KARPAGAM ACADEMY OF HIGHER EDUCATION

(Deemed to be University)

(Established Under Section 3 of UGC Act 1956)

Coimbatore- 641 021

(For the candidates admitted from 2017 onwards)

DEPARTMENT OF CIVIL ENGINEERING

SUBJECT CODE: 17BECE405 **SUBJECT: Surveying II**

SEMESTER: IV **CLASS: II Civil Engineering** **L T P C = 3 0 0 3**

Course Outcomes:

- Skill to carry survey and to decide appropriate type of execution in construction works.
- Numerical solutions for carrying out surveying in civil engineering field. Advanced surveying equipments.

UINT-I **9**

TACHEOMETRIC SURVEYING: Tacheometric systems - Tangential, stadia and subtense methods - Stadia systems - Horizontal and inclined sights - Vertical and normal staffing - Fixed and movable hairs - Stadia constants - Analytic lens - Subtense bar.

UINT-II **9**

CONTROL SURVEYING: Working from whole to part - Horizontal and vertical control methods - Triangulation - Signals - Base line - Instruments and accessories - Corrections - Satellite station - Reduction to Centre - Trigonometriclevelling - Single and reciprocal observations - Modern trends – Bench marking

UINT-III **9**

SURVEY ADJUSTMENTS: Errors - Sources, precautions and corrections - Classification of errors - True and most probable values - weighted observations - Method of equal shifts - Principle of least squares - Normal equation - Correlates - Level nets - Adjustment of simple triangulation networks.

UINT-IV **9**

REMOTE SENSING and GPS: Field of Applications –Natural Resources-Agriculture-Soil-Water Resources-Wasteland Management-Social resources-Cadastral Records-LIS
Basic concepts of GPS and its applications

UINT-V **9**

OTHER TOPICS: Fundamental principal:(Demo)Photogrammetry - Introduction - Terrestrial and aerial Photographs - Stereoscopy - Parallax –Introduction to Total Station- Electromagnetic distance measurement - Carrier waves - Principles - Instruments - Trilateration - Hydrographic Surveying - Tides - MSL - Sounding methods - Location of soundings and methods

TOTAL: 45HRS

TEXT BOOKS

S.No	Title of Book	Author of Book	Publisher	Year of Publishing
1	Surveying, Volume I, II and III	Punmia B.C	LaxmiPublications,Delhi	2012

REFERENCES

S.No	Title of Book	Author of Book	Publisher	Year of Publishing
1	Plane and Geodetic Surveying, Volume I and II	Aylmer Johnson	CRC Press , New York	2004
2	Introduction to Surveying	James M.Anderson and Edward M.Mikhail	McGraw-Hill Book Company, New York, Fifth Edition	2009
3	Elements of Cartography	Harley	McGraw-Hill Book Company New York, Fifth Edition	2001
4	Surveying and Levelling, Volume I and II	Kanetkar T.P	United Book Corporation, Pune	2007

WEBSITES:

1. http://www.icivilengineer.com
2. http://www.engineeringcivil.com/
3. http://www.aboutcivil.com/
4. http://www.engineersdaily.com
5. http://www.asce.org/
6. http://www.cif.org/
7. http://icevirtuallibrary.com/
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9. http://www.engineering-software.com/ce/

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DEPARTMENT OF CIVIL ENGINEERING

LECTURE PLAN

SURVEYING II(17BECE405)

LECTURER : **Mr. S Sanjay**
SEMESTER : **IV (2018-2019) Even**
NUMBER OF CREDITS : **3**
COURSE TYPE : **Regular Course**

S.No	Hours	Topics to be Covered	Text Book	Page No.
UNIT I- TACHEOMETRIC SURVEYING				
1.	1	Tacheometric systems - Tangential, stadia and subtense methods	T1	411-456
2.	1	Stadia systems	T1	411-456
3.	1	Horizontal and inclined sights	T1	411-456
4.	1	Vertical and normal staffing	T1	411-456
5.	1	Fixed and movable hairs	T1	411-456
6.	1	Fixed and movable hairs	T1	411-456
7.	1	Stadia constants	T1	411-456
8.	1	Analytic lens	T1	411-456
9.	1	Subtense bar.	T1	411-456
				Total 09 hours
UNIT II- CONTROL SURVEYING				
10.	1	Working from whole to part	T1	349-361
11.	1	Horizontal and vertical control methods	T1	349-361
12.	1	Triangulation	T1	349-361
13.	1	Signals - Base line	T1	349-361
14.	1	Instruments and accessories	T1	349-361
15.	1	Corrections	T1	349-361
16.	1	Satellite station - Reduction to Centre	T1	349-361
17.	1	Trigonometric levelling - Single and reciprocal observations	T1	349-361
18.	1	Modern trends – Bench marking	T1	349-361
				Total 09 hours
UNIT III- SURVEY ADJUSTMENTS				
19.	1	Errors - Sources, precautions and corrections	T1	27-36
20.	1	Classification of errors	T1	27-36
21.	1	True and most probable values	T1	27-36
22.	1	weighted observations	T1	27-36
23.	1	Method of equal shifts	T1	27-36
24.	1	Principle of least squares	T1	27-36
25.	1	Normal equation	T1	27-36
26.	1	Correlates - Level nets	T1	27-36
27.	1	Adjustment of simple triangulation networks.	T1	27-36
				Total 09 hours
UNIT IV- REMOTE SENSING and GPS				

28.	1	Field of Applications	T1	623-653
29.	1	Natural Resources	T1	623-653
30.	1	Agriculture-Soil	T1	623-653
31.	1	Water Resources	T1	623-653
32.	1	Wasteland Management	T1	623-653
33.	1	Social resources	T1	623-653
34.	1	Cadastral Records	T1	623-653
35.	1	LIS Basic concepts of GPS	T1	623-653
36.	1	GPS and its applications	T1	623-653
				Total 09 hours
		UNIT V- OTHER TOPICS		
37.	1	Fundamental principal:(Demo)	T1	523-582
38.	1	Photogrammetry – Introduction	T1	523-582
39.	1	Terrestrial and aerial Photographs -	T1	523-582
40.	1	Stereoscopy – Parallax	T1	523-582
41.	1	Introduction to Total Station- Electromagnetic distance measurement	T1	523-582
42.	1	Carrier waves	T1	523-582
43.	1	Principles – Instruments	T1	523-582
44.	1	Trilateration - Hydrographic Surveying - Tides – MSL	T1	523-582
45.	1	Sounding methods - Location of soundings and methods	T1	523-582
				Total 09 hours
				Total 45 hours

TEXT BOOKS:

S.No	**Title of Book**	**Author of Book**	**Publisher**	**Year of Publishing**
1	Surveying, Volume I, II and III	Punmia B.C	LaxmiPublications,Delhi	2012

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S.No	**Title of Book**	**Author of Book**	**Publisher**	**Year of Publishing**
1	Plane and Geodetic Surveying, Volume I and II	Aylmer Johnson	CRC Press , New York	2004
2	Introduction to Surveying	James M.Anderson and Edward M.Mikhail	McGraw-Hill Book Company, New York, Fifth Edition	2009
3	Elements of Cartography	Harley	McGraw-Hill Book Company	2001

			New York, Fifth Edition	
4	Surveying and Levelling, Volume I and II	Kanetkar T.P	United Book Corporation, Pune	2007
5	Surveying	Bannister A. and Raymond S	ELBS, Seventh Edition	2004
6	Surveying and Levelling	Basak.N.N	McGraw-Hill Book Company	2011

Unit 1
Introduction to Surveying

<u>Principles of Surveying</u>
The fundamental principle upon which the various methods of plane surveying are based can be stated under the following two aspects.

Location of a point by measurement from two points of reference
According to this principle, the relative position of a point to be surveyed should be located by measurement from at least two points of reference, the positions of which have already been fixed.

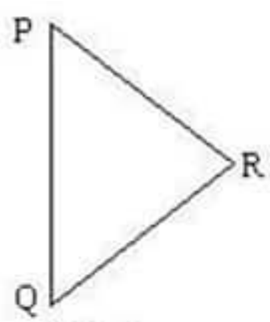


Fig. a

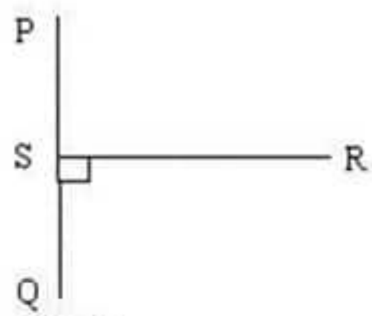


Fig. b

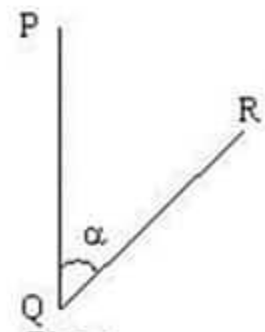


Fig. c

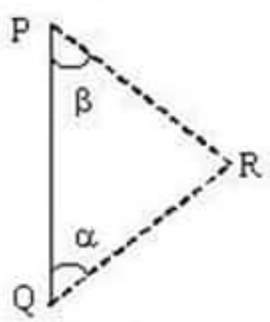


Fig. d

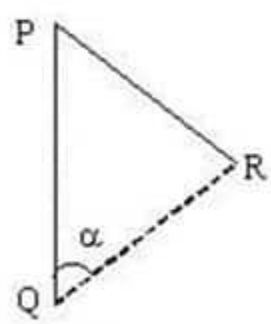
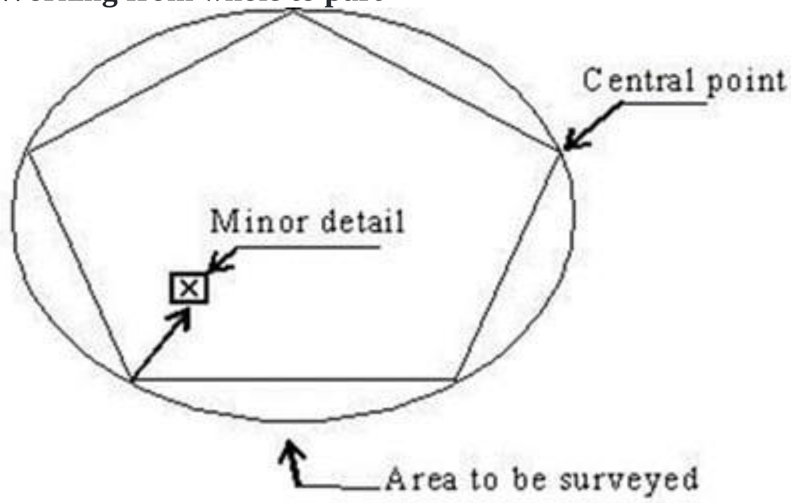


Fig. e

If P and Q are the two reference points on the ground, any other point, such as R, can be located by any of the direct methods shown in the above figures. But, although a single method is sufficient to locate the relative position of ‘R’ with respect to reference points P and Q, it is necessary to adopt at least any two methods to fix the position of point ‘R’.

While the measurements made in the either of the first method or second method will be helpful in locating the point ‘R’, the measurements made in the other method will act as a check.

Working from whole to part



According to this principle, it is always desirable to carryout survey work from whole to part. This means, when an area is to be surveyed, first a system of control points is to be established covering the whole area with very high precision. Then minor details are located by less precise methods.

The idea of working this way is to prevent the accumulation of errors and to control and localize minor errors which, otherwise, would expand to greater magnitudes if the reverse process is followed, thus making the work uncontrolled at the end.

Method of Surveying in Civil Engineering
Primary types of Surveying are:

- Plane surveying
- Geodetic surveying

1. Plane surveying
Plane surveying is conducted by state agencies as well as private agencies. As we know earth is spherical in shape but its diameter is big enough to consider plane in small dimensions. It is that type of surveying in which the mean surface of the earth is considered as a plane and the spheroidal shape is neglected. All triangles formed by survey lines are considered as plane triangles. The level line is considered as straight and plumb lines are considered parallel. Plane surveying is done of the area of survey is less than 250 km^2.

2. Geodetic surveying
Geodetic survey is conducted by survey department of the country. It is that type of surveying in which the curved shape of the earth is taken in to account. The object of geodetic survey is to determine the precise position on the surface of the earth, of a system of widely distant points which form control stations in which surveys of less precision may be referred. . Line joining two points is considered as curved line and angles are assumed as spherical angles. It is carried out if the area exceeds over 250 km^2.

Secondary classification of Surveying

Surveys may be classified based on the nature of the field of survey, object of survey and instruments used.

1) Surveying based on Nature of Survey
a) Topographical Surveys
They are carried out determine the position of natural features of a region such as rivers, streams, hills etc. and artificial features such as roads and canals. The purpose of such surveys is to prepare maps and such maps of are called topo-sheets.

b) Hydrographic Survey
Hydro-graphic survey is carried out to determine M.S.L. (Mean Sea Level), water spread area, depth of water bodies, velocity of flow in streams, cross-section area of flow etc.

c) Astronomical Survey
The Astronomical Survey is carried out to determine the absolute location of any point on the surface of earth. The survey consists of making observations to heavenly bodies such as stars.

d) Engineering Survey
This type of survey is undertaken whenever sufficient data is to be collected for the purpose of planning and designing engineering works such as roads, bridges and reservoirs.

e) Archeological Survey
This type of survey is carried out to gather information about sites that are important from archeological considerations and for unearthing relics of antiquity.

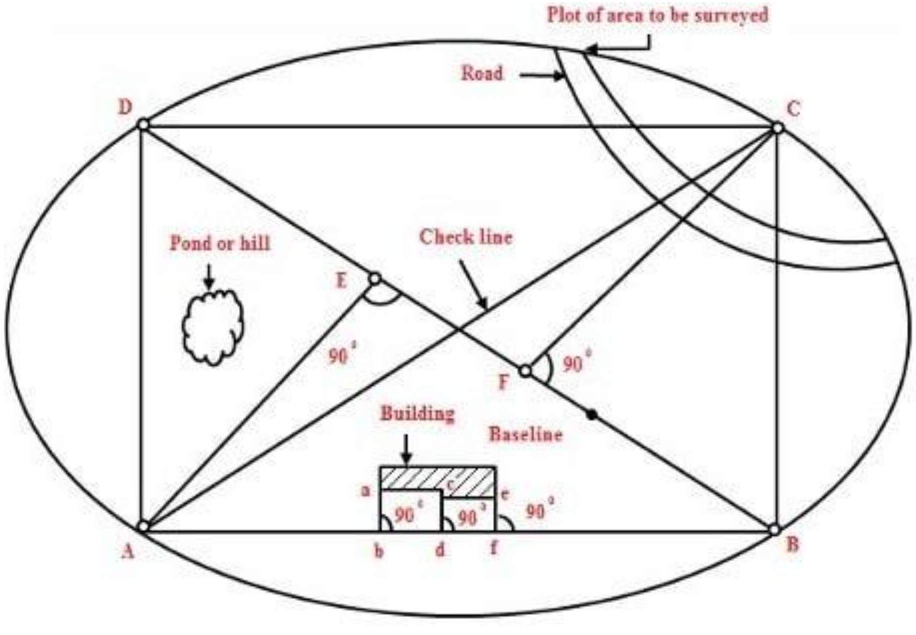
f) Photographic Survey
In this type of survey, information is collected by taking photographs from selected points using a camera.

g) Aerial Survey
In this type of survey data about large tracks of land is collected by taking photographs from an aero-plane.

h) Reconnaissance Survey
In this type of survey, data is collected by marking physical observation and some measurements using simple survey instruments.

2) Surveying based on Type of Instruments
a) Chain Surveying
Chain surveying is the basic and oldest type of surveying. The principle involved in chain survey is of triangulation. The area to be surveyed is divided into a number of small triangles. Angles of triangles must not be less than 30 degree and greater than 120 degree. Equilateral triangles are considered to be ideal triangles. No angular measurements are taken, tie line and check lines control accuracy of the work.

This method is suitable on level ground with little undulations and area to be survey is small.



