and a location near a major road or crossroads are typical.

Fig.7.21Association
http://hosting.soonet.ca/eliris/remotesensing/bl130lec5.html

Time

Temporal aspects of a series of photographs can aid in determining historical change in a region (for example, looking at a series of shots of a city taken in different years can aid in determining suburban neighbourhood growth).

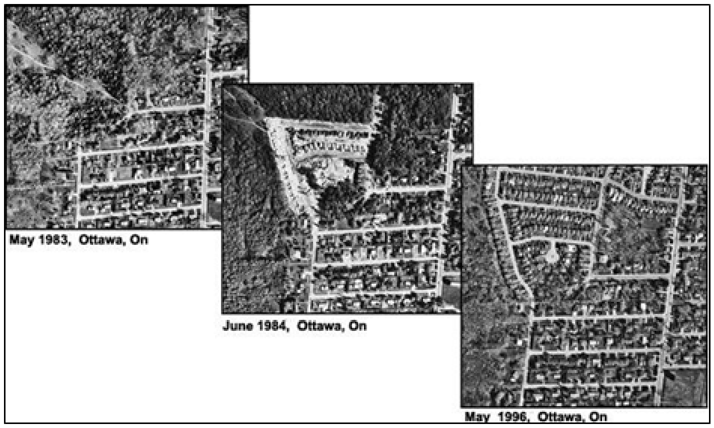

Fig.7.22A series of shots of a city taken in different years
https://www.researchgate.net/publication/326988868_Aerial_Photography_and_Photogrammetary

Check Your Progress

Q.5 What are the elements of aerial photo interpretation?

Q.6 What is importance of shadow in the photo interpretation?

Q.7 Fill in the blank-.

a) -------------- is the process of identifying and extracting the meaning of items from a photograph
b) A ------------ is a system that combines hardware and software to capture, manipulate, analyse, store, display, and produce softcopy photographs.

Q.8 True false against the following-

a) The height, shape, and direction of an object are all revealed by its color.
b) Temporal aspects of a series of photographs can aid in determining historical change in a region.

7.4 SUMMARY

In this unit, you have studied about:

- Geometry of an aerial photograph
- Methods of computing scale of aerial photo;
- Definition of aerial photo interpretation and interpretation key/ elements
-

7.5 GLOSSARY

Scale: Ratio of the distance on an image to the equivalent distance on the ground.

Stereoscopy: Science of viewing a pair of stereoscopic photographs or images by looking at the left image with the left eye and the right image with the right eye.

Principal Point-The principal point is the intersection of the photo image and the perpendicular projected via the lens's centre.
Nadir-At the time of exposure, the Nadir is the point vertically underneath the camera centre.
Isocenter - On the snapshot, the point that is half-way between the primary point and the Nadir point.
Photogrammetric workstation: A photogrammetric workstation is a system that combines hardware and software to capture, manipulate, analyse, store, display, and produce softcopy photographs.
Aerial Photo Interpretation: Photo interpretation is the process of identifying and extracting the meaning of items from a photograph.
Interpretation key: Criteria for identification of an object with elements of interpretation.

7.6 ANSWER TO CHECK YOUR PROGRESS

Ans.1 It is the geometric centre of the photograph, as well as the point where the X and Y axes connect. The principle point is the spot on the ground directly beneath the camera lens as seen from above.

Ans. 2 The point at which the vertical line passing through the center of the camera lens touches the film is called the plumb point. Like the principal point, the plumb point also has a homologous point on the surface.

Ans.3 Fill in the blank-

a) principal Point
b) Map distance

Ans.4

a) True
b) True

Ans.5tone/ color, shape, size, texture, pattern, association, shadow, time etc.

Ans.6 The height, shape, and direction of an object are all revealed by its shadow (e.g. tree species).

Ans .7 Fill in the blank-

a) Photo interpretation
b) photogrammetric workstation

Ans.8 True false against the following-

a) False
b) True

7.7 REFERENCES

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7.8 TERMINAL QUESTIONS

Q.1 Write a short note on geometry of the aerial photograph.
Q.2 Describe the methods of computing scale of aerial photographs.
Q.3 Write a short note on relief displacement.
Q.4 What is deference between principal point and nadir point?
Q.5 What is photogrammetric workstation?
Q.6 Write a short note on elements of the aerial photograph interpretation.

UNIT 8 – SENSOR RESOLUTIONS

8.1 OBJECTIVES

After reading this unit you will be able to understand that:

- Definition and types of resolution.
- Characteristics of resolution types.
- Radiometric Resolution and Classification Accuracy.
- Trade-offs between Spatial, Spectral and Radiometric Resolutions.

8.2 INTRODUCTION

You have learnt remote sensing platforms and sensors in the previous chapter. The specifications of the platform and the sensor determine the resolutions of the remotely sensed data. In remote sensing the term resolution is used to represent the resolving power, which includes not only the capability to identify the presence of two objects, but also their properties. Before understanding the concept of resolution you should understand the sensor foot prints, Instantaneous Field of View IFOV) and the factors related to all the types of resolutions viz., spatial, spectral, temporal and radiometric.

For some remote sensing instruments, the distance between the target being imaged and the platform, plays a large role in determining the detail of information obtained and the total area imaged by the sensor. Sensors onboard platforms far away from their targets, typically view a larger area, but cannot provide great detail. Compare what an astronaut onboard the space shuttle sees of the Earth to what you can see from an airplane. The astronaut might see your whole province or country in one glance, but couldn't distinguish individual houses. Flying over a city or town, you would be able to see individual buildings and cars, but you would be viewing a much smaller area than the astronaut. There is a similar difference between satellite images and aerial photographs.

Spatial resolution of a sensor defines the clarity of an image, not the number of pixels in an image, and thus helps to identify the smallest object on an image. Sensors that acquire images with large spatial extents generally have a lower resolution than images acquired at a higher resolution. High-resolution images are excellent for measuring a range of forest characteristics suitable for assessing ecosystem services, such as forest gap sizes and distribution, locations of highly valued trees, identification of invasive plants/trees, and riparian zone mapping. For example, World View imagery is suitable for measuring tree locations and crown diameter and Landsat imagery is ideal for mapping homogeneous forest stands.

Improved sensor characteristics with respect to spatial, spectral, temporal and radiometric resolution are generally assumed to increase the potential accuracy of image classification and information extraction from remote sensing imagery. However, the increase in data volume caused by these improvements raise challenges associated with the selection, storage, and processing of this data, and with the cost-effective and timely analysis of the remote sensing datasets. The research in this field has extensively assessed the relevance and impact of spatial, spectral and temporal resolution of satellite data on classification accuracy.

In recent years, the improvements in spatial, spectral, radiometric, and temporal resolution of remote sensing imagery data has led to increased interest in the scientific community, as well as among end users in employing remote sensing data to new applications and operational needs.

However, as resolution increases, the complexity of data also increases and in order to fully exploit the potential of the new generation of remote sensing computers and sensors, a number of challenges need to be addressed. Improvement of resolution also results in high data volumes and storage issues. With regard to storage requirements, for example, NASA's Earth Observing System Data and Information System (EOSDIS) has an extensive archive of remote sensing data, currently exceeding 7.5 petabytes, with their data undergoing a growth of 4 TB daily. These huge data volumes require the usage of image compression techniques, providing either 'lossless' compression or 'lossy' compression. Furthermore, the majority of traditional image processing algorithms fail when the data resolution is greatly increased and it is often necessary to create new processing algorithms.

8.3 SENSOR RESOLUTION

8.3.1 Resolution

Resolution refers to the degree of fineness with which an image can be produced and the degree of detail that can be discerned.

- In general, the resolution is the minimum distance between two objects that can be distinguished in the image.
- In qualitative terms resolution is the amount of details that can be observed in an image. Thus an image that shows finer details is said to be of finer resolution compared to the image that shows coarser details.

8.3.2 Resolution types

In remote sensing, following are four relevant types of resolution:

- Spatial resolution
- Spectral resolution
- Temporal resolution and
- Radiometric resolution

The above resolution types are defined in the following ways:

8.3.2.1 Spatial Resolution

- Spatial resolution is a measure of the smallest object that can be resolved by the sensor, or the ground area imaged for the instantaneous field of view (IFOV) of the sensor, or the linear dimension on the ground represented by each pixel.
- Spatial resolution is a measure of the finest detail distinguishable in an image.
- Spatial resolution (or horizontal cell size) is a measurement's geographical area on the ground that the upwelling radiation originates from.
- The ability to "resolve," or separate, small details is one way of describing what we call spatial resolution.

8. 3.2.2 Spectral Resolution

- The spectral resolution describes the number and width of spectral bands in a sensor system.
- Spectral resolution refers to the specific wavelength intervals in the electromagnetic spectrum for which a satellite sensor can record the data.
- It can also be defined as the number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote sensing instrument is sensitive.
- Spectral resolution represents the spectral band width of the filter and the sensitiveness of the detector.
- The spectral resolution may be defined as the ability of a sensor to define fine wavelength intervals or the ability of a sensor to resolve the energy received in a spectral bandwidth to characterize different constituents of earth surface. The finer the spectral resolution, the narrower the wavelength ranges for a particular channel or band.

8.3.2.3 Temporal Resolution

- Temporal resolution is a measure of the repeat cycle or frequency with which a sensor revisits the same part of the Earth's surface. The frequency characteristics are determined by the design of the satellite sensor and its orbit pattern. The temporal resolutions of common sensors are also shown in Table 2 of unit 1
- Temporal resolution refers to the frequency at which data are captured for a specific place on the earth. The more frequently data are captured by a particular sensor, the better or finer is the temporal resolution of that sensor.
- Temporal resolution is often quoted as a "revisit time" or "repeat cycle."
- Temporal resolution is revisit duration of a sensor to the same location of the Earth's surface.
- Temporal resolution is defined as the number of times an object is sampled or how often data are obtained for the same area

8.3.2.4 Radiometric Resolution

- Radiometric resolution refers to the dynamic range, or the number of different output numbers in each band of data, and is determined by the number of bits into which the recorded radiation is divided.

- Radiometric resolution refers to the ability of a sensor to detect differences in energy magnitude. Sensors with low radiometric resolution are able to detect only relatively large differences in the amount of energy received; sensors with high radiometric resolution are able to detect relatively small differences.
- Radiometric Resolution refers to the smallest change in intensity level that can be detected by the sensing system.
- Radiometric resolution is the degree of intensities of radiation the sensor is able to distinguish.
- Radiometric resolution of a sensor is a measure of how many grey levels are measured between pure black (no reflectance) to pure white.
- Radiometric resolution represents the sensitivity of the sensor to the magnitude of the electromagnetic energy.
- The finer the radiometric resolution of a sensor the more sensitive it is to detecting small differences in reflected or emitted energy or in other words the system can measure more number of grey levels.

8.3.3 Characteristics of resolution types

8.3.3.1 Spatial resolution

Spatial Resolution describes how much detail in a photographic image is visible to the human eye. Spatial resolution of images acquired by satellite sensor systems is usually expressed in meters. For example, we often speak of Landsat as having "30-meter" resolution, which means that two objects, thirty meters long or wide, sitting side by side, can be separated (resolved) on a Landsat image.

For remote sensing instruments, the distance between the sensor and the target plays a large role in the amount and quality of data produced. Also, due to the factors consisting of instantaneous field of view, nadir and limb, the spatial resolution will vary from image center to the edge of the swath. Instantaneous Field of View (IFOV) is the angular cone of visibility of a remote sensor (Figure 8.1). It determines the area on the Earth's surface sensed at a particular moment in time. Nadir is the point on the Earth's surface directly below the satellite. Spatial Resolution is optimal at this point. It is also called the sub-satellite point. Limb is the edge of the apparent disk of a celestial body. It is also used to refer to either edge of the sensor's swath. Since the sensor IFOV is distorted at the limb (Figure 8.1a), spatial resolution will be lower here. While considering the spatial resolution you should know how the simulation of sensor footprint, changing the sensor IFOV (spot size) and sampling rate affect the data generated from the area. When making adjustments, one can see i) when the sensor footprint is small, it is more distorted (oblong) at the limb and ii) when the sampling rate is low, the area between samples will have to be represented by data from the previous sample in the output imagery.

