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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEEERING

UNIT – I –SURVEYING-II– SCIA1404

HYDROGRAPHIC SURVEYING

Introduction

- It is the branch of surveying which deals with any body of still or running water such as lake, harbour, stream or river
- Science of study of underwater topography
- Mapping of features

Shape of coastline

Location of possible obstruction's and physical features of water bodies

Shape of seafloor (unconsolidated material)

Safe and efficient movement of offshore transportation system.

Shore signals.

Each range line is marked by means of signals erected at two points on it at a considerable distance apart. Signals can be constructed in a variety of ways. They should bereadily seen and easily distinguished from each other. The most satisfactory and economic type of signal is a wooden tripod structure dressed with white and coloured signal of cloth. The position of the signals should be located very accurately since all the soundings are to be located with reference to these signals.

Location by Cross-Rope

This is the most accurate method of locating the soundings and may be used for rivers, narrow lakes and for harbours. It is also used to determine the quantity of materials removed by dredging the soundings being taken before and after the dredging work is done. A single wire or rope is stretched across the channel etc. as shown in Fig.4.6 and is marked by metal tags at appropriate known distance along the wire from a reference point or zero station on shore. The soundings are then taken by a weighted pole. The position of the pole during a sounding is given by the graduated rope or line.

In another method, specially used for harbours etc., a reel boat is used to stretch the rope. The zero end of the rope is attached to a spike or any other attachment on one shore. The rope is would on a drum on the reel boat. The reel boat is then rowed across the line of sounding, thus unwinding the rope as it proceeds. When the reel boat reaches the other shore, its anchor is taken ashore and the rope is wound as tightly as possible. If anchoring is not possible, the reel is taken ashore and spiked down. Another boat, known as the sounding boat, then starts from the previous shore and soundings are taken against each tag of the rope. At the end of the soundings along that line, the reel boat is rowed back along the line thus winding in the rope. The work thus proceeds.

Location by Range and Time Intervals

In this method, the boat is kept in range with the two signals on the shore and is rowed along it at constant speed. Soundings are taken at different time intervals. Knowing the constant speed and the total time elapsed at the instant of sounding, the distance of the total point can be known along the range. The method is used when the width of channel is small and when great degree of accuracy is not required. However, the method is used in conjunction with other methods, in which case the first and the last soundings along a range are located by
angles from the shore and the intermediate soundings are located by interpolation according to time intervals.

Location by Range and One Angle from the Shore

In this method, the boat is ranged in line with the two shore signals and rowed along the ranges. The point where sounding is taken is fixed on the range by observation of the angle from the shore. As the boat proceeds along the shore, other soundings are also fixed by the observations of angles from the shore. Thus B is the instrument station, **A1 A2** is the range along which the boat is rowed and **α1, α2, α3** etc., are the angles measured at B from points 1, 2, 3 etc. The method is very accurate and very convenient for plotting. However, if the angle at the sounding point (say angle β) is less than 30°, the fix becomes poor. The nearer the intersection angle (β) is to a right angle, the better. If the angle diminishes to about 30° a new instrument station must be chosen. The only defect of the method is that the surveyor does not have an immediate control in all the observation. If all the points are to be fixed by angular observations from the shore, a notekeeper will also be required along with the instrument man at shore since the observations and the recordings are to be done rapidly. Generally, the first and last soundings and every tenth sounding are fixed by angular observations and the intermediate points are fixed by time intervals. Thus the points with round mark are fixed by angular observations from the shore and the points with cross marks are fixed by time intervals. The arrows show the course of the boat, seaward and shoreward on alternate sections.

To fix a point by observations from the shore, the instrument man at B orients his line of sight towards a shore signal or any other prominent point (known on the plan) when the reading is zero. He then directs the telescope towards the leadsman or the bow of the boat, and is kept continually pointing towards the boat as it moves. The surveyor on the boat holds a flag for a few seconds and on the fall of the flag, the sounding and the angle are observed simultaneously.

The angles are generally observed to the nearest 5 minutes. The time at which the flag falls is also recorded both by the instrument man as well as on the boat. In order to avoid acute intersections, the lines of soundings are previously drawn on the plan and suitable instrument stations are selected.

Location by Range and One Angle from the Boat

The method is exactly similar to the previous one except that the angular fix is made by angular observation from the boat. The boat is kept in range with the two shore signals and is rowed along it. At the instant the sounding is taken, the angle, subtended at the point between the range and some prominent point B on the sore is measured with the help of sextant. The telescope is directed on the range signals, and the side object is brought into coincidence at the instant the sounding is taken. The accuracy and ease of plotting is the same as obtained in the previous method. Generally, the first and the last soundings, and some of the intermediate soundings are located by angular observations and the rest of the soundings are located by time intervals.

As compared to the previous methods, this method has the following advantages :

1. Since all the observations are taken from the boat, the surveyor has better control over the operations.
2. The mistakes in booking are reduced since the recorder books the readings directly as they are measured.

3. On important fixes, check may be obtained by measuring a second angle towards some other signal on the shore.

4. The obtain good intersections throughout, different shore objects may be used for reference to measure the angles.

Location by Two Angles from the Shore

In this method, a point is fixed independent of the range by angular observations from two points on the shore. The method is generally used to locate some isolated points. If this method is used on an extensive survey, the boat should be run on a series of approximate ranges. Two instruments and two instrument men are required. The position of instrument is selected in such a way that a strong fix is obtained. New instrument stations should be chosen when the intersection angle (θ) falls below 30°. Thus A and B are the two instrument stations. The distance d between them is very accuarately measured. The instrument stations A and B are precisely connected to the ground traverse or triangulation, and their positions on plan are known. With both the plates clamped to zero, the instrument man at A

bisects B ; similarly with both the plates clamped to zero, the instrument man at B bisects A. Both the instrument men then direct the line of sight of the telescope towards the leadsman and continuously follow it as the boat moves. The surveyor on the boat holds a flag for a few seconds, and on the fall of the flag the sounding and the angles are observed simultaneously. The co-ordinates of the position P of the sounding may be computed from the relations :

The method has got the following advantages:

1. The preliminary work of setting out and erecting range signals is eliminated.
2. It is useful when there are strong currents due to which it is difficult to row the boat along the range line.

The method is, however, laborious and requires two instruments and two instrument men.

Location by Two Angles from the Boat

In this method, the position of the boat can be located by the solution of the three-point problem by observing the two angles subtended at the boat by three suitable shore objects of known position. The three-shore points should be well-defined and clearly visible. Prominent natural objects such as church spire, lighthouse, flagstaff, buoys etc., are selected for this purpose. If such points are not available, range poles or shore signals may be taken. Thus A, B and C are the shore objects and P is the position of the boat from which the angles α and β are measured. Both the angles should be observed simultaneously with the help of two sextants, at the instant the sounding is taken. If both the angles are observed by surveyor alone, very little time should be lost in taking the observation. The angles on the circle are read afterwards. The method is used to take the soundings at isolated points. The surveyor has better control on the operations since the survey party is concentrated in one boat. If sufficient number of prominent points are available on the shore, preliminary work o setting out and erecting range signals is eliminated. The position of the boat is located by the solution of the three point problem either analytically or graphically.

Location by One Angle from the Shore and the other from the Boat

This method is the combination of methods 5 and 6 described above and is used to locate the isolated points where soundings are taken. Two points A and B are chosen on the
shore, one of the points (say A) is the instrument station where a theodolite is set up, and the other (say B) is a shore signal or any other prominent object. At the instant the sounding is taken at P, the angle α at A is measured with the help of a sextant. Knowing the distance d between the two points A and B by ground survey, the position of P can be located by calculating the two co-ordinates x and y.

Location by Intersecting Ranges

This method is used when it is required to determine by periodical sounding at the same points, the rate at which silting or scouring is taking place. This is very essential on the harbors and reservoirs. The position of sounding is located by the intersection of two ranges, thus completely avoiding the angular observations. Suitable signals are erected at the shore. The boat is rowed along a range perpendicular to the shore and soundings are taken at the points in which inclined ranges intersect the range, as illustrated in Fig. 4.12. However, in order to avoid the confusion, a definite system of flagging the range poles is necessary. The position of the range poles is determined very accurately by ground survey.

Location by Tacheometric Observations

The method is very much useful in smooth waters. The position of the boat is located by tacheometric observations from the shore on a staff kept vertically on the boat. Observing the staff intercept s at the instant the sounding is taken, the horizontal distance between the instrument stations and the boat is calculated by

The direction of the boat (P) is established by observing the angle (α) at the instrument station B with reference to any prominent object A The transit station should be near the water level so that there will be no need to read vertical angles. The method is unsuitable when soundings are taken far from shore.

Explain reduction of soundings with a example.

The reduced soundings are the reduced levels of the sub-marine surface in terms of the adopted datum. When the soundings are taken, the depth of water is measured with reference to the existing water level at that time. If the gauge readings are also taken at the same time, the soundings can be reduced to a common unvarying datum. The datum most

commonly adopted is the ‘mean level of low water of spring tides’ and is written either as L.W.O.S.T. (low water, ordinary spring tides) or

M.L.W.S. (mean low water springs). For reducing the soundings, a correction equal to the difference of level between the actual water level (read by gauges) and the datum is applied to the observed soundings, as illustrated in the table given below :

Gauge Reading at L.W.O.S.T. = 3.0 m.

Time	Gauge (m)	Distance	Soluction (m)	Correction	Reduced sounding (m)	Remarks
8.00 A.M.	**3.5**	**10**	**2.5**	**-0.5**	**2.00**	
		20	**3.2**		**2.7**	
		30	**3.9**		**3.4**	
		40	**4.6**		**4.1**	
8.10 A.M.	**3.5**	**50**	**5.3**	**-0.5**	**4.8**	
		60	**5.4**		**4.9**	
		70	**5.1**		**4.6**	
		80	**4.7**		**4.2**	
		90	**3.6**		**3.1**	
8.10 A.M.	**3.5**	**100**	**2.1**	**-0.5**	**1.6**	

Three point problem

Given the three shore signals A, B and C, and the angles α and β subtended by AP, BP and CP at the boat P, it is required to plot the position of P

1. Mechanical Solution

(i) By Tracing Paper

Protract angles α and β between three radiating lines from any point on a piece of tracing paper. Plot the positions of signals A, B, C on the plan. Applying the tracing paper to the plan, move it about until all the three rays simultaneously pass through A, B and C. The apex of the angles is then the position of P which can be pricked through.

(ii) By Station Pointer :

The station pointer is a three-armed protractor and consists of a graduated circle with fixed arm and two movable arms to the either side of the fixed arm. All the three arms have beveled or fiducial edges. The fiducial edge of the central fixed arm corresponds to the zero of the circle. The fiducial edges of the two moving arms can be set to any desired reading and can be clamped in position. They are also provided with verniers and slow motion screws to set the angle very precisely. To plot position of P, the movable arms are clamped to read the angles α and β very precisely. The station pointer is then moved on the plan till the three fiducial edges simultaneously touch A, B and C. The centre of the pointer then represents the position of P which can be recorded by a prick mark.

2. Graphical Solutions

(a) First Method :

Let a, b and c be the plotted positions of the shore signals A, B and C respectively and let α and β be the angles subtended at the boat. The point p of the boat position p can be obtained as under :

1. Join a and c.
2. At a, draw ad making an angle β with ac. At c, draw cd making an angle α with ca. Let both these lines meet at d.
3. Draw a circle passing through the points a, d and c.
4. Join d and b, and prolong it to meet the circle at the point p which is the required position of the boat.

Proof. From the properties of a circle,
$\angle apd = \angle acd = \alpha$ and $\angle cpd = \angle cad = \beta$

which is the required condition for the solution.

(b) Second Method :

Join ab and bc.

1. From a and b, draw lines **ao1 and bo1** each making an angle (90° - α) with ab on the side towards p. Let them intersect at **01.**
2. Similarly, from b and c, draw lines = each making an angle (90° -

β) with ab on the side towards p. Let them intersect at --.

3. With – as the centre, draw a circle to pass through a and b. Similarly, with – as the centre draw a circle to pass through b and c. Let both the circles intersect each other at a point p. p is then the required position of the boat.

Proof. $\angle ao1b = 180° - 2\,(90° - \alpha) = 2\alpha$

$\angle apb = ½\ \angle ao1b = \alpha$

Similarly, $\angle bo2c = 180° - 2\,(90° - \beta) = 2\beta$

and $\angle bpc = ½\ \angle bo2c = \beta$.

The above method is sometimes known as the method of two intersecting circles.

(c) Third Method :

1. Join ab and bc.
2. At a and c, erect perpendiculars ad and ce.
3. At b, draw a line bd subtending angle (90° - α) with ba, to meet the perpendicular through a in d.
4. Similarly, draw a line be subtending an angle (90° - β) with bc, to meet the perpendicular through c in e.
5. Join d and e.
6. Drop a perpendicular on de from b. The foot of the perpendicular (i.e. p) is then the required position of the boat.

TIDES

All celestial bodies exert a gravitational force on each other. These forces of attraction between earth and other celestial bodies (mainly moon and sun) cause periodical variations in the level of a water surface, commonly known as tides. There are several theories about the tides but none adequately explains all the phenomenon of tides. However, the commonly used theory is after Newton, and is known as the equilibrium theory. According to this theory, a force of attraction exists between two celestial bodies, acting in the straight line joining the centre of masses of the two bodies, and the magnitude of this force is proportional to the product of the masses of the bodies and is inversely proportional to the square of the distance between them. We shall apply this theory to the tides produced on earth due to the force of attraction between earth and moon. However, the following assumptions are made in the equilibrium theory :

1. The earth is covered all round by an ocean of uniform depth.
2. The ocean is capable of assuming instantaneously the equilibrium , required by the tide producing forces. This is possible if we neglect (i) inertia of water, (ii) viscosity of water, and (iii) force of attraction between parts of itself.

The Lunar Tides

(a) centres of masses of earth and moon are $O1$ and $O2$ respectively. Since moon is very near to the earth, it is the major tide producing force. To start with, we will ignore the daily rotation of the earth on its axis. Both earth and moon attract each other, and the force of attraction would act along $O1O2$. Let O be the common centre of gravity of earth and moon. The earth and moon revolve monthly about O, and due to this revolution their separate positions are maintained. The distribution of force is not uniform, but it is more for the points facing the moon and less for remote points. Due to the revolution of earth about the common centre of gravity O, centrifugal force of uniform intensity is exerted on all the particles of the earth. The direction of this centrifugal force is parallel to $O1O2$ and acts outward. Thus, the total force of attraction due to moon is counter-balanced by the total centrifugal force, and the earth maintains its position relative to the moon. However, since the fore of attraction is not uniform, the resultant force will very all along. The resultant forces are the tide producing forces. Assuming that water has no inertia and viscosity, the

ocean enveloping the earth’s surface will adjust itself to the unbalanced resultant forces, giving rise to the equilibrium. Thus, there are two lunar tides at A and B, and two low water positions at C and D. The tide at A is called the superior lunar tide or tide of moon's upper transit, While tide at B is called inferior or antilunar tide.

Now let us consider the earth's rotation on its axis. Assuming the moon to remain stationary, the major axis of lunar tidal equilibrium figure would maintain a constant position. Due to rotation of earth about its axis from west to east, once in 24 hours, point A would occupy successive position C, B and D at intervals of 6 h. Thus, point A would experience regular variation in the level of water. It will experience high water (tide) at intervals of 12 h and low water midway between. This interval of 6 h variation is true only if moon is assumed stationary. However, in a lunation of 29.53 days the moon makes one revolution relative to sun from the new moon to new moon. This revolution is in the same direction as the diurnal rotation of earth, and hence there are 29.53 transits of moon across a meridian in 29.53 mean solar days. This is on the assumption that the moon does this revolution in a plane passing through the equator. Thus, the interval between successive transits of moon or any meridian will be 24 h, 50.5 m. Thus, the average interval between successive high waters would be about 12 h 25 m. The interval of 24 h 50.5 m between two successive transits of moon over a meridian is called the tidal day.

The Solar Tides

The phenomenon of production of tides due to force of attraction between earth and sun is similar to the lunar tides. Thus, there will be superior solar tide and an inferior or anti-solar tide. However, sun is at a large distance from the earth and hence the tide producing force due to sun is much less.

$$\text{Solar tide} = 0.458 \text{ Lunar tide.}$$

Combined effect : Spring and neap tides

Solar tide = 0.458 Lunar tide.

Above equation shows that the solar tide force is less than half the lunar tide force. However, their combined effect is important, specially at the new moon when both the sun and moon have the same celestial longitude, they cross a meridian at the same instant.

Assuming that both the sun and moon lie in the same horizontal plane passing through the equator, the effects of both the tides are added, giving rise to maximum or spring tide of new moon. The term ‘spring’ does not refer to the season, but to the springing or waxing of the moon. After the new moon, the moon falls behind the sun and crosses each meridian 50 minutes later each day. In after 7 ½ days, the difference between longitude of the moon and that of sun becomes 90°, and the moon is in quadrature . The crest of moon tide coincides with the trough of the solar tide, giving rise to the neap tide of the first quarter. During the neap tide, the high water level is below the average while the low water level is above the average. After about 15 days of the start of lunation, when full moon occurs, the difference between moon’s longitude and of sun’s longitude is 180°, and the moon is in opposition. However, the crests of both the tides coincide, giving rise to spring tide of full moon. In about 22 days after the start of lunation, the difference in longitudes of the moon and the sun becomes 270° and neap tide of third quarter is formed. Finally, when the moon reaches to its new moon position, after about 29 ½ days of the previous new moon, both of them have the same celestial longitude and the spring tide of new moon is again formed making the beginning of another cycle of spring and neap tides.

Other Effects

The length of the tidal day, assumed to be 24 hours and 50.5 minutes is not constant because of (i) varying relative positions of the sun and moon, (ii) relative attraction of the sun and moon, (iii) ellipticity of the orbit of the moon (assumed circular earlier) and earth, (v) declination (or deviation from the plane of equator) of the sun and the moon, (v) effects of the land masses and (vi) deviation of the shape of the earth from the spheroid. Due to these, the high water at a place may not occur exactly at the moon’s upper or lower transit. The effect of varying relative positions of the sun and moon gives rise to what are known as priming of tide and lagging of tide.

At the new moon position, the crest of the composite tide is under the moon and normal tide is formed. For the positions of the moon between new moon and first quarter, the high water at any place occurs before the moon's transit, the interval between successive high

water is less than the average of 12 hours 25 minutes and the tide is said to prime. For positions of moon between the first quarter and the full moon , the high water at any place occurs after the moon transits, the interval between successive high water is more than the average , and tide is said to lag. Similarly, between full moon and 3rd quarter position, the tide primes while between the 3rd quarter and full moon position, the tide lags. At first quarter, full moon and third quarter position of moon, normal tide occurs.

Due to the several assumptions made in the equilibrium theory, and due to several other factors affecting the magnitude and period of tides, close agreement between the results of the theory, and the actual field observations is not available. Due to obstruction of land masses, tide may be heaped up at some places. Due to inertia and viscosity of sea water, equilibrium figure is not achieved instantaneously. Hence prediction of the tides at a place must be based largely on observations.

Mean Sea Level and Datum

For all important surveys, the datum selected is the mean sea level at a certain place. The mean sea level may be defined as the mean level of the sea, obtained by taking the mean of all the height of the tide, as measured at hourly intervals over some stated period covering a whole number of complete tides, The mean sea level, defined above shows appreciable variations from day to day, from month to month and from year to year. Hence the period for which observations should be taken depends upon the purpose for which levels are required. The daily changes in the level of sea may be more. The monthly changes are more or less periodic. The mean sea level in particular month may be low while it may be high in some other moths. Mean sea level may also show appreciable variations in its annual values. Due to variations in the annual values and due to greater accuracy needed in modern geodetic levelling, it is essential to base the mean sea level on observations extending over a period of about 19 years. During this period, the moon's nodes complete one entire revolution. The height of mean sea level so determined is referred to the datum of tide gauge at which the observations are taken. The point or place at which these observations are taken is known as a tidal station. If the observations are taken on two stations, situated say at a distance of 200 to

500 kms on an open coast, one of the station is called primary tidal station while the other is called secondary tidal station. Both the stations may then be connected by a line of levels.

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Photogrammetric surveying

Introduction

Photogram metric surveying or photogrammetry is the science and art of obtaining accurate measurements by use of photographs, for various purposes such as the construction of planimetric and topographic maps, classification of soils, interpretation of geology, acquisition of military intelligence and the preparation of composite pictures of the ground. The photographs are taken either from the air or from station on the ground. Terrestrial photogrammetry is that Brach of photogrammetry wherein photographs are taken from a fixed position on or near the ground. Aerial photogrammetry is that branch of photogrammetry wherein the photographs are taken by a camera mounted in an aircraft flying over the area. Mapping from aerial photographs is the best mapping procedures yet developed for large projects, and are invaluable for military intelligence. The major users of aerial mapping methods are the civilian and military mapping agencies of the Government.

The conception of using photographs for purposes of measurement appears to have originated with the experiments of Aime Laussedat of the Corps of the French Army, who in 1851 produced the first measuring camera. He developed the mathematical analysis of photographs as perspective projections, thereby increasing their application to topography. Aerial photography from balloons probably began about 1858. Almost concurrently (1858), but independently of Laussedat, Meydenbauer in Germany carried out the first experiments in making critical measurements of architectural details by the intersection method in the basis of two photographs of the building. The ground photography was perfected in Canada by Capt. Deville, then Surveyor General of Canada in 1888. In Germany, most of the progress on the theoretical side was due to Hauck.