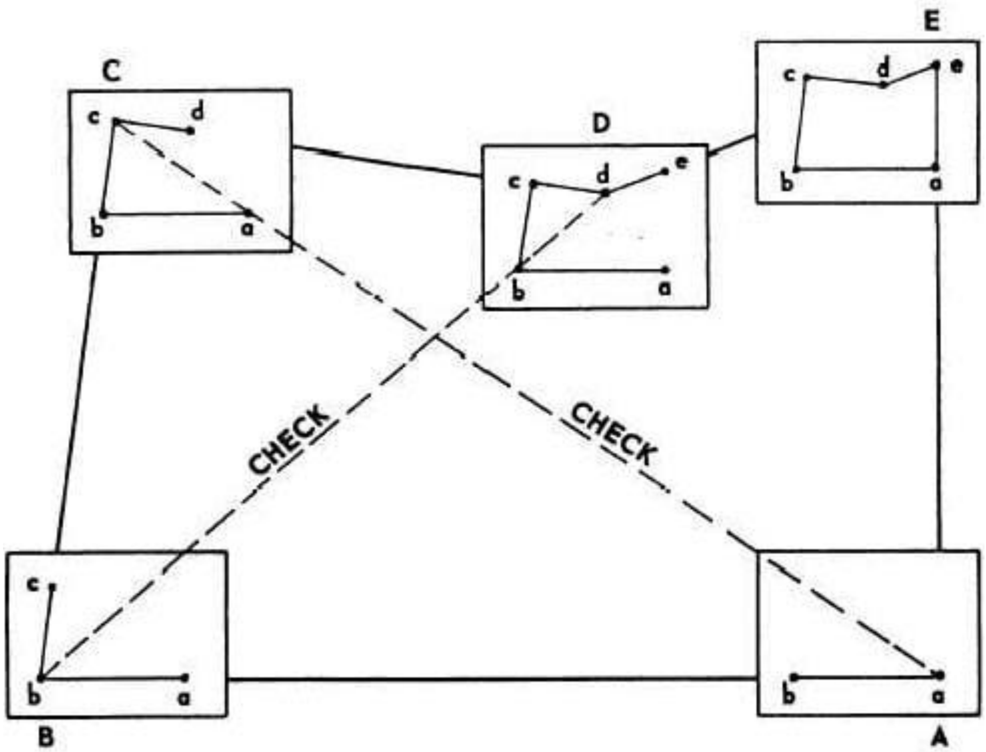
A simple networks of triangle in a plot of land to be surveyed

b) Compass Surveying
Compass survey uses the principle of traversing. This method does not requires the need to create triangles. It uses a prismatic compass for measuring magnetic bearing of line and the distance is measured by chain. A series of connecting lines is prepared using compass and measuring distances using chain. Interior details are located using offset from main survey lines.

They suitable for large area surveying crowded with many details. It can be used to survey a river course.

c) Plane Table Surveying
The principle of plane table survey is parallelism. They are plotted directly on paper with their relative position. The rays are drawn from station to object on ground. The table is placed at each of the successive station parallel to the position of the last station.

They are basically suitable for filling interior detailing and is recommended when great accuracy is not required.

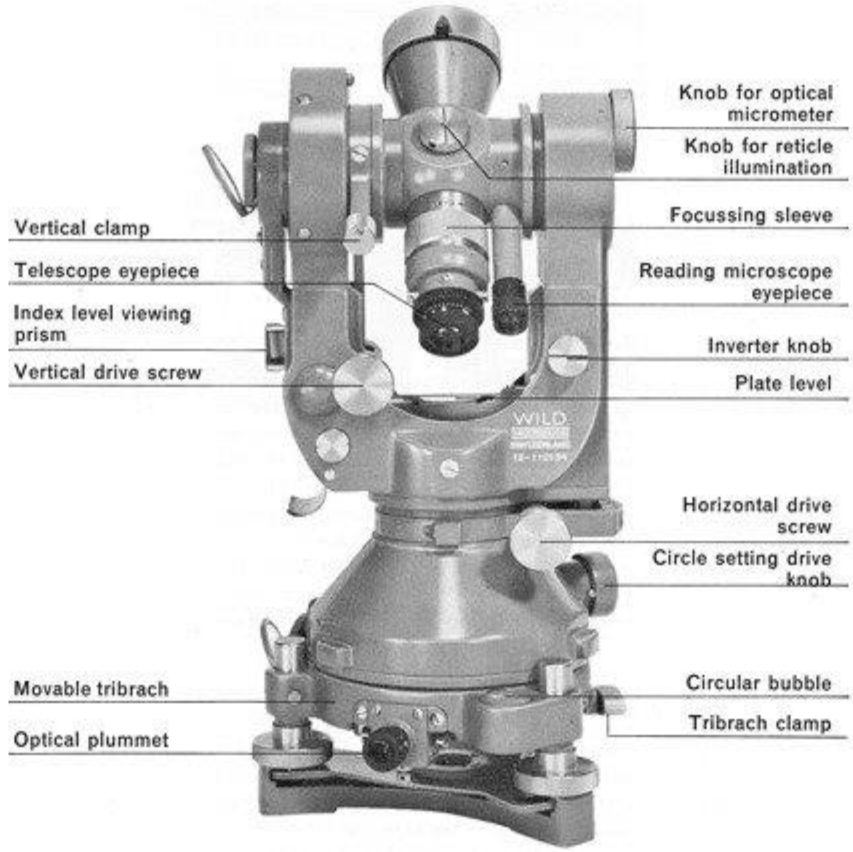


d) Theodolite Surveying
The theodolite is an instrument used mainly for accurate measurement of the horizontal and vertical angles. They are accurate to measure up to 10″ or 20″ angles.

Theodolite can be used to measure:

- Horizontal angles
- Vertical angles
- Deflection angle
- Magnetic bearing
- Horizontal distance between two points
- Vertical height between two points
- Difference in elevation

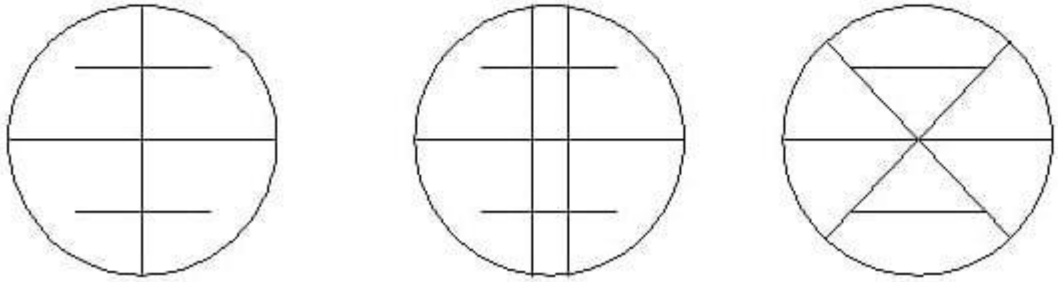
Nowadays theodolite is shadowed and replaced by the use of Total Station which can perform the same task with greater ease and accurate results



e) Tacheometric Surveying

Tacheometry is a branch of surveying in which horizontal and vertical distances are determined by taking angular observations with an instrument known as a tacheometer. Tacheometer is nothing but a transit theodolite fitted with a stadia diaphragm and an anallatic lens. There is no need for chaining in such survey. The principle of Tacheometer is based on property of isosceles triangle, where ratio of the distance of the base from the apex and the length of the base is always constant.

Different form of stadia diaphragm commonly used:



f) Photographic Surveying

Photographic survey is based on technique of taking photographs from different angle to prepare topographic details with relative high speed.

There are two type of photographic surveying

i). Terrestrial or ground photogrammetry

In terrestrial photogrammetry maps are prepared from ground photographs from different points on the earth surface for measurement purpose.

ii). Aerial photogrammetry

In aerial photogrammetry maps are produced from air from an airplane or helicopter.

Photogrammetry encompasses two major area of specialization.

- Metrical photogrammetry
- Interpretive photogrammetry

Metrical photogrammetry is of principal interest to surveyors since it is applied to determine distances, elevations, areas, volume, etc. to compile topographic maps made from measurements on photographs.

Intuitive photogrammetry involves objects from their photographic image and their significance. Critical factors considered in identifying object of shape, sizes, patterns, shadow.

Levelling:

Levelling or **leveling** is a branch of surveying, the object of which is to establish or verify or measure the height of specified points relative to a datum. It is widely used in cartography to measure geodetic height, and in construction to measure height differences of construction artifacts.

Principle of leveling

The principle of levelling is to obtain horizontal line of sight with respect to which vertical distances of the points above or below this line of sight are found.

What is Profile levelling?

Profile leveling is one of the most common applications of running levels and vertical distance measurement for the surveyor. The results are plotted in the form of a profile, which is a drawing that shows a vertical cross section. Profiles are required for the design and construction of roads, curbs, sidewalks, pipelines, etc. In short, profile leveling refers to the process of determining the elevation of points on the ground at mostly uniform intervals along a continuous line.

Equipment used for profile leveling

1. Dumpy level
2. Leveling staff
3. Tripod
4. Staff bubble
5. Chain or Tape

Procedure for profile leveling

1.Longitudinal levelling

Profile leveling is essentially the same as benchmark leveling, with one basic difference. At each instrument position, where an HI is determined by a back sight rod reading on a benchmark or turning point, several additional foresight readings may be taken on as many points as desired. These additional readings are called rod shots, and the elevation of all those points is determined by subtracting the rod shot from the HI at that instrument location. (See figure 1)

Plotting the Profile

The profile drawing is basically a graph of elevations, plotted on the vertical axis, as a function of stations, plotted on horizontal axis. A gridded sheet called profile paper is used to plot the profile data from the field book. All profile drawings must have a proper title block, and both axes must be fully labeled with stations and elevations.

The elevation or elevation scale is typically exaggerated; that is, it is 'stretched' in comparison to the horizontal scale. For example the vertical scale might be 10 times larger. The horizontal line at the bottom of the profile does not necessary have to start at zero elevation

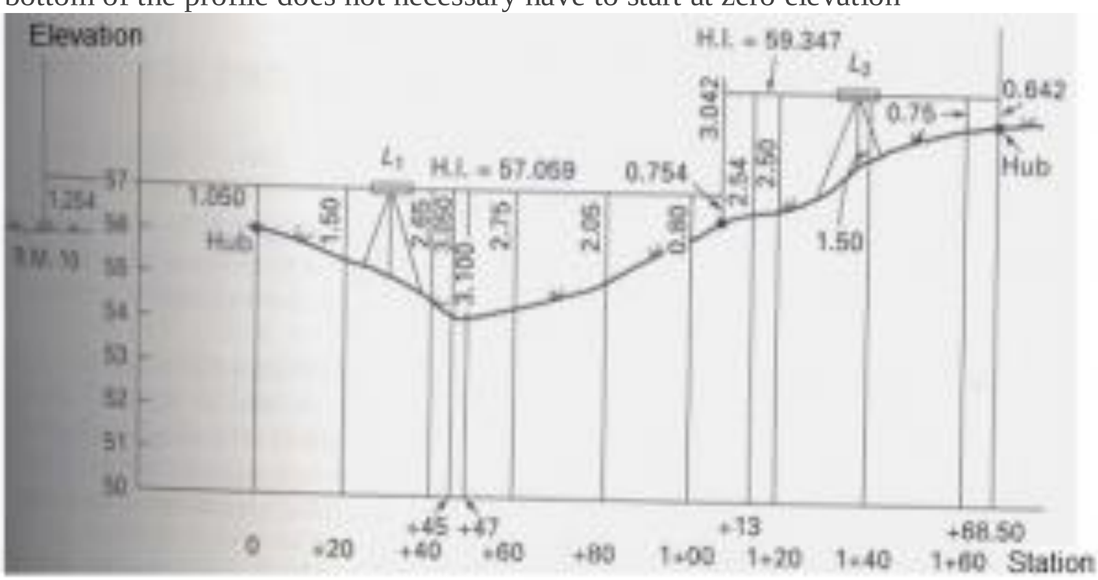


Figure 1: Profile leveling

2.Cross sectioning levelling

Cross sectioning levelling is another method in profile levelling. The term cross-section generally refers to a relatively short profile view of the ground, which is drawn perpendicular to the route centerline of a highway or other types of linear projects.

Cross-sectional drawings are particularly important for estimating the earthwork volumes needed to construct a roadway; they show the existing ground elevations, the proposed cut or fill side slopes, and the grade elevation for the road base.
There is really no difference in procedure between profile and cross-section leveling except for the form of the field notes. Cross-section rod shots are usually taken during the route profile survey from the same instrument positions used to take rod shots along the centerline.
Cross-section data are obtained at the same locations along the route that are used for the profile rod-shot stations. (See figure 2 a and b).

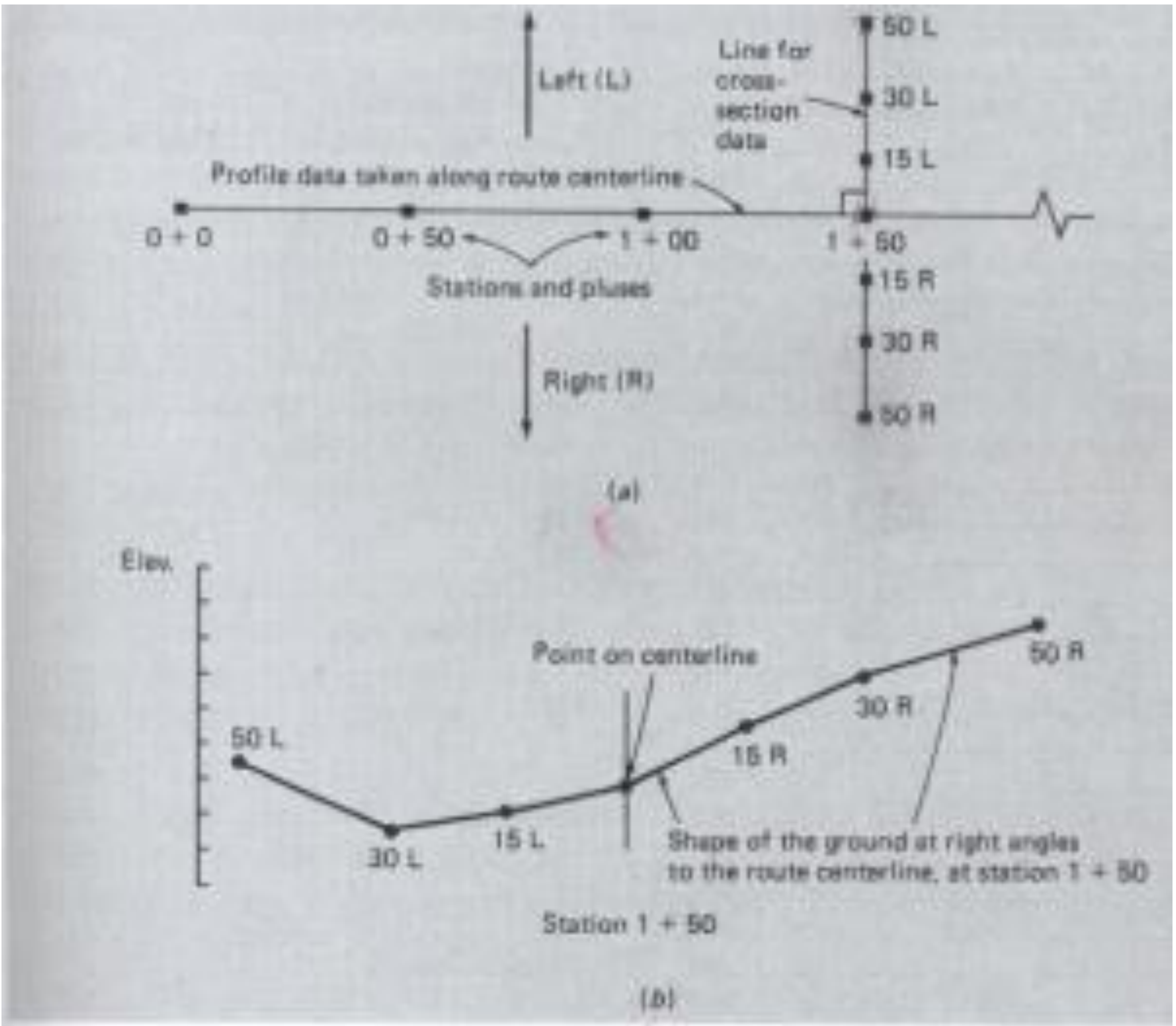


Figure 2
(a) Top view showing the route center line and the line for cross-section leveling at station 1+ 50.
(b) The cross-section showing ground elevations at points left and right of the centerline.
Hope you can understand this post, profile levelling (longitudinal and cross-section levelling)

Contouring:
Contouring in surveying is the determination of elevation of various points on the ground and fixing these points of same horizontal positions in the contour map.

To exercise vertical control leveling work is carried out and simultaneously to exercise horizontal control chain survey or compass survey or plane table survey is to be carried out.

If the theodolite is used, both horizontal and vertical controls can be achieved from the same instrument. Based on the instruments used one can classify the contouring in different groups.

Methods of Contour Surveying
There are two methods of contour surveying:

1. Direct method
2. Indirect method

Direct Method of Contouring
It consists in finding vertical and horizontal controls of the points which lie on the selected contour line.

For vertical control levelling instrument is commonly used. A level is set on a commanding position in the area after taking fly levels from the nearby bench mark. The plane of collimation/height of instrument is found and the required staff reading for a contour line is calculated.

The instrument man asks staff man to move up and down in the area till the required staff reading is found. A surveyor establishes the horizontal control of that point using his instruments.

After that instrument man directs the staff man to another point where the same staff reading can be found. It is followed by establishing horizontal control.

Thus, several points are established on a contour line on one or two contour lines and suitably noted down. Plane table survey is ideally suited for this work.