A spatial resolution depends on the sensor design and is often inversely related to the size of the image footprint. Sensors with very large footprints tend to have low spatial resolution, and sensors with very high spatial resolution tend to have small footprints. Spatial resolution will determine whether individual houses can be distinguished in a scene and to what degree detailed features of the house or damage to the house can be seen. For imaging satellites of potential interest to the housing inspection program, spatial resolution varies from tens of kilometers per pixel to sub-meter. Spatial resolution is closely tied to Ground Sample Distance (GSD) which is the nominal dimension of a single side of a square pixel in ground units.

Figure 8.1 "A Push-Broom" Scanner showing an imaging system commonly used in optical remote sensing satellites. It has a linear detector array consisting of a number of detector elements; each projects an "instantaneous field of view (IFOV)" on the ground, records signal proportional to the total radiation collected within its IFOV. At any instant, a row of pixels are formed which sweeps along to generate a two-dimensional image.

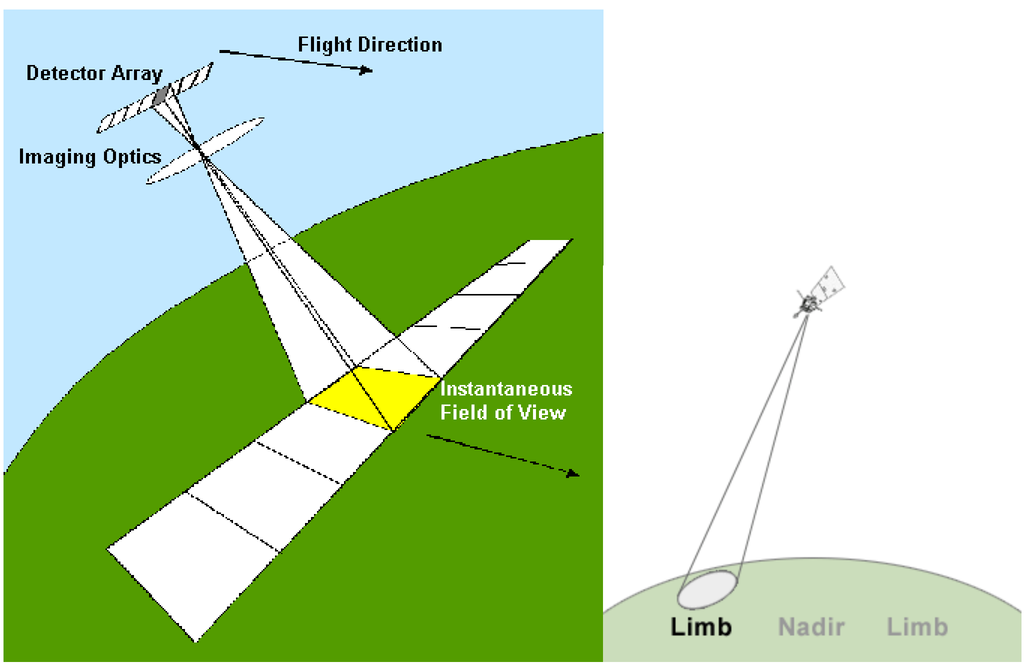


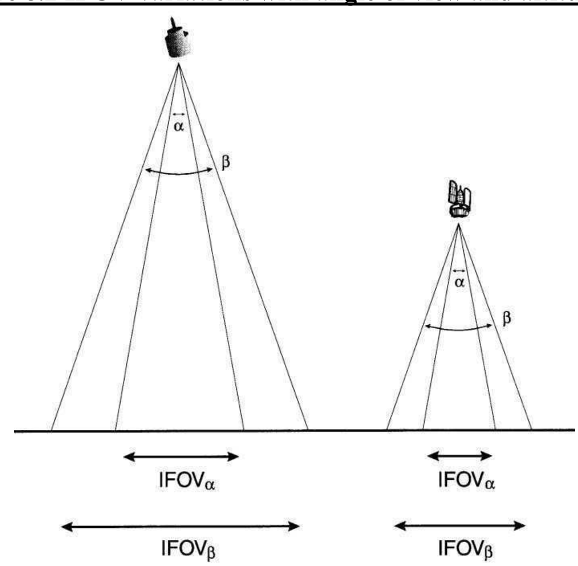
Figure 8.1a: Distortion of image at Limb

Space-borne and airborne measurements quantify the geodetic location of the energy received by projecting the antenna's FWHM footprint on to the Earth's surface. The 3-dB footprints can project a circle or more often an ellipse. For a conical scanner, the major and minor axis of the elliptical footprint stays consistent across the scan, but the cross-track scanner will have the cross-track axis (vs. the along or down track axis) increase as the scan angle increases. Therefore, the cross track has very unequal spatial resolution across the scan. Even though the cross track scanner might have a larger swath width, the utility of the most oblique measurements is limited due to the increased spatial resolution. Most modern instruments collect data as the system is integrating, which effectively smears the antenna pattern in the scan direction for both cross-track and conical scanners. The nomenclature calls the FWHM beam width as the Instantaneous Field of View (IFOV). The Effective Field of View (EFOV) is the resulting spatial resolution of the smeared antenna pattern, which is also defined as the effective beam width as the angle subtended between the effective antenna pattern's half power points.

A new antenna pattern can be comprised of measurements already taken. By summing weighted nearby measurements, which effectively makes a composite antenna pattern out of the original antenna patterns, a new antenna pattern can be formed. This is often termed the Composite Field of View (CFOV). One technique is called the Backus–Gilbert technique that minimizes a cost function between trying to fit the new composite antenna pattern to a target antenna pattern or reducing the instrument noise through increased averaging.

A narrow viewing angle produces a smaller IFOV as shown in Figure 8.2. It can be seen that viewing angle β being greater than the viewing angle α, IFOVβ is greater than IFOVα. IFOV also increases with altitude of the sensor as shown in Figure 8.2. IFOVβ and IFOVα of the sensor at smaller altitude are less compared to those of the higher altitude sensor.

Figure 8.2 IFOV variations with angle of view and altitude of the sensor



The size of the area viewed on the ground can be obtained by multiplying the IFOV (in radians) by the distance from the ground to the sensor. This area on the ground is called the ground resolution or ground resolution cell. It is also referred as the spatial resolution of the remote sensing system.

For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If more than one feature is present within the IFOV or ground resolution cell, the signal response recorded includes a mixture of the signals from all the features. When the average brightness of all features in that resolution cell is recorded, any one particular feature among them may not be detectable. However, smaller features may sometimes be detectable if their reflectance dominates within a particular resolution cell allowing sub-pixel or resolution cell detection.

8.3.3.1.1 Spatial Resolution and Pixel Size

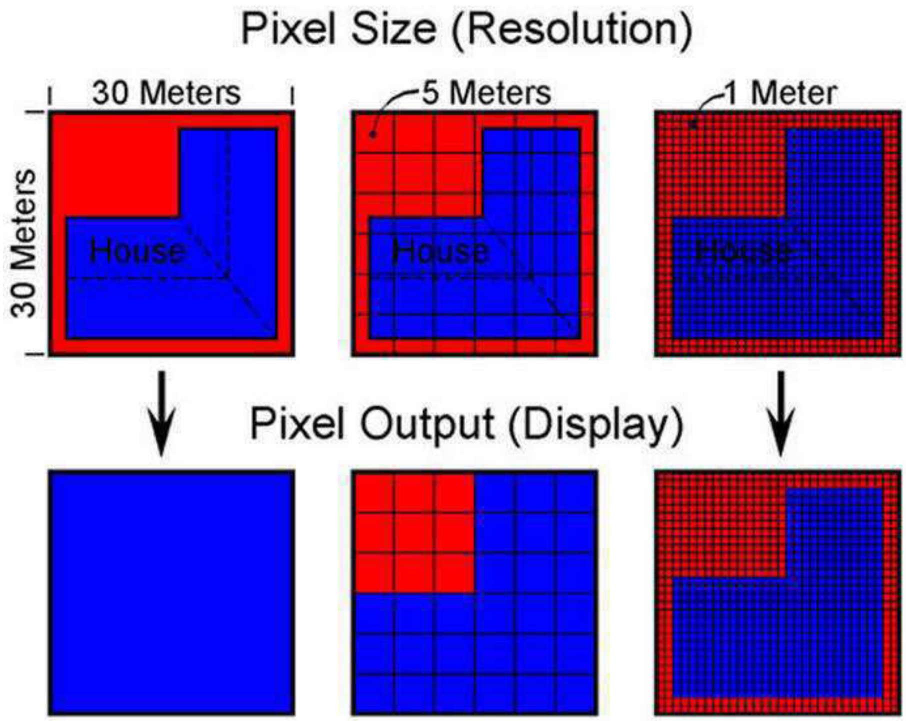
A digital image consists of an array of pixels. Each pixel contains information about a small area on the land surface, which is considered as a single object. Spatial resolution is a measure of the area or size of the smallest dimension on the Earth's surface over which an independent measurement can be made by the sensor. It is expressed by the size of the pixel on the ground in meters. Figure 8.3 shows the examples of coarse and fine resolution images.

A measure of size of pixel is given by the Instantaneous Field of View (IFOV). The IFOV is the angular cone of visibility of the sensor, or the area on the Earth's surface that is seen at one particular moment of time. IFOV is dependent on the altitude of the sensor above the ground level and the viewing angle of the sensor.

Figure 8. 3 Examples of a coarse and fine resolution images

Figure 8.4 gives an example of how the identification of a feature (a house in this case) varies with spatial resolution. In the example, for the 30m resolution image, the signature from the "house" dominates for the cell and hence the entire cell is classified as "house". On the other hand, in the fine resolution images, the shape and the spatial extent of the feature is better captured. In the 5m resolution image, along the boundary of the feature, some of the cells that are partially covered under the feature are classified as "house" based on the dominance of the signals from the feature. In the very fine resolution image, the feature shape and the spatial extent is more precisely identified.

Figure 8.4 Schematic representation of feature identification at different spatial resolutions



(Source: http://www.satimagingcorp.com/)

The image resolution and pixel size are often used interchangeably. In reality, they are not equivalent. An image sampled at a small pixel size does not necessarily have a high resolution. The following three images (Figure 8.5) illustrate this point. The first image is a SPOT image of 10 m pixel size. It was derived by merging a SPOT panchromatic image of 10 m resolution with a SPOT multispectral image of 20 m resolution. The merging procedure "colours" the panchromtic image using the colours derived from the multispectral image. The effective resolution is thus determined by the resolution of the panchromatic image, which is 10 m. This image is further processed to degrade the resolution while maintaining the same pixel size. The next two images are the blurred versions of the image with larger resolution size, but still digitized at the same pixel size of 10 m. Even though they have the same pixel size as the first image, they do not have the same resolution.

Figure 8.5 An illustration of different spatial resolution for same pixel size

10 m resolution, 10 m pixel size | 30 m resolution, 10 m pixel size | 80 m resolution, 10 m pixel size

8.3.3.1.2 Influence of spatial resolution in different field of Applications

Spatial resolution plays an important role for a certain number of applications, in particular those related to the characterization of complex environments, such as dense urban zones, or to the detection and the recognition of small targets. Low resolution sensors are well adapted to the observation of phenomena at a large scale since they operate in large spatial coverage modes, but such sensors are not adapted to the refined characterization of urban environments that appear as compact zones, with strong reflectivity. This type of image is not well adapted to small target detection for which the response inside a resolution cell is dominated by the ambient clutter. The improvement in resolution allows us to retrieve a large number of characteristic details of certain types of scattering mechanisms (layover, shadowing) and is generally accompanied by a singular increase of the complexity of the images. Very high resolution data allows us to foresee an important quantity of new applications, such as the characterization of very small vegetal zones in urban environments, and the inspection of structures and buildings that was not possible in the past.

Spatial resolution is often expressed in terms of CTF (contrast transfer function) which gives the contrast versus the frequency, in terms of line pairs per mm. One can also have a more intuitive idea with the resolving power, which can be defined as the minimum distance for which two radioactive sources can be resolved. Based on the spatial resolution, satellite systems can be classified as follows.

- Low resolution systems
- Medium resolution systems
- High resolution systems
- Very high resolution systems

Remote sensing systems with spatial resolution more than 1km are generally considered as low resolution systems. MODIS and AVHRR are some of the very low resolution sensors used in the satellite remote sensing. When the spatial resolution is 100m – 1km, such systems are considered as moderate resolution systems. IRS WiFS (188m), band 6 i.e., thermal infrared band, of the Landsat TM (120m), and bands 1-7 of MODIS having resolution 250-500m come under this class. Remote sensing systems with spatial resolution approximately in the range 5-100m are classified as high resolution systems. Landsat ETM+ (30m), IRS LISS-III (23m MSS and 6m Panchromatic) and A WiFS (56-70m), SPOT 5(2.5-5m Panchromatic) are some of the high resolution sensors. Very high resolution systems are those which provide less than 5m spatial resolution. Geo Eye (0.45m for Panchromatic and 1.65m for MSS), IKONOS (0.8-1m Panchromatic), and Quick bird (2.4-2.8 m) are examples of very high resolution systems.