In 1901, Pulfrich in Jena introduced the stereoscopic principle of measurement and designed the stereo comparator. The stereoaitograph was designed (1909) at the Zeiss workshops in Jena, and this opened a wide field of practical application. Scheimpflug, an Australian captain, developed the idea of double projector in 1898. He originated the theory of perspective transformation and incorporated its principles in the photoperspecto graph. He also gave the idea of radial triangulation. His work paved the way for the development of aerial surveying and aerial photogrammetry.

In 1875, Oscar Messter built the first aerial camera in Germany and J.W.Bagloy and A.Brock produced the first aerial cameras in U.S.A. In 1923, Bauersfeld designed the Zeiss stereoplanigraph. The optical industries of Germany, Switzerland, Italy and France, and later also those of the U.S.A and U.S.S.R. took up the manufacture and constant further development of the cameras and plotting instruments. In World War II, both the sides made extensive use of aerial photographs for their military operations. World War II gave rise to new developments of aerial photography techniques, such as the application of radio control to photoflight navigation, the new wide-angle lenses and devices to achieve true vertical photographs.

Principles behind terrestrial photogrammetry.

The principle of terrestrial photogrammetry was improved upon and perfected by Capt. Deville, then Surveyor General of Canada in 1888. In terrestrial photogrammetry, photographs are taken with the camera supported on the ground. The photographs are taken by means of a photo theodolite which is a combination of a camera and a theodolite. Maps are then compiled from the photographs.

The principle underlying the method of terrestrial photogrammetry is exactly similar to that of plane table surveying, i.e. if the directions of same objects photographed from two extremities of measured base are known, their position can be located by the intersection of two rays to the same object. However, the difference between this and plane tabling is that more details are at once obtained from the photographs and their subsequent plotting etc. is done by the office while in plane tabling all the detailing is done in the field itself.

Thus in Fig , A and B are the two stations at the ends of base AB. The arrows indicate the directions of horizontal pointing (in plan) of the camera. For each pair of pictures taken from the two ends, the camera axis is kept parallel to each other. From economy and speed point of view, minimum number of photographs should be used to cover the whole area and to achieve this, it is essential to select the best positions of the camera stations. A thorough study of the area should be done from the existing maps, and a ground reconnaissance should be made. The selection of actual stations depends upon the size and ruggedness of the area to be surveyed. The camera should be directed downward rather than upward, and the stations should be at the higher points on the area.

The terrestrial photogrammetry can be divided into two branches:

(i) Plane-table photogrammetry.

(ii) Terrestrial stereo photogrammetry

The plane table photogrammetry consists essentially in taking a photograph of the area to be mapped from each of the two or three stations. The photograph perpendiculars may be oriented at any angle to the base, but usually from an acute angle with the latter. The main difficulty arises in the identifications of image points in a pair of photographs. In the case of homogeneous areas of sand or grass, identification becomes impossible. The principles of stereo photogrammetry, however, produced the remedy.

In terrestrial stereo photogrammetry, due to considerable improvement of accuracy obtained by the stereoscopic measurement of pairs of photographs, the camera base and the angles of intersection of the datum rays to the points to be measured can be considerably reduced since the camera axes at the two stations exhibit great similarity to each other. The image points which are parallactically displaced relative to each other in the two photographs are fused to a single spatial image by the stereoscopic measurement.

Introduction

- The photogrammetry has been derived from three Greek words:
    - Photos: means light
    - Gramma: means something drawn or written
    - Metron: means to measure
- This definition, over the years, has been enhanced to include interpretation as well as measurement with photographs.

Definition

The art, science, and technology of obtaining reliable information about physical objects and the environment through process of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and phenomenon (American Society of Photogrammetry, Slama).

- Originally photogrammetry was considered as the science of analysing only photographs.
- But now it also includes analysis of other records as well, such as radiated acoustical energy patterns and magnetic phenomenon.

Definition of photogrammetry includes two areas:

(1) Metric:

It involves making precise measurements from photos and other information source to determine, in general, relative location of points. Most common application: preparation of plannimetric and topographic maps.

(2) Interpretative:

It involves recognition and identification of objects and judging their significance through careful and systematic analysis. It includes photographic interpretation which is the study of photographic images. It also includes interpretation of images acquired in Remote Sensing using photographic images, MSS, Infrared, TIR, SLAR etc.

Definitions

Aerial photogrammetry

Photographs of terrain in an area are taken by a precision photogrammetric camera mounted in an aircraft flying over an area.

Terrestrial photogrammetry

Photographs of terrain in an area are taken from fixed and usually known position or near the ground and with the camera axis horizontal or nearly so. Photo-interpretationAerial/terrestrial photographs are used to evaluate, analyse, and classify and interpret images of objects which can be seen on the photographs.

Applications of photogrammetry

Photogrammetry has been used in several areas. The following description give an overview of various applications areas of photogrammetry (Rampal, 1982)

(1) Geology:

Structural geology, investigation of water resources, analysis of thermal patterns on earth's surface, geomorphological studies including investigations of shore features.

- engineering geology
- stratigraphics studies
- general geologic applications
- study of luminescence phenomenon
- recording and analysis of catastrophic events
- earthquakes, floods, and eruption.

(2) Forestry:

Timber inventories, cover maps, acreage studies

(3) Agriculture

Soil type, soil conservation, crop planting, crop disease, crop-acreage.

(4) Design and construction

Data needed for site and route studies specifically for alternate schemes for photogrammetry. Used in design and construction of dams, bridges, transmission lines.

(5) Planning of cities and highways

New highway locations, detailed design of construction contracts, planning of civic improvements.

(6) Cadastre

Cadastral problems such as determination of land lines for assessment of taxes. Large scale cadastral maps are prepared for reapportionment of land.

(7) Environmental Studies

Land-use studies.

(8) Exploration

To identify and zero down to areas for various exploratory jobs such as oil or mineral exploration.

(9) Military intelligence

Reconnaissance for deployment of forces, planning manoeuvres, assessing effects of operation, initiating problems related to topography, terrain conditions or works.

(10) Medicine and surgery

Stereoscopic measurements on human body, X-ray photogrammetry in location of foreign material in body and location and examinations of fractures and grooves, biostereometrics.

(11) Miscellaneous

Crime detection, traffic studies, oceanography, meteorological observation, Architectural and archaeological surveys, contouring beef cattle for animal husbandry etc.

Classification of Photographs

The following paragraphs give details of classification of photographs used in different applications

(1) On the basis of the alignment of optical axis

(a) Vertical : If optical axis of the camera is held in a vertical or nearly vertical position
(b) Tilted : An unintentional and unavoidable inclination of the optical axis from vertical produces a tilted photograph.
(c) Oblique : Photograph taken with the optical axis intentionally inclined to the vertical.

Following are different types of oblique photographs:

(i) High oblique: Oblique which contains the apparent horizon of the earth.
(ii) Low oblique: Apparent horizon does not appear.
(iii) Trimetrogon: Combination of a vertical and two oblique photographs in which the central photo is vertical and side ones are oblique. Mainly used for reconnaissance.
(iv) Convergent: A pair of low obliques taken in sequence along a flight line in such a manner that both the photographs cover essentially the same area with their axes tilted at a fixed inclination from the vertical in opposite directions in the direction of flight line so that the forward exposure of the first station forms a stereo-pair with the backward exposure of the next station.

Comparison of photographs

Table-1

Type of photo	Vertical	Low oblique	High oblique
Characteristics	Tilt < 3^o	Horizon does not appear	Horizon appears
Coverage	Least	Less	Greatest
Area	Rectangular	Trapezoidal	Trapezoidal
Scale	Uniform if flat	Decreases from foreground to background	Decreases from foreground to background
Difference with map	Least	Less	Greatest
Advantage	Easiest to map	-	Economical and illustrative

(2). On the basis of the scale

(a) Small scale - 1 : 30000 to 1 : 250000, used for rigorous mapping of undeveloped terrain and reconnaissance of vast areas.
(b) Medium scale - 1 : 5000 to 1 : 30000, used for reconnaissance, preliminary survey and intelligence purpose.
(c) Large scale - 1 : 1000 to 1 : 5000, used for engineering survey, exploring mines.

(3). On the basis of angle of coverage

The angle of coverage is defined as the angle, the diagonal of the negative format subtends at the real node of the lens of the apex angle of the cone of rays passing through the front nodal point of the lens.

Table-1

Name	Coverage angle	Format size (cm)	Focal length (cm)
Standard or normal angle	60^o	(i) 18 (ii) 23	(i) 21 (ii) 30
Wide angle	90^o	(i) 18 (ii) 23	(i) 11.5 (ii) 15
Super wide or ultra wide angle	120^o	(i) 18 (ii) 23	(i) 7 (ii) 8.8
Narrow angle	< 60^o		

Information recorded on photographs

The following information is recorded on a typical aerial photograph

1. Fiducial marks for determination of principal points.
2. Altimeter recording to find flying height at the moment of exposure.
3. Watch recording giving the time of exposure.
4. Level bubble recording indicating tilt of camera axis.
5. Principal distance for determining the scale of photograph.
6. Number of photograph, the strip and specification no. for easy handling and indexing.
7. Number of camera to obtain camera calibration report.
8. Date of photograph

ntroductory definitions for photographs

Vertical photograph
A photograph taken with the optical axis coinciding with direction of gravity.
Tilted or near vertical
Photograph taken with optical axis unintentionally tilted from vertical by a small amount (usually < 3°)
Focal length (f)
Distance from front nodal point to the plane of the photograph (from near nodal point to image plane).
Exposure station (point L)
Position of frontal nodal point at the instant of exposure (L)
Flying height (H)
Elevation of exposure station above sea level or above selected datum.

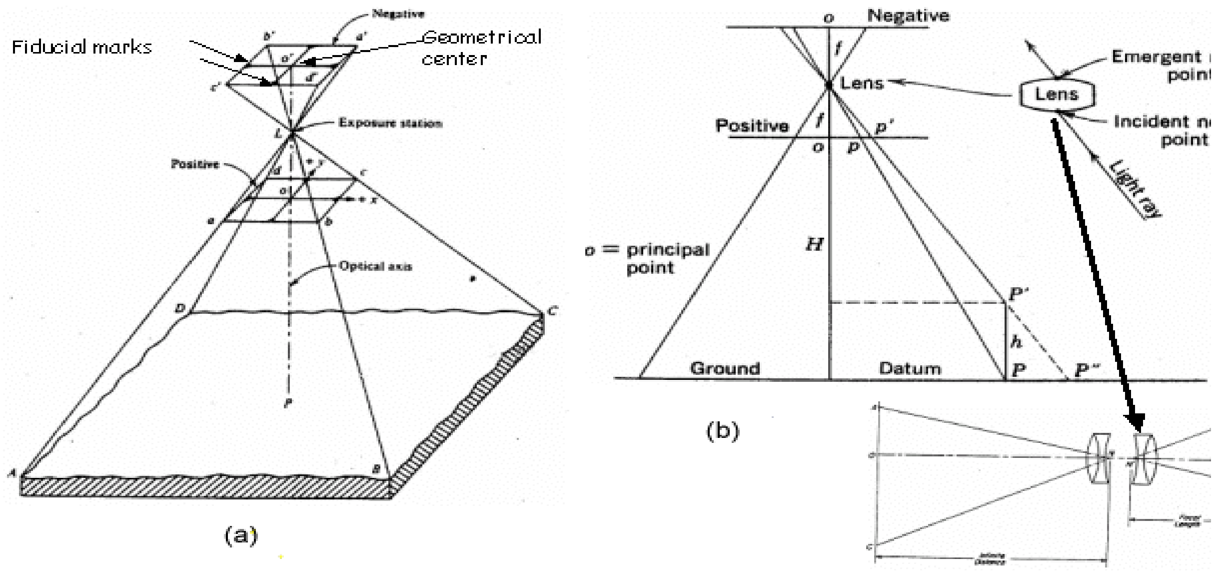

Figure 3: Aerial photographs showing various elements as defined

(a) Elements of vertical photograph (b) Section of imaging geometry showing various elements.

X-axis
Line on photo between opposite collimation marks, which most nearly parallels the flight direction.
Y-axis
Line normal to x-axis and join opposite collimation marks.

Principle Point (o):

The point where the perpendicular dropped from the front nodal point strikes the photograph or the point in which camera axis pierces the image plane.

Camera Axis

It is a ray of light incident at front nodal point in the object space and at right angles to the image plane.

Fiducial marks or collimation marks:

Index marks usually four in number, rigidly connected with the camera lens through the camera body and forming images on the photographs to which the position on the photograph can be referred.

Photograpgh Center:

The geometrical center of the photograph as defined by the intersection of the lines joining the fiducial marks.

Format
It is the planar dimension of photograph (9" x 9", 7" x 7", 23 cm x 23 cm, 18 cm x 18 cm, 15 cm x 15 cm).

Photogram
Photograph taken with a photogrammetric camera having fixed distance between negative plane and lens and equipped with fiducial or collimating marks. For photograms the bundle of rays on the object side at the moment of exposure can be reproduced. To achieve this the following data known as the elements of interior orientation must be known:

- Calibrated focal length
- Lens distortion data
- Location of the principal point with reference to the photograph center (normally these

two coincide)

Hence, a photogram is a photograph with known interior orientation

Difference between near vertical photographs and map

1. Production : Quickest possible and most economical method of obtaining information about areas of interest. Boon for difficult areas. Enlarging and reducing easier in case of photographs than maps.
2. Content : Map gives an abstract representation of surface with a selection from nearly infinite number of features on ground. Photograph shows images of surface itself. Maps often represent non-visible phenomenon (like text) This may make interpretation difficult for photograph. Special films like color and infrared films can bring about special features of terrain.
3. Metric accuracy: Map is geometrically correct representation, photos are generally not. Maps are orthogonal projections, photo is central projection. Map has same scale throughout photo has variable scale. Bearing on photographs may not be true.
4. Training requirement: A little training and familiarity with the particular legend used in the map enables proper use of map. Photo-interpretation requires special training although initially it may appear quite simple as it gives a faithful representation of ground.

Perspective geometry of vertical photographs

- The figure shows camera axis SP of a camera, perpendicular to the photographic plane ABCD, tilted at angle θ from the vertical at exposure so that the plane of the photograph itself is inclined by an angle θ to the horizontal plane CDEF, representing a level ground. S represents perspective center as defined by the inner or rear node of the lens system.

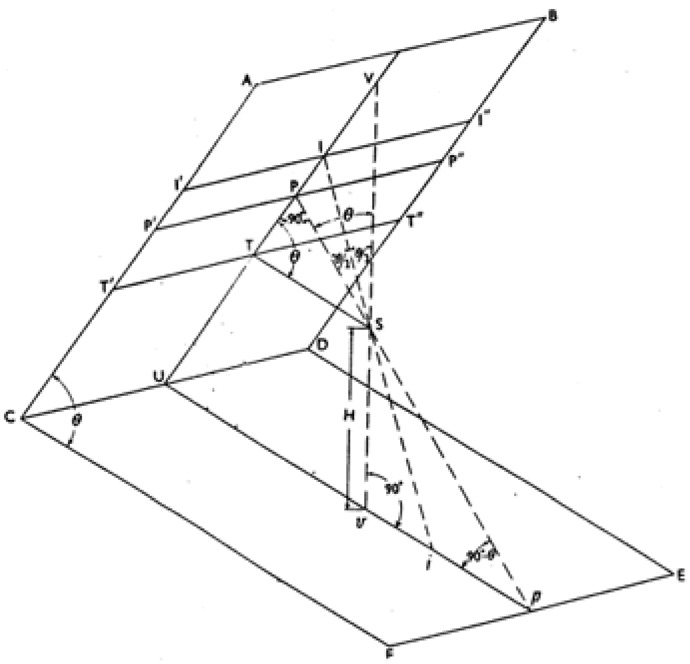

Figure 2: Perspective geometry of aerial photo

- One can identify pair of points v and V (ground and photo nadir point), i and I (ground and photo isocentre), p and P (ground and photo principal point) on photographic plane and ground plane respectively. These point pairs are called homologous pair. In fact any corresponding point pair on photo and ground plane is a homologue pair.

Perspective Axis

- Line CD where the two plane meet is called the perspective axis or horizontal trace.

Principal lines

- A line UP drawn perpendicular to the perspective axis along the photograph plane. This projects as Up on ground plane (CDEF) and is also perpendicular to perspective axis. These lines are called the photo and ground principal lines respectively.

Principal plane

- A plane containing P, V, and S is called the principal plane. Photo principal line (VP) and ground principal lines (vp) are contained in this plane.

Plate parallels or plate horizontals

- Horizontal lines drawn in the photo plane are called plate parallels or plate horizontals. Line iI is the bisector of tilt angle θ. It meets photo plane at i and ground plane at I. These points are known as photo isocentre and ground isocentre respectively.
- For a truly vertical photograph taken from exposure station S, various photo plate parallels are lines I'I", P'P", etc. The plate parallel through I is also called isometric plate parallel.

Scale of a vertical photograph

Due to perspective geometry of photographs, the scale of photograph varies as a function of focal length, flying height, and the reduced level of terrain over a certain reference datum. In figure 2, for a vertical photograph, L is exposure station, f is its focal length, H is the flying height above datum, h represents the height of ground point A above datum. Point A is imaged as a in the photograph. From the construction and using similar triangles Loa and LO_AA, we can write the following relations (Wolf and Dewitt, 2000)

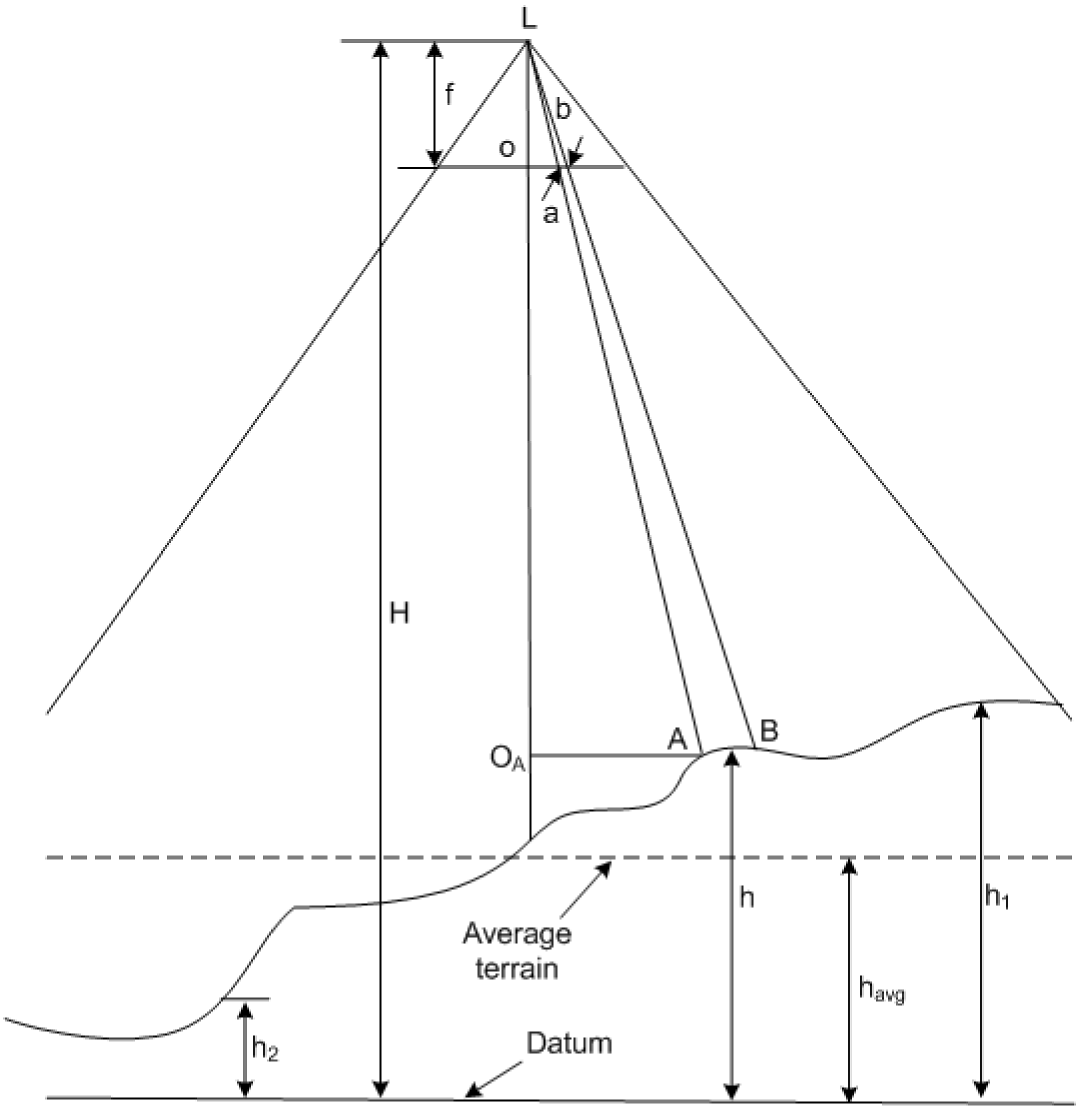

Figure 3: Scale for vertical photo

h_{avg} Average terrain elevation
S_{avg} *Best single scale to use for a photo or group of photographs*

$$Scale = \frac{ao}{AO_A} = \frac{f}{H - h_A}$$

$$Datum\ scale = S_d = \frac{f}{H}$$

$$Average\ scale = S_{avg} = \frac{f}{H - h_{avg}}$$

Determination of Scale of photograph

Scale of photograph can be determined by various methods such as

1. By using known full length and altimeter reading, the datum scale can be found.
2. Any scale can be determined if h_{avg} known. h_{avg} can be obtained from a topographic map.
3. By comparing length of the line on the photo with the corresponding ground length. To arrive at fairly representative scale for entire photo, get several lines in different area and the average of various scales can be adopted.
4. Use the formula

$$\frac{\text{Photo scale}}{\text{Map scale}} = \frac{\text{Photo distance}}{\text{Map distance}}$$

Scale along plate parallels

Referring to figure 1, the scale along various plate parallels are as follows:

1. Scale through the plate parallels passing through principal point, *P* with *q* as tilt angle

$$S_p = \frac{SP}{Sp} = \frac{f}{H\sec\theta}$$

2. Scale along an isometric parallel through nadir point, *V*

$$S_n = \frac{SV}{Sv} = \frac{f\sec\theta}{H}$$

3. Scale along an isometric parallel through isocentre *I*

$$S_i = \frac{SI}{Si} = \frac{f\sec(\theta/2)}{H\sec(\theta/2)} = \frac{f}{H}$$

This shows that the scale along plate parallel through isocentre of a tilted photo is same as that over the whole surface of a vertical photo if ground surface is plane. For any other plate parallel, scale will depend on the tilt angle. Also, the scale along any plate parallel is constant.