After required points are established from the instrument setting, the instrument is shifted to another point to cover more area. The level and survey instrument need not be shifted at the same time. It is better if both are nearby to communicate easily.

For getting speed in levelling some times hand level and Abney levels are also used. This method is slow, tedious but accurate. It is suitable for small areas.

Indirect Method of Contouring
In this method, levels are taken at some selected points and their levels are reduced. Thus in this method horizontal control is established first and then the levels of those points found.

After locating the points on the plan, reduced levels are marked and contour lines are interpolated between the selected points.

For selecting points any of the following methods can be used:

1. Method of squares
2. Method of cross-section
3. Radial line method

Method of Squares
In this method area is divided into a number of squares and all grid points are marked (Ref. Fig. 1).

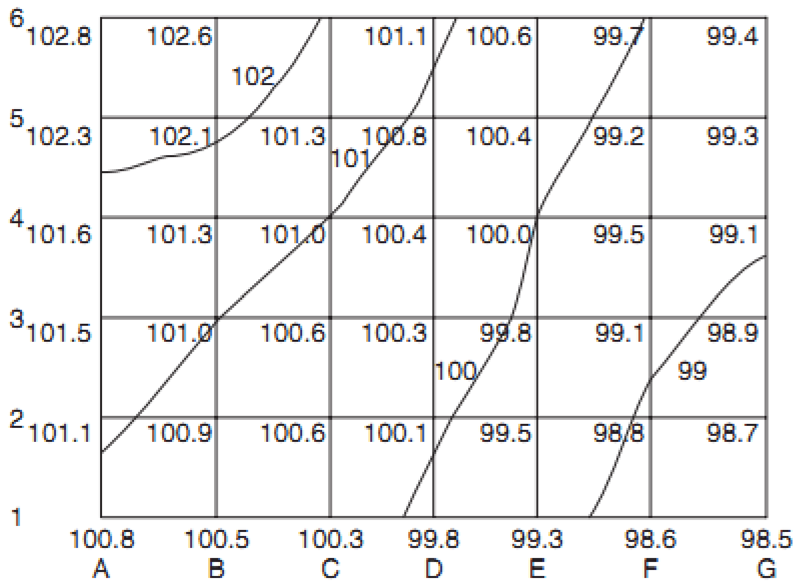


Fig. 1

Commonly used size of square varies from 5 m × 5 m to 20 m × 20 m. Levels of all grid points are established by levelling. Then grid square is plotted on the drawing sheet. Reduced levels of grid points marked and contour lines are drawn by interpolation [Ref. Fig. 1].

Method of Cross-Section
In this method cross-sectional points are taken at regular interval. By levelling the reduced level of all those points are established. The points are marked on the drawing sheets, their reduced levels (RL) are marked and contour lines interpolated.

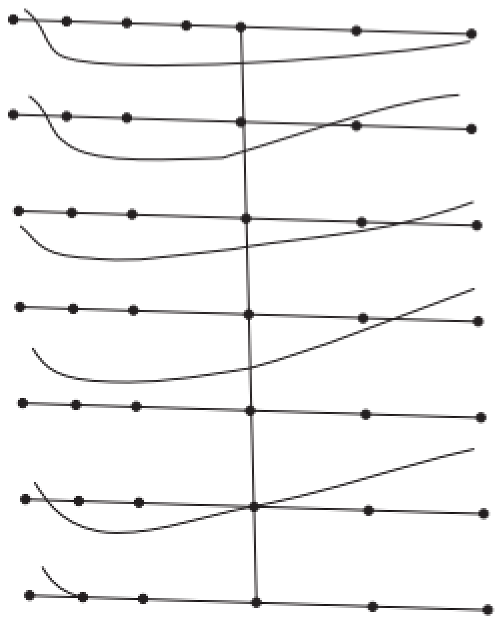


Fig. 2

Figure 2 shows a typical planning of this work. The spacing of cross-section depends upon the nature of the ground, scale of the map and the contour interval required. It varies from 20 m to 100 m. Closer intervals are required if ground level varies abruptly.

The cross- sectional line need not be always be at right angles to the main line. This method is ideally suited for road and railway projects.

Radial Line Method

[Fig. 3]. In this method several radial lines are taken from a point in the area. The direction of each line is noted. On these lines at selected distances points are marked and levels determined. This method is ideally suited for hilly areas. In this survey theodolite with tacheometry facility is commonly used.

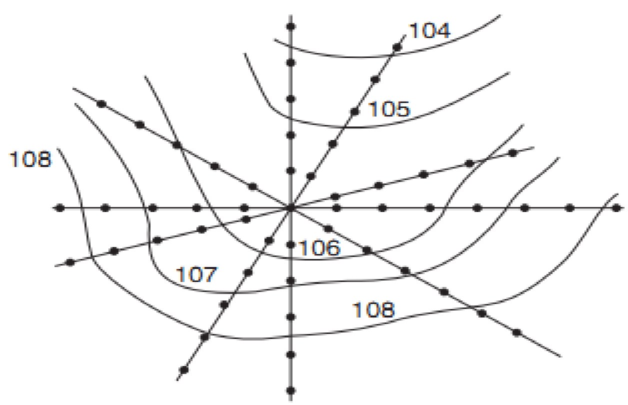


Fig. 3

For **interpolating contour points** between the two points any one of the following method may be used:
(a) Estimation
(b) Arithmetic calculation
(c) Mechanical or graphical method.

Mechanical or graphical method of interpolation consist in linearly interpolating contour points using tracing sheet:
On a tracing sheet several parallel lines are drawn at regular interval. Every 10th or 5th line is made darker for easy counting. If RL of A is 97.4 and that of B is 99.2 m. Assume the bottom most dark line represents 97 m RL and every parallel line is at 0.2 m intervals. Then hold the second parallel line on A.

Rotate the tracing sheet so that 100.2 the parallel line passes through point B. Then the intersection of dark lines on AB represents the points on 98 m and 99 m contours [Ref. Fig. 4].

Similarly the contour points along any line connecting two neighbouring points may be obtained and the points pricked. This method maintains the accuracy of arithmetic calculations at the same time it is fast.

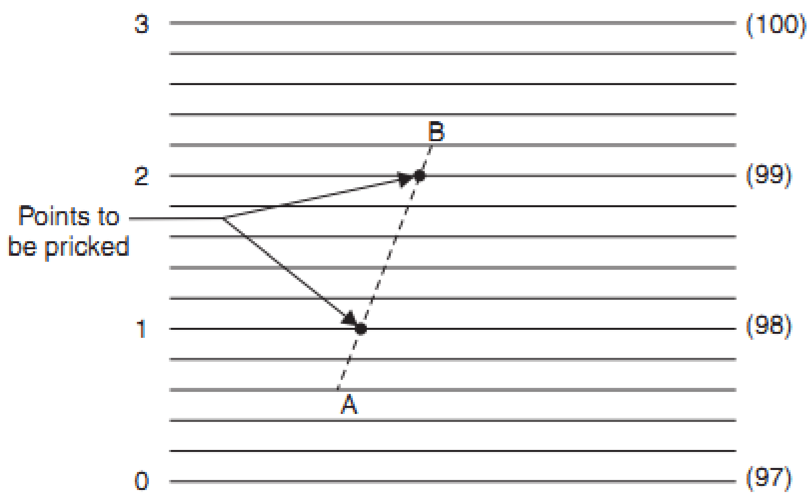


Fig. 4

Drawing Contours

After locating contour points smooth contour lines are drawn connecting corresponding points on a contour line. French curves may be used for drawing smooth lines. A surveyor should not lose the sight of the characteristic feature on the ground. Every fifth contour line is made thicker for easy readability. On every contour line its elevation is written. If the map size is large, it is written at the ends also.

Contour Maps and Its Uses

A contour maps consists of contour lines which are imaginary lines connecting points of equal elevation. Such lines are drawn on the plan of an area after establishing reduced levels of several points in the area.

The contour lines in an area are drawn keeping difference in elevation of between two consecutive lines constant. For example, the contour map in fig. 1 shows contours in an area with contour interval of 1 m. On contour lines the level of lines is also written.

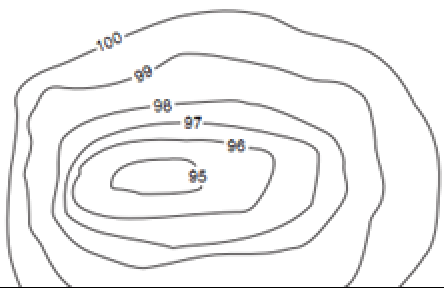


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Fig. 1: Contours

Characteristics of Contour Maps

The contours maps have the following characteristics:

1. Contour lines must close, not necessarily in the limits of the plan.
2. Widely spaced contour indicates flat surface.
3. Closely spaced contour indicates steep ground.
4. Equally spaced contour indicates uniform slope.
5. Irregular contours indicate uneven surface.
6. Approximately concentric closed contours with decreasing values towards centre (Fig. 1) indicate a pond.
7. Approximately concentric closed contours with increasing values towards centre indicate hills.
8. Contour lines with U-shape with convexity towards lower ground indicate ridge (Fig. 2).

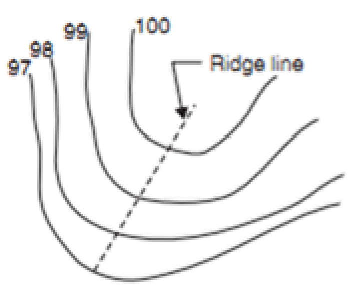


Fig. 2

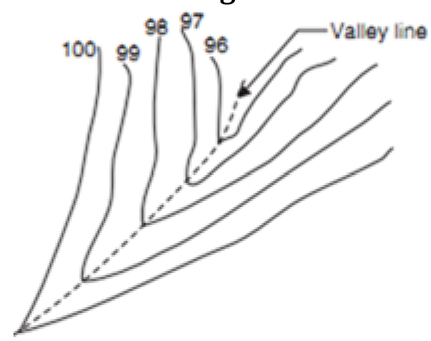


Fig. 3

9. Contour lines with V-shaped with convexity towards higher ground indicate valley (Fig.3).

10. Contour lines generally do not meet or intersect each other.

11. If contour lines are meeting in some portion, it shows existence of a vertical cliff (Fig. 4).

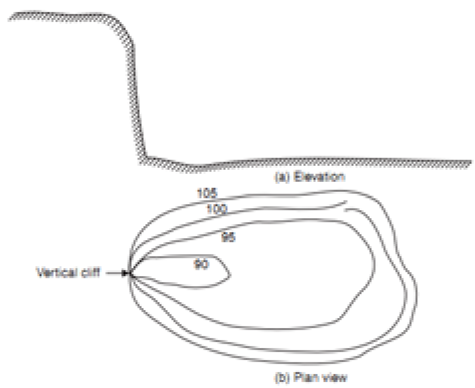


Fig. 4

12. If contour lines cross each other, it shows existence of overhanging cliffs or a cave (Fig. 5).

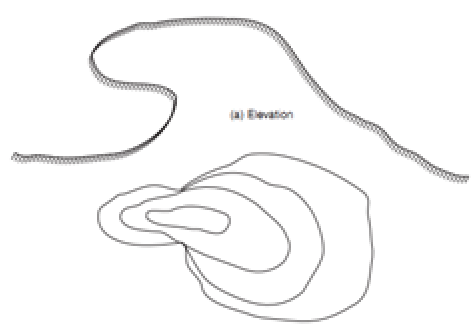


Fig. 5

Uses of Contour Maps

Contour maps are extremely useful for various engineering works:

1. A civil engineer studies the contours and finds out the nature of the ground to identify. Suitable site for the project works to be taken up.
2. By drawing the section in the plan, it is possible to find out profile of the ground along that line. It helps in finding out depth of cutting and filling, if formation level of road/railway is decided.
3. Intervisibility of any two points can be found by drawing profile of the ground along that line.
4. The routes of the railway, road, canal or sewer lines can be decided so as to minimize and balance earthworks.
5. Catchment area and hence quantity of water flow at any point of nalla or river can be found. This study is very important in locating bunds, dams and also to find out flood levels.
6. From the contours, it is possible to determine the capacity of a reservoir.

UNIT II

Curves

Definition of Curves:

Curves are regular bends provided in the lines of communication like roads, railways etc. and also in canals to bring about the gradual change of direction. They are also used in the vertical plane at all changes of grade to avoid the abrupt change of grade at the apex.

Curves provided in the horizontal plane to have the gradual change in direction are known as Horizontal curves, whereas those provided in the vertical plane to obtain the gradual change in grade are known as vertical curves. Curves are laid out on the ground along the centre line of the work. They may be circular or parabolic.

Classification of Curves:

(i) Simple,
(ii) Compound
(iii) Reverse and
(iv) Deviation

(i) Simple Curve:

A simple curve consists of a single arc of a circle connecting two straights. It has radius of the same magnitude throughout. In fig. 11.1 T_1 D T_2 is the simple curve with T_1O as its radius.

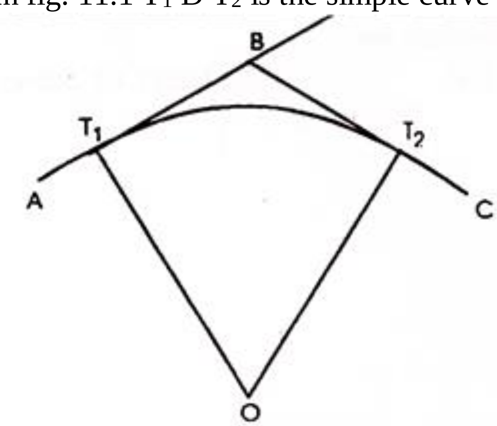


Fig 11.1

(ii) Compound Curve:

A compound curve consists of two or more simple curves having different radii bending in the same direction and lying on the same side of the common tangent. Their centres lie on the same side of the curve. In fig. 11.2, T_1 P T_2 is the compound curve with T_1O_1 and PO_2 as its radii.

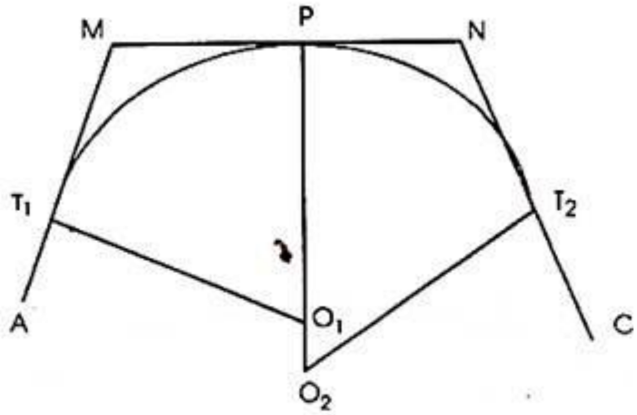


Fig 11.2

(iii) Reverse (or Serpentine) Curve:

A reverse or serpentine curve is made up of two arcs having equal or different radii bending in opposite directions with a common tangent at their junction. Their centres lie of opposite sides of the curve. In fig. 11.3 T_1 P T_2 is the reverse curve with T_1O_1 and PO_2 as its radii.

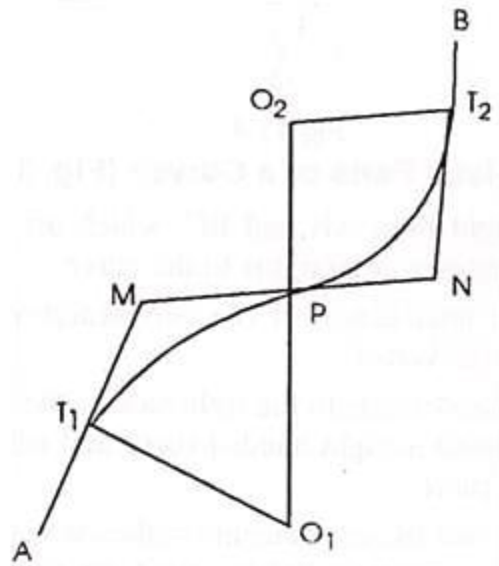


Fig 11 3

Reverse curves are used when the straights arc parallel or intersect at a very small angle. They are commonly used in railway sidings and sometimes on railway tracks and roads meant for low speeds. They should be avoided as far as possible on main railway lines and highways where speeds are necessarily high.

(iv) Deviation Curve:

A deviation curve is simply a combination of two reverse curves. It is used when it becomes necessary to deviate from a given straight path in order to avoid intervening obstructions such as a bend of river, a building, etc. In fig. 11.4. T_1 $EDFT_2$ is the deviation curve with T_1O, EO_2 and FO_2 as its radii.