The ratio of distance on an image or map, to actual ground distance is referred to as scale. If we have a map with a scale of 1:100,000, an object of 1cm length on the map would actually be an object 100,000cm (1km) long on the ground. Maps or images with small "map-to-ground ratios" are referred to as small scale (e.g. 1:100,000), and those with larger ratios (e.g. 1:5,000) are called large scale. Thus, large scale maps/images provide finer spatial resolution compared to small scale maps/images.

8.3.3.1.3 Methodical considerations and limitations

The spatial resolution of an imaging sensor determines the size of the smallest object it can image coherently. The ability of a sensor to image individual components of the built environment depends not only on its spatial resolution but also on the characteristic scale of the individual objects. This characteristic scale varies both within and among built environments worldwide but is generally considered to be on the order of 10 m. As the scale of the sensor's instantaneous field of view (IFOV) approaches the characteristic scale of the LC units, the spatial coherence of the image changes considerably.

Spatial resolution refers to the size of the smallest object that can be resolved on the ground. In a digital image, the resolution is limited by the pixel size, i.e. the smallest resolvable object cannot be smaller than the pixel size. The intrinsic resolution of an imaging system is determined primarily by the instantaneous field of view (IFOV) of the sensor, which is a measure of the ground area viewed by a single detector element in a given instant in time. However this intrinsic resolution can often be degraded by other factors which introduce blurring of the image, such as improper focusing, atmospheric scattering and target motion. The pixel size is determined by the sampling distance.

A "High Resolution" image refers to one with a small resolution size. Fine details can be seen in a high resolution image. On the other hand, a "Low Resolution" image is one with a large resolution size, i.e. only coarse features can be observed in the image.

Depending on the specific application and the scale of analysis, individual objects may be resolved into sub-elements or aggregated into larger structures. For many mapping and monitoring applications, it is sufficient to distinguish the aggregate response of a built environment from its surroundings or to identify internal variations in physical properties from aggregate response at the scale of the sensor's IFOV. In these cases, it is often sufficient to resolve the sub-pixel response of the instrument using approaches like spectral un-mixing. To avoid confusion resulting from subjective terms like high, medium, and low, we specify spatial resolution scales explicitly using the metric prefixes sub meter ($\lambda < 1.0$ m), meter ($1.0 \leq \lambda < 10$ m), decameter ($10 \leq \lambda < 100$ m), hectometer ($100 \leq \lambda < 1000$ m), and kilometer ($1.0 \leq \lambda < 10$ km).

8.3.3.2 Satellite Sensor resolution

Spatial resolution is the measure of smallest object that can be detected by a satellite sensor. It represents area covered by a pixel on the ground. Mostly, it is measured in meters. For example, CARTOSAT-1 sensor has a spatial resolution of 2.5x2.5 m , IRS P6 LISS IV sensor has a spatial resolution of 5.6x5.6 m for its multispectral bands and LISS III has spatial resolution of 23.5x23.5 m in its first three bands. The smaller the spatial resolution, the greater the resolving power of the sensor system.

That's why one can detect even a car in the satellite image acquired by IKONOS (spatial resolution 1x1 m) but can see hardly even a village in a satellite image acquired by AVHRR (spatial resolution 1.1x1.1 km).

8.3.3.3 Spectral resolution

Spectral Resolution highlights the following in the remote sensing data:

- Number of spectral bands (red, green, blue, NIR, Mid-IR, thermal, etc.)
- Width of each band.
- Certain spectral bands (or combinations) are good for identifying specific ground features
- Panchromatic – 1 band (B&W)
- Color – 3 bands (RGB)
- Multispectral – 4+ bands (e.g. RGBNIR)
- Hyperspectral – hundreds of bands

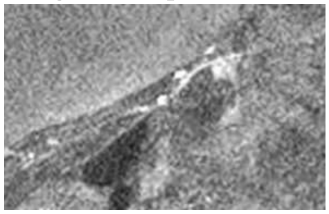
Many remote sensing systems are multi-spectral, that record energy over separate wavelength ranges at various spectral resolutions. For example IRS LISS-III uses 4 bands: 0.52-0.59 (green), 0.62-0.68 (red), 0.77-0.86 (near IR) and 1.55-1.70 (mid-IR). The Aqua/Terra MODIS instruments use 36 spectral bands, including three in the visible spectrum. Recent development is the hyper-spectral sensors, which detect hundreds of very narrow spectral bands. Figure 5 shows the hypothetical representation of remote sensing systems with different spectral resolution. The first representation shows the DN values obtained over 9 pixels using imagery captured in a single band. Similarly, the second and third representations depict the DN values obtained in 3 and 6 bands using the respective sensors. If the area imaged is say *A* km2, the same area is being viewed using 1, 3 and 6 number of bands. Generally surface features can be better distinguished from multiple narrow bands, than from a single wide band.

Spectral resolution describes the way an optical sensor responds to various wavelengths of light. High spectral resolution means that the sensor distinguishes between very narrow bands of wavelength; a "hyperspectral" sensor can discern and distinguish between many shades of a color, recording up to 256 degrees of color across the infrared, visible, and ultraviolet wavelengths. Low spectral resolution means the sensor records the energy in a wide band of wavelengths as a single measurement; the most common "multispectral" sensors divide the electromagnetic spectrum from infrared to visible wavelengths into four generalized bands: infrared, red, green, and blue. The way a particular object or surface reflects incoming light can be characterized as a spectral signature and can be used to classify objects or surfaces within a remotely sensed scene. For example, an asphalt parking lot, a cornfield, and a stand of pine trees will have all have different spectral signatures. Automated techniques can be used to separate various types of objects within a scene.

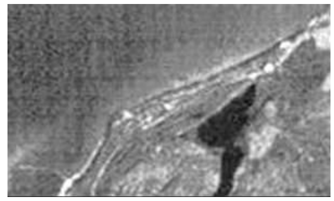
Many sensor systems have a panchromatic band, which is one single wide band in the visible spectrum, and multispectral bands in the visible-near-IR or thermal-IR spectrum as shown in the previous chapters. Hyperspectral systems usually have hundreds of spectral narrow bands; for example, Hyperion on EO-1 satellite has 220 bands at 30-m spatial resolution. Spectral resolution refers the number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote sensing instrument is sensitive. For example, band 1 of the Landsat TM sensor records energy between 0.45 and 0.52 µm in the visible part of the spectrum.The spectral channels containing wide intervals in the electromagnetic spectrum are referred to as coarse spectral resolution and narrow intervals are referred to as fine spectral resolution. For instance the SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51 and 0.73 µm. on the other hand; band 2 of the ASTER sensor has fine spectral resolution because it records EMR between 0.63 and 0.69 µm.

In remote sensing, different features are identified from the image by comparing their responses over different distinct spectral bands. Broad classes, such as water and vegetation, can be easily separated using very broad wavelength ranges like visible and near-infrared. However, for more specific classes viz., vegetation type, rock classification etc, much finer wavelength ranges and hence finer spectral resolution are required. For example, Figure 8.6 shows the difference in the spectral responses of an area in different bands of the Landsat TM image.

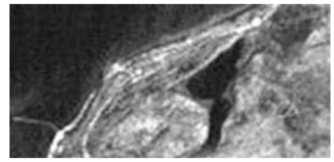
Figure 8.6 Spectral band characteristics of Landsat TM - 7 bands for the same area



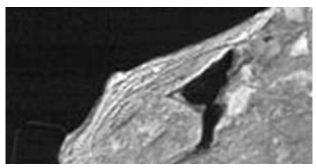
TM Band 1- 0.45-0.52 µm (Blue)



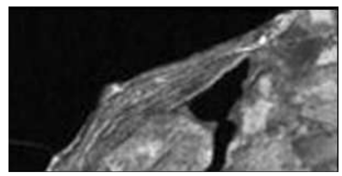
TM Band 2- 0.52-0.60 µm (Green)



TM Band 3- 0.63-0.69 µm (Red)

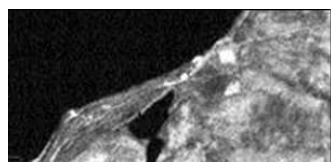


TM Band 4- 0.76-0.90 µm (NIR)



TM Band 5- 1.55-1.75 µm (MIR)

TM Band 6- 10.4-12.5 µm (TIR)



TM Band 7- 2.08-2.35 µm (MIR)

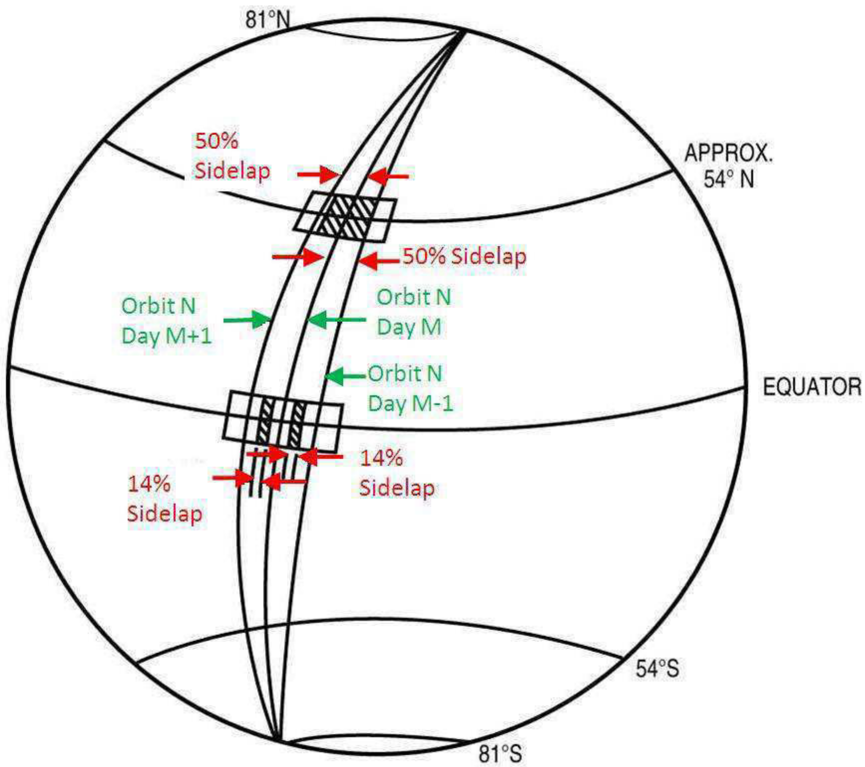
8.3.3.4 Temporal Resolution

The temporal resolution is characterized on the basis of following lines:

- Temporal resolution is a description of how often a sensor can obtain imagery of a particular area of interest. For example, the Landsat satellite revisits an area every 16 days as it orbits the Earth, while the SPOT satellite can image an area every 1 to 4 days.
- Temporal resolution describes the number of times an object is sampled or how often data are obtained for the same area .The absolute temporal resolution of a remote sensing system to image the same area at the same viewing angle a second time is equal to the repeat cycle of a satellite.
- The repeat cycle of a near polar orbiting satellite is usually several days, eg., for IRS-1C and Resourcesat-2 it is 24 days, and for Landsat it is 18 days. However due to the off-nadir viewing capabilities of the sensors and the side lap of the satellite swaths in the adjacent orbits the actual revisit period is in general less than the repeat cycle.
- The actual temporal resolution of a sensor therefore depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude.

- Because of some degree of overlap in the imaging swaths of the adjacent orbits, more frequent imaging of some of the areas is possible. Figure 8.7 shows the schematic of the image swath side lap in a typical near polar orbital satellite.