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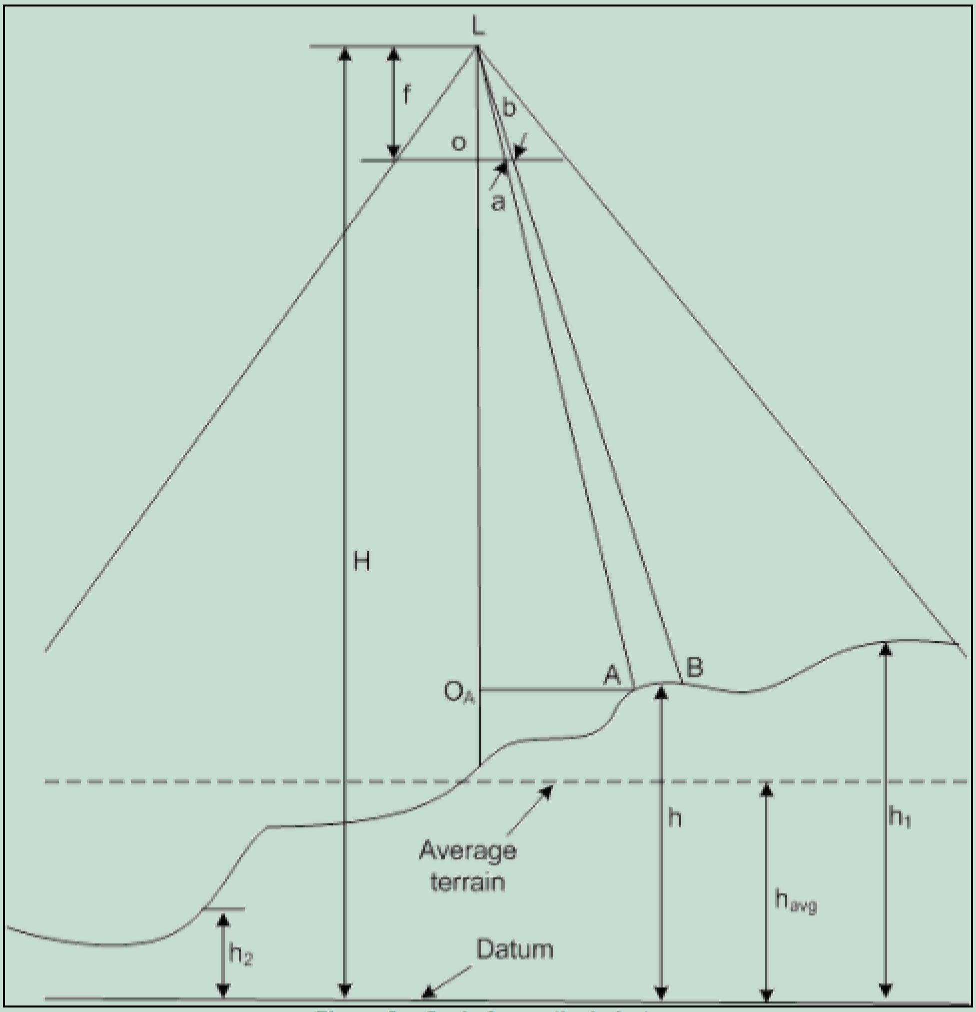

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Ground co-ordinates for vertical photographs

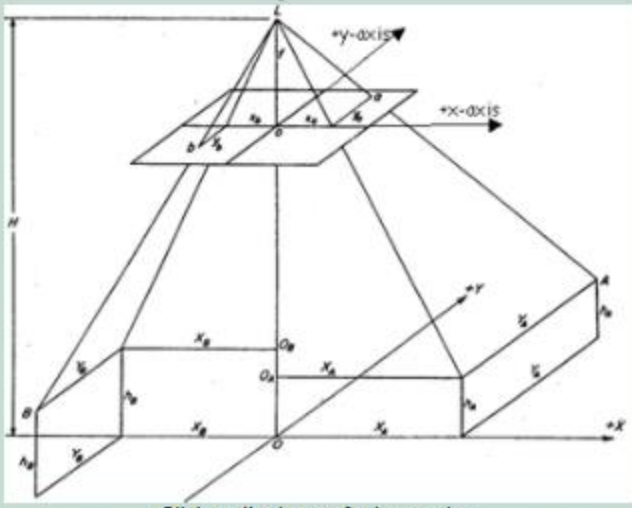
In figure 3, *X* and *Y* are ground co-ordinates with respect to a set of axes whose directions are parallel with the photographic axes and whose origin is directly below the exposure station, x and y indicate x and y photo coordinates with respect

$$\frac{Lo}{LO_A} = \frac{x_a}{X_A} = \frac{y_a}{Y_A} = \frac{f}{H-h_A}$$

$$\frac{Lo}{LO_B} = \frac{x_b}{X_B} = \frac{y_b}{Y_A} = \frac{f}{H-h_B}$$

$$X = \frac{H-h}{f}.x$$

$$Y = \frac{H-h}{f}.y$$



Click on the image for larger view

Figure 3: Ground coordinates from vertical photographs

Flying height for vertical photographs

The flying height can be calculated by two approaches

- Direct
- Indirect

Direct Method

In this method, if the ground coordinates of two points, A and B are given (X_A, Y_A) and (X_B, Y_B), then a quadratic equation can be formed to derive the flying height as given below:

$$D^2 = (\text{length of line})^2 = (X_A - X_B)^2 + (Y_B - Y_A)^2$$

$$D^2 = \left[\frac{H-h_B}{f}.x_b - \frac{H-h_A}{f}.x_a\right]^2 + \left[\frac{H-h_B}{f}.y_b - \frac{H-h_A}{f}.y_a\right]^2$$

$$aH^2 + bH + c = 0$$

$$H = \frac{-b+\sqrt{b^2-4ac}}{2a}$$

Indirect Method

In this method, one can find the flying height by an iterative approach. For this one can use equations (1) and (2) where h_{AB} = average elevation of points *A*, *B*, H_{app} is approximate height and *AB* = known ground distance

Get H_{app} *by equation*

$$\frac{f}{H_{app} - h_{AB}} = \frac{ab}{AB} \qquad (1)$$

$$\frac{H - h_{AB}}{H_{app} - h_{AB}} = \frac{Correct\ AB}{Computed\ AB} \qquad (2)$$

1. Using Eq. (1), get H_{app}.
2. Using H_{app}, get X_A, X_B, Y_A, Y_B using formulae for measurement of coordinates.
3. Get computed AB using X_A, X_B, Y_A, Y_B.
4. Again use Eq. (2) to get new H value.
5. If the required precision been obtained (i.e. old H_{app} and new H values have converged and do not differ by more than a threshold value), then stop else go to (b) and repeat.

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$$D^2 = \left[\frac{H - h_B}{f}.x_b - \frac{H - h_A}{f}.x_a\right]^2 + \left[\frac{H - h_B}{f}.y_b - \frac{H - h_A}{f}.y_a\right]^2$$

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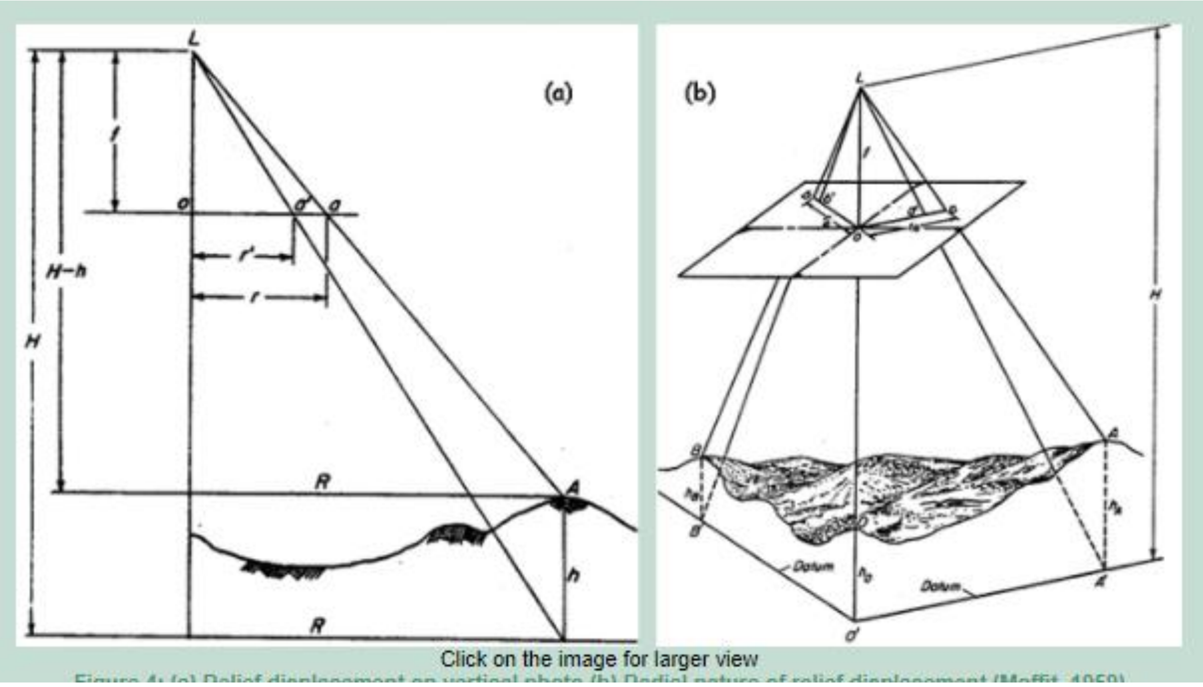
5. If the required precision been obtained (i.e. old H_{app} and new H values have converged and

do not differ by more than a threshold value), then stop else go to (b) and repeat.

Relief displacement on Vertical photographs

- In figure, L is the perspective center of the camera system. A is the point on ground at an elevation of h with respect to the datum. a is the image of ground point on photograph. a' is the location of projected point A' on the datum. These figures indicate that although point A is vertically above point B, their images are not coinciding and are displaced on photographic plane due to relief.



- The displacement of the point a on the photograph from its true position, due to height, is called the height or relief displacement or relief distortion (RD). This distortion is due to the perspective geometry.
- It can also be noticed form these figures that the relief displacement is radial from nadir point. In case of vertical photographs, the nadir point and the principal point coincide. Hence, in this case relief displacement can be considered to be radial from the principal point also. The following derivation using figure 4(a) provides the magnitude of relief distortion

$$\frac{f}{H-h}=\frac{r}{R}$$

$$\frac{f}{H}=\frac{r'}{R}$$

$$r=\frac{Rf}{Hh}\ and\ r'=\frac{Rf}{H}$$

$$R=\frac{r(H-h)}{f}\quad and\quad R=\frac{r'H}{f}$$

$$\text{Relif Distortion}=d=r-r'=\frac{Rf}{H-h}-\frac{Rf}{H}=\frac{Rfh}{H\left(H-h\right)}$$

$$d=r-r'=\frac{rh}{H}=\frac{r'h}{H-h}$$

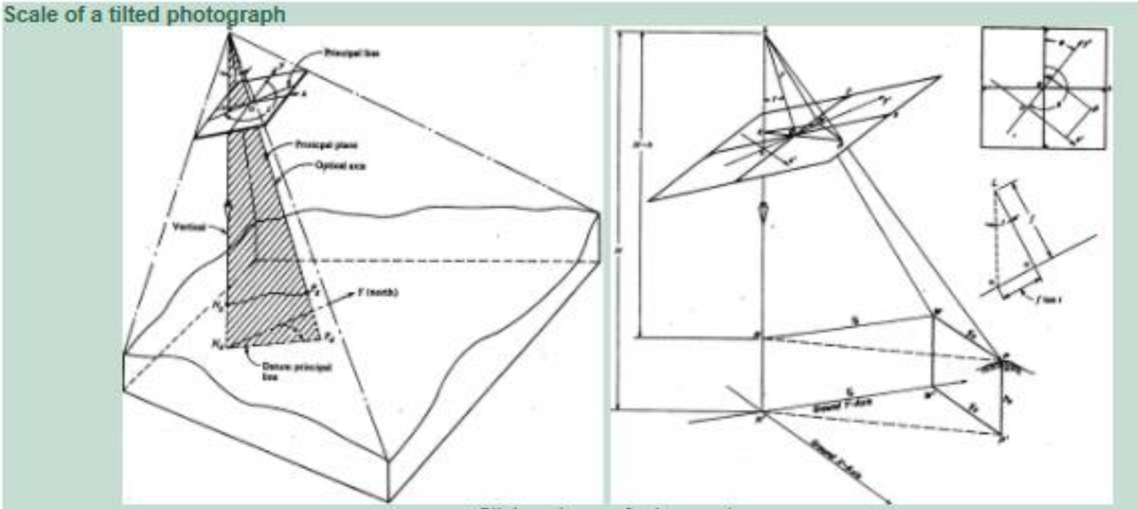
Differentiating d with respect to H gives $\frac{\partial d}{\partial H}=-\frac{rh}{H^2}$

From these equations, the following observations can be made:

1. For a given elevation, RD of a point increases as the distance from principal point increases.
2. Other things being equal, an increase in H decreases RD of a point. (This point is important for mosaicing or combining photographs along common features). For the same reason, for satellite imagery, RD is very small since H is large.
3. If ground point is above datum then RD will be outward or positive; if point below datum then *h* has negative sign and RD will be inward or negative.
4. RD is radial from nadir point regardless of unintentional or accidental tilt of the camera. This is a fundamental concept of photography. It has important implication for photo rectification (this concept will not be discussed in this course).
5. Large relief displacement is objectionable in pure plannimetric mapping by graphical methods but advantageous in contouring with stereoplotting instruments. Most effective way to control *RD* is to select proper flying height.

SCALE OF TILTED PHOTOGRAPH

Scale of a tilted photograph



Click on image for larger view

Figure 1 Tilt-swing-azimuth relationship in tilted photo (Moffit, 1959)

The figure shows a tilted photograph. In this figure, rotate y -axis till the new y -axis or the y '-axis coincides with the principal line having a positive direction *no* as shown (Moffit).
θ = Amount of rotation = 180 ° - s
s = swing angle

- In the same figure, P is the point lying at an elevation h_p above datum, p is its image on tilted photo, x, y ; photo-coordinates, x and y are measured with respect to axes defined by collimation marks. O - principal point, n - nadir point, s - swing angle.
- Since θ is clockwise it must be negative. Co-ordinates in rotated system can be given below. Translating x' axis from o to w, the co-ordinates of p after translation

$$\left.\begin{aligned} x' &= x\cos\theta + y\sin\theta \\ y' &= -x\sin\theta + y\cos\theta \end{aligned}\right\}$$

$$\left.\begin{aligned} x' &= x\cos\theta + y\sin\theta \\ y' &= -x\sin\theta + y\cos\theta + on \\ &= -x\sin\theta + y\cos\theta + f\tan t \end{aligned}\right\} \because on = f.\tan t$$

- Construct line wk perpendicular to line Ln. This is a horizontal line (because Ln is a vertical line). Since wp is perpendicular to the principal line, it is also a horizontal line. Therefore, plane kwp is a horizontal plane.

- Also, $PP' = WW' = NN' = h_p$*(from construction) and therefore, plane* *nwp* *is also horizontal. In* Δ^s *Lkp and LNP*

$$\frac{kp}{Np} = \frac{Lk}{LN} = \frac{Lk}{H-h}$$

- But $Lk = Ln - kn. = f\sec t - y'\sin t$. Therefore,

$$\frac{kp}{NP} = \frac{f\sec t - y'\sin t}{H-h}$$

- But *kp/NP* = scale for a point lying in a plane *kwp*. Since p lies on this plane

$$S_t = \frac{f\sec t - y'\sin t}{H-h}$$

Where
St scale of a tilted photograph at a point whose elevation is h.
f focallength.
t tiltangle
H flyingheightabovedatum.
y' y -co-ordinate of the point with respect to a set of axes whose origin is at the nadir point andwhose y' axis
coincides with the principal line.

Ground co-ordinates on tilted photograph

- Referring to figure 1, the coordinates can be derived by assuming the following situation:

    1. Y-co-ordinate axis lies in the principal plane.

    2. X-co-ordinate axis passes through ground nadir point.

Therefore, ground nadir point is the origin of co-ordinates

wp = x', WP = X

Therefore, scale relationship between plane *kwp* and *KWP* is given by

$$\frac{wp}{WP} = \frac{x'}{X} = \frac{f\sec t - y'\sin t}{H-h}$$

$$\frac{kw}{NW} = \frac{kw}{Y} = \frac{nw\cos t}{Y} = \frac{y'\cos t}{Y} = \frac{f\sec t - y'\sin t}{H-h}$$

$$\left.\begin{aligned} X &= \frac{H-h}{f\sec t - y'\sin t}.x' \\ Y &= \frac{H-h}{f\sec t - y'\sin t}.y'\cos t \end{aligned}\right\}$$

X,Y Ground co-ordinates
x', y' Co-ordinate of point with respect to axes whose origin is at the nadir point and whose y' axis coincides with the principal line
t tilt.