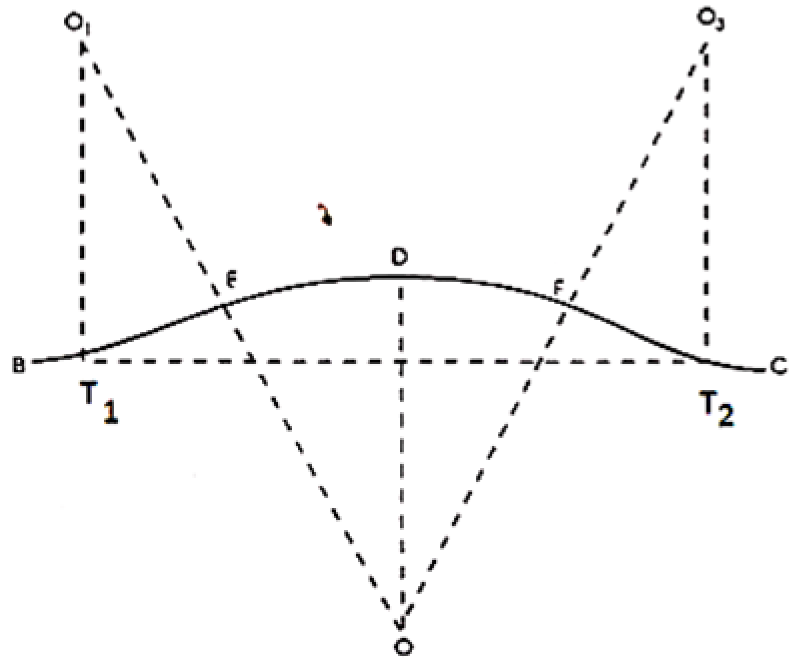


Fig 11.4

Names of Various Parts of a Curve: (Fig. 11.5):

(i) The two straight lines AB and BC, which are connected by the curve are called the tangents or straights to the curve.

(ii) The points of intersection of the two straights (B) is called the intersection point or the vertex.

(iii) When the curve deflects to the right side of the progress of survey as in fig. 11.5, it is termed as right handed curve and when to the left, it is termed as left handed curve.

(iv) The lines AB and BC are tangents to the curves. AB is called the first tangent or the rear tangent BC is called the second tangent or the forward tangent.

(v) The points (T_1 and T_2) at which the curve touches the tangents are called the tangent points. The beginning of the curve (T_1) is called the tangent curve point and the end of the curve (T2) is called the curve tangent point.

(vi) The angle between the tangent lines AB and BC (ABC) is called the angle of intersection (I)

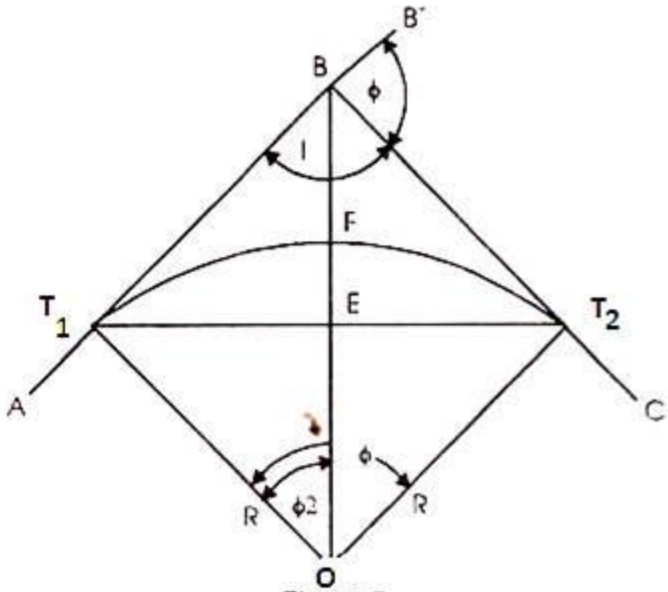


Fig 11.5

(vii) The angle by which the forward tangent deflects from the rear tangent is called the deflection angle (ϕ) of the curve.

(viii) The distance the two tangent point of intersection to the tangent point is called the tangent length (BT_1 and BT_2).

(ix) The line joining the two tangent points (T_1 and T_2) is known as the long-chord

(x) The arc T_1FT_2 is called the length of the curve.

(xi) The mid-point (F) of the arc (T_1FT_2) in called summit or apex of the curve.

(xii) The distance from the point of intersection to the apex of the curve BF is called the apex distance.

(xiii) The distance between the apex of the curve and the midpoint of the long chord (EF) is called the versed sine of the curve.

(xiv) The angle subtended at the centre of the curve by the arc T_1FT_2 is known as the Central angle and is equal to the deflection angle (ϕ).

Elements of a Curve (Fig. 11.5):

(*i*) Angle of intersection + Deflection angle = 180°

or $I + \phi = 180°$ ... ...(Eqn. 11.1)

(*ii*) $\angle T_1OT_2 = 180° - I = \phi$ ... ...(Eqn. 11.2.)

(*i.e.* the central angle = the deflection angle).

(*iii*) Tangent length $= BT_1 = BT_2 = OT_1 \tan \frac{\phi}{2}$

$= R \tan \frac{\phi}{2}$ ... ...(Eqn. 11.3)

(*iv*) Length of Long Chord $= 2T_1E = 2 \times OT_1 \sin\left(\frac{\phi}{2}\right)$

$= 2R \sin \frac{\phi}{2}$ ... ... (Eqn. 11.4)

(*v*) Length of the curve = Length of the arc T_1FT_2

$= R\phi$ (in radians)

$= \frac{\pi R\phi}{180°}$ ... ... (Eqn. 11.5)

(*vi*) Apex distance $= BF = BO - OF$

$= R \sec \frac{\phi}{2} - R$

$= R\left(\sec\frac{\phi}{2} - 1\right)$ ... ...(Eqn. 11.6)

(*vii*) Versed sine of the curve $= EF = OF - OE$

$= R - R\cos\frac{\phi}{2}$

$= R\left(1 - \cos\frac{\phi}{2}\right) = R \text{ versine } \frac{\phi}{2}$ ... ...(Eqn. 11.7)

Designation of Curves:

A curve may be designated either by the radius or by the angle subtended at the centre by a chord of particular length In India, a curve is designated by the angle (in degrees) subtended at the centre by a chord of 30 metres (100 ft.) length. This angle is called the degree of the curve (D).

The relation between the radius and the degree of the curve may be determined as follows: Refer to fig 11.6:

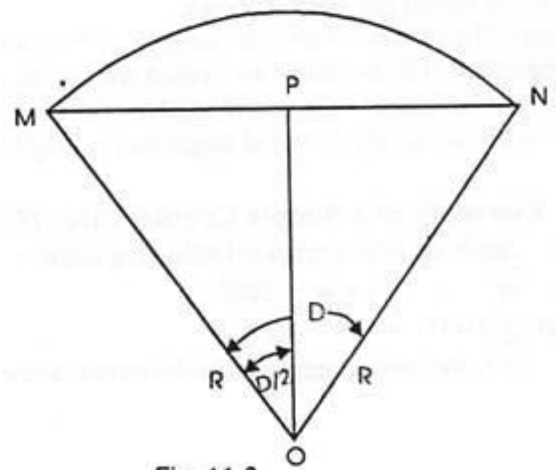


Fig. 11.6

Let R= The radius of the curves in meters

D= The degree of the curve

MN= The chord, 30m long

P= The mid-point of the chord

In Δ OMP, OM = R

$$MP = \frac{1}{2}MN = 15\text{ m}$$

$$\angle MOP = \frac{D}{2}$$

Then, $\sin\frac{D}{2} = \frac{MP}{OM}, \frac{15}{R}$

or $R = \dfrac{15}{\sin\frac{D}{2}}$ **(Exact)** ... **...(Eqn. 11.8)**

But when D is small, $\sin\frac{D}{2}$ may be assumed approximately equal to $= \frac{D}{2}$ in radians.

$$R = \frac{15}{\frac{D}{2} \times \frac{\pi}{180^\circ}} = \frac{15 \times 360}{\pi D}$$

$$= \frac{171.87}{D}$$

or say, $R = \dfrac{1719}{D}$ **(approximate)** ... **... (Eqn. 11.9)**

The approximate relation holds good up to 5° curves. For higher degree curves, the exact relation should be used.

Methods of Curve Ranging:

A curve may be set out:

1. By linear methods, where chain and tape are used.

2. By angular or instrumental methods, where a theodolite with or without a chain is used.

Before starting setting out a curve by any method, the exact positions of the tangent points between which the curve lies, must be determined.

For this, proceed as follows: (Fig. 11.5)

(i) Having fixed the directions of the straights, produce them to meet at point (B).

(ii) Set up a theodolite at the intersection point (B) and measure the angle of intersection (I). Then find the deflection angle (ϕ) by subtracting (I) from 180°. i.e., $\phi = 180° — I$

(iii) Calculate the tangent length from the Eqn. 11.3:

$$\left(\tan \text{lenght} = R \tan \frac{\Phi}{2}\right)$$

(iv) Measure the tangent length (BT_1) backward along the rear tangent BA from the intersection point B, thus locating the position of T_1.

(v) Similarly, locate the position of T_2 by measuring the same distance forward along the forward tangent BC from B,

Having located the positions of the tangent points T_1 and T_2; their changes may be determined. The change of T_1 is obtained by subtracting the tangent length from the known change of the intersection point B. And the change of T_2 is found by adding the length of the curve to the change to T_1.

Then the pegs are fixed at equal intervals on the curve. The interval between the pegs is usually 30 m or one chain length. This distance should actually be measured along the arc, but in practice it is measured along the chord, as the difference between the chord and the corresponding arc is small and hence negligible. In order that this difference is always small and negligible, the length of the chord should not be more than 1/20th of the radius of the curve. The curve is then obtained by joining all these pegs.

The distances along the centre line of the curve are continuously measured from the point of beginning of the line upto the end, i.e., the pegs along the centre line of the work should be at equal interval from the beginning of the line to the end. There should be no break in the regularity of their spacing in passing from a tangent to a curve or from a curve to a tangent.

For this reason, the first peg on the curve is fixed at such a distance from the first tangent point (T_1) that its change becomes the whole number of chains i.e. the whole number of peg interval. The length of the first chord is thus less than the peg interval and is called as a sub- chord. Similarly there will be a sub chord at the end of the curve. Thus a curve usually consists of two-chords and a number of full chords. This is made clear from the following example.

Transition Curves:

A non-circular curve of varying radius introduced between a straight and a circular curve for the purpose of giving easy changes of direction of a route is called a transition or easement curve. It is also inserted between two branches of a compound or reverse curve.

Advantages of providing a transition curve at each end of a circular curve:

(i) The transition from the tangent to the circular curve and from the circular curve to the tangent is made gradual.

(ii) It provides satisfactory means of obtaining a gradual increase of super-elevation from zero on the tangent to the required full amount on the main circular curve.

(iii) Danger of derailment, side skidding or overturning of vehicles is eliminated.

(iv) Discomfort to passengers is eliminated.

Conditions to be fulfilled by the transition curve:

(i) It should meet the tangent line as well as the circular curve tangentially.

(ii) The rate of increase of curvature along the transition curve should be the same as that of increase of super-elevation.

(iii) The length of the transition curve should be such that the full super-elevation is attained at the junction with the circular curve.

(iv) Its radius at the junction with the circular curve should be equal to that of circular curve.

There are three types of transition curves in common use:
(1) A cubic parabola,

(2) A cubical spiral, and

(3) A lemniscate, the first two are used on railways and highways both, while the third on highways only.

When the transition curves are introduced at each end of the main circular curve, the combination thus obtained is known as combined or Composite Curve.

Super-Elevation or Cant:
When a vehicle passes from a straight to a curve, it is acted upon by a centrifugal force in addition to its own weight, both acting through the centre of gravity of the vehicle. The centrifugal force acts horizontally and tends to push the vehicle off the track.

In order to counteract this effect the outer edge of the track is super elevated or raised above the inner one. This raising of the outer edge above the inner one is called super elevation or cant. The amount of super-elevation depends upon the speed of the vehicle and radius of the curve.

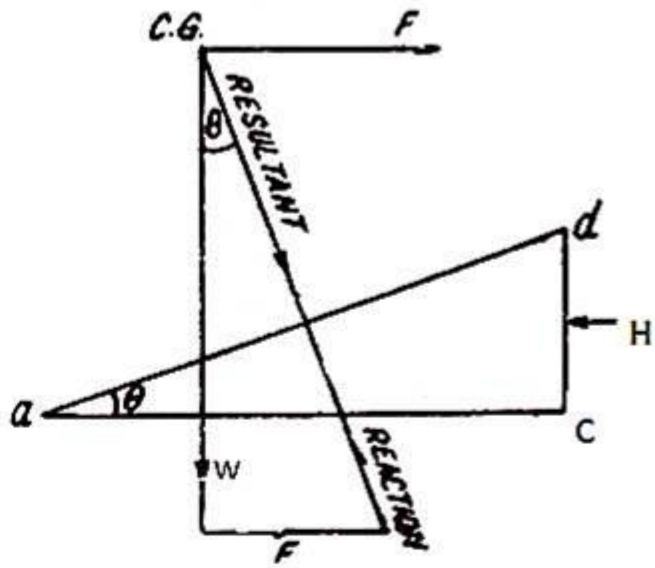


Fig. 11.24

Let:

W = the weight of vehicle acting vertically downwards.

F = the centrifugal force acting horizontally,

v = the speed of the vehicle in metres/sec.

g = the acceleration due to gravity, 9.81 metres/sec^2.
R = the radius of the curve in metres,

h = the super-elevation in metres.

b = the breadth of the road or the distance between the centres of the rails in metres.

Then for equilibrium, the resultant of the weight and the centrifugal force should be equal and opposite to the reaction perpendicular to the road or rail surface.

The centrifugal force, $F = \frac{Wv^2}{gR}$

$$\therefore \quad \frac{F}{W} = \frac{v^2}{gR}$$

If θ is the inclination of the road or rail surface, the inclination of the vertical is also θ

$$\tan \theta = \frac{dc}{ac} = \frac{F}{W} = \frac{v^2}{gR}$$

uper-elevation = $b \tan \theta$.

$$= \frac{bv^2}{gR} \quad \ldots \quad \ldots \quad \text{(Eqn. 11.28)}$$

Characteristics of a Transition Curve (Fig 11.25):
Here two straights AB and BC make a deflection angle Δ, and a circular curve EE' of radius R, with two transition curves TE and E'T' at the two ends, has been inserted between the straights.

(i) It is clear from the figure that in order to fit in the transition curves at the ends, a circular imaginary curve ($T_1F_1T_2$) of slightly greater radius has to be shifted towards the centre as(E_1 EF E E_1. The distance through which the curve is shifted is known as shift (S) of the curve, and is equal to $\frac{L^2}{24R}$, where L is the length of each transition curve and R is the radius of the desired circular curve (EFE'). The length of shift (T_1E_1) and the transition curve (TE) mutually bisect each other.

Fig. 11.25:

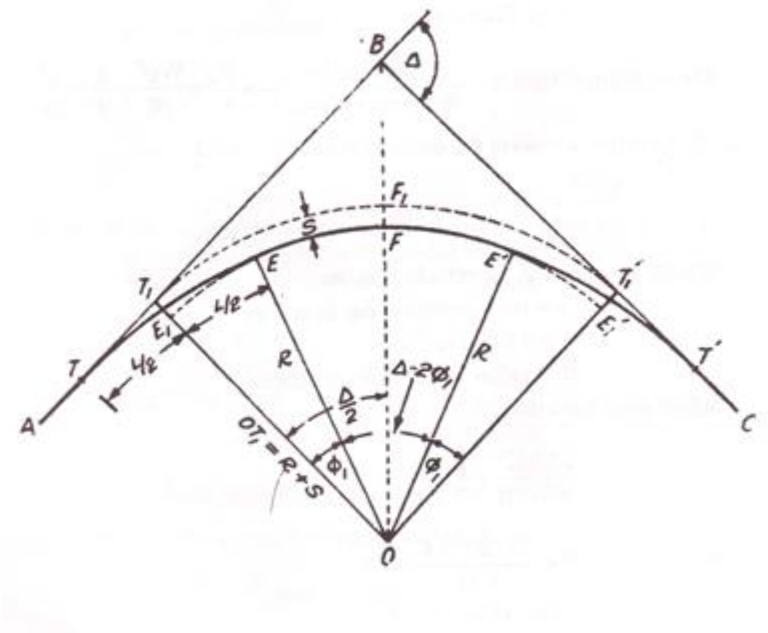


Fig 11.25

(ii) The tangent length for the combined curve

$$= OT_1 \tan\frac{\Delta}{2} + \frac{L}{2}$$

$$= (R + S) \tan\frac{\Delta}{2} + \frac{L}{2}$$

(iii) The spiral angle $\varphi_1 = \frac{\frac{L}{2}}{R} = \frac{L}{2R}\ radians$

(iv) The central angle for the circular curve:

$\angle EOE' = \Delta 2\phi_1$

(v) Length of the circular curve EFE'

$$= \frac{\pi R(\Delta - 2\phi_1)}{180^\circ}, \text{ where } \Delta \text{ and } \phi_1 \text{ are in degrees.}$$

(vi) Length of the combined curve TEE'T"

$$= TE + EE' + E'T'$$

$$= L + \frac{\pi R(\Delta - 2\phi_1)}{180^\circ} + L$$

$$= \frac{\pi R(\Delta - 2\phi_1)}{180^\circ} + 2L$$

(vii) Change of beginning (T) of the combined curve = Change of the intersection point (B)-total tangent length for the combined curve (BT).