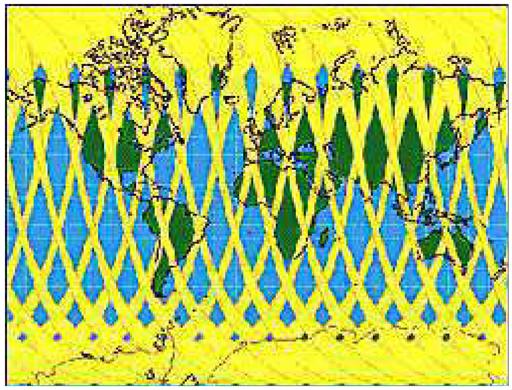
Figure 8.7 Sidelap in a typical near polar satellite orbit



(Source: http://eros.usgs.gov/)

From Figure 8.8 it can be seen that the sidelap increases with latitude. Towards the polar region, satellite orbits come closer to each other compared to the equatorial regions. Therefore, for the polar region, the sidelap is more and as a result more frequent images are available. Figure 4.8 shows the path of a typical near-polar satellite.

Figure 8.8 Orbit of a typical near-polar satellite



(Source: http://www.nrcan.gc.ca/earth-sciences)

In addition to the side lap, more frequent imaging of any particular area of interest is achieved in some of the satellites by pointing their sensors to image the area of interest between different satellite passes. This is referred as the off-nadir viewing capability like IKONOS.
Images of the same area of the Earth's surface at different periods of time show the variation in the spectral characteristics of different features or areas over time. Such multi-temporal data is essential for the following studies:

• Land use/ land cover classification and change detection.
• Temporal variation in land use / land cover
• Monitoring of a dynamic event like
– Cyclone
– Flood
– Volcano
– Earthquake

The details of applications of temporal resolution are described in change detection stidies.

8.3.3.5 Radiometric resolution

Radiometric Resolution highlights the following:

- Every time an image is acquired by a sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution.
- The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.
- Imagery data are represented by positive digital numbers which vary from 0 to a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2.

Radiometric resolution represents the sensitivity of a remote sensing detector to differentiate in signal strength as it records the radiant flux reflected or emitted from the terrain. It refers to the dynamic range, or number of possible data-file values in each band. This is referred to by the number of bits into which the recorded energy is divided. For instance, ASTER records data in 8-bit for its first nine bands, it means the data file values range from 0 to 255 for each pixel, while the radiometric resolution of LISS III is 7-bit, here the data file values for each pixel ranges from 0 to 128.

As such the radiometric resolution is measured in bits where each bit records an exponent of power 2 (e.g. 1 bit = 21 = 2). The maximum number of brightness levels available depends on the number of bits used in representing the recorded energy. For example, Table 8.1 shows the radiometric resolution and the corresponding brightness levels/values available.

Table 8.1 Radiometric resolution and corresponding brightness levels

Radiometric resolution	Number of levels	Example-Remote sensing platforms and sensors
1bit	2^1-2 levels	None
7 bit	2^7-128 levels	IRS-1A & 1 B, LISS-2
8 bit	2^8- 256 levels	Landsat TM, IRS-1C & 1D
11 bit	2^{11}-2048 levels	NOAA-AVHRR

Thus, if a sensor used 11 bits to record the data, there would be 211=2048 digital values available,
ranging from 0 to 2047. However, if only 8 bits were used, then only 28=256 values ranging from 0 to 255 would be available. Thus, the radiometric resolution would be much less.

Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data). By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions. In an 8 bit system, black is measured as 0 and white is measured as 255. The variation between black to white is scaled into 256 classes ranging from 0 to 255. Similarly, 2048 levels are used in an 11 bit system. Finer the radiometric resolution, more the number of grey levels that the system can record and hence more details can be captured in the image. Figure 8.9 shows the comparison of a 2-bit image (coarse resolution) with an 8-bit image (fine resolution), from which a large difference in the level of details is apparent depending on their radiometric resolutions. As radiometric resolution increases, the degree of details and precision available will also increase. However, increased radiometric resolution may increase the data storage requirements.

Figure 8.9 Comparison of coarse resolution 2 bit image with a fine resolution 8 bit image

2 bit data-coarse resolution 8 bit data-fine resolution

The intrinsic radiometric resolution of a sensing system depends on the signal to noise ratio of the detector. In a digital image, the radiometric resolution is limited by the number of discrete quantization levels used to digitize the continuous intensity value. In 8-bit data, the digital numbers (DN) can range from 0 to 255 for each pixel ($2^8 = 256$ total possible numbers). Obviously more bits results in higher radiometric accuracy of the sensor, as shown in Figure 8.10.

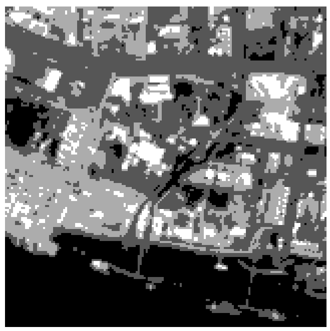
The following images illustrate the effects of the number of quantization levels on the digital image. The first image is a SPOT panchromatic image quantized at 8 bits (i.e. 256 levels) per pixel. The subsequent images show the effects of degrading the radiometric resolution by using fewer quantization levels.

Figure 8.10 Effects of the number of quantization levels on the digital image.

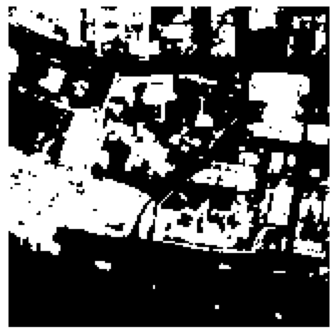
	
8-bit quantization (256 levels)	6-bit quantization (64 levels)

4-bit quantization (16 levels)

3-bit quantization (8 levels)



2-bit quantization (4 levels)



1-bit quantization (2 levels)

Therefore when two images are to be compared, they must be of same radiometric resolution.

8.3.4 Radiometric resolution and classification accuracy

The key findings indicate the low impact of radiometric resolution in classification accuracy. In the case of texture classification, the different experiments also indicated differences in classification accuracies up to 7% except from one case. In object-based classification of the multi-seasonal spectral indices, classification accuracy difference between higher and lower radiometric resolution datasets were much lower (1%) compared to pixel-based experiments. Higher radiometric resolution did not appear to have a significant effect on BCT classification times, except for the object-based approach.

The research suggests some hints on selecting or modifying radiometric resolution for certain classification tasks, as it provides indications that lower radiometric resolution is not always at the expense of classification accuracy.

The potential benefits of higher radiometry of satellite data have only been partially examined in literature. The first studies conducted on the effect of radiometric resolution on image information were focused on the comparison of 8-bit data from the Thematic Mapper (TM) sensor with 6-bit data from the multispectral scanner system (MSS) sensor, of the Landsat-4 satellite. The relationship between radiometric resolution and the ability to distinguish vegetation in 256-level (8 bits) TM and 64-level (6 bits) MSS images was studied. The study came to the conclusion that there was an overall improvement of only 2–3% in the TM image. The effect of radiometric resolution of actual and degraded TM data, on pixel- based maximum likelihood classification was examined, while keeping constant spatial and spectral resolution. The study found increases of overall accuracies up to 8% in the 8-bit data over the degraded 6-bit data.

The emergence of hyper-spectral imagery led to studies which compared hyperspectral data of higher radiometric resolution with artificially simulated data of same-type sensors, by degrading their radiometric resolution. The results indicated that images with higher radiometry had an improved accuracy of 0.8–6%.

In a study devoted entirely to radiometric resolution, it was also found that overall classification accuracy of higher radiometry data over an agricultural area, increased by only 3%. In a similar study, it was demonstrated that using 12-bit instead of 7-bit data for Leaf Area Index (LAI) computation using the Normalized Difference Vegetation Index (NDVI), had a marginal increase in the accuracy (1–2%).

Adopting a different approach, the percentage of green coverage resulting from data of different radiometric resolutions was compared over the same study area, demonstrating that the 12-bit EO-1 ALI data had a standard deviation of an estimated green percentage slightly lower (±5.61%) from the 8-bit ETM+ data (±6.15%). Finally, using a different approach, the impact of radiometric resolution was investigated on multispectral video cameras, using laboratory reference data, coming from a spectral radiometer. The video camera with the higher radiometric resolution showed a slight improvement in accuracy.
The spatial, temporal and radiometric resolution impact by comparing NDVI-based classification results was also assessed. The researchers identified that, spectral resolution is more important than spatial or radiometric resolution to improve classification accuracy.

8.3.5 Trade-offs between spatial, spectral and radiometric resolutions

In remote sensing, energy recorded at the sensor depends on the spatial and spectral resolution of the sensor. Radiometric resolution of the sensor varies with the amount of energy received at the sensor. Fine spatial resolution requires a small IFOV. Smaller the IFOV, smaller would be the area of the ground resolution cell and hence less energy is received from that area. When the energy received is less, lesser would be the ability of the sensor to detect the fine energy differences, thereby leading to poor radiometric resolution.

The data recorded on a sensor are composed of the signal (say reflectance) and noise (from aberrations in the electronics, moving parts or defects in the scanning system as they degrade over time). If the signal-to-noise ratio (SNR) is high, it becomes easy to differentiate the noise from the actual signals. SNR depends on strength of signal available and the noise of the system.

Increasing the spectral and spatial resolution reduces the energy received or the strength of the signal. Consequently, the SNR decreases. Also, finer radiometric resolution results in larger number of grey levels and if the difference in the energy level between the two levels is less than the noise, reliability of the recorded grey level diminishes.

Use of narrow spectral bands increases the spectral resolution, whereas it reduces the energy received at the sensor in the particular band. A wider band increases the reflected energy. To increase the amount of energy received and hence to improve the radiometric resolution without reducing the spatial resolution, broader wavelength band can be used. However, this would reduce the spectral resolution of the sensor.

Thus, there are trade-offs between spatial, spectral, and radiometric resolution. These three types of resolution must be balanced against the desired capabilities and objectives of the sensor. Thus, finer spatial, spectral and radiometric resolutions of a system may decrease the SNR to such an extent that the data may not be reliable.

8.4 SUMMARY

In remote sensing, the term resolution is used to represent the resolving power, which includes not only the capability to identify the presence of two objects, but also their properties. Improved sensor characteristics with respect to spatial, spectral, temporal and radiometric resolution are generally assumed to increase the potential accuracy of image classification and information extraction from remote sensing imagery. But, as the resolution increases, the complexity of data also increases and in order to fully exploit the potential of the new generation of remote sensing computers and sensors, a number of challenges need to be addressed. Improvement of resolution also results in high data volumes and storage issues.

Spatial resolution of a sensor defines the clarity of an image, not the number of pixels in an image, and thus helps to identify the smallest object on an image. For remote sensing instruments, the distance between the sensor and the target plays a large role in the amount and quality of data produced. Also, due to the factors consisting of instantaneous field of view, nadir and limb, the spatial resolution will vary from image center to the edge of the swath. A spatial resolution depends on the sensor design and is often inversely related to the size of the image footprint.

Low resolution sensors are well adapted to the observation of phenomena at a large scale since they operate in large spatial coverage modes. The improvement in resolution allows us to retrieve a large number of characteristic details of certain types of scattering mechanisms (layover, shadowing) and is generally accompanied by a singular increase of the complexity of the images. Very high resolution data allows us to foresee an important quantity of new applications, such as the characterization of very small vegetal zones in urban environments, and the inspection of structures and buildings that was not possible in the past.

Spectral Resolution highlights the number of spectral bands and Width of each band. Different features are identified from the image by comparing their responses over different distinct spectral bands. Broad classes, such as water and vegetation, can be easily separated using very broad wavelength ranges like visible and near-infrared. For more specific classes viz., vegetation type, rock classification etc, much finer wavelength ranges and hence finer spectral resolution are required. Images of the same area of the Earth's surface at different periods of time show the variation in the spectral characteristics of different features or areas over time. Such multi-temporal data is essential for studying land use /land cover classes and changes over the period.

Radiometric resolution represents the sensitivity of a remote sensing detector to differentiate in signal strength as it records the radiant flux reflected or emitted from the terrain. Radiometric resolution has also witnessed some major improvements along the course of remote sensing evolution. While the first optical satellite systems that were developed used sensors with a 6-bit radiometric resolution (Landsat multispectral scanner sensors), over the years, along with the development of technology, radiometry of sensors also improved, resulting in products of up to 14 bits (KOMPSAT 3 satellite sensor). In most of the studies, the key findings indicate the low impact of radiometric resolution in classification accuracy.