Flying height for tilted photo

- The flying height can be derived in a similar as that for the vertical photograph explained earlier. The procedure is given below:

1. Get photo-coordinates of the end points of control line with respect to axes defined by the collimation marks.
2. Photographic length of line is scaled directly.
3. Use ratio of photographic length to known ground length to get first approximation as

$$\frac{f}{H_{app} - h_{AB}} = \frac{ab}{AB}$$

By using H_{app}*, together with other scale data, one can solve the following equations*

$$\theta = 180° - s$$
$$x' = x\cos\theta + y\sin\theta$$
$$y' = -x\sin\theta + y\cos\theta + f\tan t$$
$$X = \frac{H - h}{f\sec t - y'\sin t}.x'$$
$$Y = \frac{H - h}{f\sec t - y'\sin t}y'\cos t$$

4. Calculate distance based on first set of ground co-ordinates.
5. Compare this computed distance for better approximation of H. Where *H* is new value of flying height, *AB* is the value of length based on first approximation height

$$\frac{H - h_{AB}}{H_{app} - h_{AB}} = \frac{correct\ AB}{computed\ AB}$$

6. Repeat the procedure till computed value of length agrees with the known ground length within the desired precision

RELIEF DISPLACEMENT OF A TILTED PHOTO

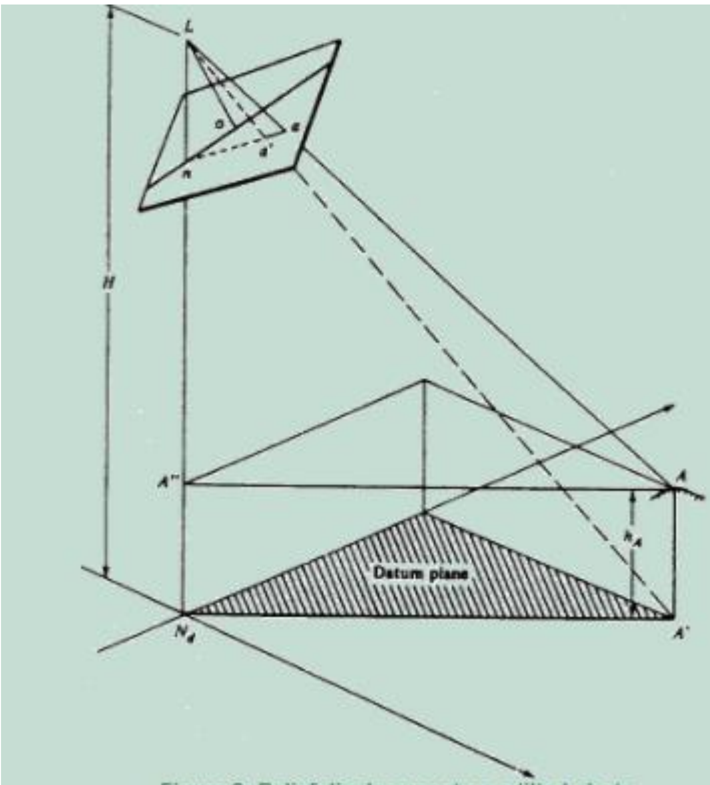


Figure 2: Relief displacement on a tilted photo

1. On a tilted photo relief displacement (a'a) are radial from nadir point (n).
2. The amount of relief displacement depends upon: (i) Flying height (ii) distance from nadir point to image (iii) elevation of ground point (iv) position of point with respect to principal line and to the axis of the tilt.
3. Compared with an equivalent relief displacement on vertical photo, the RD on a tilted photo will be
    - less on the half of the photograph upward from the axis of the tilt,
    - identical for points lying on the axis of the tilt and
    - greater on downward half of the photo.
4. Image displacement due to the tilt (explained later) tends to compensate relief displacement on the upward half and will be added to RD on the downward half.
5. Because tilts in near-vertical photos rarely > 3^o, therefore the value of RD is given with sufficient accuracy with following equation. However, the radial distance should be measured from the nadir point rather than from the principal point

$$d = \frac{rh}{H} = \frac{r'h}{H - h}$$

Tilt displacement (TD) on a Tilted photo

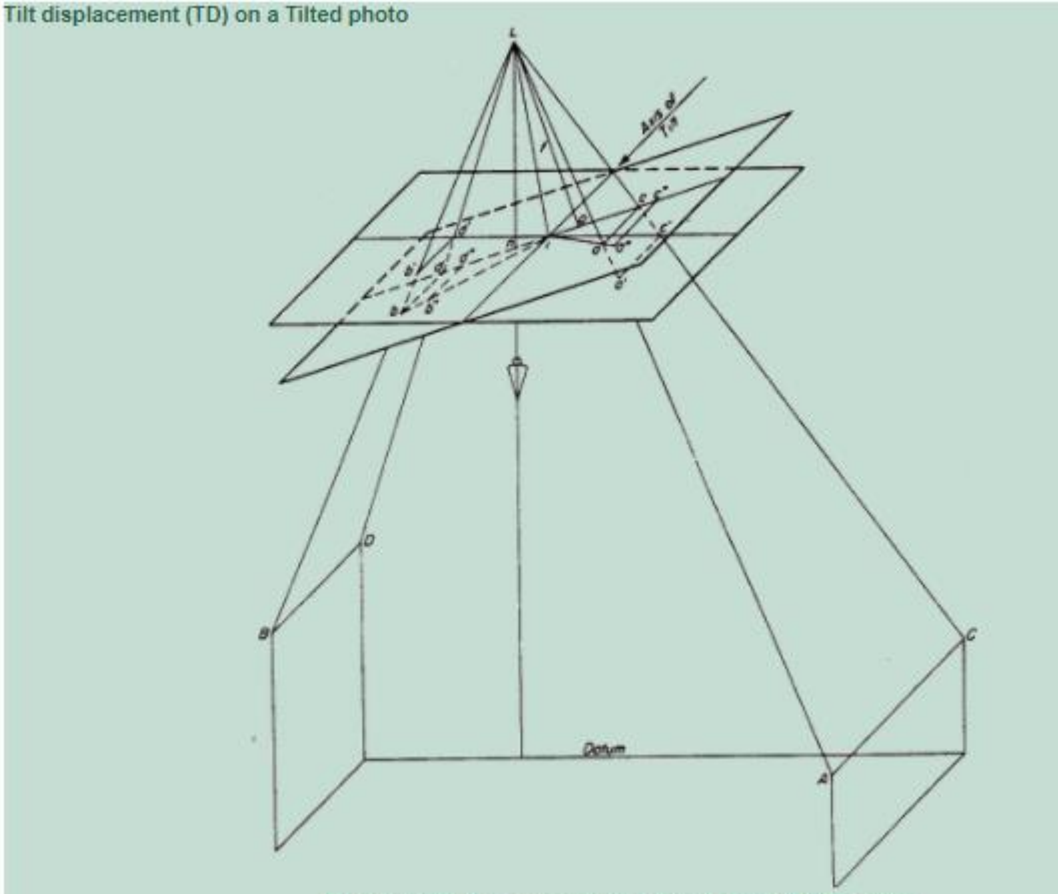


Figure 3: Tilt displacement on a Tilted photo (Moffit, 1959)

1. Tilted and corresponding vertical photo taken from same flying height and with same focal length will match along the axis of the tilt (passing from the isocentre) where they intersect.

2. In the figure, image points A, B, C, D appear as images a, b, c, d on tilted photo, and as a', b', c', d' on an equivalent vertical photo. If we rotate equivalent vertical photograph (EVP) about axis of tilt, till it is in the plane of tilted photo then for any point other than lying on the tilt axis, it will be displaced either outward or inward with respect to equivalent position on a vertical photograph:

    - If point lies on the half of photo upward from the axis of tilt, it will be displaced inwards.

    - If lies on downward half, then displaced outward.

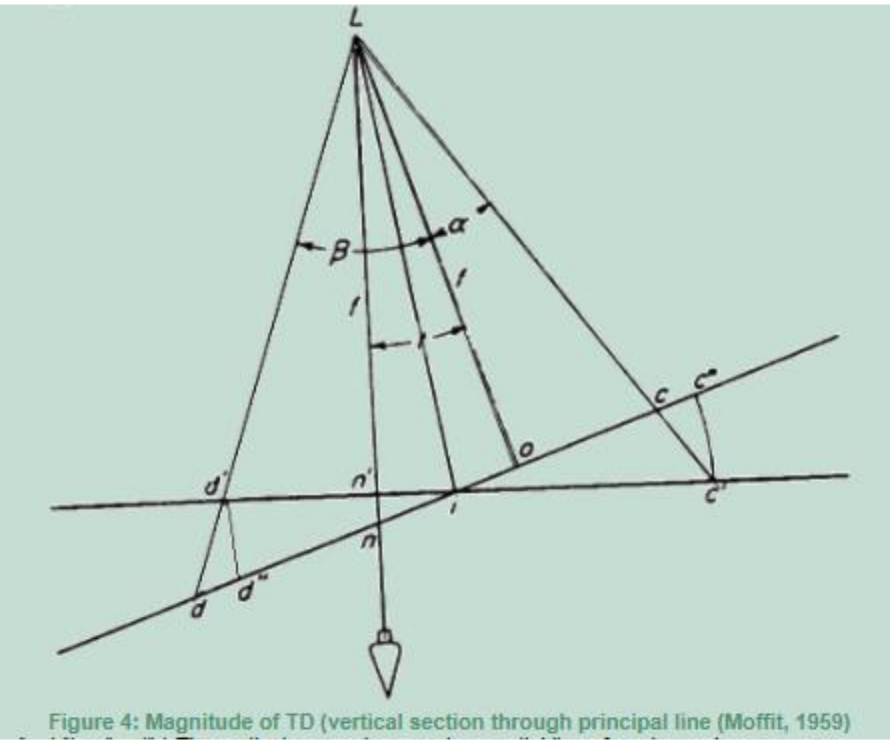


Figure 4: Magnitude of TD (vertical section through principal line (Moffit, 1959)

- The TD is *a"a, b"b, c"c, d"d.* These displacement occur along radial lines from isocentre.
- Although *a* and *c* lie at the same distance from axis of tilt, but the displacement of *a* is greater than that of *c.* This ratio = secant of ∠ *cia*
- Tilt displacement also depends upon the position of point with respect to both the axes of the tilt and the principal line *no.*
- For *c* lying in principal line, TD is given as *c"c*

α is obtained by measuring the distance to the point from a line through the principal point and parallel with the axis of the tilt. When point lies on principal line, as does the point C, the distance is measured from principal point itself to the image point. This distance is then divided by focal length to obtain tan α.

$$\left.\begin{aligned}
c''c &= ic'' - ic = ic' - ic = (n'c' - n'i) - (io + oc)\\
n'c' &= f\tan(t+\alpha)\\
n'i &= Ln'\tan t/2 = f\tan t/2\\
io &= f\tan t/2\\
oc &= f\tan\alpha
\end{aligned}\right\}$$

$$\left.\begin{aligned}
c'c &= \left[f\left(\tan\left(t+\alpha\right)\right) - f\tan t/2\right] - \left[f\tan t/2 + f\tan\alpha\right]\\
c'c &= f\left[\tan\left(t+\alpha\right) - 2\tan t/2 - \tan\alpha\right]
\end{aligned}\right\}$$

The following observations should also be noted for the tilt displacement:

1. Tilt displacement for a point not lying on the principal line is greater than that of a corresponding point on principal line.
2. Above ratio is equal to the secant of angle at isocentre from principal line to the point. Therefore, tilt displacement on upper half of tilted photo is inward and is given as:

$$d_u = f\sec I\left[\tan(\alpha+t) - 2\tan(t/2) - \tan\alpha\right]$$

For a point lying in lower half or nadir point half is outward

$$d_D = f\sec I\left[\tan\beta - \tan(\beta - t) - 2\tan(t/2)\right]$$

I = angle measured at the isocentre from principal line to the point.
t = tilt
α = angle in the principal plane formed at the exposure station.

Another expression for tilt displacement

For a point *b* on upper half of photo and using similar triangles *Lqb* and *ibb'*. *q* is intersection of horizontal line through L meeting extension of tilted line *ab* (Wolf and Dewitt, 2000)

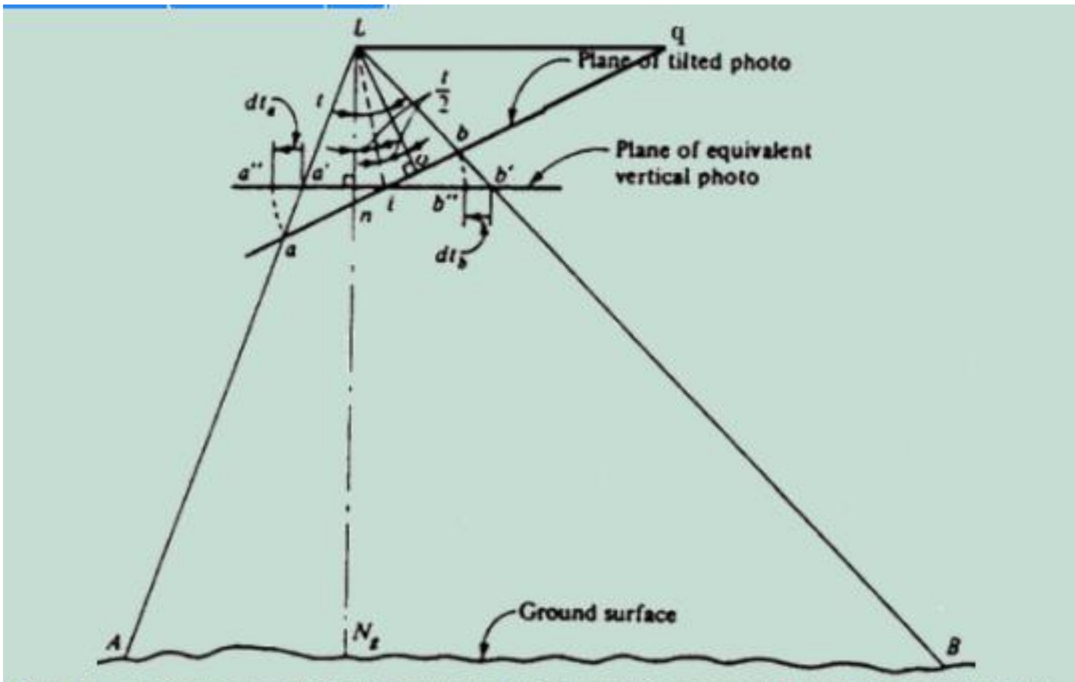


Figure 5 Tilt displacement with respect to an equivalent vertical photograph (Wolf and Dewitt, 2000)

$$d = ib' - r = ib' - ib'' = ib' - ib \; (\because ib = ib'' = r)$$

$$\frac{d}{ib} = \frac{ib'}{ib} - 1$$

$$\frac{d}{ib} = \frac{Lq}{bq} - 1$$

$$= \frac{Lq}{iq - ib} - 1$$

$$= \frac{Lq}{Lq - ib} - 1 \; (\because \angle qLi = \angle qiL = 90 - \frac{t}{2})$$

$$= \frac{f \operatorname{cosec} t}{f \operatorname{cosec} t - ib} - 1$$

$$= \frac{ib \sin t}{f - ib \sin t}$$

$$d = \frac{ib^2 \sin t}{f - ib \sin t}$$

$ia = ib \cos\alpha$

Hence, displacement along ia

$$d = \frac{(ib\cos\alpha)^2 \sin t}{f \pm ib\cos\alpha \sin t}$$

Hence, displacement along ib

$$d' = \frac{(ib)^2 \cos\alpha \sin t}{f \pm ib\cos\alpha \sin t}$$

Denoting $ib = r$

$$d' = \frac{r^2 \cos\alpha \sin t}{f \pm r\cos\alpha \sin t}$$

Stereoscope

- If two photographs taken from two exposure stations L1 and L2 are laid on table so that left photograph is seen by left eye and the right photo is seen with right eye, a 3D-model is obtained. However, viewing in this arrangement is quite difficult due to following reasons:
    - Eye strain and focusing difficulty due to close range.
    - There is disparity in viewing. The eyes are focused at short range on photos lying on table where as the brain perceives parallactic angles which tends to form the stereoscopic model at some depth below the table.
- By using stereoscope, these problems can be alleviated. Different types of stereoscopes are available for different purposes - from pocket (inexpensive) for viewing small area to mirror (expensive) for viewing larger area.

Geometry of overlapping vertical photos

- Figure 5 shows two photographs taken from two exposure stations L_1 (left) and L_2 (right). Ground point A appears in these two photos at a and a' in left and right photos. The image coordinates of these photo points a and a' are (x_a, y_a) and (x'_a, y'_a) respectively.
- A pair of vertical photographs which have some common area imaged is known as a stereopair. This stereopair can be used for estimation of depth by measurement of parallax which will explained next.

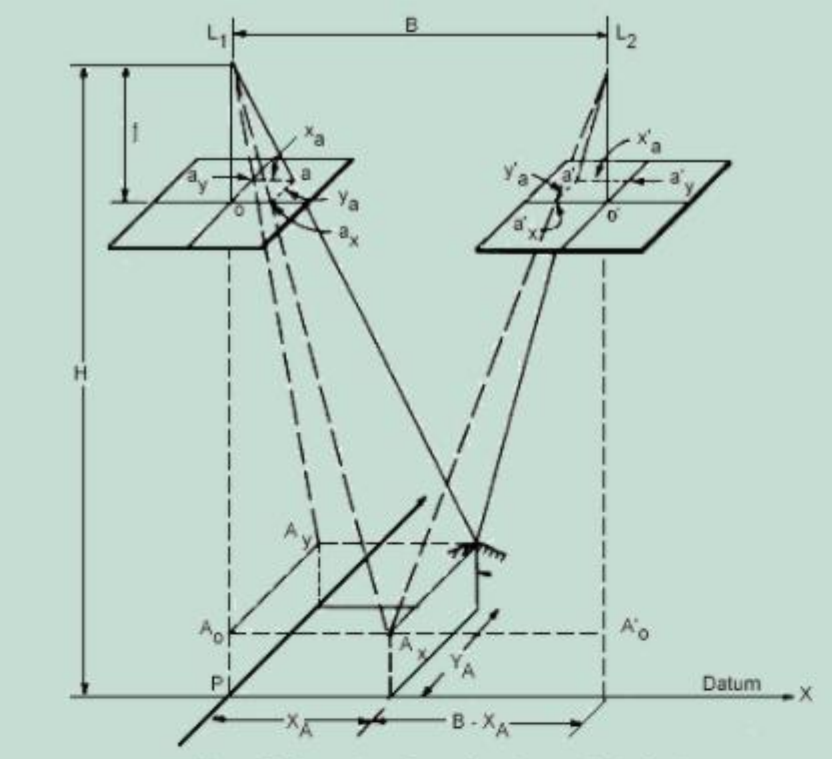


Figure 5: Geometry of overlapping vertical photos

Parallax

- It is the central concept to the geometry of overlapping photographs and is defined as the apparent shift in the position of a body with respect to a reference point caused by a shift in the point of observation
- In photogrammetry, it refers to the relative difference in position of an image point that appears in each of the overlapping photo.

Absolute Parallax:

Absolute X parallax (P_X) is given by (x_l - x_r), where x_l and x_r are x coordinates on left and right photographs respectively

$P_x = x_l - x_r$

Other names:

X-parallax, horizontal parallax, linear parallax, absolute stereo parallax, or just parallax

For the following photograph pair, the parallax is given as follows.

$P_x = x_b - (-x_b')$

It can be noted that the value of parallax has been used with sign

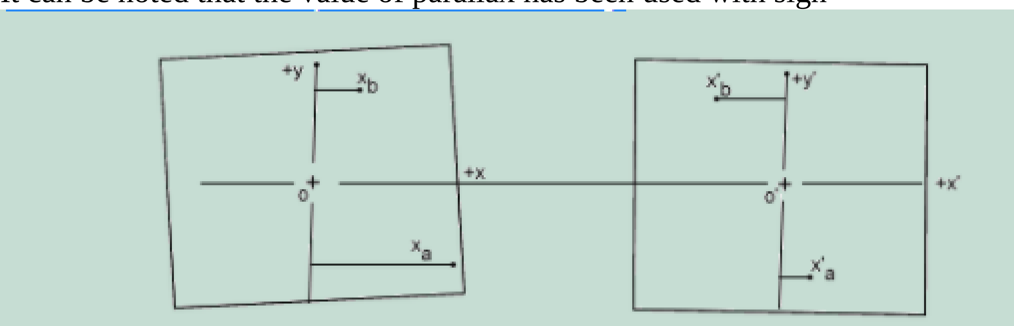


Figure 7: Parallax in photograph pair

$$P = \frac{fB}{H - h}$$

$$\frac{\partial P}{\partial h} = -\frac{fB}{(H - h)^2}$$

$$\frac{b_m}{f} = \frac{B}{H - h}$$

$$fB = b_m \, . \, (H - h)$$

$$\frac{\partial P}{\partial h} = -\frac{b_m}{H - h}; \frac{\partial h}{\partial P} = -\frac{(H - h)}{b_m}$$

$$\partial h = -\frac{(H - h)}{b_m} . \partial P$$

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEEERING

UNIT – III –SURVEYING-II– SCIA1404

REMOTE SENSING

Introduction:

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

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

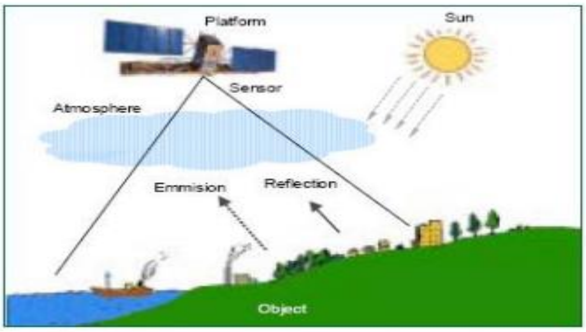


Fig. 1. Schematic representation of remote sensing technique

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

Electromagnetic Energy

Electromagnetic energy or electromagnetic radiation (EMR) is the energy propagated in the form of an advancing interaction between electric and magnetic fields (Sabbins, 1978). It travels with the velocity of light. Visible light, ultraviolet rays, infrared rays, heat, radio waves, X-rays all are different forms of electro-magnetic energy. Electro-magnetic energy (E) can be expressed either in terms of frequency (f) or wave length (λ) of radiation as

E = h c f or h c / λ (1) (1)

where h is Planck's constant (6.626 x 10-34 Joules-sec), c is a constant that expresses the celerity or speed of light (3 x 108 m/sec), f is frequency expressed in Hertz and λ is the wavelength expressed in micro meters (1µm = 10-6 m). As can be observed from equation (1), shorter wavelengths have higher energy content and longer wavelengths have lower energy content. Distribution of the continuum of energy can be plotted as a function of wavelength (or frequency) and is known as the EMR spectrum (Fig. 2).