(viii) Change of the junction point (E) of the transition curve and the circular curve = Change of T + length of the transition curve (L).

(ix) Change of the other junction point (E') of the circular curve and the other transition curve- change of E + length of the circular curve.

(x) Change of the end point (T') of the combined curve = change of E' + length of the transition curve.

Check:
The change of T thus obtained should be = change of T + length of the combined curve.

Note:
The points on the combined curve should be pegged out with through change so that there will be sub-chords at each end of the transition curve and of the circular curve.

(xi) The deflection angle for any point on the transition curve distant I from the beginnings of combined curve (T),

$$\alpha = \frac{l^2}{6RL} \text{ radians} = \frac{1800 l^2}{\pi RL} \text{ minutes.}$$

$$= \frac{573 l^2}{RL} \text{ minutes.}$$

Check:
The deflection angle for the full length of the transition curve:

$$\alpha = \frac{l^2}{6RL} = \frac{L^2}{6RL} \quad (\because l = L)$$

$$= \frac{L}{6R} \text{ radians} = \frac{1}{3}\phi_1$$

(xii) The deflection angles for the circular curve are found from:

$$\delta_n = 1718.9 \; \frac{C_n}{R} \text{ minutes.}$$

Check:
The deflection angle for the full length of the circular curve:

$$\Delta_n = \frac{1}{2} \times \text{Central angle}$$

i.e., $\Delta_n = \frac{1}{2} \times (\Delta - 2\emptyset_1)$

(xiii) The offsets for the transition curve are found from:

Perpendicular offset, $y = \frac{x^3}{6RL}$, where x is measured along the tangent TB

Tangentail offset ,$y = \frac{l^3}{6RL}$, where I is measured along the curve

Check : *(a)* The offset at half the length of the transition curve,

$$y = \frac{l^3}{6RL} = \frac{(L/2)^3}{6RL} \quad (\because l = L/2)$$

$$= \frac{L^2}{48R} = \tfrac{1}{2} S$$

(b) The offset at junction point on the transition curve,

$$y = \frac{l^3}{6RL} = \frac{L^3}{6RL} = \frac{L^2}{6R} \quad (\because l = L)$$

$$= 4S$$

(xiv) The offsets for the circular curve from chords producers are found from:

$$O_n = \frac{C_n\,(C_{n-1} + C_n)}{2R}$$

Method of Setting Out Combined Curve by reflection Angles (Fig. 11.25):

The first transition curve is set out from T by the deflection angles and the circular curve from the junction point E. The second transition curve is then set out from T' and the work is checked on the junction point E' which has been previously fixed from E.

(i) Assume or calculate the length of the transition curve.

(ii) Calculate the value of the shift by:

$$S = \frac{L^2}{24R}$$

(iii) Locate the tangent point T by measuring backward the total tangent length BT (article 11.14, ii) from the intersection point B along BA, and the other tangent T by measuring forward the same distance from B along BC.

(iv) Set up a theodolite at T, set the vernier A to zero and bisect B.

(v) Release the upper clamp and set the vernier to the first deflection angle (x_1) As obtained from the table of deflection angles, the line of sight is thus directed along the first point on the transition curve. Place zero end of the tape at T and measure along this line a distance equal to first sub chords, thus locating first point on the transition curve.

(vi) Repeat the process, until the end of the curve E is reached.

Check:

The last deflection angle should be equal to $\varphi_1/3$, and the perpendicular offset from the tangent TB for the last point E should be equal to 4S.

Note:

The distance to each of the successive points on the transition curve is measured from T.

(vii) Having laid the transition curve, shift the theodolite to E and set it up and level it accurately.

(viii) Set the vernier to a reading(360°-2/3 $\varphi 1$) for a right-hand curve (or 2/3 $\varphi 1$) for a left-hand curve and lake a back sight on T. Loosen the upper clamp and turn the telescope clockwise through an angle 2/3 $\varphi 1$ the telescope is thus directed towards common tangent at E and the vernier reads 360°. Transit the telescope, now it points towards the forward direction of the common tangent at E i.e. towards the tangent for the circular curve.

(ix) Set the vernier to the first tabulated deflection angle for the circular curve, and locate the first point on the circular curve as already explained in simple curves.

(x) Set out the complete circular curve up to E' in the usual way

Check:

The last deflection angle should be equal to $\frac{1}{2}(\Delta - 2\phi_1)$

(xi) Set out the other transition curve from T as before. The point E' to be set from T should be the same as already set out from E.

Method of Setting Out a Combined Curve by Tangential Offsets (Fig. 11.25):

(i) Assume or calculate the length of the transition curve.

(ii) find the value of the shift train, $S = \frac{L^2}{24R}$.

(iii) Locate the tangent points T and T as in article (11.15, iii),

(iv) Calculate the offset for the transition curve as in article (11.14 xiv)

(v) Locate die points on the transition curve as well as on the circular curves by setting out the respective offsets.

II

UNIT IV

PHOTOGRAMMETRY SURVEYING

Aerial photography refers to taking photograph of earth surface from space. Platform of aerial photography includes aircraft, helicopter, balloon, parachute etc. Aerial photography was first practiced by the French photographer and balloonist Gaspard-Félix Tournachon, known as "Nadar", in 1858 over Paris, France. It was the first means of remote sensing with immense application potentiality even uses now-a-days in the age of satellites with sophisticated electronic devices.

Types of Aerial Photos

Aerial photos can be distinguished depending on the position of camera axis with respect to the vertical and motion of the aircraft. Aerial photographs are divided into two major groups, vertical and oblique photos.

i) Vertical photos: The optical axis of the camera or camera axis is directed vertically as straight down as possible (Fig 7.1). The nadir and central point of the photograph are coincident. But in real a truly vertical aerial photograph is rarely obtainable because of unavoidable angular rotation or tilts of aircraft. The allowable tolerance is usually $+3^{o}$ from the perpendicular (plumb) line to the camera axis. Vertical photographs are taken for most common use in remote sensing and mapping purposes.

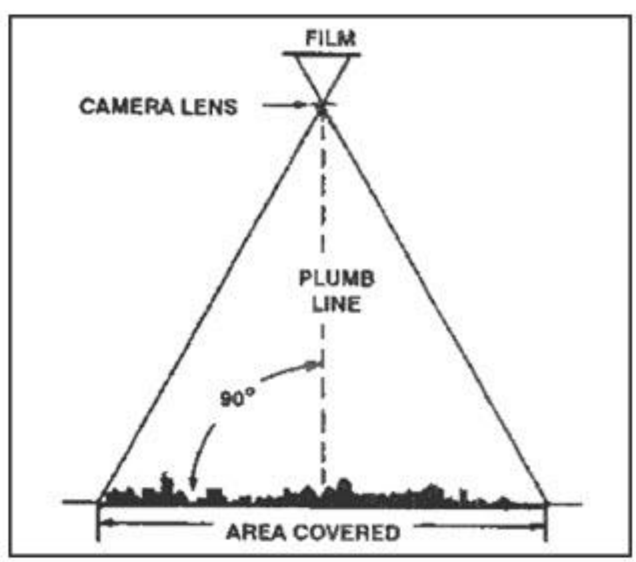


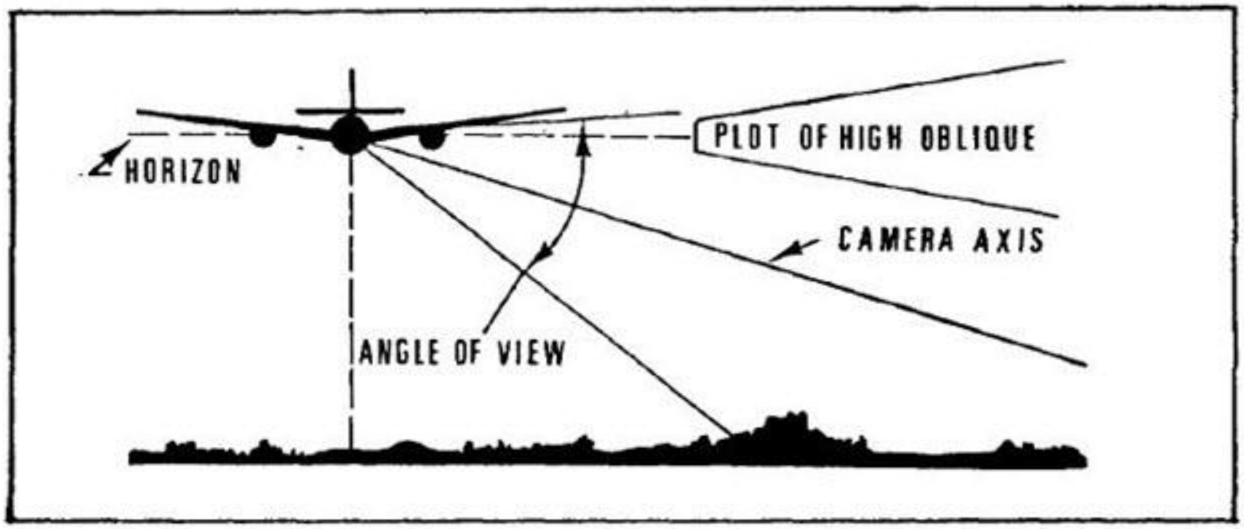
Fig. 7.1. Schematic diagram of taking a vertical photograph.

A vertical photograph has the following characteristics:
(1) The camera axis is perpendicular to the surface of the earth.
(2) It covers relatively small area than oblique photographs.
(3) The shape of the ground covered on a single vertical photo closely approximates a square or rectangle.
(4) Being a view from above, it gives an unfamiliar view of the ground.
(5) Distance and directions may approach the accuracy of maps if taken over flat terrain.
(6) Relief is not readily apparent.

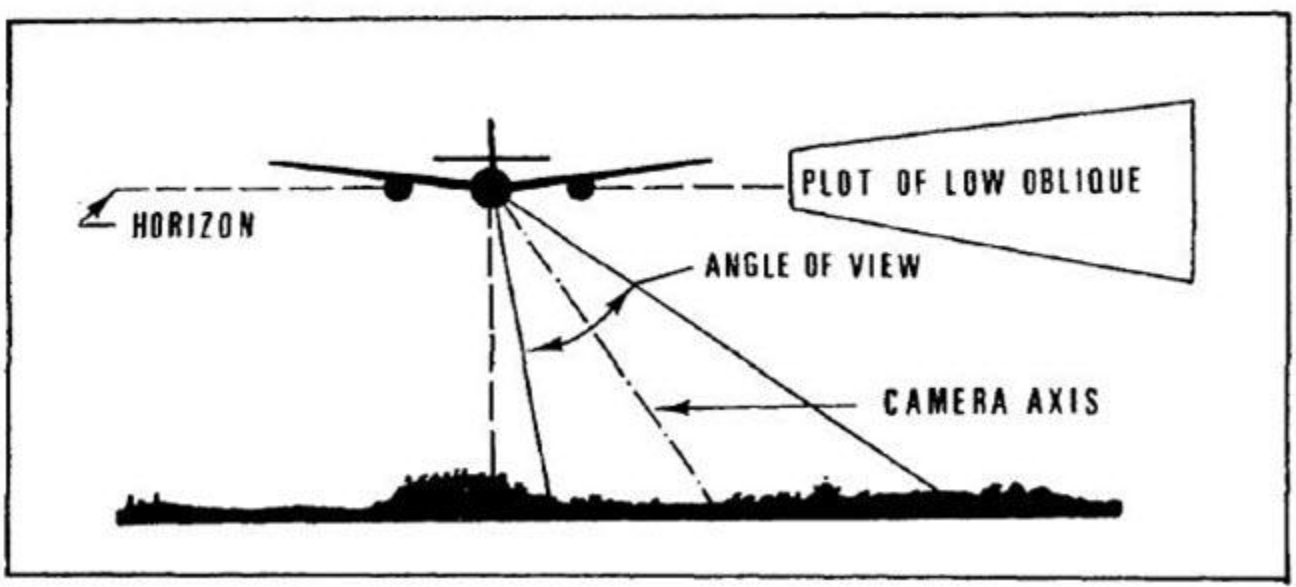
ii) Oblique photos: When the optical of the camera forms an angle of more than 5^0 with the vertical, oblique photographs are obtained (Fig. 7.2). The nadir and central point of the photograph are not coincident.

Fig. 7.2. Vertical and oblique photography.

There are two types of oblique aerial photography – high angle and low angle. In high angle oblique aerial photography the resulting images shows the apparent horizon and in low angle oblique photograph does not. Oblique photographs can be useful for covering very large areas in a single image and for depicting terrain relief and scale.



(a)



(b)

Fig. 7.3. (a) High oblique and (b) low oblique photographs.

A square outline on the ground appears as a trapezium in oblique aerial photo. These photographs can be distinguished as high oblique and low oblique (Fig.7.3). But these are not widely used for mapping as distortions in scale from foreground to the background preclude easy measurements of distance, area, and elevation.

An oblique photograph has the following characteristics:

1. Low oblique photograph covers relatively small area than high oblique photographs.

2. The ground area covered is trapezoid, but the photograph is square or rectangular. Hence scale is not applicable and direction (azimuth) also cannot be measured.

3. The relief is discernible but distorted.

Basic Geometric Characteristics of Aerial Photographs

Aerial photographs are taken using a camera fitted at the bottom of a aircraft along a line is termed as *flight line* or *flight strips* and the line traced on ground directly beneath the camera is called nadir line. The point on photograph where the nadir line meets the ground is termed as *principal point*. Lines drawn to connect marks located along opposite sides of the photo (*fiducial marks*) intersect precisely at the principal point. The point on the photo that falls on a line half- way between the principal point and the Nadir point is known as i*socenter*. The ground distance between the photo centers (principal points) is called *air base*.

In aerial photography, the aircraft acquires a series of exposures along each strip of multiple flight lines. Successive photographs are generally taken with some degree of overlap, which is known as endlap (Fig. 7.4). Standard endlap is 60%, which may be 80-90% in special cases such as in mountainous terrain. It ensures that each point of the ground appears in at least two successive photographs essential for stereoscopic coverage. Stereoscopic coverage consists of adjacent pairs of overlapping vertical photographs called stereopairs. Beside endlap the photograph is taken with some overlap of photographs of a strip with the adjacent strip, known as sidelap (Fig 7.5). It varies from 20% to 30% to ensure that no area of the ground is missing out to be photograph.

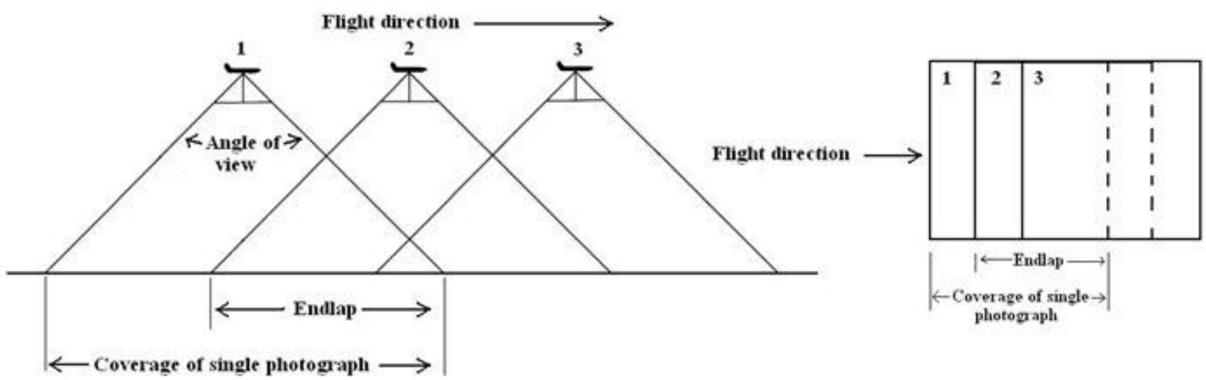


Fig. 7.4. Photographic coverage along flight line: endlap.