8.5 GLOSSARY

- **EFOV** - Effective Field of View
- **CFOV** - Composite Field of View
- **FWHM** - Full Width Half Maxima (Antina foot prints -beam width as the Instantaneous Field of View-IFOV)
- **CTF** - Contrast Transfer Function
- **SNR** **-** Signal-to-Noise Ratio
- **SWIR** - Short Wave Infra-Red
- **EOSDIS** - Earth Observing System Data and Information System

8.6 ANSWER TO CHECK PROGRESS

Q1- Define types of resolution?
Q2- Define types of resolution?
Q3- Define Characteristics of resolution?
Q4- Define Radiometric Resolution?
Q5- Define Classification Accuracy?

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8.8 TERMINAL QUESTIONS

1-Define resolution and resolution types.
2-Elaborate the concept of Instantaneous Field of View (IFOV) for spatial resolution.
3-Highlight the Influence of spatial resolution in different field of Applications.
4-Describe the spectral characteristics of different types of remote sensing data.
5-How temporal resolution is useful in the field of remote sensing? Write the characteristics of polar sun-synchronous satellite orbit pass and sidelap.
6-Describe radiometric resolution and explain its impact on classification accuracy of remote sensing data.
7-Highlight the points of trade - offs between spatial, spectral and radiometric resolution.

UNIT 9 – ELEMENTS OF IMAGE INERPRETATION

9.1 OBJECTIVES

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

- Satellite remote sensing instrument types
- Remote Sensing data interpretation concept, definition and principles
- Criterion of image interpretation and ground truth collection
- Image elements
- Types and methods of Remote sensing data interpretation

9.2 INTRODUCTION

The previous chapters (units) have provided you the opportunity to study the basics of remote sensing, electromagnetic radiation, platforms, sensors and the characteristics of resolution types, Aerial Photography. Such inputs will certainly be helpful to learn the description of contents of this unit. Remote sensing data interpretation is one of the most commonly used techniques for mapping and analysis of earth resources. To meet the data requirement of development planning, one may adopt either the conventional methods of ground surveys or use advanced and sophisticated techniques of remote sensing. It should always be kept in mind that remote sensing cannot replace the ground survey work, but with the help of remote sensing, combined with limited ground checks, desired information can be extracted accurately for mapping of existing varieties of earth resources at a particular period of time for their planning, development, management and conservation. It depends upon the purpose of the resource manager, as to what amount of information is required by him? Information obtained using remote sensing techniques can help the resource manager to prepare resource map accurately in lesser time and cost effective manner.

In India, National Remote Sensing Centre (NRSC) has used 1:1 million scale satellite images for assessing forest/vegetation cover in the country during the year 1983. Prior to this Forest Survey of India (FSI) used small to medium scale satellite images for research and developmental work in the field of forestry. Later on, a lot of studies have been undertaken at Indian Institute of Remote Sensing (IIRS), Space Application Centre (SAC), National Remote Sensing Agency (NRSA) and other State Remote Sensing Application Centers, which demonstrate the application of satellite images (1:1 million scale to 1:50,000 scale) for structural analysis of vegetation at various levels and many of the other disciplines.

While interpreting remote sensing data the objects are distinguished by its characteristic inherent-properties or patterns, which are familiar on the images. It proceeds with the process of detection. Analysis is a process of resolving on separating objects or features having similar set of characteristics. In analysis lines of separation are drawn between groups of objects. Classification is a process of identification and grouping of objects or features i.e., vegetation structure groups resolved by analysis. It arranges 'features of recurrence' in the same structural class or group to which the feature belong. Deduction with regard to various vegetation structure groups should be made with proper pre-interpretation check in the field; otherwise it may be misleading and result in wrong classification. Idealization is a process of drawing ideal or standard representation from what is actually identified and interpreted from the image. This process helps in developing the image interpretation key. Producing images on a computer monitor has always been a prime concern of remote sensing. We use images for inspecting raw data and for performing various rectification and restoration tasks. Once data are corrected we convert them again to images and use these for information extraction by visual interpretation or to support digital image processing/classification. Many remote sensing applications make use of multispectral data; to visualize them we have to rely on colours. In this unit we are mainly focusing on visual interpretation in which FCC analogue (paper print) data is used. Stereoscopic interpretation of aerial photographs and the digital image interpretation/digital image processing is not being dealt in this unit. Therefore the topic of this unit is aimed at the following objectives:

9.3 ELEMENTS OF IMAGE INTERPRETATION

9.3.1 Satellite remote sensing instrument types

Satellite remote sensing involves gathering information about features on the Earth's surface from orbiting satellites. There are two types of remote sensing instruments—passive and active. Passive instruments detect natural energy that is reflected or emitted from the observed scene. Passive instruments sense only radiation emitted by the object being viewed or reflected by the object from a source other than the instrument. Reflected sunlight is the most common external source of radiation sensed by passive instruments.

9.3.1.1 Passive System

It generally consists of an array of small sensors or detectors, which records the amount of electro-magnetic radiation reflected and/or emitted from the Earth's surface. Thus, passive remote sensing relies on naturally reflected or emitted energy of the imaged surface. A multi-spectral scanner is an example of a passive system. Passive visible and near-infrared data are used in a variety of GIS applications, for example in the classification of vegetation and land-use, and may be performed at a variety of temporal and spatial scales. Following are the passive remote sensors.

9.3.1.2 Radiometer

An instrument that quantitatively measures the intensity of electromagnetic radiation in some band of wavelengths in the spectrum. Usually a radiometer is further identified by the portion of the spectrum it covers; for example, visible, infrared, or microwave.

9.3.1.2a Imaging Radiometer

A radiometer that includes a scanning capability to provide a two-dimensional array of pixels from which an image may be produced is called an imaging radiometer. Scanning can be performed mechanically or electronically by using an array of detectors.

9.3.1.2b Spectrometer

A device designed to detect, measure, and analyze the spectral content of the incident electromagnetic radiation is called a spectrometer. Conventional, imaging spectrometers use gratings or prisms to disperse the radiation for spectral discrimination.

9.3.1.2c Spectroradiometer

A radiometer that can measure the intensity of radiation in multiple wavelength bands (i.e., multispectral). Oftentimes the bands are of a high spectral resolution—designed for the remote sensing of specific parameters such as sea surface temperature, cloud characteristics, ocean color, vegetation, trace chemical species in the atmosphere, etc.

9.3.1.2 Active System

This type of a system propagates its own electro-magnetic radiation and measures the intensity of the return signal. Thus, active remote sensing means that the sensor provides its own illumination and measures what comes back. Remote sensing technologies that use this type of system include lidar (laser) and radar. Active instruments provide their own energy (electromagnetic radiation) to illuminate the object or scene they observe. They send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Following are active remote sensors.

Synthetic Aperture Radar (SAR) is an example of an active system. Active remote sensing (radar and lidar) systems are rapidly increasing in use since the launch of the ERS-1 Synthetic Aperture Radar (SAR) satellite in 1991. In comparison to visible/near-infrared imagery, radars are sensitive to very different surface properties.

As for example, radar images are sensitive to the shape, orientation and size of leaves and their moisture content, rather than the vegetation color. Similarly, airborne lidars have been largely used for mapping surface topography in three dimensions. Existing and planned radar and lidar altimeters will also help in monitoring closely the elevation of the world's ice caps and sea level with centimeter precision.

9.3.1.2.1 Radar (Radio Detection and Ranging)

Radar uses a transmitter operating at either radio or microwave frequencies to emit electromagnetic radiation and a directional antenna or receiver to measure the time of arrival of reflected or backscattered pulses of radiation from distant objects. Distance to the object can be determined since electromagnetic radiation propagates at the speed of light.

9.3.1.2.2 Scatterometer

A scatterometer is high frequency microwave radar designed specifically to measure backscattered radiation. Over ocean surfaces, measurements of backscattered radiation in the microwave spectral region can be used to derive maps of surface wind speed and direction.

9.3.1.2.3 Lidar (Light Detection and Ranging)

A lidar uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light. Distance to the object is determined by recording the time between the transmitted and backscattered pulses and using the speed of light to calculate the distance traveled. Lidars can determine atmospheric profiles of aerosols, clouds, and other constituents of the atmosphere.

9.3.1.2.4 Laser Altimeter

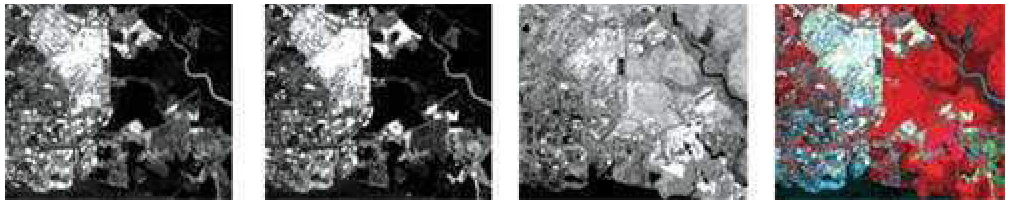
A laser altimeter uses a lidar (see above) to measure the height of the instrument platform above the surface. By independently knowing the height of the platform with respect to the mean Earth's surface, the topography of the underlying surface can be determined.

9.3.2 Remote sensing data interpretation

9.3.2.1 Preliminary concepts

Remote sensing technology includes both Satellite and aerial remote sensing. The basic source for this technology is electromagnetic radiation from the sun. It strikes to the earth surface, reflected/radiated back to atmosphere and recorded by the sensor of satellite orbiting the earth or the photographic film, in case of aerial remote sensing. The product from the aerial camera is called photograph and the term image is used for any pictorial representation of image data. The reflectance/remittance/absorption of energy by an object forms the base for the brightness or darkness in an image or photographs. This is further interpreted for the identification of the features. The earlier stage aerial and satellite data were in black & white and subsequent advancement in sensor development and colour film leads the generation of colour photographs and images. The significant advance in sensor technology stemmed from subdividing spectral ranges of electromagnetic radiation into several bands allowing sensors in several bands to form multispectral images In general there are three different types of data products namely black and white photograph or panchromatic image (single band), normal colour and false colour composite (Multispectral). Single band image displays as a gray scale but combination of three bands at a time generates colour composite images (Figure 9.1).

Figure 9.1 Combination of 3 bands generates colour composite images



Green band (1)	Red band (2)	Near IR band (3)	False colour Composite (123)

Source:www.sci-ctr.edu.sg/ssc/publication/remotesense/opt_int.html

9.3.2.1a Remote sensing data Procurement Facilities

Before taking the task of remote sensing data interpretation you should have the idea of availability of remote sensing data particularly in your own country. National Remote Sensing Centre (NRSC), Hyderabad has the mandate for establishment of ground stations for receiving satellite data, generation of data products, dissemination to the users, and development of techniques for remote sensing applications including disaster management support, geospatial services for good governance and capacity building for professionals, faculty and students. NRSC is the only organization under ISRO, Department of Space for remote sensing data procurement.

ISRO has a vibrant Indian Remote Sensing program since 1988 with a gamut of Indian Remote Sensing Missions (IRS) observing Earth with Optical, microwave and hyper-spectral instruments flown on-board to provide necessary data in various spatial, spectral and temporal resolutions to cater to different user requirements in the country and for global usage.

NRSC is the nodal centre for hosting Satellite Data Products from more than 13 IRS satellites right from the first IRS optical mission namely IRS-1A and SAR imaging missions. Satellites are primarily tasked to cover India and surroundings in a programmatic manner or on-demand as required by user as per mission capability. NRSC also acquires and archives data of global regions for disasters, calibrations and specific studies. Near real time data products from IRS weather wensors is delivered for climate and weather models for a global coverage. Georeferenced, Orthokit, Orthorectified products are provided in standard formats like Geotiff, HDF. Customized value added products are generated based on the requirements from the user for large AOI.

NRSC Data archive is extensively utilized for Land use land cover monitoring, Ocean studies, weather applications and scientific research. The Government agencies, industries and academia is highly benefiting by the valuable huge data products archive and technology to meet their respective end objectives.