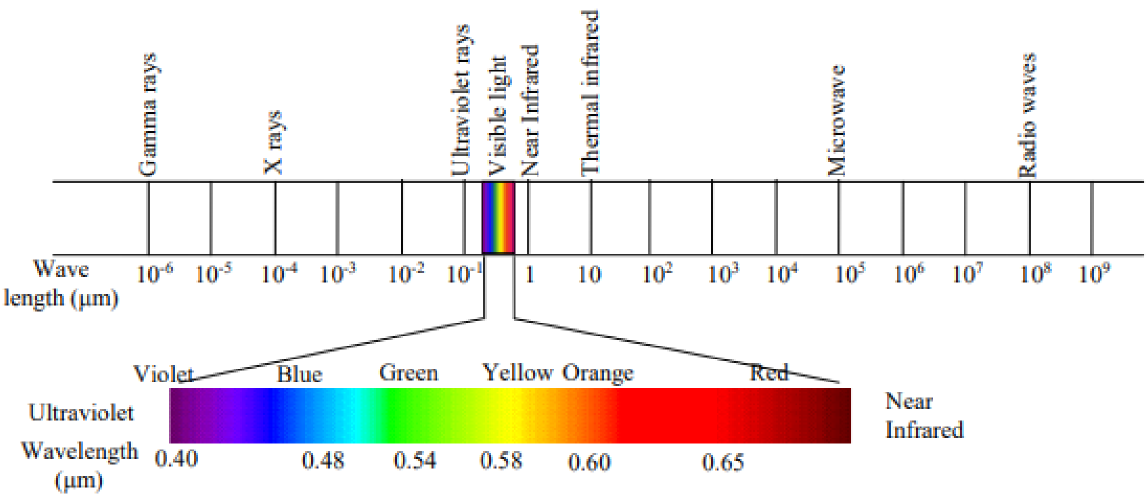


Fig. 2. Electromagnetic radiation spectrum

In remote sensing terminology, electromagnetic energy is generally expressed in terms of wavelength, λ. All matters reflect, emit or radiate a range of electromagnetic energy, depending upon the material characteristics. In remote sensing, it is the measurement of electromagnetic radiation reflected or emitted from an object, is the used to identify the target and to infer its properties. 3. Principles of Remote Sensing Different objects reflect or emit different amounts of energy in different bands of the electromagnetic spectrum. The amount of energy reflected or emitted depends on the properties of both the material and the incident energy (angle of incidence, intensity and wavelength). Detection and discrimination of objects or surface features is done through the uniqueness of the reflected or emitted electromagnetic radiation from the object. A device to detect this reflected or emitted electro-magnetic radiation from an object is called a “sensor” (e.g., cameras and scanners). A vehicle used to carry the sensor is called a “platform” (e.g., aircrafts and satellites).

Main stages in remote sensing are the following.

A.Emission of electromagnetic radiation

The Sun or an EMR source located on the platform

B. Transmission of energy from the source to the object

Absorption and scattering of the EMR while transmission

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

D. Transmission of energy from the object to the sensor

E. Recording of energy by the sensor

Photographic or non-photographic sensors

F. Transmission of the recorded information to the ground station

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

H. Analysis of data

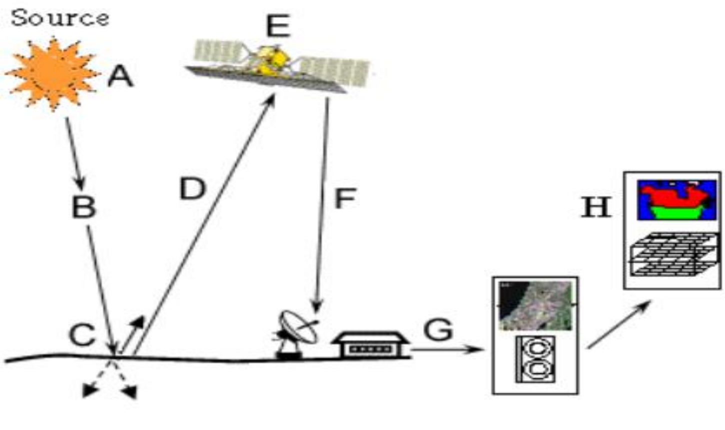


Fig.3 Important stages in remote sensing

EMR SPECTRUM

Introduction

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

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

Electromagnetic energy

Electromagnetic (EM) energy includes all energy moving in a harmonic sinusoidal wave pattern with a velocity equal to that of light. Harmonic pattern means waves occurring at frequent intervals of time. Electromagnetic energy has both electric and magnetic components which oscillate perpendicular to each other and also perpendicular to the direction of energy propagation as shown in Fig. 1. It can be detected only through its interaction with matter.

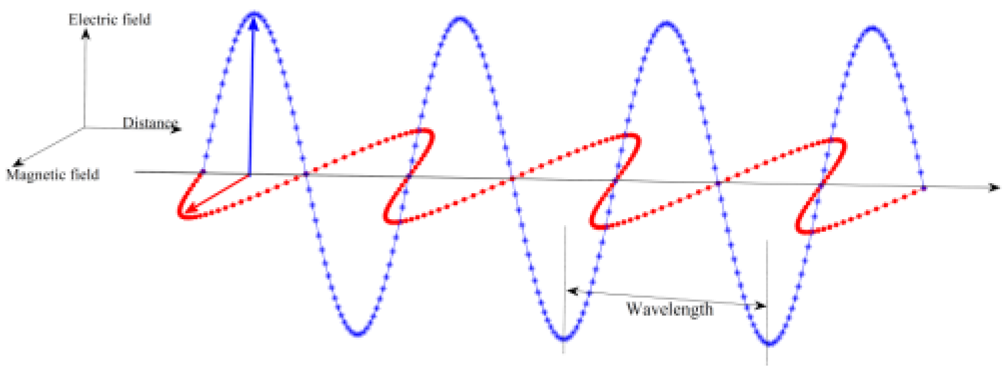
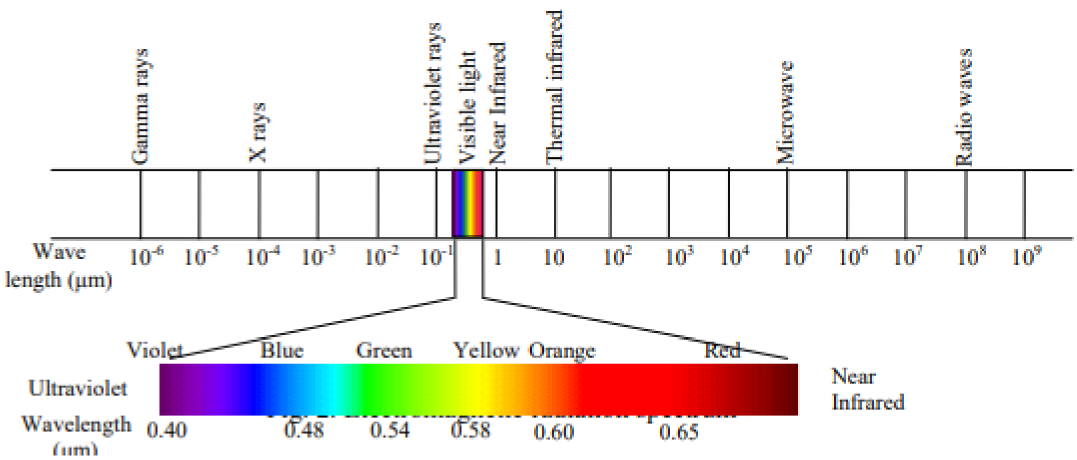


Fig.1. Electromagnetic wave

Examples of different forms of electromagnetic energy: Light, heat etc. EM energy can be described in terms of its velocity, wavelength and frequency. All EM waves travel at the speed of light, c, which is approximately equal to 3×108 m/s. Wavelength λ of EM wave is the distance from any point on one wave to the same position on the next wave (e.g., distance between two successive peaks). The wavelengths commonly used in remote sensing are very small. It is normally expressed in micrometers (μm). 1 μm is equal to 1×10-6 m. Frequency f is the number of waves passing a fixed point per unit time. It is expressed in Hertz (Hz).

The three attributes are related by c = λ f (1) which implies that wavelength and frequency are inversely related since c is a constant. Longer wavelengths have smaller frequency compared to shorter wavelengths. Engineers use frequency attribute to indicate radio and radar regions. However, in remote sensing EM waves are categorized in terms of their wavelength location in the EMR spectrum.

Another important theory about the electromagnetic radiation is the particle theory, which suggests that electromagnetic radiation is composed of discrete units called photons or quanta. 3. Electro-Magnetic Radiation (EMR) spectrum Distribution of the continuum of radiant energy can be plotted as a function of wavelength (or frequency) and is known as the electromagnetic radiation (EMR) spectrum. EMR spectrum is divided into regions or intervals of different wavelengths and such regions are denoted by different names. However, there is no strict dividing line between one spectral region and its adjacent one. Different regions in EMR spectrum are indicated in Fig. 2.



The EM spectrum ranges from gamma rays with very short wavelengths to radio waves with very long wavelengths. The EM spectrum is shown in a logarithmic scale in order to portray shorter wavelengths. The visible region (human eye is sensitive to this region) occupies a very small region in the range between 0.4 and 0.7 μm. The approximate range of color “blue” is 0.4 – 0.5 μm, “green” is 0.5-0.6 μm and “red” is 0.6-0.7 μm. Ultraviolet (UV) region adjoins the blue end of the visible region and infrared (IR) region adjoins the red end. The infrared (IR) region, spanning between 0.7 and 100 μm, has four subintervals of special interest for remote sensing:

(1) Reflected IR (0.7 - 3.0 μm)

(2) Film responsive subset,

the photographic IR (0.7 - 0.9 μm) (3) and (4) Thermal bands at (3 - 5 μm) and (8 - 14 μm). Longer wavelength intervals beyond this region are referred in units ranging from 0.1 to 100 cm. The microwave region spreads across 0.1 to 100 cm, which includes all the intervals used by radar systems. The radar systems generate their own active radiation and direct it towards the targets of interest. The details of various regions and the corresponding wavelengths are given in table 1

Table 1

Region	Wavelength (μm)	Remarks
Gamma rays	$< 3\times10^{-5}$	Not available for remote sensing. Incoming radiation is absorbed by the atmosphere
X-ray	3×10^{-5} - 3×10^{-3}	Not available for remote sensing since it is absorbed by atmosphere
Ultraviolet (UV) rays	0.03 - 0.4	Wavelengths less than 0.3 are absorbed by the ozone layer in the upper atmosphere. Wavelengths between 0.3- 0.4 μm are transmitted and termed as "Photographic UV band".
Visible	0.4 - 0.7	Detectable with film and photodetectors.
Infrared (IR)	0.7 - 100	Atmospheric windows exist which allows maximum transmission. Portion between 0.7 and 0.9 μm is called photographic IR band, since it is detectable with film. Two principal atmospheric windows exist in the thermal IR region (3 - 5 μm and 8 - 14 μm).
Microwave	10^3 - 10^6	Can penetrate rain, fog and clouds. Both active and passive remote sensing is possible. Radar uses wavelength in this range.
Radio	$> 10^6$	Have the longest wavelength. Used for remote sensing by some radars.

Energy in the gamma rays, X-rays and most of the UV rays are absorbed by the Earth's atmosphere and hence not used in remote sensing. Most of the remote sensing systems

Energy sources and radiation principles

Solar radiation Primary source of energy that illuminates different features on the earth surface is the Sun. Solar radiation (also called insolation) arrives at the Earth at wavelengths determined by the photosphere temperature of the sun (peaking near 5,600 °C). Although the Sun produces electromagnetic radiation in a wide range of wavelengths, the amount of energy it produces is not uniform across all wavelengths. Fig.3. shows the solar irradiance (power of electromagnetic radiation per unit area incident on a surface) distribution of the Sun. Almost 99% of the solar energy is within the wavelength range of 0.28-4.96 μm. Within this range, 43% is radiated in the visible wavelength region between 0.4-0.7 μm. The maximum energy (E) is available at 0.48 μm wave length, which is in the visible green region.

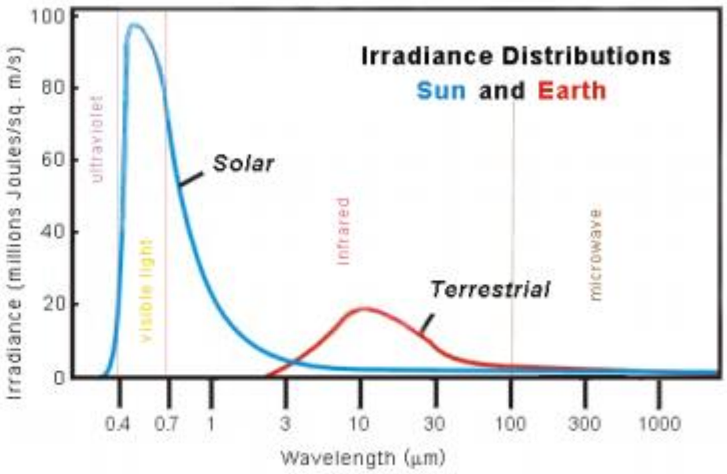


Fig 4.Irradiance distribution of Sun and Earth

Using the particle theory, the energy of a quantum (Q) is considered to be proportional to the frequency. Q = h f (2)

where h is the Plank's constant (6.626 x 10-34 J Sec) and f is the frequency. Using the relationship between c, λ and f (Eq.1), the above equation can be written as follows

Q = h c / λ (3)

The energy per unit quantum is thus inversely proportional to the wavelength. Shorter wavelengths are associated with higher energy compared to the longer wavelengths. For example, longer wavelength electromagnetic radiations like microwave radiations are associated with lower energy compared to the IR regions and are difficult to sense in remote sensing. For operating with long wavelength radiations, the coverage area should be large enough to obtain a detectable signal. 4.2

Radiation from the Earth Other than the solar radiation, the Earth and the terrestrial objects also are the sources of electromagnetic radiation. All matter at temperature above absolute zero (0oK or -273oC) emits electromagnetic radiations continuously. The amount of radiation from such objects is a function of the temperature of the object as shown below. M = σ T4 (4) This is known as Stefan-Boltzmann law. M is the total radiant exitance from the source (Watts / m2), σ is the Stefan-Boltzmann constant (5.6697 x 10-8 Watts m-2 k -4) and T is the absolute temperature of the emitting material in Kelvin. Since the Earth's ambient temperature is about 300 K, it emits electromagnetic radiations, which is maximum in the wavelength region of 9.7 μm, as shown in Fig.3. This is considered as thermal IR radiation. This thermal IR emission from the Earth can be sensed using scanners and radiometers. According to the Stefan-Boltzmann law, the radiant exitance increases rapidly with the temperature. However, this law is applicable for objects that behave as a blackbody. The relationship can be represented as shown below

INTRODUCTION

In many respects, remote sensing can be thought of as a reading process. Using various sensors, we remotely collect data that are analysed to obtain information about the objects, areas or phenomena being investigated. In most cases the sensors are electromagnetic sensors either air-borne or space-borne for inventorying. The sensors record the energy reflected or emitted by the target features. In remote sensing, all radiations traverse through the atmosphere for some distance to reach the sensor. As the radiation passes through the atmosphere, the gases and the particles in the atmosphere interact with them causing changes in the magnitude, wavelength, velocity, direction, and polarization. In this lecture electromagnetic energy interactions in atmosphere are explained

1. Composition of the atmosphere In order to understand the interactions of the electromagnetic radiations with the atmospheric particles, basic knowledge about the composition of the atmosphere is essential. Atmosphere is the gaseous envelop that surrounds the Earth's surface. Much of the gases are concentrated within the lower 100km of the atmosphere. Only 3x10-5 percent of the gases are found above 100 km (Gibbson, 2000)

Table 2 shows the gaseous composition of the Earth's atmosphere

Component	Percentage
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.94
Argon	0.93
Carbon Dioxide (CO_2)	0.0314
Ozone (O_3)	0.00000004

Oxygen and Nitrogen are present in the ratio 1:4, and both together add to 99 percent of the total gaseous composition in the atmosphere. Ozone is present in very small quantities and is mostly concentrated in the atmosphere between 19 and 23km.

In addition to the above gases, the atmosphere also contains water vapor, methane, dust particles, pollen from vegetation, smoke particles etc. Dust particles and pollen from vegetation together form about 50 percent of the total particles present in the atmosphere. Size of these particles in the atmosphere varies from approximately 0.01µm to 100µm.

The gases and the particles present in the atmosphere cause scattering and absorption of the electromagnetic radiation passing through it

Energy Interaction

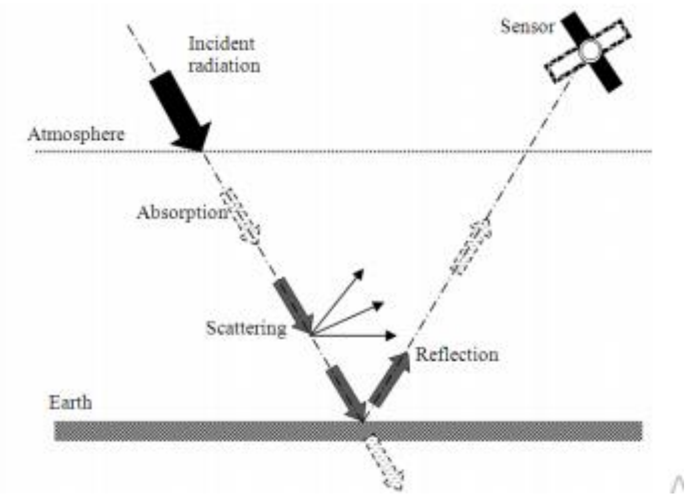


Fig 5.Interaction in the atmosphere

The distance travelled by the radiation through the atmosphere is called the path length. The path length varies depending on the remote sensing techniques and sources.

For example, the path length is twice the thickness of the earth's atmosphere in the case of space photography which uses sunlight as its source. For airborne thermal sensors which use emitted energy from the objects on the earth, the path length is only the length of the one way distance from the Earth's surface to the sensor, and is considerably small.

The effect of atmosphere on the radiation depends on the properties of the radiation such as magnitude and wavelength, atmospheric conditions and also the path length. Intensity and spectral composition of the incident radiation are altered by the atmospheric effects. The interaction of the electromagnetic radiation with the atmospheric particles may be a surface phenomenon (e.g., scattering) or volume phenomenon (e.g., absorption). Scattering and absorption are the main processes that alter the properties of the electromagnetic radiation in the atmosphere.

Scattering

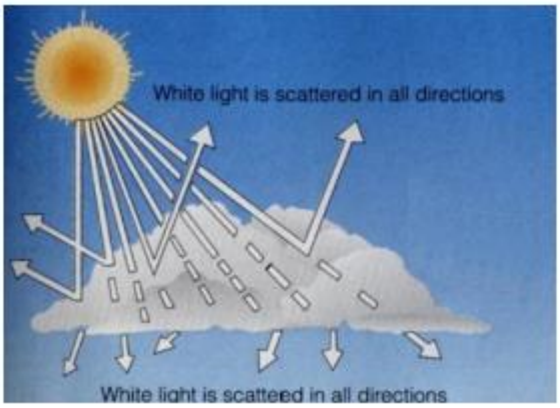


Fig.6 Scattering

There are three different types of scattering:

 Rayleigh scattering

 Mie scattering

 Non-selective scattering

Rayleigh scattering

Rayleigh scattering mainly consists of scattering caused by atmospheric molecules and other tiny particles. This occurs when the particles causing the scattering are much smaller in diameter (less than one tenth) than the wavelengths of radiation interacting with them. Smaller particles present in the atmosphere scatter the shorter wavelengths more compared to the longer wavelengths.

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

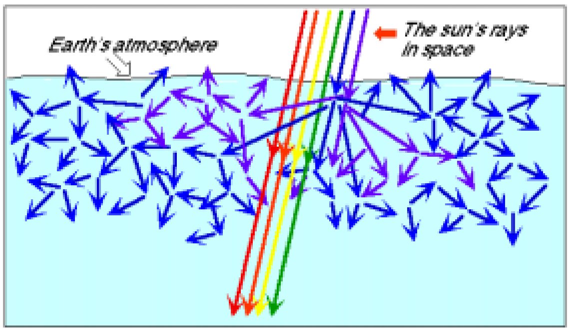


Fig 7. Rayleigh scattering

Rayleigh scattering is also known as selective scattering or molecular scattering.

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

The haze in imagery and the bluish-grey cast in a color image when taken from high altitude are mainly due to Rayleigh scatter.

Mie Scattering

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

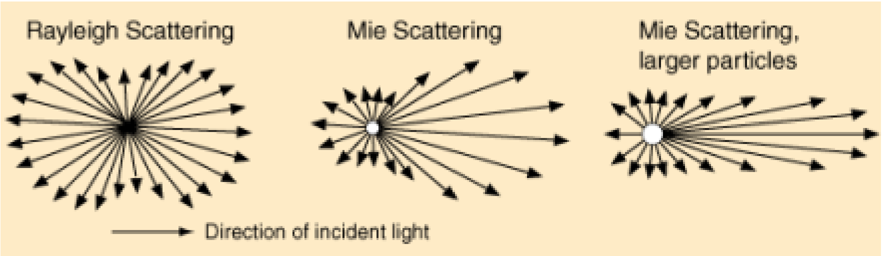


Fig 8. Mie scattering

In Mie scattering, intensity of the scattered light varies approximately as the inverse of the wavelength

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

Non-selective scattering

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

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

Absorption

Absorption is the process in which incident energy is retained by particles in the atmosphere at a given wavelength. Unlike scattering, atmospheric absorption causes an effective loss of energy to atmospheric constituents. The absorbing medium will not only absorb a portion of the total energy, but will also reflect, refract or scatter the energy. The absorbed energy may also be transmitted back to the atmosphere. The most efficient absorbers of solar radiation are water vapour, carbon dioxide, and ozone. Gaseous components of the atmosphere are selective absorbers of the electromagnetic radiation, i.e., these gases absorb electromagnetic energy in specific wavelength bands. Arrangement of the gaseous molecules and their energy levels determine the wavelengths that are absorbed.