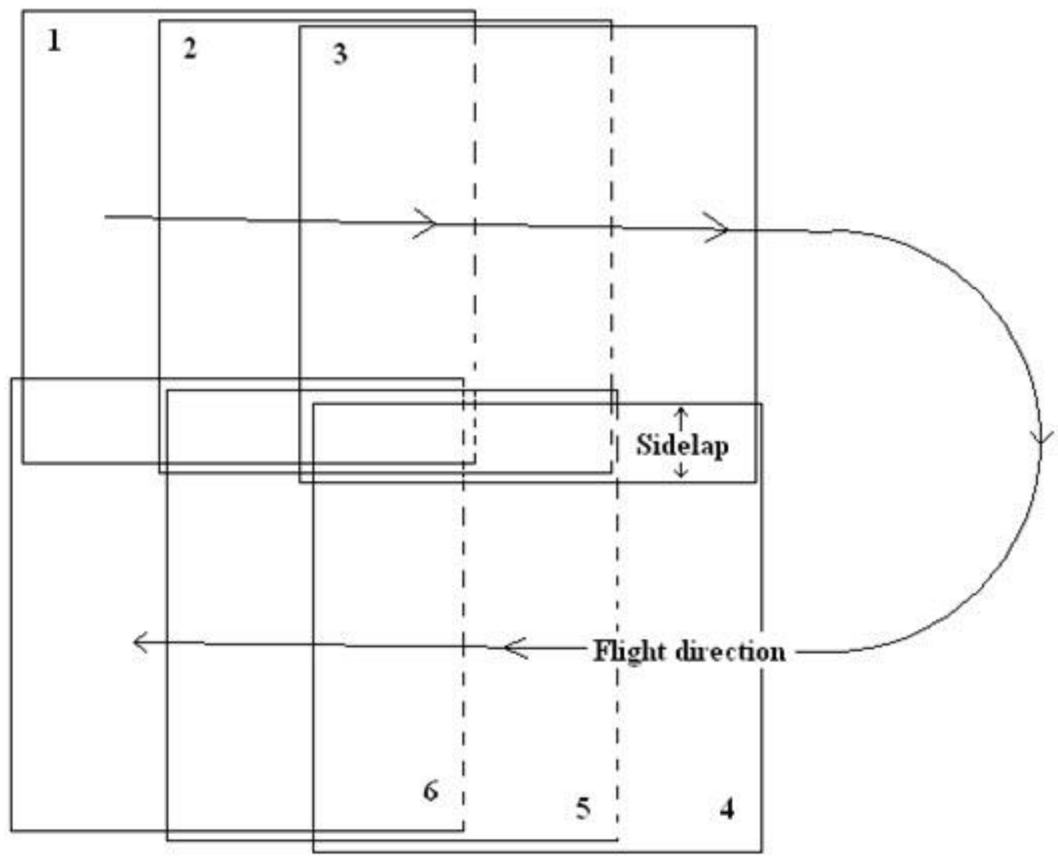


Fig. 7.5. Positions of aerial photos: sidelap.

A truly vertical photograph is rarely obtained because of unavoidable angular rotations or tilts, caused by the atmospheric conditions (air pockets or currents), human error of the pilot fails to maintain a steady flight and imperfections in the camera mounting. There are three kinds of tilts as it can be seen from Fig 7.6.

1. Tilting forward and backwards (pitch)
2. Tilting sideways (roll)
3. Tilting in the direction of flight (yaw)

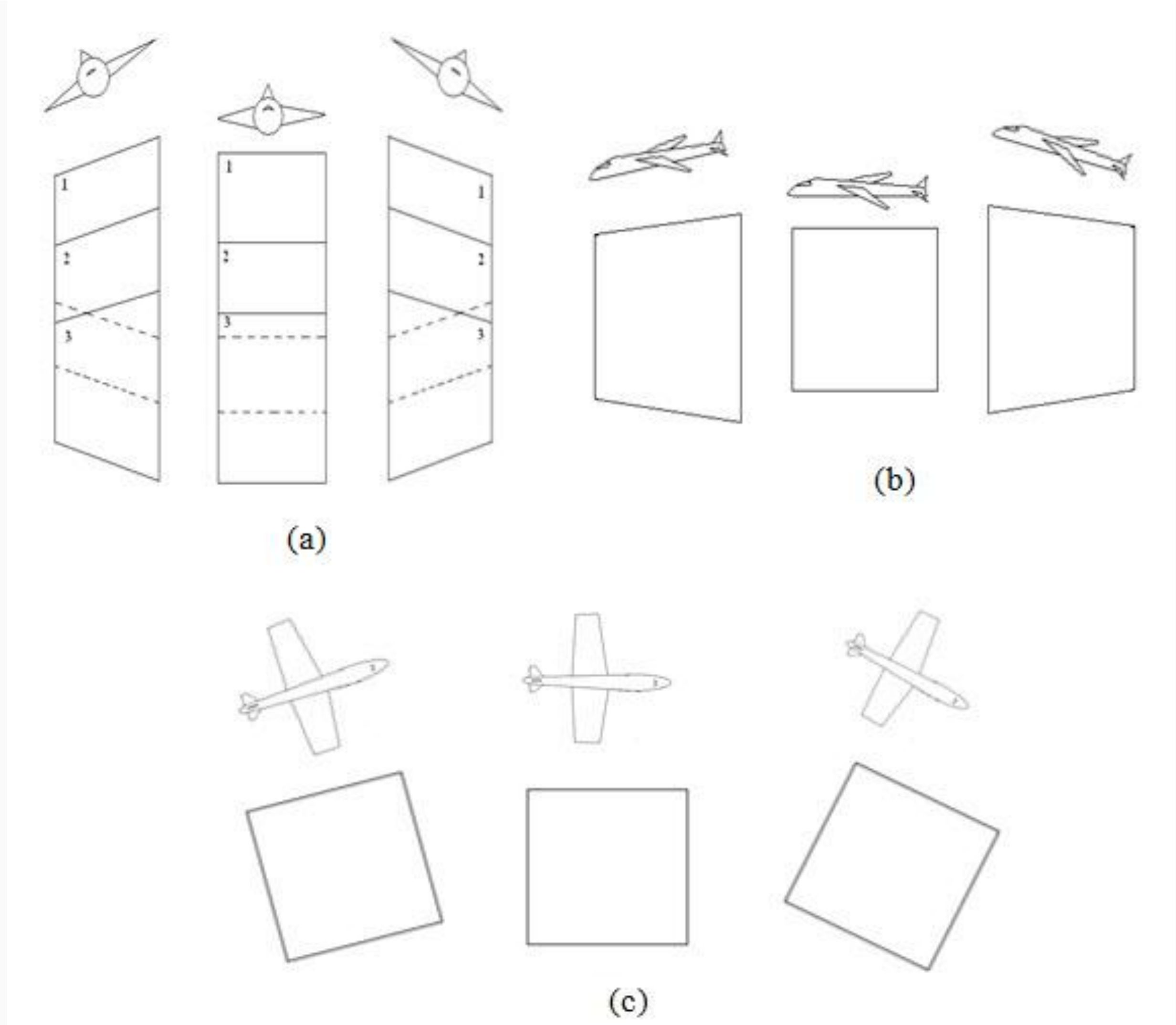


Fig. 7.6. (a) Roll, (b) Pitch, (c) Yow tilting of aircraft and corresponding ground coverage of aerial photograph.

In order to understand the geometric characteristics of an aerial photograph it is also necessary to understand the viewing perspective and projection. In case of viewing perspective on a map the objects and features are both planimetrically and geometrically accurate, because the objects and features is located in the same position relative to each other as they are on the ground or on the surface of earth. But there is a change in scale. On the other hand in aerial photography, central or perspective projection system is used as it can be seen from Fig 7.7. Therefore, there are not only changes in scale but also change in relative position and geometry between the objects depending on the location of the camera.

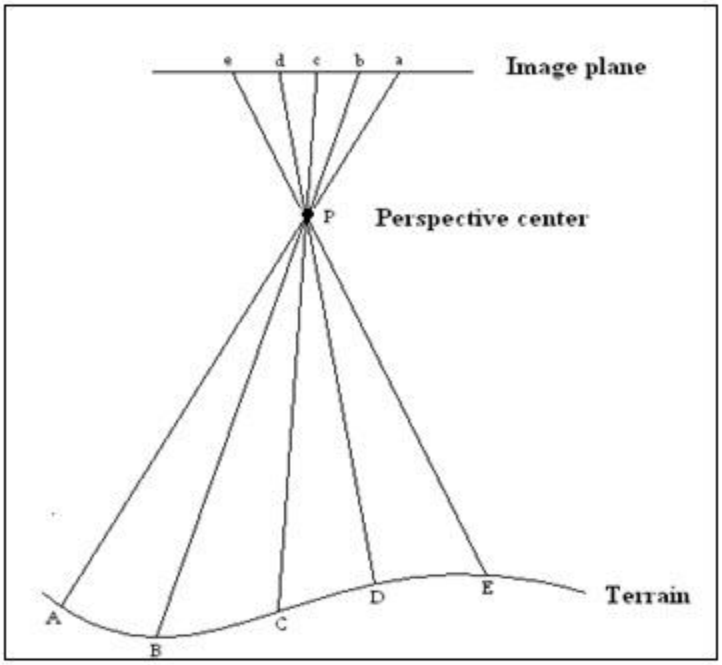


Fig. 7.7. Central or perspective projection.

Relief displacement: Relief is the difference in elevation between the high and low points of a feature or object. Due to central perspective projection system used in aerial photography, vertical objects standing above datum (average elevation) other than principal point lean outward and objects standing below the datum (average elevation) lean inward in an aerial photograph. This distortion is called relief displacement (Fig 7.8). An aerial photograph is a three-dimensional scene transferred onto a two-dimensional plane. Thus three-dimensional squashes literally due to lack of vertical dimension. Therefore image objects above and below mean ground level or datum are displaced from their true horizontal location or relief displacement takes place. Camera tilts, earth curvature, terrain relief, object height and object position in respect to principal point are the main causes of relief displacement. Relief displacement allows the measurement of objects height from a single photo or stereopair.

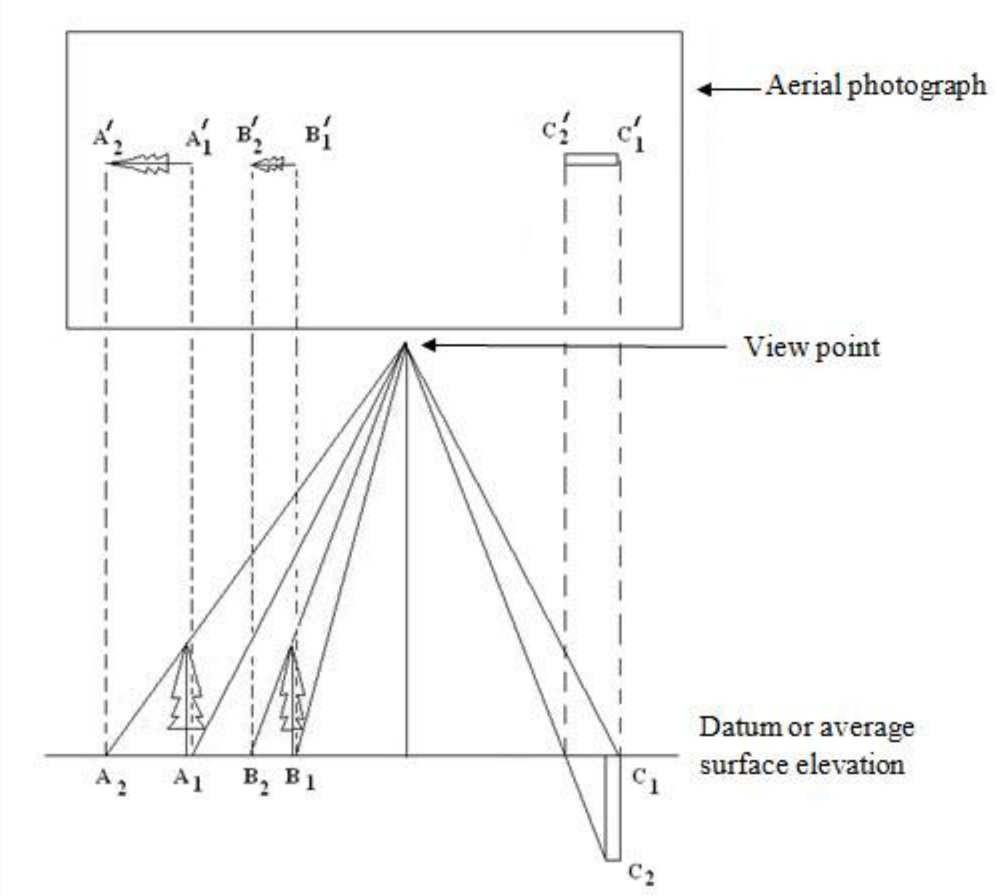


Fig. 7.8. Relief displacement in aerial photography.

Parallax: The term parallax refers to the apparent change in relative position due to change in viewing position. Objects near to the observer will move faster than the objects of far. When one views objects from the window of a moving train, objects nearer to the train will move faster than objects are at far. More details are available in lesson no. 8.

Orthophotos: (These are also referred as Orthoimages, which are the digital version of orthophotos) that has been orthorectified. They do not contain relief displacement, tilt, scale variation caused by different errors includes aircraft movement, camera tilt, curvature of earth, elevation changes in topography etc. Therefore like photos, orthophotos show actual detail and like maps they have only one scale.

7.4 Photographic Scale

The scale of a map or photograph is defined as the ratio of distance measured on the map to the same distance on the ground. The amount of detail in an aerial photograph depends on the scale of the photograph. Scales may be expressed as unit equivalents or dimensionless representative fractions and ratios. For example, if 1 mm on a photograph represents 25 m on the ground, the scale of the photograph can be expressed as 1mm =25m (Unit equivalents), or 1/25,000(representative fraction) or 1:25,000 (ratio).

A convenient way to clear confusion between large scale and small scale photograph is that the same objects are smaller on a small scale photograph than on a large scale photograph. For example, two photographs having scale 1:50,000 and 1:10,000. Aerial photo with scale 1:10,000 images shows ground features at a larger, more detailed size but less ground coverage than 1:50,000 scale photo. Hence, in spite of its smaller ground coverage, the 1:10,000 photos would be termed the large scale photo.

The most straightforward method for determining photo scale is to measure the corresponding photo and ground distances between any two points (Fig 7.9). The scale S is then computed as the ratio of the photo distance d to the ground distance D.

In the Figure 7.8 the triangle ΔLab and ΔLAB are similar.

Hence, ao/AO=Lo/LO

or, d/D= f/H

S = d/D= focal length/flying height

where,

S= scale of photograph

d= distance in photograph

D= distance in ground

f= focal length

H= flying height

Hence Scale of a photo α focal length of camera (f)

α 1/flying height (H)

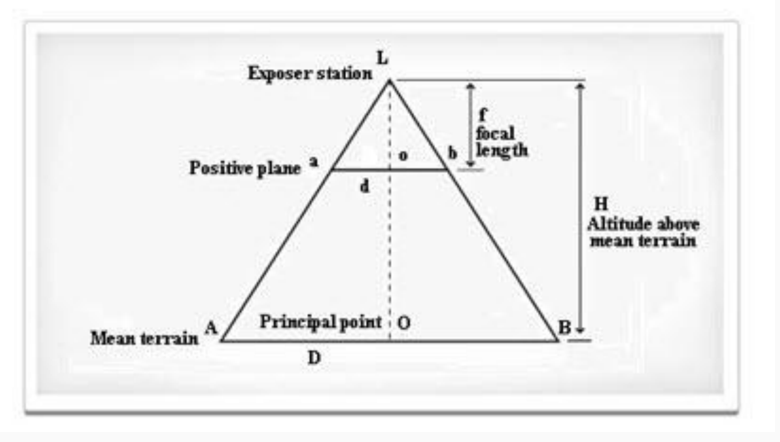


Fig. 7.9. Measurement of scale of an aerial photograph.

7.5 Ground Coverage of Aerial Photograph

The ground coverage of a photograph is, among other things, a function of camera format size. For example, an image taken with a camera having a 230×230 mm format (on 240 mm film) has about 17.5 times the ground area coverage of an image of equal scale taken with a camera having a 55×55-mm format (on 70-mm film) and about 61 times the ground area coverage of an image of equal scale taken with a camera having a 24×36-mm format (on 35-mm film). The ground coverage of a photo obtained with any given format is a function of focal length (f) and flying height above ground (H). The area covered in a photograph or ground coverage is inversely proportional to the scale of the photograph. Hence, for a constant flying height, the width of the ground area covered by a photo varies inversely with focal length and directly with flying height above terrain. Photos taken with shorter focal length lenses have larger areas of converge than taken with longer focal length lenses. On the other hand the ground coverage increases with increase in flying height.

武漢大學
WUHAN UNIVERSITY

LECTURE NOTES

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Prof. John TRINDER
School of Civil and Environmental Engineering
Telephone: (02) 9 385 5020
Fax: (02) 9 313 7493
j.trinder@unsw.edu.au

CONTENTS

1. SENSORS AND PLATFORMS FOR ACQUISITION OF AERIAL AND SATELLITE IMAGE DATA

This chapter will discuss the various sensors that are available for the acquisition of image and other data for applications in photogrammetry and remote sensing, as well as for data collection for GIS, and subsequent analysis. 'Photogrammetry and remote sensing' are often traditional terms used for the extraction of metric and semantic information respectively from aerial, including unmanned aerial systems (UAS, also referred to as UAV, Remote Piloted Aerial Systems RPAS and drones) and satellite images, as well as from images taken at close range to an object. The terms will be used often in these notes. A typical definition is:

Photogrammetry and Remote Sensing is the art, science, and technology of obtaining reliable information from non-contact imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analyzing and representation.