In addition to above information you should know the following before data interpretation as the basic idea of interpretation is related to tonal variability or spectral characteristics of objects/cover types:

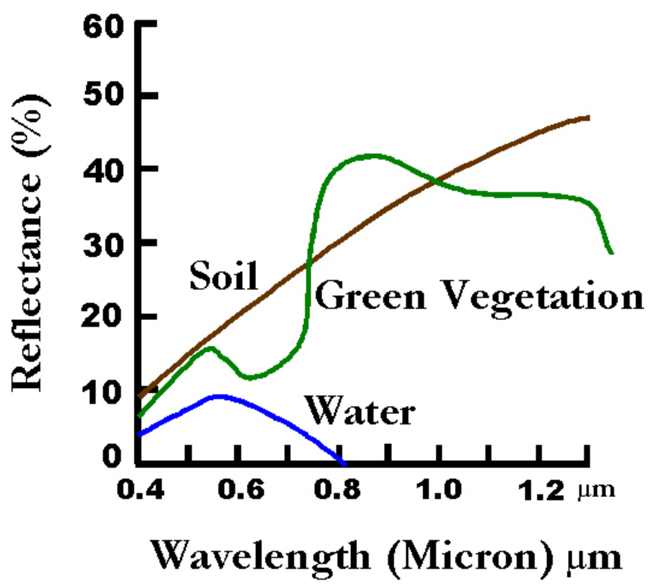
9.3.2.1b Infrared imagery: Healthy vegetation reflects Infrared radiation much stronger than green energy and appears very bright in the image. A simple example is the appearance of light tone by vegetation species, white to dull white tone of soil, and dark tone by water. The spectral curve (Figure 9.2) represents the proof of this. Figure 1 is also showing higher reflectance in the form of shades of red colour/tone. But in thermal infrared images the brightness tone represents warmest temperature and darkness represent coolest temperature. The image (Figure 9.2) illustrates day time and night time thermal data. The changes in kinetic water temperature cause for the tonal changes. Hence time is also to be taken consideration before interpretation.

9.3.2.1c Radar Imagery: Smooth surfaces reflect high and area blocked from radar signal appear dark. Bridges and cities show very bright tone, on the contrary calm water, pavement and dry lake beds appear in a very dark tone. Careful examination needs to identify the features in the imagery combined with field information.

9.3.2.2Preliminary aids for data interpretation

9.3.2.2a Study area: This is helpful in building the mental image of the vegetation or other features likely to occur in that area. It is better to acquire ancillary data/information either through literature or ground reconnaissance survey before initiating interpretation.

Figure 9.2 Spectral curves highlighting the strong reflectance (tone) of green vegetation, soil and water



9.3.2.2b spatial resolution: Spatial resolution is important to visualize the details of features depicted on satellite data. This is the first preliminary information giving us the idea of details of information to be collected and the quality of the data.

9.3.2.2c Season: Date of acquisition is important to get an idea about the phenological status of the vegetation. Phenological types like evergreen, deciduous, semi evergreen etc. are easily recognizable on satellite data of proper season. Similar is the case of season for agriculture and other cover types. Selection of proper season highlights a specific spectral characteristic of the said types for their identification.

9.3.2.2d Physiography: It is important to remember that vegetation often has close relationship with physiography. While interpreting the data it is advisable to interpret the land units in different physiographic units like, plateau, gentle slopes, flood plains, piedmont zone etc. Physiographic involvement generally intermix the pictorial /image elements of cover types and as a result an interpreter tend to commit mistake of wrong interpretation. Reconnaissance field visit before preliminary interpretation, ground truth collection during final interpretation and again field verification after finishing the interpretation is most essential to overcome such mistakes and the mistakes due to many other reasons like season, time of day, soil, soil moisture, rocks etc. The following aids are equally important for good interpretation.

9.3.2.2e Topographical map: Topographical maps are required to i) correct the satellite images geometrically (computerized geometric correction of satellite data-it will be explained in the coming units) ii) collect ground truths iii) use as reference material for interpretation and iv) improve the quality of interpretation.

9.3.2.2f Existing preliminary map of the discipline selected for interpretation: These are either fresh or old maps prepared by using conventional ground survey methods in conjunction with topographical map. We need different kinds of maps based on our objectives. For example, if our objective is to prepare forest vegetation type and density map based on satellite image interpretation or aerial photo-interpretation, we shall be in need of Forest Working Plan Map which shows mainly the details of forest age gradation, type, growing stock and management units. These maps facilitate to extract more updated information through data interpreting. Similarly maps like Geology, Soil, Agriculture, Geo-hydromorphology etc. are required.

9.3.2.2g Report/available relevant literatures: While interpreting the data we need the literature in the form of reports and other relevant reading material to enhance the knowledge of the concerned subject so as to extract more and outstanding information.
It is evident that in ground survey methods, we need more time, higher amount of money and more man power but lesser the amount of details as ground visibility is restricted to a certain extent followed by inaccessibility of terrain (in a certain conditions). Availability of above material and information for data interpretation certainly overcome the said pitfalls.
The preliminary aids for data interpretation also include the following points:

- Training and Experience.
- Nature of object or phenomenon.
- Quality of data and equipments.

9.3.3 Definition

Remote sensing data Interpretation can be defined in the following ways:

- Image interpretation is defined as the act of examining images to identify objects and judge their significance for the purpose of identification.
- Interpretation is the processes of detection, identification, description and assessment of significant of an object and pattern imaged.
- Photographic or satellite image interpretation is an information extraction process.

9.3.4 Basic Principle of Image Interpretation

An image taken from the air or space is a pictorial or spectral representation of pattern of landscape.

- Pattern indicates type of objects and their physical, biological, and cultural relationships
- Similar objects under similar conditions reflect similarly.
- A systematic examination of photos and supporting material.
- Interpretation is made of physical nature of the object.
- Information extracted is proportional to knowledge, skill and experience of analyst; the methods and equipment used.

9.3.5 Criterion and ground truth collection

While interpreting and starting the annotation/stratification on the image /data we should follow the following criterion otherwise we cannot say what is what within the strata and nominate the objects/cover types.

9.3.5a Reconnaissance and Preparation of Interpretation Key

Before starting interpretation you should develop general idea about the topography, vegetation and other land use/land cover types of study area. This is based on your reconnaissance (general survey) visit of the area assigned for interpretation. While surveying and taking the ground samples, the variability among the following image elements are taken into consideration so that sample information could be taken from each of them. This is based on the correlation of ground cover types/objects with the respective image elements depicted on the hard copy of image. For example, in the FCC image of IRS-1C hard copy (analogue data) wherein green, red and infrared spectral bands have been added together after assigning respective blue , green and red colours in the computer; medium maroon colour/ tone, generally represent Deodar forest on the ground, and dull white bluish tinge on the image represent dense habitation on the ground. Based on the identification of different colours/tones and other concerned image elements on the image and respective cover types/objects on the ground, an interpretation key in the tabular form is prepared. This interpretation key highlights the ready made reference for interpreting the image of whole area.

9.3.5b Capability to differentiate Image Elements

The interpreter should develop the capability to differentiate image elements for stratification of image into different classes. This is based on the preliminary knowledge of respective disciplines and the remote sensing data interpretation. The capability of differentiation within the image elements and the ground cover is utmost essential for good quality and better accuracy interpretation. In case of digital interpretation/digital image processing the additional knowledge of data processing in the computer is equally important.

9.3.5c Process of Elimination

Discard/eliminate those cover types/objects whose presence in that locality is not possible; but the image is showing the said presence due to intermixing of image elements. Sometimes, because of topographical influence or any other influence, two different objects or cover types represent the same image element. This mistake is not rectified unless we follow the map or collect ground information and eliminate that cover type. For example dense habitation and hanging cliffs/rock outcrops are showing the same image element of dull bluish white and as a result an interpreter will interpret hanging cliff as habitation or vice versa. The process of elimination is quite frequent when different kinds of vegetation are occurring in hilly and mountainous areas.

9.3.5d Skill, mental and visual acuity

The success of interpretation depends on the interpreter`s skill, mental and visual acuity. One should be very much particular about the concept that more the vision, devoting more time of continuous gazing for searching the objects of interest will result the success of extracting information.

9.3.6 Ground Truth Collection and Preparation of Final Image Interpretation Key

Collection of `ground truth` data is necessary in order to relate remotely sensed images to the ground. Ground truth collection for remote sensing data interpretation is an act of examining variable image elements and correlating them with ground surface realities/information so as to give correct code related to that information. Ground truths are collected before preliminary interpretation and during the course of final interpretation. The purpose in acquiring ground truth is ultimately to aid in the calibration and interpretation of remotely recorded surveys by checking out realities from within the scene. Since human interpreters normally experience the Earth as ground dwellers, their view of the world from a horizontal or low-angle panorama is the customary frame of reference. In fact, both the remote sensing specialist and the novice should retain a surface-based perspective during all phases of data collection, analysis, and applications inasmuch as most interpretations and decisions dealing with natural resources and land use will eventually be implemented at the ground level.

Among many ground-oriented data sources are field observations, in situ spectral measurements, aerial reconnaissance and photography, descriptive reports and inventory tallies, and maps. For visual, stereoscopic and digital data interpretation/digital image processing (it will be described in other unit) the types of tasks and operations associated with obtaining and utilizing ground truth are summarized below:

- Correlate surface features and localities as known from familiar ground perspectives with their expression in satellite imagery.
- Provide input and control during the first stages of planning for analysis, interpretation, and application of remote sensing data (landmark identification, logistics of access. etc.)
- Reduce data and sampling requirements (e.g., areas of needed coverage) for exploration, monitoring, and inventory activities
- Select test areas for aircraft and other multistage support missions (e.g., under flights simultaneous with spacecraft passes)
- Identify classes established by unsupervised classification
- Select and categorize training sites for supervised classification
- Verify accuracy of classification (error types and rates) by using quantitative statistical techniques
- Obtain quantitative estimates relevant to class distributions (e.g. field size; forest acreage)
- Collect physical samples for laboratory analysis of phenomena detected from remote sensing data (e.g., water quality; rock types; insect-induced disease)
- Acquire supplementary (ancillary) non-remote sensing data for interpretive model analysis or for integration into Geographic Information Systems
- Develop standard sets of spectral signatures by using ground-based instruments
- Measure spectral and other physical properties needed to stipulate characteristics and parameters pertinent to designing new sensor systems

Examples of typical observations and measurements conducted in the field, commonly as the remote sensing platform is passing over, or shortly thereafter, include these:

1. Meteorological conditions (air temperature, wind velocity, humidity, etc.).
2. Insolation (solar irradiance).
3. On-site calibration of reflectance.
4. Soil and soil moisture.
5. Water levels and level of contamination (stream gauge data).
6. Snow cover and snow thickness.
7. Siltation in lakes and rivers.
8. Growth stages of all kinds of vegetation, density and types of forest vegetation.
9. Distribution of urban subclasses.
10. Soil and rock types.
11. Many of other covers types and individual objects based on the objectives of image interpretation.

The above observations may or may not possible because of many obstacles and limitations. But ground truth collection is utmost important irrespective of passing over the satellite in due course of time and other favourable conditions. This is because of the fact that during ground

truth collection you can have at least a comparative evaluation of spectral/tonal variability between the cover types which facilitate quick interpretation and achieve better accuracy.
Ground truth activities are an integral part of the "multi" approach. Thus, data should be procured whenever possible from different platforms (multistage), at various distances from Earth's surface (multilevel). This gives rise to multi scaled images or classification maps. Multi sensor systems should be employed simultaneously to provide data over various regions of the spectrum (multispectral). The data must often be obtained at different times (multi temporal), whenever seasonal effects or illumination differences are factors or change detection is the objective. Supporting ground observations should come from many relevant, but not necessarily interrelated, sources (multisource). Some types of surface data may be correlated with one another and with other types of remote sensing data (multiphase).

Probably the most common reasons for conducting field activities lie either in the necessity of selecting training sites prior to supervised classification or identification of key classes after unsupervised classification. The best way to do this, if feasible, is simply to spend a few days in the field examining the terrain for which a classification is to be prepared. Obviously, the scale of this effort depends on the areal extent to be classified: one or more full Landsat scenes may require considerable travel and field time whereas examination of a typical subscene (such as 512 x 512 pixels) can often be accomplished in a day or two. If field operations are limited by logistics or circumstances (e.g., in an inaccessible foreign area or during an off-season such as winter), then one may fall back instead on aerial photography, maps, literature research, interviews with residents (perhaps over the Internet), etc. In practice, specification of training sites generally involves integration of these several sources of information -- direct observations, photo documentation, a variety of maps, personal familiarity, etc.

9.3.6.1 Image Interpretation Keys

Image interpretation keys (historically referred to as photo interpretation keys) are designed to aid in the identification of features. Image interpretation keys are typically project specific, and are most often employed in those cases where a group of image analysts are interpreting individual areas, but must generate a consistent product. Image interpretation keys are prepared, in tabular form, at the time of reconnaissance visit and final interpretation. The table contains location point, name of image element and the name of respective object/cover type. There is no formal structure, content, or layout to an image interpretation key, but well-designed keys have two components:

- The appearance of the features/classes of interest are described using Olson's elements of image interpretation
- Examples are provided using the source imagery for the project, or if not available, similar imagery; and these examples include annotation where appropriate.