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

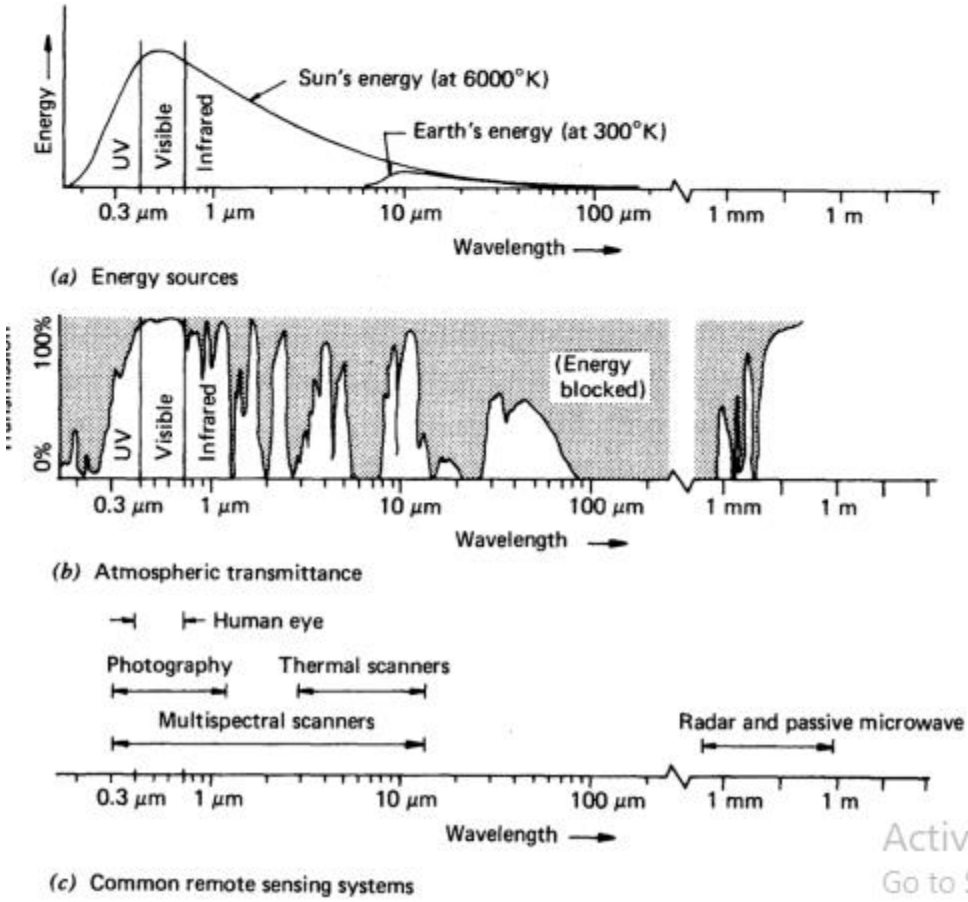


Fig. 8. (a) Spectral characteristics of main energy sources (b) Atmospheric windows and (c) Common remote sensing systems at different wavelengths (Source: Lillesand et al., 2004)

From Fig.8 it can be observed that electromagnetic radiation at different wavelengths is completely absorbed, partially absorbed or totally transmitted through the atmosphere. Nitrogen and other gaseous components in the atmosphere cause absorption of wavelengths shorter than 0.1 µm. Wavelengths shorter than 0.3µm (X-rays, Gamma rays and part of ultraviolet rays) are mostly absorbed in the atmosphere. This is caused by the ozone (O3) present in the upper atmosphere. Oxygen in the atmosphere causes absorption centered at 6.3µm.

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

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

Radar and Passive microwave systems operate through a window in the 1 mm to 1 m region

Table 3.Major atmospheric windows used for remote sensing

Table 2. Major atmospheric windows used in remote sensing and their characteristics

Atmospheric window	Wavelength band µm	Characteristics
Upper ultraviolet, Visible and photographic IR	0.3-1 apprx.	95% transmission
Reflected infrared	1.3, 1.6, 2.2	Three narrow bands
Thermal infrared	3.0-5.0 8.0-14.0	Two broad bands
Microwave	> 5000	Atmosphere is mostly transparent

Sensor selection for remote sensing

While selecting a sensor the following factors should be considered:

i. The spectral sensitivity of the available sensors

ii. ii. The available atmospheric windows in the spectral range(s) considered. The spectral range of the sensor is selected by considering the energy interactions with the features under investigation.

iii. iii. The source, magnitude, and spectral composition of the energy available in the particular range.

iv. iv. Multi Spectral Sensors sense simultaneously through multiple, narrow wavelength ranges that can be located at various points in visible through the thermal spectral regions

ENERGY INTERACTIONS WITH EARTH SURFACE FEATURES

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

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

Energy Interactions

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

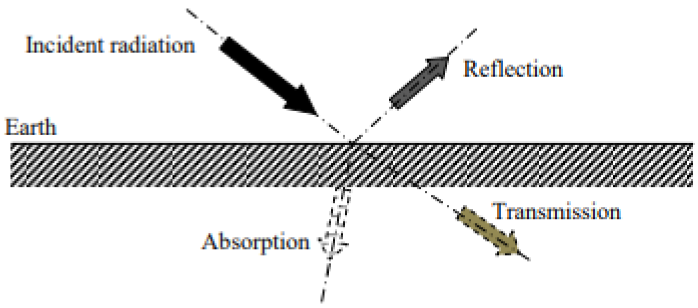


Fig 9.Energy interactions with earth surface features

Reflection occurs when radiation is redirected after hitting the target. According to the law of reflection, the angle of incidence is equal to the angle of reflection.

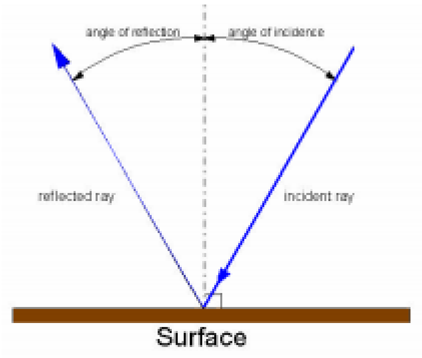


Fig 10. Reflection

Energy reflection

Absorption occurs when radiation is absorbed by the target. The portion of the EM energy which is absorbed by the Earth's surface is available for emission and as thermal radiation at longer wavelengths

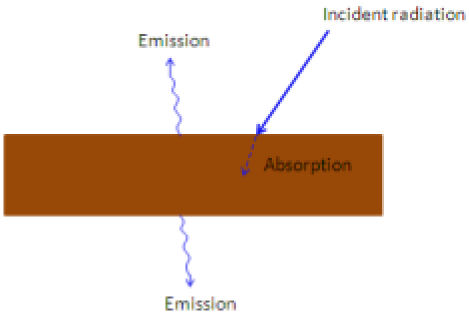


Fig11 .Energy absorption and emission

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

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

- Wavelength of the radiation
- Angle at which the radiation intersects the surface
- Composition and physical properties of the surface

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

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

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

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

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

Reflection

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

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

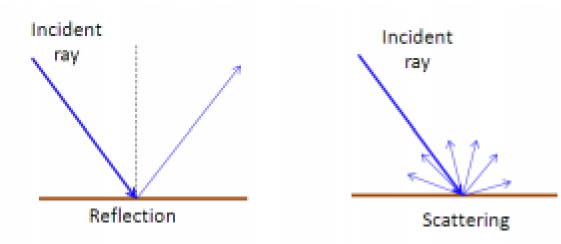


Fig 12.Reflection and scattering

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

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

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

Diffuse and Specular Reflection

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

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

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

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

Based on the nature of reflection, surface features can be classified as Specular reflectors, Lambertian reflectors

An ideal specular reflector completely reflects the incident energy with angle of reflection equal to the angle incidence

An ideal Lambertian or diffuse reflector scatters all the incident energy equally in all the directions.

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

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

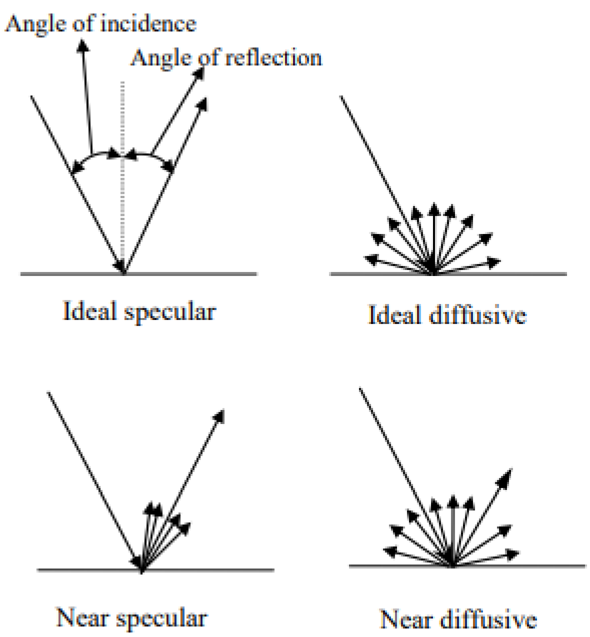


Fig 13.Different types of reflectors

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

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

Spectral Reflectance Curves

The reflectance characteristics of earth surface features are expressed as the ratio of energy reflected by the surface to the energy incident on the surface. This is measured as a function of wavelength and is called spectral reflectance, $R\lambda$. It is also known as albedo of the surface. Spectral reflectance or albedo can be mathematically defined as

$$\begin{aligned} R_\lambda &= \frac{E_R(\lambda)}{E_I(\lambda)} \\ &= \frac{\text{Energy of wavelength } \lambda \text{ reflected from the object}}{\text{Energy of wavelength } \lambda \text{ incident on the object}} \times 100 \end{aligned}$$

Table 4 :Albedo of various Earth surface features (From Gibson, 2000)

Surface type	Albedo %
Grass	25
Concrete	20
Water	5-70
Fresh snow	80
Forest	5-10
Thick cloud	75
Dark soil	5-10

Albedo of fresh snow is generally very high. Dry snow reflects almost 80% of the energy incident on it. Clouds also reflect a majority of the incident energy. Dark soil and concrete generally show very low albedo. Albedo of vegetation is also generally low, but varies with the canopy density. Albedo of forest areas with good canopy cover is as low as 5-10%. Albedo of water ranges from 5 to 70 percentage, due to the specular reflection characteristics. Albedo is low at lower incidence angle and increases for higher incidence angles.

The energy that is reflected by features on the earth's surface over a variety of different wavelengths will give their spectral responses. The graphical representation of the spectral response of an object over different wavelengths of the electromagnetic spectrum is termed as spectral reflectance curve. These curves give an insight into the spectral characteristics of different objects, hence used in the selection of a particular wavelength band for remote sensing data acquisition

For example, Fig. 7 shows the generalized spectral reflectance curves for deciduous (broadleaved) and coniferous (needle-bearing) trees. Spectral reflectances varies within a given material i.e., spectral reflectance of one decisuous tree will not be identical with another. Hence the generalized curves are shown as a “ribbon” and not as a single line. These curves help in the selection of proper sensor system in order to differentiate deciduous and coniferous trees.

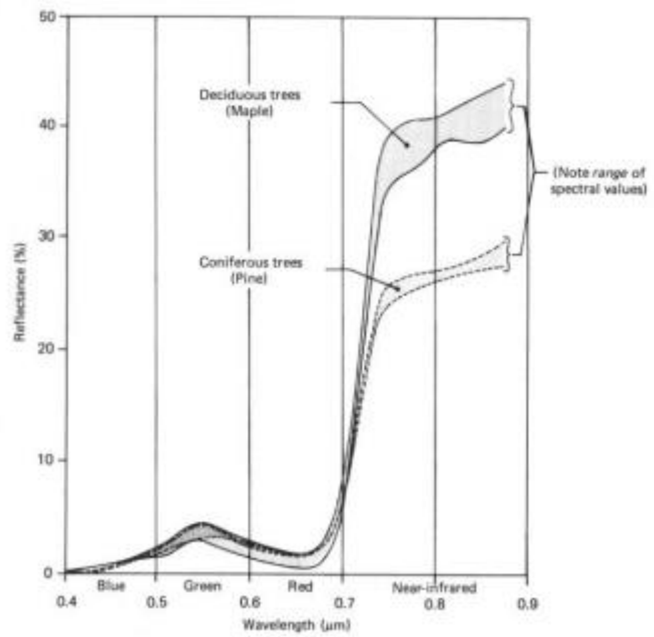


Fig 14.Spectral reflectance curves for deciduous and coniferous trees (Lillesand et al., 2004)

spectral reflectance curves for each tree type are overlapping in most of the visible portion. A choice of visible spectrum is not a feasible option for differentiation since both the deciduous and coniferous trees will essentially be seen in shades of green. However, in the near infra red (NIR) they are quite different and distinguishable. Within the electromagnetic spectrum, the NIR represents a wavelength range from (0.7-1) to 5 microns.

A comparison of photographs taken in visible band and NIR band is shown in Fig. 8. It should be noted that panchromatic refers to black and white imagery that is exposed by all visible light. In visible band, the tone is same for both trees. However, on infrared photographs, deciduous trees show a much lighter tone due to its higher infrared reflectance than conifers.

Passive/ Active Remote Sensing

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

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

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

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

Remote Sensing Platforms

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

Ground level remote sensing

- Low altitude aerial remote sensing
- High altitude aerial remote sensing

Space borne remote sensing

- Space shuttles

- Polar orbiting satellites
- Geo-stationary satellites

Advantages and Disadvantages of Remote Sensing

Advantages of remote sensing are:

a) Provides data of large areas

b) Provides data of very remote and inaccessible regions

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

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

e) Easy and rapid collection of data f) Rapid production of maps for interpretation

Disadvantages of remote sensing are:

a) The interpretation of imagery requires a certain skill level

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

c) Data from multiple sources may create confusion

d) Objects can be misclassified or confused

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

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DEPARTMENT OF CIVIL ENGINEEERING

UNIT – IV –SURVEYING-II– SCIA1404

Astronomical Surveying

Astronomy

Astronomy is a natural science that deals with the study of celestial objects (such as stars, planets, comets, nebulae, star clusters and galaxies) and phenomena that originate outside the Earth's atmosphere (such as the cosmic background radiation).

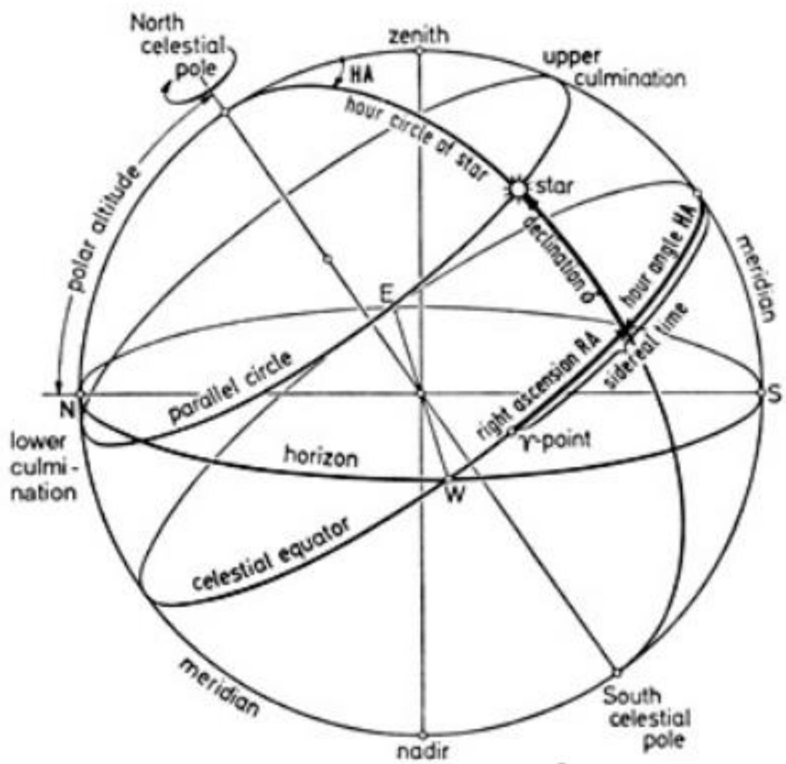


Fig.1 Astronomical terms

Celestial sphere

The imaginary sphere on which the star appears to lie or to be studded is known as celestial sphere.

Celestial Poles

The points at which the polar axis when produced, intersects the celestial sphere are known as celestial sphere.

Celestial Horizon

It is the greatest circle traced upon the celestial sphere by that plane which is perpendicular to the Zenith-Nadir line, and which passes through the centre of the earth.

The Zenith and Nadir

The Zenith (Z) is the point on the upper portion of the celestial sphere marked by plumb line above the observer.

The Nadir (N) is the point on the lower portion of the celestial sphere marked by plumb line below the observer.

Hour Angle

Hour angle is the angle between celestial meridians, or hour circles; but its origin is the meridian that passes through the observer's zenith (or point on the celestial sphere directly above the observer). The hour angle of a star is defined as the angular distance, measured westward along the celestial equator, between the observer's meridian and the hour circle or meridian of the star. This angle is often called the local hour angle. (LHA)

Declination

The declination of a celestial body (star, sun, or planet) is its angular distance north or south of the celestial equator.

Azimuth (A)

The azimuth of a celestial body is the angle between the observer's meridian and the vertical circle through the celestial body. It is generally measured from 0 to 360 degree.

Hour Circle

Projection of the meridians or longitudinal circles in infinite numbers to intersections with the celestial sphere is called hour circle.

Vertical Circle

These are the great circle of the celestial sphere through the zenith and nadir

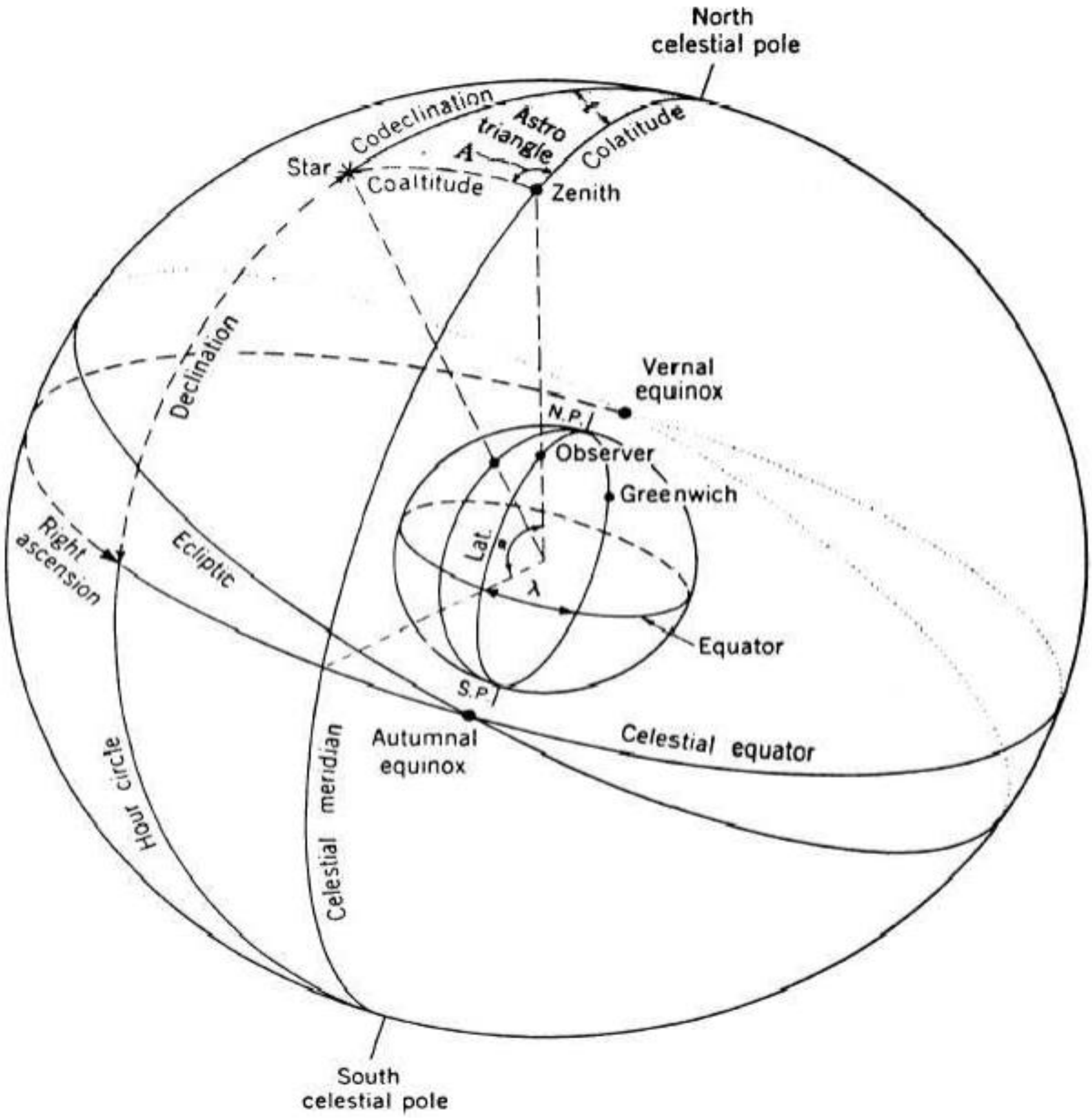


Fig.2

Prime vertical

A vertical circle which is at right angles to the meridian is known as prime vertical.