1.1 Types of image sensors

Sensors used in photogrammetry and remote sensing can be separated into 'passive' and 'active'. Passive sensors simply record light, usually solar radiation that is projected by a lens system onto a digital sensor. In the case of close range applications (distances nominally less than 300 metres), the lighting may be from artificial sources. Active sensors emit their own illumination and then record the time and intensity of the signal that is reflected from the ground or other objects.

Passive Sensors

- Digital cameras and film cameras, which are referred to 'analogue photographic sensors', record visible and near infra-red electro-magnetic radiation. Film images can be digitised for use in digital photogrammetric systems although this process is being phased out.
- Pushbroom or Whiskbroom (sometimes referred to as electro-optical sensors), which scan the terrain surface, comprising special devices for detecting and then recording multispectral images of reflected electromagnetic radiation.

Active Sensors

- Radar sensors emit microwave radiation, and record the time of transmission to the ground and back to the sensor, as well as the intensity of the reflected radiation from the terrain surface. All current systems are based on Synthetic Aperture Radar (SAR). Interferometric SAR (InSAR) is a technique used to determine elevations from SAR images based on the phase differences between SAR images received by two separate antennas.
- Airborne Laser Scan (ALS) or lidar (**Li**ght **D**etection **a**nd **R**anging and also written as LiDAR) are techniques for determining elevations on the terrain surface or characteristics of vegetation canopy from aircraft or satellite. Terrestrial Laser Scanners (TLS) are ground based lidar systems. Only airborne lidar sensors will be discussed in this course.
- Other forms of active imaging may also be used for measurement, such as electron microscope and X-rays.

1.2 Platforms

The platforms on which the sensors are placed may be an aeroplane, UAS (unmanned aerial system), a satellite in space, or a suitable mount on or near the terrain surface, if close range imaging is undertaken. The principles of the geometry of sensors will not normally be affected by the platform on which they are placed. However, accuracies of extracted information from images will depend on the distance of the sensor to the object. For aerial photography, the positions of the sensor will be determined by Real-Time Kinematic (RTK) from GNSS receivers installed on the aircraft, while tilts of the camera may be determined by an inertial measuring unit (IMU), also referred to as inertial navigation system (INS). The three position and three tilt parameters are referred to as the parameters of *exterior orientation* of the sensor. These systems may be integrated to provide what is referred to as *direct orientation* of the sensor. The exterior orientation of an earth observation satellite in space may be determined by GNSS, satellite tracking systems and star trackers. In close range photogrammetry, the position of a camera can usually be determined on the ground by standard survey methods.

1.3 Digital Aerial Cameras

Digital aerial cameras have only become available in about the last 15 years and have now replaced film cameras in many parts of the world. Their design must satisfy the need to produce high quality images and also provide a wide coverage of the terrain surface. Modern digital aerial cameras continue to be improved as new digital imaging technologies are developed. The characteristics of modern digital aerial cameras are as follows:

- They acquire high spatial resolution images of more than 200 Mpixels, comprising Ground Sampling Distance (GSD) of 5 cm and larger with high geometric accuracy
- They have adequate angles of field of coverage for efficient for geospatial information extraction
- They take advantage of the particular characteristics of digital image acquisition, with quantization levels of 11 bit or 12 bits, that is, 2048 or 4096 grey scale values and improved image quality.
- They acquire 4 bands of multispectral images with the same or lower spatial resolution as the panchromatic images.

Currently digital aerial cameras used in photogrammetry are classified as '*high-resolution'* and '*medium resolution'*. High spatial resolution digital aerial cameras have the potential to collect hundreds of Mpixels while medium spatial resolution cameras usually are based on a smaller single area array chips with about100 Mpixel.

Advantages of using digital images are:

- Image processing for target location, automatic height measurement and semi-automatic information extraction can be carried out on the image data, using stereo observation on the screen
- Digital orthophotos can be automatically derived from the data, thus providing for much greater flexibility in correcting variations in density of neighbouring images
- Future developments based on machine vision techniques will enable the automatic extraction of semantic information from the images

Disadvantages of using digital images:

- An analogue photo is an extremely efficient way to store information about an object and can be stored for decades.
- Algorithms for the automatic extraction and identification of information from images have not been developed, which impacts on the type of products that can currently be extracted from digital aerial images.
- Storage of digital image data requires regular backups onto new storage technology and as the old storage devices become obsolete.

Since digital aerial cameras are undergoing continual development and new models and types are being released onto the market on a regular basis. In the development of the new digital high spatial resolution aerial cameras two approaches have been adopted as described below.

1.3.1 High Spatial Resolution Digital Aerial Cameras

(i) Systems based on CCD linear arrays - referred to as 'Pushbroom' sensors. Linear array scanners acquire data by scanning the terrain with one or more linear arrays oriented normal to the flight direction as the aircraft moves over the terrain, (likened to a broom sweeping a surface). The Leica system comprises three linear arrays, one pointing forward, one pointing vertically and one pointing backwards to acquire **three separate overlapping images** of the terrain surface. The acquisition of overlapping images is essential for determining 3D coordinates of objects, including elevations, as will be described later in these notes. The systems are usually designed for acquiring panchromatic (ie black and white) and also colour or multispectral images including in the short wavelength infrared region of the spectrum (CIR – colour and infrared), with wavelengths up to about 0.9 μm wavelength, at the same or reduced resolution as the panchromatic images. **An integrated GNSS/IMU (Inertial Measuring Unit) system is essential** for this camera configuration for determining camera position and tilts, because the image acquisition is a continuous process and not frame based. Images from pushbroom sensors cannot be processed by standard frame image software. An example of this type of digital camera is:

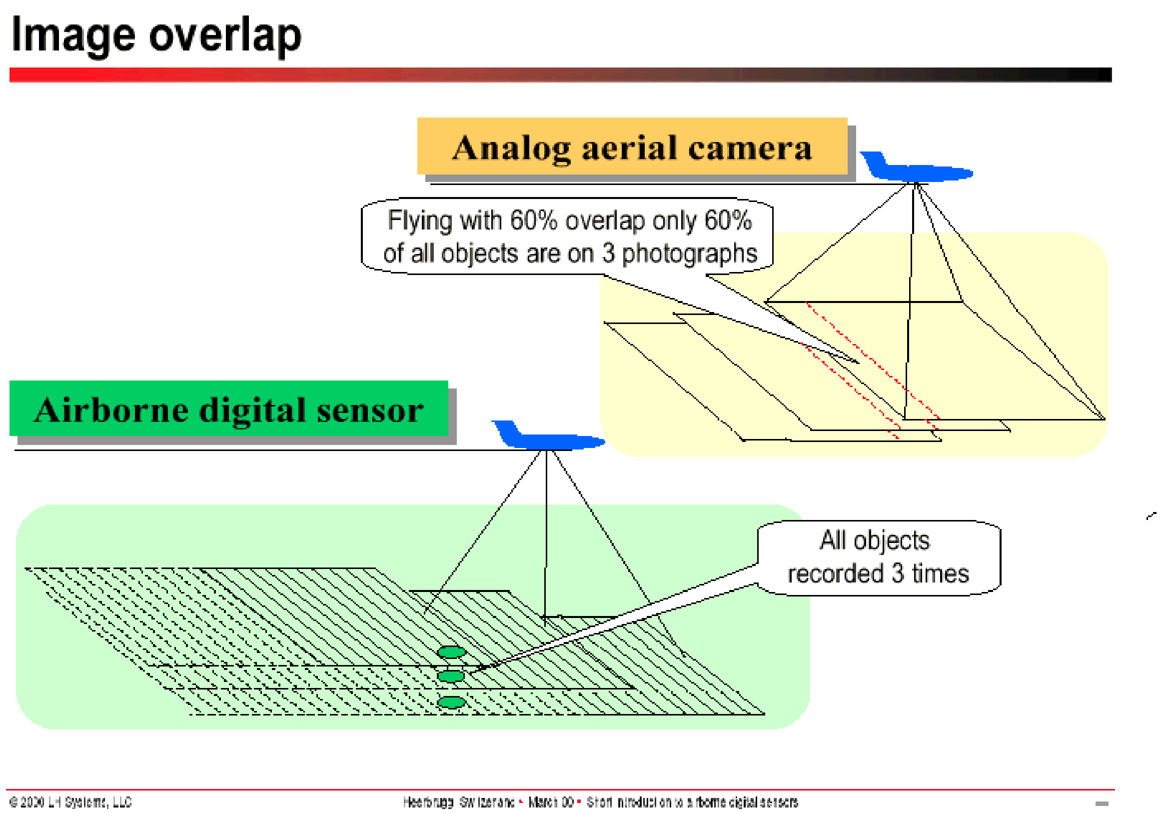


Figure 1.1 Comparison of linear array camera of Leica Geosystems (ADS100) and normal frame camera configurations

- **Leica ADS100** (Figure 1.1) acquires overlapping panchromatic and multi-spectral images, all with the same resolution, by 3 CCD linear arrays, looking forward, vertical and aft, by the SH100/SH120 camera heads.

(ii) Frame systems based on area arrays. These systems involve single large rectangular array or multiple small area arrays whose images are stitched together to form larger usually rectangular frame images. These images can be processed using standard digital photogrammetric software for frame images. GNSS/IMU systems are not essential for the operation of this type of camera, but some or all components of such a system may be included as an option. Cameras based on this configuration are:

- The DMC (Leica) cameras. The 1st generation was composed of 4 separately directed camera heads (7kx4k) for panchromatic images which were stitched together, and 4 camera heads (3kx2k) for 4 channels of multispectral images, each pointed so that they cover the required area of the terrain. The 2nd DMCII and 3rd generations DMCIII (various versions with different chip sizes are available) are based on a single monolithic area array. The multispectral images have a resolution 3.2 times less than the panchromatic images. The 3rd generation with 390 Mpixels is based on CMOS sensor (as opposed to CCD sensor for DMCII) with pixel sizes of 3.9 μm, 26113 pixels across the swath and 15,000 in the flight direction, together with mechanical forward motion compensation (FMC).
- The Vexcel UltraCam (Figure 1.2) is based on 'syntopic' imaging by 9 small format frame cameras for the panchromatic images, which are recorded sequentially during flight with 4 CCD arrays, so that the image acquisition for all arrays is based on the perspective centres of the cameras cones being in the same position. The separate images are stitched together to form a single area array. The multispectral images are acquired with 4 cameras cones each on a single CCD array at a lower resolution than the panchromatic images.

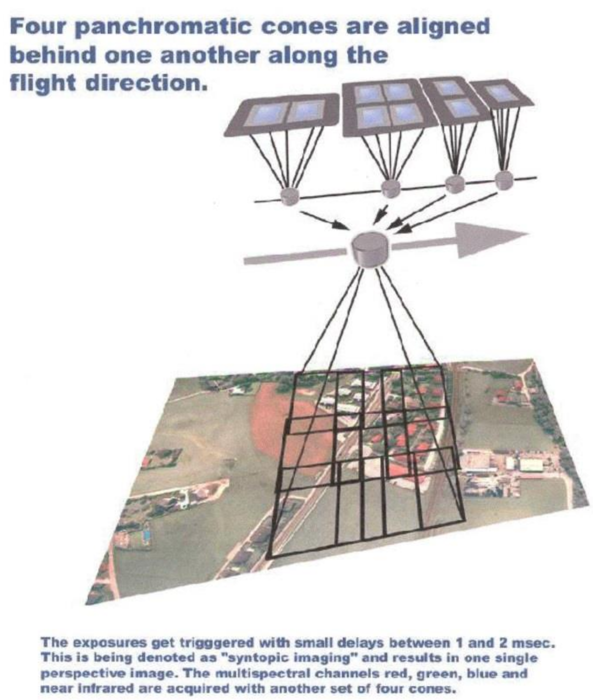


Figure 1.2 Digital frame camera (UltraCam) configuration by the Microsoft Vexcel Camera

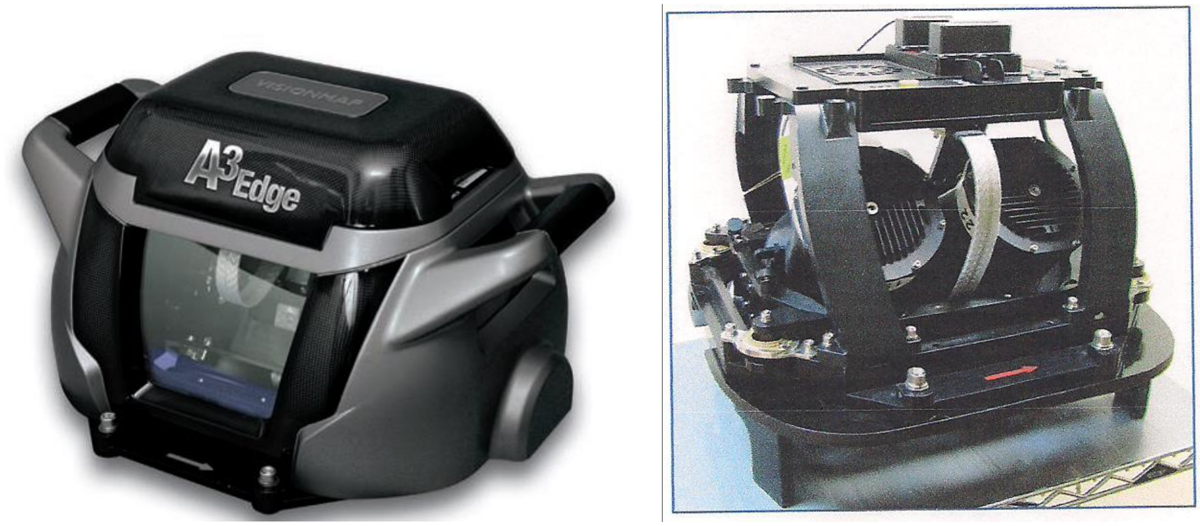


Figure 1.3 VisionMap A3 Edge camera and scanning system

- VisionMap System A3 Edge (Figure 1.3) from Israel is based on a double camera scanning system by which sequences of frames frames are imaged in the cross-track direction achieving very wide angle coverage of 100º FOV (field of view). The systems consist of dual CCD arrays with 300 mm lenses, a fast data compression system and a dual frequency GNSS system but no IMU is required. Given the unusual design, special fully automated software is required to process the data, which is also supplied by the company. The company claims that the advantages of this system are the higher productivity than other digital aerial cameras since it has much higher angle of field and very high scan rates.

1.3.2 Medium Resolution Digital Aerial Cameras

Medium resolution cameras, as the name suggests, are of lower resolution than the high resolution cameras, with most comprising a single area array of varying sizes for the capture of multi-spectral images. There are a number of these cameras on the market developed by different companies and they are undergoing considerable development with resolutions increasing as the development of chip technology improves. They are suitable for lower resolution aerial mapping or in combination with other forms of data, such as lidar.

1.3.3 General description of high spatial resolution near vertical aerial photogrammetric image acquisition

Most so-called 'near vertical aerial photography' is recorded with tilts from the vertical of less than 2˚. This has been traditional approach for film aerial photography and generally still applies for digital images. Such small tilts limit the distortions in the images which enable their processing to orthophotos to be less problematic. That is not to say that images with larger tilts cannot be processed to orthophotos, but the significant scale variations of photos with large tilts can lead to variations in the quality of the orthophoto, and large tilts can also cause important areas to be hidden behind buildings.

The theoretical assumptions made about the geometric processing of images are that all frame images are perspective projections. That is, all light rays forming an image pass through a single point, called a 'perspective centre'. For linear array or pushbroom cameras the assumption of a perspective projection only applies along each scanline formed by each linear array. All aerial images are subject to certain distortions, due to tilts of the camera, elevation differences on the terrain for aerial images, deformations in the image formation process, particularly in the lens and atmospheric refraction which is a minor effect.

All photogrammetric measurements are based on overlapping images in order to obtain 3D object geometry. Typical overlaps on film images were 60% along track (forward overlap) and a minimum of 15% to 20% side overlap (sidelap) as shown in Figure 1.4. For the new era of digital imaging using area array cameras, the forward overlaps can be as large as 85%-90% and as high as 60% for sideways overlap between neighbouring strips of photography, also called 'sidelap'. For linear array cameras the 3 overlapping strips are acquired simultaneously. The side overlaps between strips may be 15% or larger.

Close range photographs are recorded with attitudes, ie tilts, designed to suit the particular application, but usually the optical axis of the camera will be directed approximately horizontally. The procedures for close range photography are therefore significantly different from aerial photography. Tilts may be much larger than 2˚ and the overlaps between photos may be up to 100%.