Following tabular information (Table 9.1) represent the interpretation key after collecting the ground truth for ASTER image (Figure 9.4)

Figure 9.4 Aster data of Thano forest (Dehradun), April, 2005

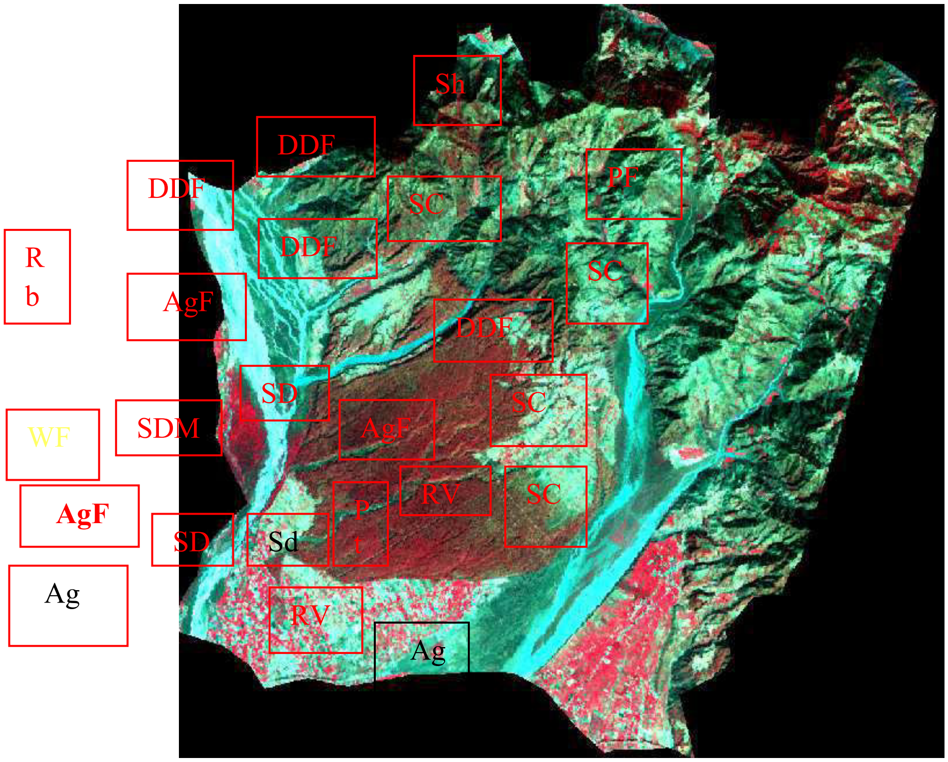


Table 9.1 Interpretation Key based on the Ground Truth of ASTER data (Figure 9.4)

Ground Truth	**Tone/colour**	**Texture**
Sal dense Forest	Maroon	Medium
Sal diseased Forest	Brown	Coarse
Sal dense mixed Forest	Blackish maroon	Medium
Water logged evergreen forest	Medium tar red	Medium
Riverine forest	Medium grey	Coarse
Dry deciduous medium to dense forest	Medium dark grey	Rough, coarse medium
Pine medium dense forest	Red, Red brown	Rough
Plantation	Medium grayish red	Medium
Scrub/shrubs of d	Medium grey	Rough, coarse
Agriculture crop (wheat & sugarcane	Tar red	Fine, medium
Agriculture fallow	Light grey-dull white	Medium
River bed	Light sky blue	Smooth
Shadow	Black	smooth

The above tabular information is based on main cover types shown on the above figure. The study area as shown in the figure is partly hilly, partly plain and undulating. The tonal and textural variation is based on not only the cover types but also the influence of topographic variations, aspect of hill slope, shadows etc. admixed with soil types, soil moisture, rock types and undergrowth.

9.3.7 Image elements for remote sensing data interpretation

Basic elements of interpretation of satellite imagery and aerial photographs involve the study of various basic characters of an object with reference to spectral bands which is useful in visual or digital analysis. The main basic elements are tone, texture, shape, size, shadows, pattern, location, association and resolution.

Analysis of remote sensing imagery involves the identification of various targets in an image, and those targets may be environmental or artificial features which consist of points, lines, or areas. Targets may be defined in terms of the way they reflect or emit radiation. This radiation is measured and recorded by a sensor, and ultimately is depicted as an image product such as an air photo or a satellite image.

What makes interpretation of imagery more difficult than the everyday visual interpretation of our surroundings? For one, we lose our sense of depth when viewing a two-dimensional image, unless we can view it *stereoscopically* so as to simulate the third dimension of height. Indeed, interpretation benefits greatly in many applications when images are viewed in stereo, as visualization (and therefore, recognition) of targets is enhanced dramatically. Viewing objects from directly above also provides a very different perspective than what we are familiar with. Combining an unfamiliar perspective with a very different scale and lack of recognizable detail can make even the most familiar object unrecognizable in an image. Finally, we are used to seeing only the visible wavelengths, and the imaging of wavelengths outside of this window is more difficult for us to comprehend.

Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements as mentioned above Visual or any other kind of method of interpretation using these elements is often a part of our daily lives, whether we are conscious of it or not. Examining satellite images on the weather report or following high speed chases by views from a helicopter are all familiar examples of visual image interpretation. Identifying targets in remotely sensed images based on these visual elements allows us to further interpret and analyze. You may simply consider that, in day to day's life, different human beings, animals, vegetation etc. or any objects have different kind of identity with respect to their colour, structure, size, association, movement, habitat condition etc. Similarly photographic objects or objects on satellite images have different kinds of identity in the form of pictorial /image elements as mentioned above. The nature of each of these interpretation elements is described below, along with an image example of each.

i) Tone: Tone is the amount of light reflected from the object, more the light reflected brighter will be the tone and on the contrary lesser the reflection of light darker the tone. Hue refers to the colour as defined in the IHS space colours. We may also define tone as relative brightness in a black and white image. Simply we may say that tone refers to the relative brightness or colour of objects in an image. Generally, tone is the fundamental element for distinguishing between different targets or features. Variations in tone also allow the elements of shape, texture, and pattern of objects to be distinguished. It is the first striking element for easy identification of object.

In case of forest vegetation or the plants under any vegetation type, all plants have chlorophyll and look green, but each species has inherent characteristics in terms of chlorophyll concentrations, age, activity, cell structure, moisture content, health etc. Age of the plant or vegetation is very important parameter. Each species has characteristic reflectance called spectral signature and appear in characteristic tones. Forests with few dominating species are easy to delineate as compared to mixed forests. Mixing of the species leads to high tonal variation and intermixing. One may be cautious about tonal variations because for many reasons the tones of same formation/community may be different in the same or adjacent area. Therefore, sufficient ancillary information is essential. It is advisable to choose the season with high contrast. High contrast in physiognomy can be seen in the leaf fall period when deciduous forest is without leaves.

In black and white (panchromatic) satellite images or photographs, we can identify at least ten grades of tone starting from i) black, ii) very dark, iii) dark grey, iv) medium dark grey, v) light dark grey, vi) medium grey, vii) medium light grey, viii) light grey ix) light, and x)white. But in case of False Colour Composite (FCC) images of satellite images (procedure will be explained in the next unit of digital image processing), we can see up to 20 to 25 colours and subsequently can identify more number of objects. Here the FCC interpretation using digital image processing techniques provide a large amount of volume of details. But it all depends on the quality of digital image followed by its spatial, spectral, temporal and radiometric resolution.

ii**) Texture:** Texture refers to the arrangement and frequency of tonal variation in particular areas of an image. You may also say that texture is the frequency of change and arrangement of tone. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation. Smooth textures are most often the result of uniform, even surfaces, such as fields, water bodies, tar roads etc. Uniform cropland and grasslands appear in fine/medium texture. Uneven/heterogenous cropland and uneven housing pattern with large gap in between the houses appear in coarse texture. If the same houses have more gaps and same is the case of cropland, the texture appears as rough one (Figure 9.6). A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance. Texture is directly related with density of cropland, housing pattern, forests etc. The coarse texture in large scale image appears as medium or fine one in small scale image. But there will be no change if tonal variability almost zero in the original scale of image, i.e., water body.

Texture is one of the most important elements for distinguishing features in radar imagery.
In some cases it is more reliable than tone. In case of forest vegetation, texture of the features depends upon the similarities and dissimilarities in species composition, age, density or gaps in the forests, formation etc. It help in estimating the crown cover. Gregarious formations and dense mixed forests will appear smooth in texture. Bamboo bushes/forest also appears in smooth texture. Forests with high amount of disturbance or canopy gaps will appear coarse in texture.
iii) Shape: Shape refers to the general form, structure, or outline of individual objects (Figure 9.6). Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural (field) targets, while natural features, such as forest edges, are generally more irregular in shape, except where man has created a road or clear cuts. Farm or crop land irrigated by rotating sprinkler systems would appear as circular shapes.
iv) Size: Size of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target. A quick approximation of target size can direct interpretation to an appropriate result more quickly. For example, if an interpreter had to distinguish zones of land use, and had identified an area with a number of buildings in it, large buildings such as factories or warehouses would suggest commercial property, whereas small buildings would indicate residential use.
Size refers to the spatial dimension of the object on the ground. It is the main interpretation key to identify the species in case of photographs. Object size depends on the scale of image and can be measured. Jhum (shifting cultivation) area can be recognized, etc).

v) Shadow: It is very helpful in interpretation as it may provide an idea of the profile and relative height (as in case of aerial photo-interpretation) of a target or targets which may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings. Shadow is also useful for enhancing or identifying topography and landforms, particularly in radar imagery.
Shadows are cast due to sun's illumination angle, size and shape of object or sensor viewing angle. the shadows resulting from subtle variations in terrain elevations, especially in the case of low sun angle images, can aid in assigning natural topographic variations that may be diagnostic of various geologic landforms and associated forest density (sometimes it causes hindrance). In satellite images the shadows are helpful in recognition of clouds, nature of hill slopes, aspect, apparent relief etc.
vi) Pattern: It refers to the spatial arrangement of visibly discernible objects. Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern. Orchards with evenly spaced trees and urban streets with regularly spaced houses are good examples of pattern.
We may also define pattern as the spatial arrangement of surface features (characteristics of both natural and manmade objects). The repetition of certain general forms or relationships is

characteristic of many objects and gives objects a pattern that aids the image interpreter in recognizing those (Plantations), e.g. field pattern.

vii) Association: Association takes into account the relationship between other recognizable objects or features in proximity to the target of interest. It may simply take into account that "a man is known or identified by the company he keeps" The identification of features that one would expect to associate with other features may provide information to facilitate identification. In the example given above, commercial properties may be associated with proximity to major transportation routes, whereas residential areas would be associated with schools, playgrounds, and sports fields. In our example, a lake is associated with boats, a marina, and adjacent recreational land.

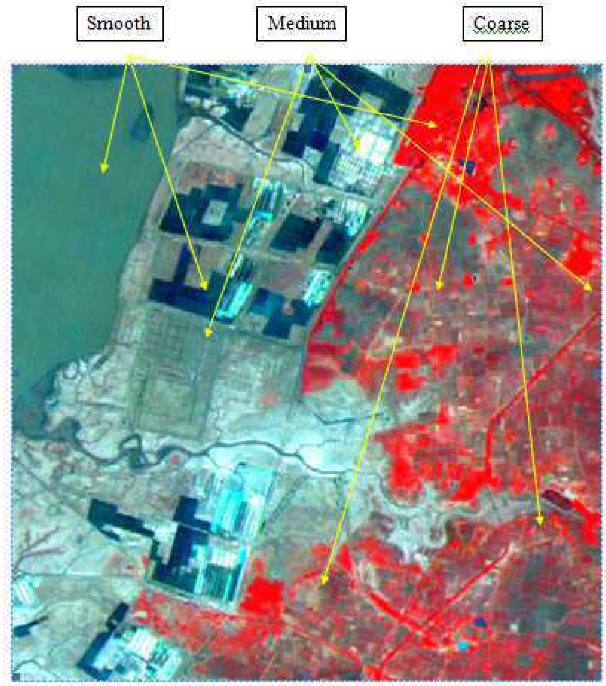
You may also develop the concept of association as it refers to the occurrence of certain features in relation to others (neighboring features). In ecological context, it is a plant community of definite floristic composition, presenting a uniform physiognomy and growing in uniform habitat conditions. Certain species can be identified by recognition of other species, which grow together e.g. *Acacia catechu* (Khair) and *Delbergia sissoo* (Sisso) is associated with fresh alluvial deposits.

viii) Location: The geographical site and location of the objects often provide the clue for identifying objects. Sometimes the forest type can be easily recognized due to its geographical location and topography (elevation is considered in the Himalayas) which can hardly be classified by other elements. Fir, Spruce, Deodar, Blue pine, Oak and Chirpine occur at certain elevation and aspect.

ix) Aspect: It refers to the direction in which a mountain hill slope faces, particularly with reference to possible amounts of sunshine and shadow. There is vegetation which favors its growth on warmer area can be ascertained while correlating with aspect and other image elements. Out of four main aspects, southern aspects are most warm followed by west, east and north. The occurrence of natural vegetation, agricultural cropping pattern and other life forms are accordingly identified on the satellite images or aerial photographs.