Altitude (α)

The altitude of a celestial body is its angular distance above the horizon as measured on the vertical passing through the body.

Co-Altitude (90º - α).

The co-altitude is also known as zenith distance. It is complement of the altitude and is written as (90º - α).

Latitude ($\boldsymbol{\theta}$)

The Latitude of a place is the angle between the direction of a plumb line at the place and the plane of the equator.

Co- Latitude (90º - $\boldsymbol{\theta}$).

The co-latitude is the distance between zenith and the celestial pole. It is complement of the altitude and is written as (90º - θ).

Declination $(\boldsymbol{\delta})$

The declination of a celestial body is the angular distance measured on a star's meridian north or south of the celestial sphere.

Co-Declination $(\mathbf{90^\circ - \boldsymbol{\delta}})$

It is the angular distance between the body and the pole and is written as (90º - θ).

Satellites

The Celestial bodies revolving around the planets are known as satellites

Star

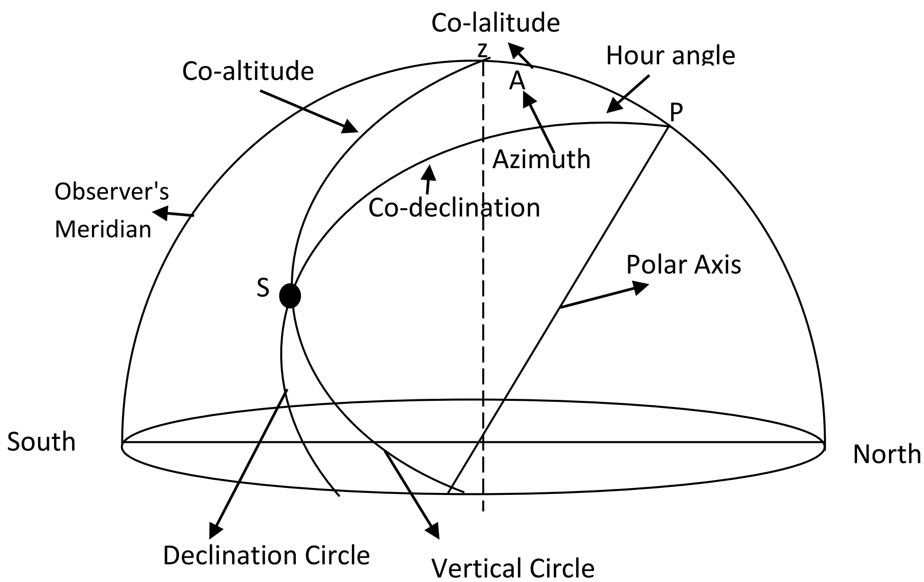
The celestial bodies whose apparent relative positions remain sensibly unchanged over long period of time.

Star Constellations

The classifying conveniently distinguishing particular stars, these have been grouped and are called Star Constellations

Spherical triangle

A triangle bounded by three arcs of great circle is known as spherical triangle.

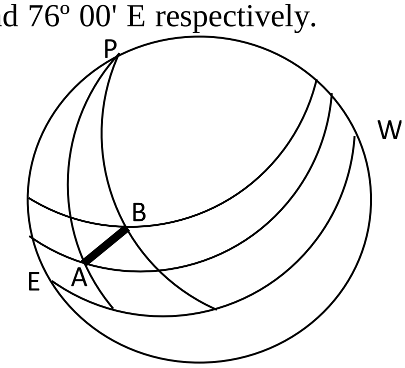


Problems

1. Find the shortest distance between two places A and B given that the latitudes of A and B are 14º 00' N and 15º 06' N and their longitudes are 70º 10' E and 76º 00' E respectively. Radius of the earth is 672 km.

Solution

In the spherical angle ABP



b = AP= 90º - Latitude of A

= 90º - 14º 00' = 76º

a = BP = 90º - Latitude of B

= 90º - 15º 06' = 74º 54'

$\angle P = \angle APB$ = Difference of longitudes of A and B

= 76º - 70º 10' = 5º 50'

Knowing the two sides, a, b and the angle P, the third side p can be obtained by using the cosine rule,

$$\cos p = \cos a \cos b + \sin a \sin b \cos P$$

$$\cos p = \cos 74^{\circ}\, 54' \cos 76^{\circ} + \sin 74^{\circ}\, 54' \sin 76^{\circ} \cos 5^{\circ}\, 50$$

= 0.99496

= 5º 45' 7.74"

Knowing the side p, the value of the arc p, i.e. the shortest distance will be

$$= \quad \text{radius x central x } \frac{6372 * 5^{\circ}\, 45'\, 7.74'' * \pi}{180^{\circ}} = 639.71\ km$$

Motion of Sun and Stars

Once people figured out how the stars moved - or thought they did - they could turn their attention to the next object - the Sun. Unfortunately, its motion isn't easy to understand. The Sun's path varies over the course of the year. Sometimes it rises in the northeast, and sometimes it rises in the southeast. Only on two days does it rise directly in the East and set directly in the West. These special dates are known as the Equinoxes. To give you their full names, they are the Vernal Equinox, which is around March 21, and the Autumnal Equinox, which is around September 21. You may recognize these dates as the beginnings of the seasons of Spring and Autumn. These dates - the Equinoxes - have nothing to do with the weather; they have to do with the location of the Sun relative to the Celestial Equator.

Now for the rest of the year, the Sun's path and its rising and setting locations vary. As seen from Iowa, during the winter the Sun rises in the southeast and sets in the southwest. In the summer it rises in the northeast and sets in the northwest. There are two days when the rising and setting locations are at their most extreme (furthest north or furthest south). These days are also the dates that the Sun travels a path that is also an extreme - very long and high above the horizon or very short and low to the horizon. These are the days known as the Winter Solstice, which occurs around December 21 (shortest day), while the other is called, oddly enough, the Summer Solstice, and it occurs around June 21. Of course, you know these days as the beginning of Winter and Summer. Like the dates of Equinoxes, they have really nothing to do with the weather, but with the position of the Sun relative to the Celestial Equator.

One thing you have to remember about the Sun is that it makes it very difficult to see anything else in the sky when it is out - even though the stars and planets are out there, the brightness of the Sun is so overwhelming that you don't have much of a chance of see them until the Sun sets. Which stars would be visible? Which constellations would be visible if we could turn off the Sun? That depends upon what time of the year you look. If you were to turn the Sun down so that you could see the stars at the same time that you could see the Sun, you would notice that the Sun appears to move slowly toward the East from one day to the next - it moves about 1º each day. In about a month it has moved 30º to the East relative to the stars; in four months, it will be about 120º east of where it started; and after one year, it will have gone about 360º. That means it is back where it started from, since there are 360º in a circle! This also explains why we see different constellations in different seasons. As the Sun moves slowly in front of various constellations, those constellations are no longer visible since they are too close to the Sun, but constellations far from them are visible, since they will be visible when the Sun has set or before it rises. Since the Sun appears to move relative to these stars, it will gradually cover up other stars, and other stars that were previously not visible will again be viewable as the Sun gets further away from them.

Actually, the folks in the old days could figure out where the Sun would be relative to the stars by looking at the stars which were visible when the Sun set. They knew which constellations the Sun covered up and when they were covered up (which time of the year they were or were not visible). If you were to map out the path of the Sun relative to the stars, you would see it as a curved line on the Celestial Sphere. Take a look at Figure 1 to see the path relative to the Celestial Equator. This image is of a flattened out Celestial Sphere, and the dates mark the locations of the Sun relative to the stars over the course of the year.

As is apparent, the path of the Sun is curved relative to the Celestial Equator. There are times during the year when it is north of the Celestial Equator and other times when it is south of it. The declination of the Sun varies throughout the year. (Of course, its R. A. changes as well, becoming slowly larger each day as the Sun moves eastward relative to the stars, but we'll pay more attention to the declination). On the days of the Equinoxes, the Sun is right on the Celestial Equator, so it has a declination of 0º, and on the Solstices, it has the most extreme value for its declination, 23.5º N on the date of the Summer Solstice and 23.5º S on the Winter Solstice. The Solstice dates mark when the Sun is at its greatest distance from the Celestial Equator.

The path the Sun appears to make amongst the stars is known as the **ecliptic**. Just like the Celestial Equator, it would make a large circle on the Celestial Sphere. In fact the ecliptic is a big circle that is tilted 23.5º relative to the circle made by the Celestial equator.

The Moon

After figuring out how the stars and the Sun move, it is time to tackle the next object - the Moon. The motion of the Moon is more complex; it doesn't follow exactly the ecliptic or the celestial equator, but does make a path around the Earth that is similar to each of those paths. What sets the Moon apart from the other objects is the fact that its appearance changes - it goes through phases. The phases of the Moon take 29.5 days to go through an entire cycle.

The phases occur in a very predictable sequence. Here is the order of the phases - New (when you can't see the Moon - it's all dark), Waxing Crescent, First Quarter (when you see the right half lit), Waxing Gibbous, Full (when you see the entire lit surface), Waning Gibbous, Third Quarter - also called Last Quarter (when you see the left side lit up), Waning Crescent, and back to where we started, New. A picture of the phases is shown in Figure 7. It takes about one week to go from one major phase to the next - by major phase I mean New, the Quarters and Full. If the Moon is New today, it will be a First Quarter Moon in about one week, and a full Moon two weeks from today. The fact that it takes about 29.5 days to go through the cycle is the reason there are about 30 days in a month, since many ancient societies used the Moon as a time keeper.

Physical Characteristics

Sun

The Sun is a star, a powerhouse of energy, undergoing constant nuclear fusion. It is luminous and extremely hot. Even though the Earth is about 150 million kilometres away from the Sun, we still feel the energy from the explosions that happen within it. Humans and many other creatures on Earth depends on the heat and light coming from the Sun.

Some stars in the universe are bigger and brighter than the Sun, but all other stars are very far away so appear as small points of light. For the part of the Earth that it is day time, the stars are hidden by the brightness of the Sun in the sky, as they are much fainter. When it is night time, with the Sun shining on the other side of the Earth, the stars can be seen in the dark sky.

Earth

A planet is an object orbiting a star which is spherical and bigger than an asteroid but smaller than a star. They can be rocky, like Earth, or gassy, like Jupiter. Earth is our home and the third planet from the Sun, with a mean distance of about 150 million kilometres. This distance and the atmosphere of Earth keep its average surface temperature above the freezing point of water (0°C) but below the boiling point of water (100°C), enabling liquid water to exist freely, giving us seas and oceans. This is not the case on Venus, where it is closer to the Sun and hotter than the boiling point of water, or Mars, where it is further away from the Sun and colder than the freezing point of water. Liquid water has been crucial for the development of life on our planet, the only known place where life exists in the universe.

The shape of the Earth is very close to a sphere. It spins, or rotates, once every 24 hours giving us the length of a day Earth only has one natural satellite, the Moon, which is thought to have played a major role in stabilising the axis of rotation of the Earth. This may have also been a favourable condition for the emergence of life.

Moon

Satellites, including moons, orbit planets. The Moon is a natural satellite of Earth. It takes close to one month (27 days 8 hours) to revolve around our home planet. The Moon and Earth are about the same distance from the Sun. Despite this, the temperatures on the Moon are extreme, reaching higher and lower temperatures than on Earth, because the Moon lacks a rich atmosphere.

Solar System

A solar system refers to a star and all the objects that orbit it. Our Solar System consists of the Sun — our home star —, eight planets and their natural satellites (such as our moon), dwarf planets, asteroids and comets. It is located in an outward spiral arm of the Milky Way galaxy.

Satellite Characteristics: Orbits and Swaths

We learned in the previous section that remote sensing instruments can be placed on a variety of platforms to view and image targets. Although ground-based and aircraft platforms may be used, satellites provide a great deal of the remote sensing imagery commonly used today. Satellites have several unique characteristics which make them particularly useful for remote sensing of the Earth's surface.

The path followed by a satellite is referred to as its orbit. Satellite orbits are matched to the capability and objective of the sensor(s) they carry. Orbit selection can vary in terms of altitude (their height above the Earth's surface) and their orientation and rotation relative to the Earth. Satellites at very high altitudes, which view the same portion of the Earth's surface at all times have geostationary orbits. These geostationary satellites, at altitudes of approximately 36,000 kilometres, revolve at speeds which match the rotation of the Earth so they seem stationary, relative to the Earth's surface. This allows the satellites to observe and collect information continuously over specific areas. Weather and communications satellites commonly have these types of orbits. Due to their high altitude, some geostationary weather satellites can monitor weather and cloud patterns covering an entire hemisphere of the Earth.

Many remote sensing platforms are designed to follow an orbit (basically north-south) which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time. These are near-polar orbits, so named for the inclination of the orbit relative to a line running between the North and South poles. Many of these satellite orbits are also sun-synchronous such that they cover each area of the world at a constant local time of day called local sun time. At any given latitude, the position of the sun in the sky as the satellite passes overhead will be the same within the same season. This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. This is an important factor for monitoring changes between images or for mosaicking adjacent images together, as they do not have to be corrected for different illumination conditions.

Most of the remote sensing satellite platforms today are in near-polar orbits, which means that the satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit. These are called ascending and descending passes, respectively. If the orbit is also sun-synchronous, the ascending pass is most likely on the shadowed side of the Earth while the descending pass is on the sunlit side. Sensors recording reflected solar energy only image the surface on a descending pass, when solar illumination is available. Active sensors which provide their own illumination or passive sensors that record emitted (e.g. thermal) radiation can also image the surface on ascending passes.

As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the swath. Imaging swaths for spaceborne sensors generally vary between tens and hundreds of kilometres wide. As the satellite orbits the Earth from pole to pole, its east-west position wouldn't change if the Earth didn't rotate. However, as seen from the Earth, it seems that the satellite is shifting westward because the Earth is rotating (from west to east) beneath it. This apparent movement allows the satellite swath to cover a new area with each consecutive pass. The satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits.

If we start with any randomly selected pass in a satellite's orbit, an orbit cycle will be completed when the satellite retraces its path, passing over the same point on the Earth's surface directly below the satellite (called the nadir point) for a second time. The exact length of time of the orbital cycle will vary with each satellite. The interval of time required for the satellite to complete its orbit cycle is not the same as the "revisit period". Using steerable sensors, an satellite-borne instrument can view an area (off-nadir) before and after the orbit passes over a target, thus making the 'revisit' time less than the orbit cycle time. The revisit period is an important consideration for a number of monitoring applications, especially when frequent imaging is required (for example, to monitor the spread of an oil spill, or the extent of flooding). In near-polar orbits, areas at high latitudes will be imaged more frequently than the equatorial zone due to the increasing overlap in adjacent swaths as the orbit paths come closer together near the poles.

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEEERING

UNIT – V –SURVEYING-II– SCIA1404

TOTAL STATION

BASIC PRINCIPLE

Although taping and theodolites are used regularly on site – total stations are also used extensively in surveying, civil engineering and construction because they can measure both distances and angles.

A typical total station is shown in the figure below

Fig 1 Total Station

Because the instrument combines both angle and distance measurement in the same unit, it is known as an integrated total station which can measure horizontal and vertical angles as well as slope distances.

Using the vertical angle, the total station can calculate the horizontal and vertical distance components of the measured slope distance.

As well as basic functions, total stations are able to perform a number of different survey tasks and associated calculations and can store large amounts of data.

As with the electronic theodolite, all the functions of a total station are controlled by its microprocessor, which is accessed thought a keyboard and display.

To use the total station, it is set over one end of the line to be measured and some reflector is positioned at the other end such that the line of sight between the instrument and the reflector is unobstructed (as seen in the figure below).

-The reflector is a prism attached to a detail pole

-The telescope is aligned and pointed at the prism

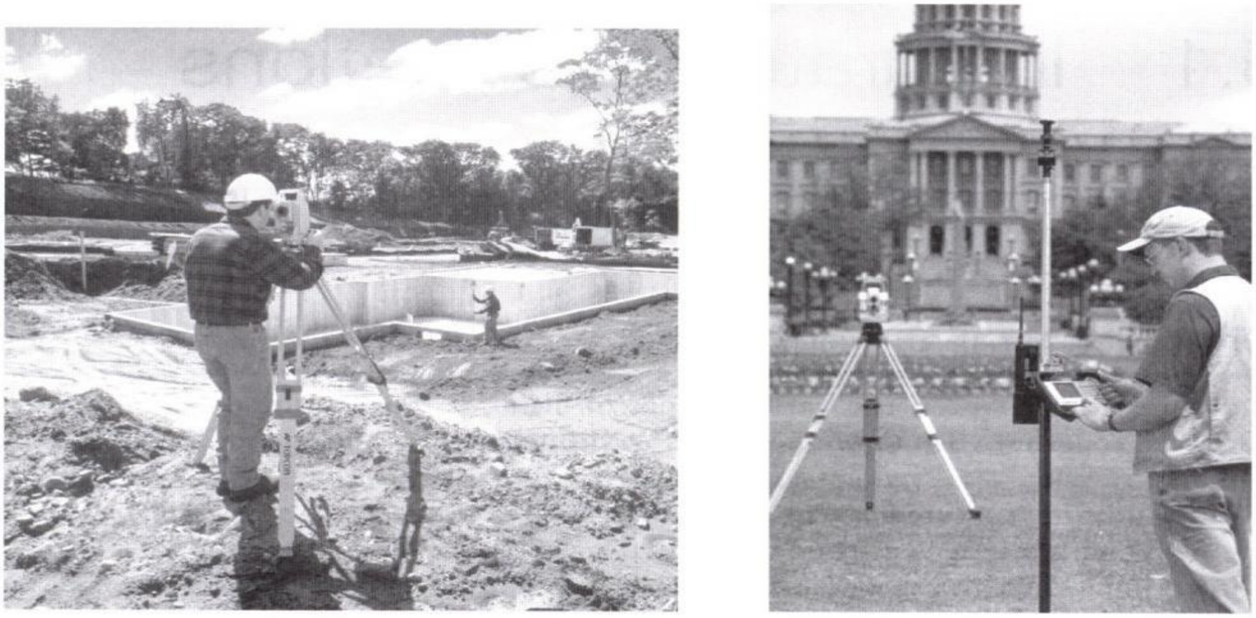
-The measuring sequence is initiated and a signal is sent to the reflector and a part of this signal is returned to the total station

-This signal is then analysed to calculate the slope distance together with the horizontal and vertical angles.

-Total stations can also be used without reflectors and the telescope is pointed at the point that needs to be measured

-Some instruments have motorised drivers and can be use automatic target recognition to search and lock into a prism – this is a fully automated process and does not require an operator.

-Some total stations can be controlled from the detail pole, enabling surveys to be conducted by one person



Measuring with a total station   Robotic total station

Fig .2 Measuring with a Total Station

Most total stations have a distance measuring range of up to a few kilometres, when using a prism, and a range of at least 100m in reflector less mode and an accuracy of 2-3mm at short ranges, which will decrease to about 4-5mm at 1km.

Although angles and distances can be measured and used separately, the most common applications for total stations occur when these are combined to define position in control surveys.

As well as the total station, site surveying is increasingly being carried out using GPS equipment. Some predictions have been made that this trend will continue, and in the long run GPS methods may replace other methods.

Although the use of GPS is increasing, total stations are one of the predominant instruments used on site for surveying and will be for some time.

Developments in both technologies will find a point where devices can be made that complement both methods.

CLASSIFICATION OF TOTAL STATIONS

ELECTRO- OPTICAL SYSTEM

DISTANCE MEASUREMENT

When a distance is measured with a total station, am electromagnetic wave or pulse is used for the measurement – this is propagated through the atmosphere from the instrument to reflector or target and back during the measurement.

Distances are measured using two methods: the phase shift method, and the pulsed laser method.

This technique uses continuous electromagnetic waves for distance measurement although these are complex in nature, electromagnetic waves can be represented in their

simplest from as periodic waves.

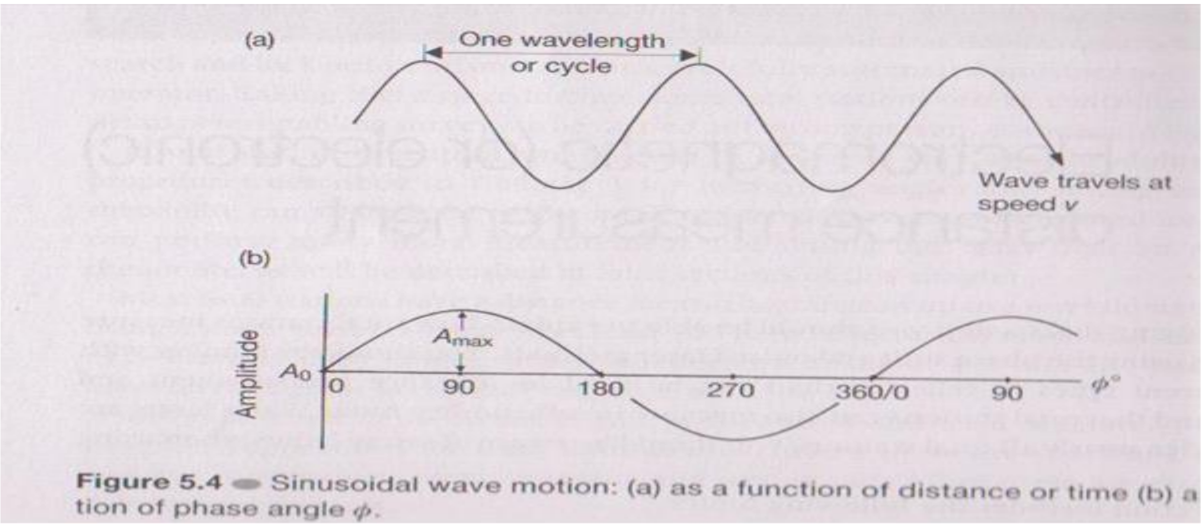


Fig .3 Sinusoidal wave motion

The wave completes a cycle when moving between identical points on the wave and the number of times in one second the wave completes the cycle is called the frequency of the wave. The speed of the wave is then used to estimate the distance.

LASER DISTANCE MEASUREMENT

In many total stations, distances are obtained by measuring the time taken for a pulse of laser radiation to travel from the instrument to a prism (or target) and back. As in the phase shift method, the pulses are derived an infrared or visible laser diode and they are transmitted through the telescope towards the remote end of the distance being measured, where they are reflected and returned to the instrument.Since the velocity v of the pulses can be accurately determined, the distance D can be obtained

using $2D = vt$, where t is the time taken for a single pulse to travel from instrument – target – instrument.

This is also known as the timed-pulse or time-of-flight measurement technique.

The *transit time t* is measured using electronic signal processing techniques. Although only a single pulse is necessary to obtain a distance, the accuracy obtained would be poor. To improve this, a large number of pulses (typically

20,000 every second) are analysed during each measurement to give a more accurate distance.

The pulse laser method is a much simpler approach to distance measurement than the phase shift method, which was originally developed about 50 years ago.

SLOPE AND HORIZONTAL DISTANCES

Both the phase shift and pulsed laser methods will measure a slope distance L from the total station along the line of sight to a reflector or target. For most surveys the horizontal distance D is required as well as the vertical component V of the slope distance.

Horizontal distance $D = L \cos\alpha = L \sin z$

Vertical distance = $V = L \sin\alpha = L \cos z$

Where α is the vertical angle and z is the is the zenith angle. As far as the user is concerned, these calculations are seldom done because the total station will

either display D and V automatically or will dislplay L first and then D and V after pressing buttons

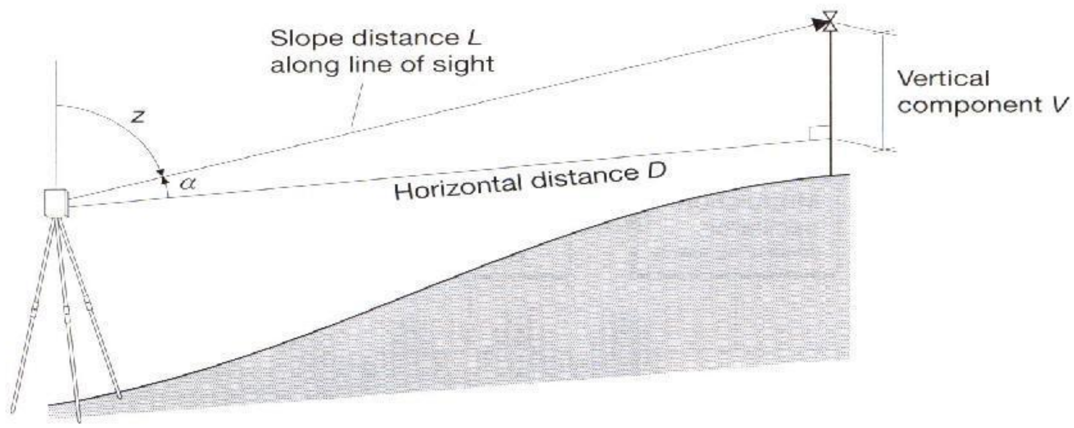


Fig 4 Slope and Distance Measured

How accuracy of distance measurement is specified

All total stations have a linear accuracy quoted in the form

±(a mm + b ppm)

The constant a is independent of the length being measured and is made up of internal

sources within the instrument that are normally beyond the control of the user. It is an estimate of the individual errors caused by such phenomena as unwanted phase shifts in electronic components, errors in phase and transit time measurements.

The systematic error b is proportional to the distance being measured, where 1 ppm (part per million) is equivalent to an additional error of 1mm for every kilometre measured.

Typical specifications for a total station vary from ±(2mm + 2ppm) to ±(5mm + 5 pmm).

For example: ±(2mm + 2ppm), at 100m the error in distance measurement will be

±2mm but at 1.5km, the error will be ±(2mm + [2mm/km * 1.5km]) = ±5m m

Reflectors used in distance measurement

Since the waves or pulses transmitted by a total station are either visible or infrared, a plane mirror could be used to reflect them. This would require a very accurate alignment of the mirror, because the transmitted wave or pulses have a narrow spread.

To get around this problem special mirror prisms are used as shown below.

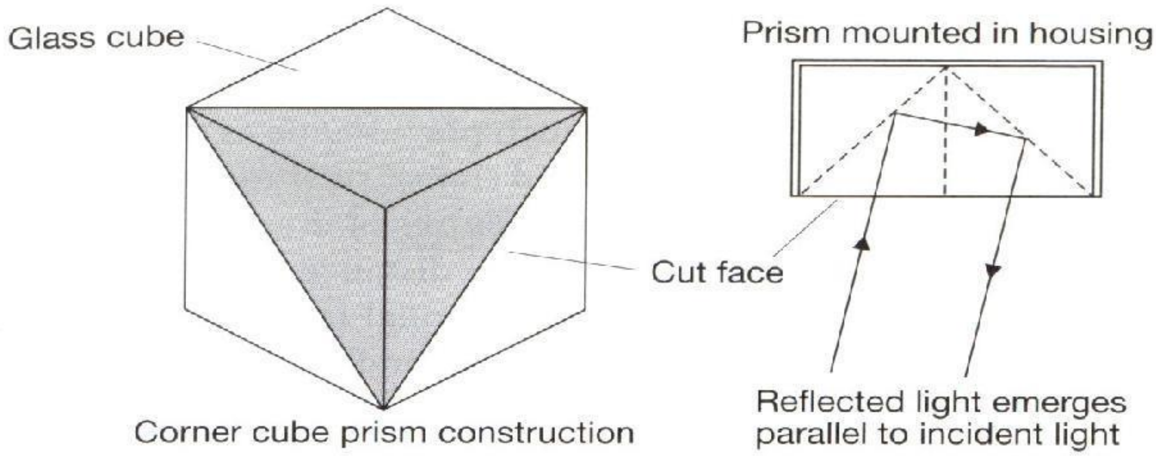


Fig 5 Reflector used in total station

FEATURES OF TOTAL STATIONS

Total stations are capable of measuring angles and distances simultaneously and combine an electronic theodolite with a distance measuring system and a microprocessor.

ANGLE MEASUREMENT

All the components of the electronic theodolite described in the previous lectures are found total stations.

The axis configuration is identical and comprises the vertical axis, the tilting axis and line of sight (or collimation). The other components include the tribatch with levelling footscrews, the keyboard with display and the telescope which is mounted on the standards and which rotates around the tilting axis.

Levelling is carried out in the same way as for a theodolite by adjusting to centralise a plate

level or electronic bubble. The telescope can be transited and used in the face left (or face I) and face right (or face II) positions. Horizontal rotation of the total station about the vertical axis is controlled by a horizontal clamp and tangent screw and rotation of the telescope about the tilting axis.

The total station is used to measure angles in the same way as the electronic theodolite.

Distance measurement

All total stations will measure a slope distance which the onboard computer uses, together with the zenith angle recorded by the line of sight to calculate the horizontal distance.

For distances taken to a prism or reflecting foil, the most accurate is precise measurement.

For phase shift system, a typical specification for this is a measurement time of about 1-2s, an accuracy of (2mm + 2ppm) and a range of

3-5km to a single prism.

Although all manufacturers quote ranges of several kilometres to a single prism.

For those construction projects where long distances are required to be measured, GPS methods are used in preference to total stations. There is no standard difference at which the change from one to the other occurs, as this will depend on a number of factors, including the accuracy required and the site topography.

Rapid measurement reduces the measurement time to a prism to between 0.5 and 1's for both phase shift and pulsed systems, but the accuracy for both may degrade slightly.

Tracking measurements are taken extensively when setting out or for machine control, since readings are updated very quickly and vary in response to movements of the prism which is usually pole-mounted.In this mode, the distance measurement is repeated automatically at intervals of less than 0.5s.

For reflector less measurements taken with a phase shift system, the range that can be obtained is about 100m, with a similar accuracy to that obtained when using a prism or foil.

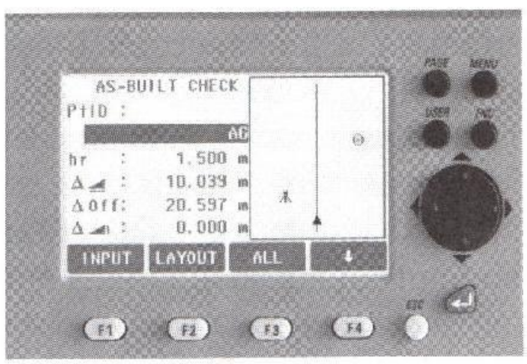
KEYBOARD AND DISPLAY

A total station is activated through its control panel, which consists of a keyboard and multiple line LCD. A number of instruments have two control panels, one on each face, which makes them easier to use.

In addition to controlling the total station, the keyboard is often used to code data generated by the instrument – this code will be used to identify the object being measured.

On some total stations it is possible to detach the keyboard and interchange them with other total stations and with GPS receivers.This is called integrated surveying

.



(a)

(b)

Fig 6 Key Board and Display

SOFTWARE APPLICATIONS

The microprocessor built into the total station is a small computer and its main function is controlling the measurement of angles and distances. The LCD screen guides the operator while taking these measurements.

The built in computer can be used for the operator to carry out calibration checks on the instrument.

The software applications available on many total stations include the following:

Slope corrections and reduced levels

Horizontal circle orientation

Coordinate measurement

Traverse measurements

Resection (or free stationing)

Missing line measurement

Remote elevation measurement

areas

Setting out.

SOURCES OF ERROR FOR TOTAL STATIONS

CALIBRATION OF TOTAL STATIONS

To maintain the high level of accuracy offered by modern total stations, there is now much more emphasis on monitoring instrumental errors, and with this in mind, some construction sites require all instruments to be checked on a regular basis using procedures outlined in the quality manuals.

Some instrumental errors are eliminated by observing on two faces of the total station and averaging, but because one face measurements are the preferred method on site, it is important to determine the magnitude of instrumental errors and correct for them.

For total stations, instrumental errors are measured and corrected using electronic calibration procedures that are carried out at any time and can be applied to the instrument on site. These are preferred to the mechanical adjustments that used to be done in labs by technician.

Since calibration parameters can change because of mechanical shock, temperature changes and rough handling of what is a high-precision instrument, an electronic calibration should be carried our on a total station as follows:

Before using the instrument for the first time

After long storage periods

After rough or long transportation

After long periods of work

Following big changes in temperature

Regularly for precision surveys

Before each calibration, it is essential to allow the total station enough to reach the ambient temperature.

HORIZONTAL COLLIMATION (OR LINE OF SIGHT ERROR)

This axial error is caused when the line of sight is not perpendicular to the tilting axis. It affects all horizontal circle readings and increases with steep sightings, but this is eliminated by observing on two faces.For single face measurements,an on-board calibration function is used to determine *c*, the deviation between the actual line of sight and a line perpendicular to the tilting axis. A correction is then applied automatically for this to all horizontal circle readings.

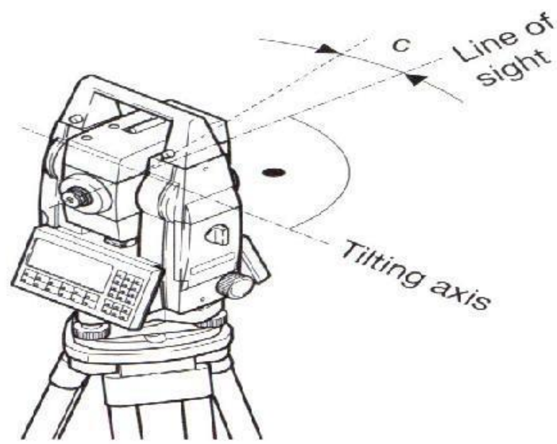


Fig 7 Line of Sight error

TILTING AXIS ERROR

This axial errors occur when the titling axis of the total station is not perpendicular to its vertical axis. This has no effect on sightings taken when the telescope is horizontal, but introduces errors into horizontal circle readings when the

telescope is tilted, especially for steep sightings. As with horizontal collimation error, this error is eliminated by two face measurements, or the tilting axis error a is measured in a calibration procedure and a correction applied for this to all horizontal circle readings – as before if a is too big, the instrument should be returned to the manufacture.

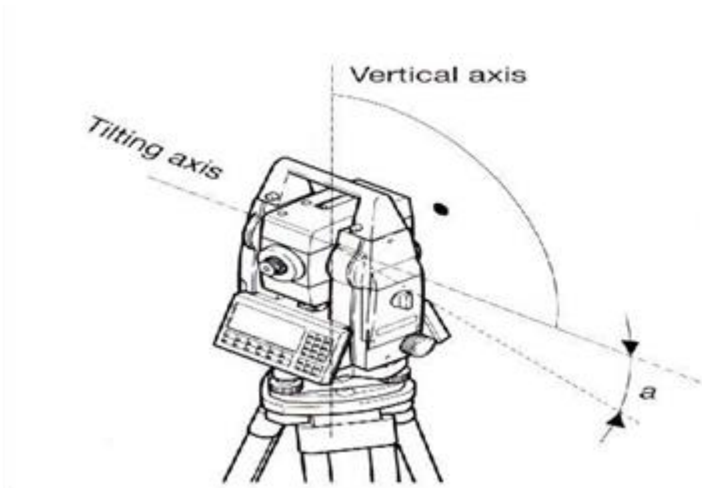


Fig 8. tilting axis error

COMPENSATOR INDEX ERROR

Errors caused by not levellinga theodolite or total station carefully cannot be eliminated by taking face left and face right readings. If the total station is fitted with a compensator it will measure residual tilts of the instrument and will apply corrections to the horizontal and vertical angles for these.

However all compensators will have a longitudinal error *l* and traverse error *t* known as zero point errors. These are averaged using face left and face right readings but for single face readings must be determined by the calibration function of the total station.

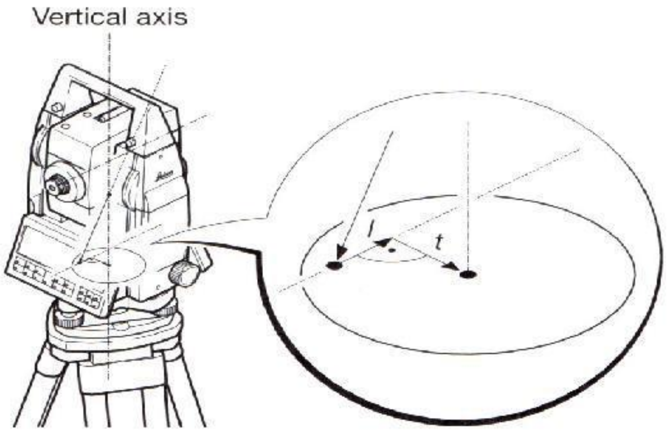
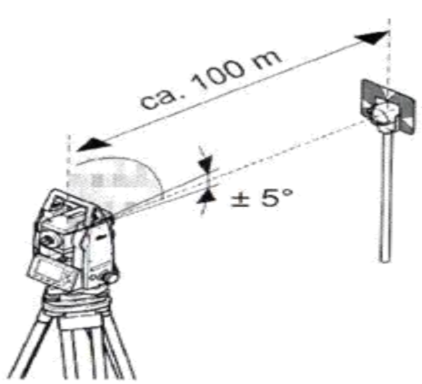


Fig 9. Compensator Index Error

A vertical collimation error exists on a total station if the 0^{o} to 180^{o} line in the vertical circle does not coincide with its vertical axis. This zero point error is present in all vertical circle readings and like the horizontal collimation error, it is eliminated by taking FL and FR readings or by determining i

For all of the above total station errors (horizontal and vertical collimation, tilting axis and compensator) the total station is calibrated using an in built function. Here the function is activated and a measurement to a target is taken as shown below.



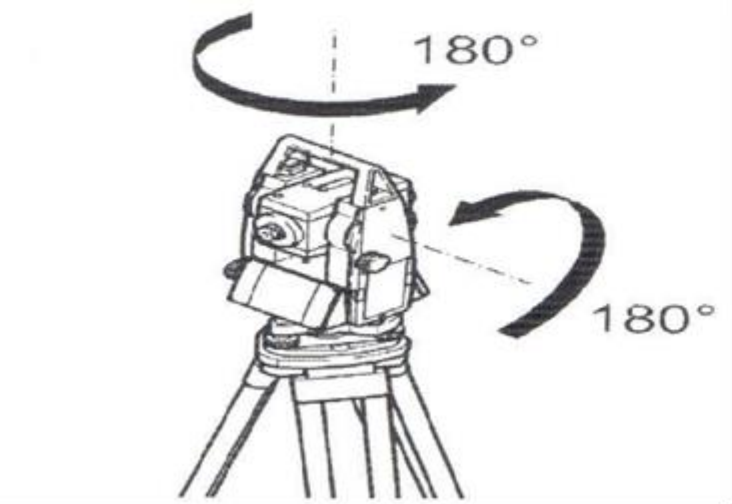


Fig 10 Compensator Index Error

Applications of Total Station

- ✓ To measure horizontal and vertical angles.
- ✓ To obtain the horizontal distance, inclined distance and vertical distance between these points.
- ✓ To get the three-dimensional co-ordinates i.e.[x,y,z] of a point in space.
- ✓ To find the length of a missing the line.
- ✓ To find the elevation of the remote object.
- ✓ To locate the points at a predetermined distance along gridlines.
- ✓ A total station is an electronic/optical instrument used in modern surveying and building construction that uses electronic transit theodolite in conjunction with electronic distance meter (EDM). It is also integrated with the microprocessor, electronic data collector, and storage system.

Components of a Total Station

TotalStation is a compact instrument which weighs around 50 N to 55 N. It consists of a distance measuring instrument (EDM), an angle measuring instrument (Theodolite) and a simple microprocessor. The components used in Total station surveying are as follows:

1. A **tripod** is used to hold the total station
2. An **electronic notebook** used to record, calculate and even manipulate the field data

3. **Prism and prism pole** which can measure lengths up to 2 km and up to 6-7 km can be measured with triple prism
4. **Battery**

Currently there are approximately more than 40 different models available. Total-station are currently the most used instrument in the surveying field. Cheapest instrument is available in the range of 2000$ to 2500$. Leica is one of the most famous total-station manufacturers.

Basic Steps involved in Totalstation surveying

Step-1: Setting up the of the instrument along with the tripod

Step-2: Levelling of the instrument approximately with the help of "bull's eye bubble" and then verifying the levelling electronically

Step-3: Adjustment of reticle focus and image.

Step-4: Recording all the measurements

Step-5: Data Processing

Functions of Total-Station

Angle Measurement:

To measure horizontal and vertical angles, the electronic theodolite of device is used with an accuracy of 2-6 seconds. For horizontal measurement of angles, any direction can be taken as reference. In case of vertical measurement of angles, upward direction is taken as reference.

Distance Measurement in TotalStation:

To measure the distance, Electronic Distance Measuring (EDM) instrument of total station is used with an accuracy of 5-10 mm per km. The range of EDM varies from 2.8-4.2 km.

Data Processing:

Computation of horizontal distances along with X, Y, Z coordinates is done by the instrument called Microprocessor. Hence, if atmospheric temperature and pressure is applied, the microprocessor applies suitable correction to the measurements.

Various software are available in the market which can be used to post-process the outputs from the device. Usually manufacturers provide their software which lets you export the survey results into other formats. Thus, output can be imported to CAD application or software like MX Roads.

Advantages of Total Station

The first and foremost advantage of using a Totalstation is that it saves time of work on the field. It understands and supports all the local languages. Setting up of the instrument on the tripod can be done easily and quickly by laser plummet. The accuracy of measurements is much higher in comparison to other conventional surveying instruments.

Computerization of old maps can be achieved by Totalstation. The computed data can be saved and simultaneously transferred to the computer. No writing or recording errors can be detected since everything is computerized. With the help of data accumulated from Total-station, map making and contour plotting can also be done. Correction for temperature and pressure can also be made.

Disadvantages

The working conditions of the totalstation should be checked beforehand by the surveyor before using it. The cost price of the instrument is higher than the other surveying instruments. Checking for errors or other things during the operation is slightly difficult for the surveyor. Essentially, skilled surveyors are required to handle it since it is a sophisticated instrument to operate.