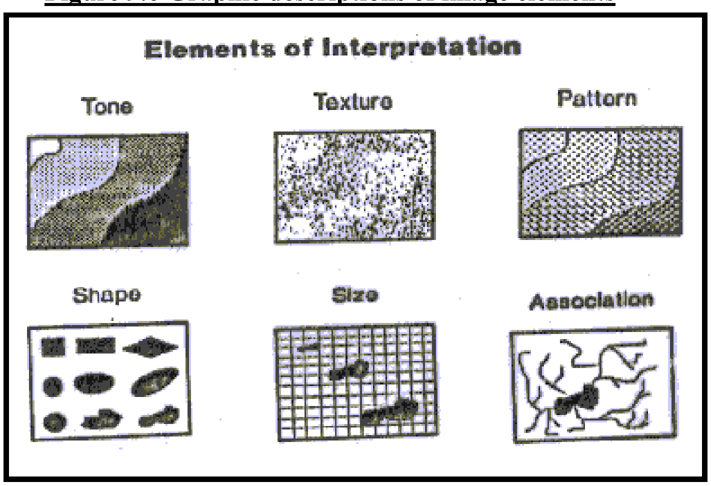
x) Resolution: Resolution is a very important element whether it is spatial, spectral, temporal or radiometric. For visual interpretation spatial and spectral resolutions contribute a lot. The spatial resolution refers to picture 'element' or 'pixel' discernible on the image of the smallest area resolvable or identifiable on the ground. Spatial resolution allows the interpreter to detect and distinguish the smallest object on the ground e.g. on Landsat TM the smallest object which can be resolved is 30m or 0.9 ha on ground and on IRS (LISS-I) imagery the smallest object which can be resolved is 73m or 0.5ha on the ground.

Figure 9.5 Ankleshwar, India (IRS 1C PAN+LISS-III)



Source: www.nrsa.gov.in

Figure 9.6 Graphic descriptions of image elements



9.3.8 Types and methods of remote sensing data interpretation

9.3.8.1 Remote sensing data interpretation types

The common method of satellite data interpretation may be either visual or digital or combination of both. The choice of visual or digital data interpretation depends on the data quality, clarity, scale, and amount of information to be extracted, infrastructure available, availability of trained man power, accuracy, availability of ground truth information from predetermined samples, and the availability of budget. Both the interpretation techniques have merits and demerits and even after the digital analysis the output are also visually analyzed. However, if all the situations are conducive, combination of both the said method in conjunction with sufficient ground truths is the best one in view of a higher degree of accuracy. In general, out of the following four methods, any one the method, is used.

- Visual interpretation
- Stereoscopic interpretation (only for aerial photographs)
- Onscreen visual interpretation
- Digital interpretation

9.3.8.2 Methodology

Methodology of image interpretation depends on:

- External knowledge available and any other sensory surveys that have been or will be made in the near future in the same area.
- Scale and other requirements of the final map.
- Instruments available.
- Kind and type of imagery or photographs available.
- The reference level of the person executing the interpretation.
- Accuracy of the results to be obtained.
- Kind of information to be interpreted.

9.3.8.3 Sequence of activities

The following sequence of activities is followed for remote sensing data interpretation:

9.3.8.3.1Remote sensing data procurement/ image sources

Getting remote sensing image for a specific project remains one of the most challenging steps in the workflow. You have to find the data most suitable for your particular objective. For example, MODIS data at 250 m spatial resolution, Landsat MSS at 79 resolutions and IRS-1A at 73 m resolution are not suitable for mapping agricultural land and forest vegetation types and inventory in India and other developing countries.

Few important properties to consider while searching the remote sensing data are (not in the order of importance):

i. Spatial resolution or pixel size
ii. Date or time of the year/season
iii. Cloud-cover
iv. Wavelengths to measure different physical properties
v. Availability of historical data
vi. Noise or artifacts in data (read about problems in Landsat ETM+)

There are many numerous choices of remote sensing data. It all depends on your objectives. In India, National Remote Sensing Centre (NRSC); earlier it was named as National Remote Sensing Agency (NRSA), is the only organization for remote sensing data source. While ordering the data you have to duly fill up the Performa based on your requirement and mentioning the above points.

9.3.8.3g Data Selection

Data selection is most important step under data procurement and ordering. Following is the example of data selection for forestry:

The repetitive coverage provided by remote sensing data helps in selecting right kind of data for forest studies. However, following aspects are to be considered necessary for selecting right kind of data –

(a) Phonological state of vegetation
(b) Phytogeographical region
(c) Land use practice
(d) Sun elevation and azimuth
(e) Cloud and snow coverage

The proper season of remote sensing data is mainly dependent upon the bioclimatic region/vegetation zones understudy (Table 9. 2)

Table 9.2 Proper Season for studying natural forest cover/vegetation in different bio-climatic regions and vegetation zones

Sl. No.	Region/Vegetation Zone	Proper Season
1.	Humid & moist evergreen and semi-green vegetation in western and eastern ghats	January – February
2.	Humid & moist evergreen and semi-evergreen vegetation of north eastern region	February – March
3.	Tropical moist deciduous vegetation of northern and Central India	December – January
4.	Temperate evergreen vegetation of western Himalayas	March – May
5.	Temperature, subalpine, alpine evergreen & deciduous vegetation of Jammu & Kashmir	September - October
6.	Arid and semi-arid dry deciduous and scrub vegetation	October – December
7.	Tropical coastal mangrove vegetation	February – March

For selection of appropriate data, it is necessary to fully understand the information requirements of the specific application. To this end you first have to analyze the spatial –temporal characteristic of the phenomena of your interest. For example, studying changing global weather patterns does not require spatially detailed information on terrain features. For identifying informal settlements, building details have to be recognized, thus we need data of high spatial resolution but not temporal differentiation.

9.3.8.4 Data Preparation

Following are the steps followed for data preparation for interpretation:

- Data downloading in the computer
- Data rectification
- Radiometric correction
- Geometric correction
- Spectral enhancement
- Radiometric enhancement
- Preparation of FCC
- Printing of FCC image for reconnaissance, ground truth collection and preparation of interpretation key.

Above steps will be described in the next unit of Digital image processing.

9.3.8.5Techniques of image interpretation

- The development of interpretation techniques has been mainly by the empirical method.
- The gap between the image on the one hand and the reference level, i.e. the level of knowledge in a specific field, in the human mind on the other hand, is bridged by the use of image-interpretation.
- The techniques adopted for one discipline may differ from those adopted for another.
- The sequence of activity and the search method may have to be modified to suit the specific requirements.

9.3.8.5.1Interpretation

The visual Image interpretation is either carried out on a transparent paper (tracing paper) affixed with satellite image mounted on light table or on a computer screen showing digitally enhanced satellite image. While interpreting the data, all the said points, guide lines, examples, figures and tabular information under preliminary concepts, criterion are taken into account as and where required. The most important are the image elements and ground truth information for all common tasks of image interpretation.

The results of image interpretation are most often delivered as a set of attributed points, lines, and/or polygons in any one of a variety of CAD or GIS data formats. The classification scheme or interpretation criteria must be agreed upon with the end user before the analysis begins.

An interpreter studies remotely sensed data and attempts through logical process to detect, identify, **measure** and evaluate the significance of environmental and cultural objects, patterns and spatial relationships.

Image interpretation is a complex process of physical, psychological activities occurring in a sequence of time. The sequence begins with the detection and identification of images and later by their measurements. Various aspects of image interpretation are as follow:

i. **Detection:** It is the determination of the presence or absence of a feature. Detection is a process of 'picking out' an object or element from the image through interpretation technique.
ii. **Recognition:** Recognition is a process of assigning an object or feature to a general class or category.
iii. **Identification:** specifying the identity of an object with enough confidence to assign it to a very specific class. You can say that identification is a process of classification.
iv. **Enumeration:** listing or counting discrete items visible on an image.
v. **Mensuration:** measurement of objects and features in terms of distance, height, volume, or area. (it is related with aerial photo-interpretation)
vi. **Delineation:** drawing boundaries around distinct regions of the image characterized by specific tones or textures.
vii. Classification: assigning objects, features, or areas to classes. This occurs at above first three levels of confidence.

9.3.8.4 Information Extraction and Mapping

The assumption in mapping based on remote sensing images is that areas looking homogeneous in the image will have similar features on the ground. The delineation/ stratification in the form of different interpretation units are based on what can be observed in the image. Different interpretation units cab be codified and described according to the image elements and respective cover types from the ground mentioned in the image interpretation key. As such the interpreted details are transferred into base map prepared from the concerned topographical map showing all geographical details. In case of on screen visual interpretation, the geographical details from topographical map are also included with the interpreted details. The final printout is taken in the map form.

9.4 SUMMARY

Image interpretation is an act of examining image elements and judging their significance for the purpose of identification. The amount of information which we can extract from an image depends on its quality, resolution, and scale, methods of interpretation along with the training, experience, skill, mental and visual acuity of interpreter.

Visual interpretation is one of the methods used to extract information from remote sensing data. For that purpose, the data need to be visualized on a computer screen or in hard copy form. Using the human vision system we can distinguish spontaneous recognition and logical inference (reasoning).

Interpretation keys or guidelines are required to instruct the image interpreter. Even if the knowledge of the area is lacking, an interpretation legend can be constructed based on interpretation elements, without considering what the units are in reality. After field work it will become clear what the units represent on the ground. In interpretation guidelines, the interpretation elements can be used to describe how to recognize certain objects.

There are two types of extraction of information from the images namely;

i) Interpretation of data by visual analysis.

ii) Semi automatic processing by computer followed by visual analysis like generation of vector layer from raster image through onscreen digitization and DTM/DEM generation. Similarly interpretation of aerial photographs through 3D generation through visual studies. In general analog format in remote sensing data is being used in visual interpretation. This involves the systematic examination of data, studying existing maps, collection of field information and works at various levels of complexity. The analysis depends upon the individual perception, and experience of the interpreter, nature of the object, quality of the data, scale, combination of special bands etc.

The entire process of visual interpretation can be divided into following few steps namely detection of an object, interpretation, recognition and identification, analysis, classification, deduction and idealization and based on this identifying an object conclusion. Hence interpretation is the combined result of identification of feature through photo recognition elements, field verification and preparation of final thematic maps. It also requires the process of observation coupled with imagination and great deal of patience.

9.5 GLOSSARY

- **DTM**-Digital Terrain Model
- **DEM**-Digital Elevation Model
- **IHS**- Intensity Hue Saturation
- **MODIS**-Moderate Resolution Imaging Spectroradiometer
- **ETM-** Enhanced Thematic Mapper

9.6ANSWER TO CHECK THE PROGRESS

Q1- What is satellite remote sensing?

Q2- What is Remote Sensing data interpretation concept?

Q3- What do you understand by Remote Sensing data interpretation principles?

Q4- What do you mean by ground truth collection?

9.7 REFERENCES

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9.8 TERMINAL QUESTIONS

1-Describe in detail Satellite remote sensing instrument types.

2-Define image interpretation, its concepts, and principles.

3-What are the criterion of image interpretation, discuss them in detail.

4-Describe the sequence of activities for ground truth collection.

5-What is the importance of image elements in remote sensing image interpretation. Explain them in detail.

6-Describe the steps for visual interpretation of remote sensing data.