The original images recorded for film and digital photography are in the so-called negative plane as shown in Figure 1.4. The reproduction of the equivalent positive for a digital image is a trivial task. Therefore, all reference to images in these notes will assume the positive image is used.

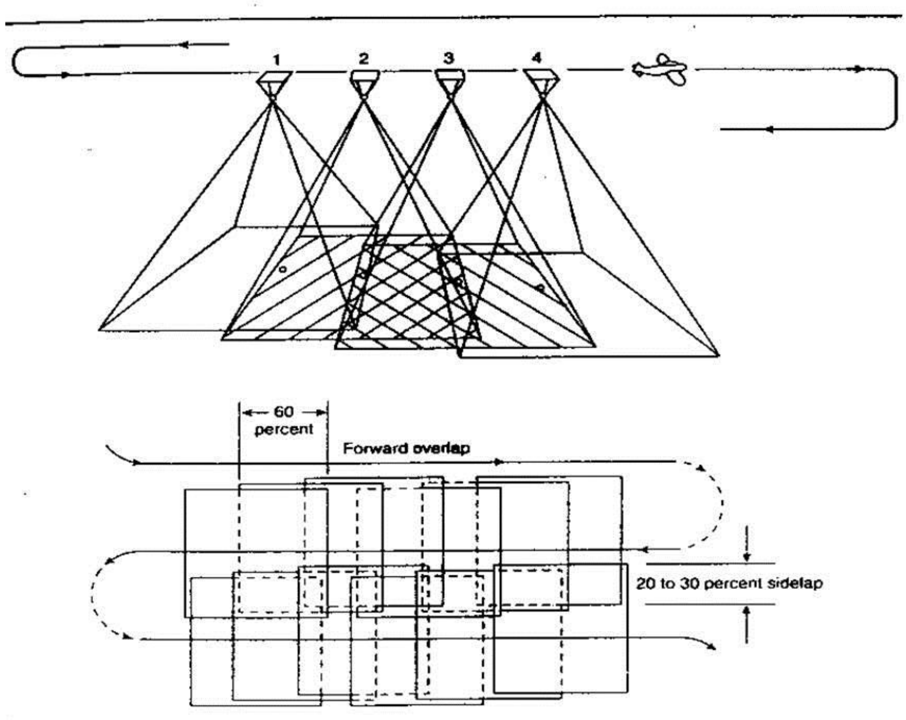


Figure 1.4 Configuration of aerial imaging with minimum overlap

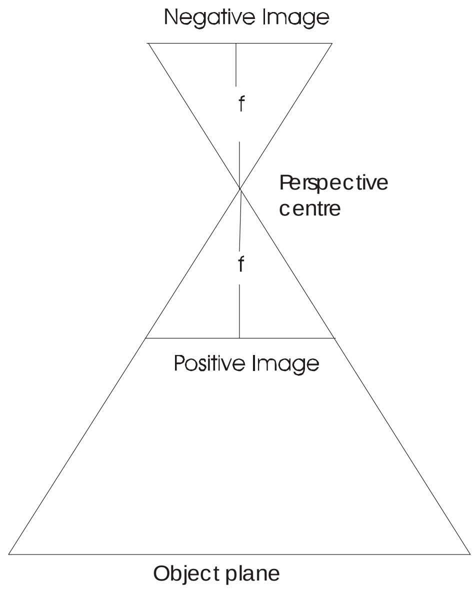


Figure 1.5 Geometric relationships between positive and negative image planes

The *principal distance* 'f', often called the *focal length*, defines the distance between the negative and positive image planes and the perspective centre (some textbooks use the symbol 'c' for the principal distance to avoid confusion with 'f' the focal length). As stated above the perspective centre defines the theoretical point in the camera, through which all light rays forming the image, are assumed to pass. The *principal point* is defined as the foot of the perpendicular from the perspective centre to the image plane. Hence the 3 components of what is known as the camera's '*interior or inner orientation'* comprise x_0 and y_0 the x and y coordinates of the principal point and the principal distance 'f'. (see Chapters 2, 3 and 6 for more details of their definitions) These components must be known before accurate measurement can be made from photographs.

1.3.4 Lens Distortion

All lenses will be subject to errors in image geometry due to design factors and manufacturing. The design of a lens is a compromise between the competing requirements of high image quality and near zero errors in the geometry of the image. Lens distortion is the deviation from a straight line path of the rays forming points in the images, which pass from the object through the perspective centre to the image plane. The largest component of lens distortion is radial to the principal point (Figure 1.6), while smaller tangential components may also occur in some lenses, but not those lenses specially designed for aerial photography. Aerial cameras will be subject to radial lens distortion of less than 5 µm, which will be symmetrical about the centre of the photograph. Recent research on digital aerial camera lenses has revealed distortions considerably less than 5 µm. Some 'non-metric' cameras used for close range photogrammetry may have lens distortions of the order of 100 µm. Lens distortions are determined as part of the process of camera calibration. It has been shown that radial-symmetric lens distortion in aerial lenses can be modelled by an odd-order polynomial of the form $dr=k_1r^3+k_2r^5+k_3r^7$, where dr is the radial distortion of a point on the image plane and r is the radial distance of the point measured from the principal point on the image plane, k_1, k_2 and k_3 are constants describing the characteristics of the distortion of a particular camera.

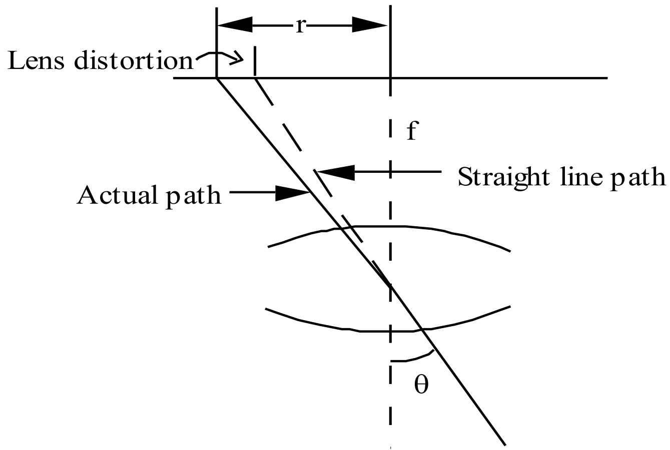
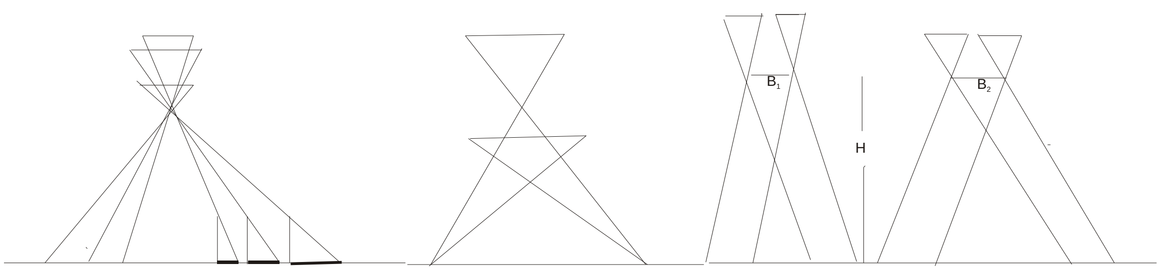


Figure 1.6 Radial lens distortion

1.3.5 Significance of the Angle of Field of a Camera

The angles of field of lens cones have a significant effect on the characteristics of photography acquired by cameras. The following general principles apply:

- The wider the angle of field, the greater the coverage for a given flying height - Figure 1.7a
- The same coverage, and hence the same scale of photography, can be obtained by varying the flying height for cameras with different angles of field. This means that for wider angle cameras, the flying height will be less - Figure 1.7b.



Figures 1.7a to 1.7c Examples of the relationships between the different camera lens cones

- The wider the angle of field, the greater will be the dead areas, ie obscured or occluded areas, hidden by buildings and steep terrain - Figure 1.7a
- The wider the angle of field, the larger the Base/Height (B/H) ratio - Figure 1.7c. In principle this will have an impact on the accuracy of height measurement.

1.3.6 Measurement of Exposure

Exposure is dependent on both the aperture in the lens and the exposure time. Doubling the aperture should enable halving the exposure time. The aperture is defined by an f/number, as a fraction of the focal length of the camera, as follows:

$$\text{Aperture f/number} = \frac{\text{Focal length (mm)}}{\text{Apertures stop diameter (mm)}} \qquad (1.1)$$

Increasing the aperture number, that is, reducing the size of the aperture, will reduce the effects of aberrations in the lens, and also increase the depth of field of the lens, ie the range over which objects are in focus. However, reducing the aperture size will also require an increase in exposure time, which may result in large image movement if either the object or camera is in motion, as is the case for aerial photography. To reduce the effects of image motion all modern digital aerial CCD frame cameras incorporate, *forward motion compensation* (FMC) by TDI (Transfer Delay and Integration). TDI is not possible with pushbroom cameras or CMOS sensor cameras, and hence other procedures need to be developed such as mechanical movement of the image plane. For close range photogrammetry, apertures would be selected to suit the application and if an object is in motion synchronized multiple cameras should be used.

1.3.7 Multi-Camera Systems

While multi-camera systems have existed for about 80 years, they have only come into regular use in modern aerial surveys over the past few years. The first modern multi-camera system was introduced by Pictometry more than 10 years ago. The system was based on 5 low cost cameras, one looking vertically and the other 4 looking obliquely in 4 directions at right angles as shown in the Figure 1.8. Subsequently other companies have developed their own version of multi-camera systems with high quality metric camera lenses, as for example the Vexcel Osprey, the IGI DigiCAM, comprising various options from one to five cameras (Penta DigiCAM), the Leica camera based on the RCD30 medium format camera and with up to 5 cameras.

Figure 1.8 Configuration of Pictometry imaging

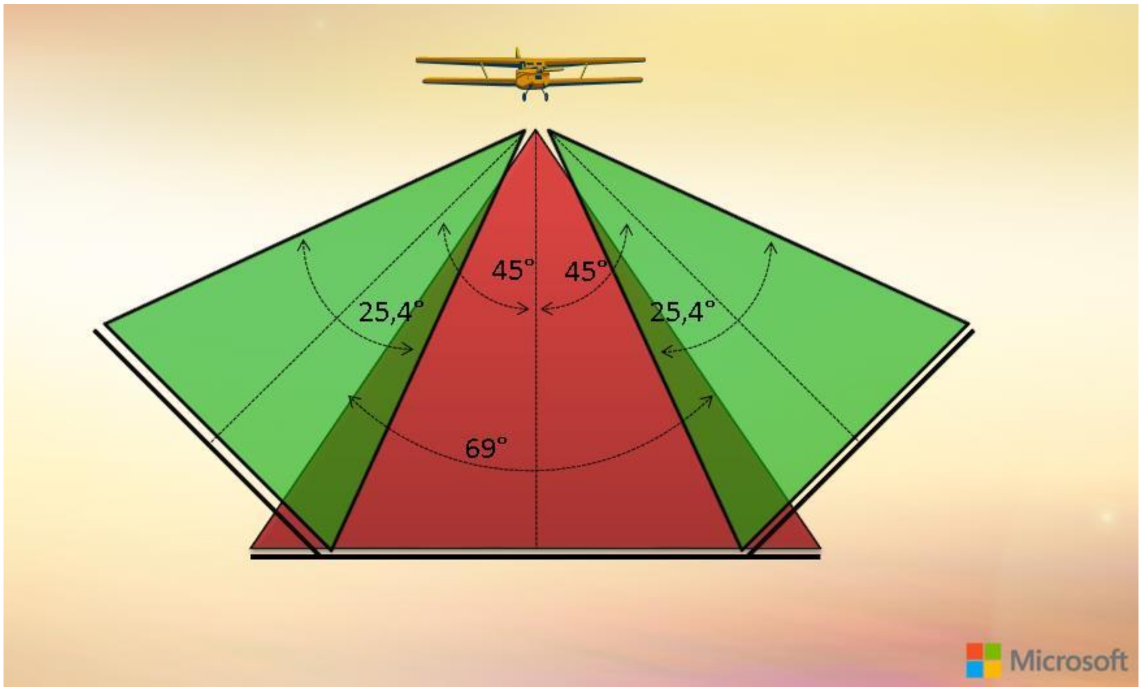


Figure 1.9. Plan view of overlaps between vertical and oblique images for Vexcel Osprey camera

The UltraCam Osprey camera for example, is designed with overlaps between the oblique and nadir images (Figure 1.9). All cameras are mounted rigidly on the platform with photogrammetric grade accuracy and are calibrated with respect to geometry and radiometry. These cameras are relatively new and therefore their applications are still being developed.

1.4 High Spatial Resolution Pushbroom Satellite Sensors

The design of satellite sensors is based on their specific purpose, but the recently developed so-called 'high spatial resolution' satellites are based on pushbroom sensors. They have resolutions or ground sampling distances (GSD) varying from about 2.5 m to about 0.3 m. Usually they detect both panchromatic images, which are black-and-white and cover the whole of the visible spectrum at the highest resolution, and up to 8 multispectral bands that have a GSD of 3 to 4 times larger than the panchromatic images. Stereo images are usually acquired by tilting the satellite forward and backwards during orbit. Most of these satellites are referred to as 'agile', since they can also acquire images by tilting sideways. Hence these satellites can acquire images within a day or so over anywhere on the earth. Typical currently available satellites with their respective ground sampling distances (GSD) are:

- IKONOS II (USA) launched in 1999 with 0.80 m panchromatic images and 3.2 m multispectral images
- Quickbird (USA) launched in 2002 with 0.60 m panchromatic images and 2.4m multispectral images; it is but now no longer operating but archive images are available
- WorldView-1 (USA) launched in 2007 with 0.50 m panchromatic images only
- CartoSat2B (India) launched in 2007 with 0.8 m panchromatic images
- GeoEye 1 (USA) launched in 2008, with 0.41 m panchromatic images and 1.65 m multispectral images

– WorldView-2 (USA) launched in 2009, with 0.4 m panchromatic images (originally supplied at 0.5 m resolution but currently available at 0.4 m resolution) and 1.85 m multi-spectral with 8 bands
– PLÉIADES (Europe) launched in 2011 with 50 cm Panchromatic and 2 m multi-spectral
– WorldView-3 (USA) launched in August 2014 with a GSD of 31 cm and 1.3 m multispectral.
– Terra Bella (formerly Skybox and now owned by Google) series of 21 satellites of which 2 are currently in orbit and all planned to be launched by end 2017. The satellites acquire panchromatic and multispectral images with <0.9 m spatial resolution and 1.1 m spatial resolution video images.
– Planet labs with over 100 microsatellites called 'Dove', with 3-5 m spatial resolution acquiring RGB using commercial grade CCD sensors. Their claim: 'In 2016 Planet Labs will have enough satellites in orbit to image the entire globe, every single day.'
– Urthecast has a sensor mounted on the International Space Station (ISS) can provide medium and high resolution imagery, with up to 75 cm pansharpened imagery available as well as video data.

The geometric processing of images from these satellites requires different procedures as will be described later.

1.5 MultiSpectral Sensing

Since the CCD technology used in pushbroom sensors is unable to detect electro-magnetic wavelengths longer than about 0.9 μm, other technologies and sensors are required to detect multiple bands with longer wavelengths for extraction of semantic information for remote sensing applications. These systems are referred to as either multispectral or hyperspectral sensors and usually described as 'whisk-broom' sensors although the designs of commercial satellites are 'commercial-in-confidence'. They are usually based on an optical scanning system, comprising a rotating mirror for aerial sensing and an oscillating mirror for satellite systems.

A typical configuration of these systems is based on either:

- **Across-track scanners** scan the Earth in a series of lines using a rotating mirror (A). The lines are oriented perpendicular to the direction of motion of the sensor platform. Successive scans build up a two-dimensional image of the Earth´s surface. The incoming reflected or emitted radiation is separated into spectral components that are detected independently and dispersed into their constituent wavelengths. A bank of internal detectors (B), each sensitive to a specific range of wavelengths between 0.4 µm at the blue end of the visible spectrum, to about 15µm in the thermal region of the spectrum, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing. The width of the bands varies according to the system design and wavelength being recorded. They may be of the order of several µm for thermal sensors to as little as 1-2 nm for hyperspectral systems, which may detect and record hundreds of very narrow bands. The IFOV (C) of the sensor and the altitude of the platform determine the ground resolution cell viewed (D), and thus the spatial resolution. The angular field of view (E) is the sweep of the mirror, measured in degrees, used to record a scan line, and determines the width of the imaged swath (F). Because the distance from the sensor to the target increases towards the edges of the swath, the ground resolution cells also become larger and introduce geometric distortions to the images. Also, the length of time the IFOV "sees" a ground resolution cell as the rotating mirror scans (called the dwell time), is generally short which influences the design of the spatial, spectral, and radiometric resolution of the sensor.

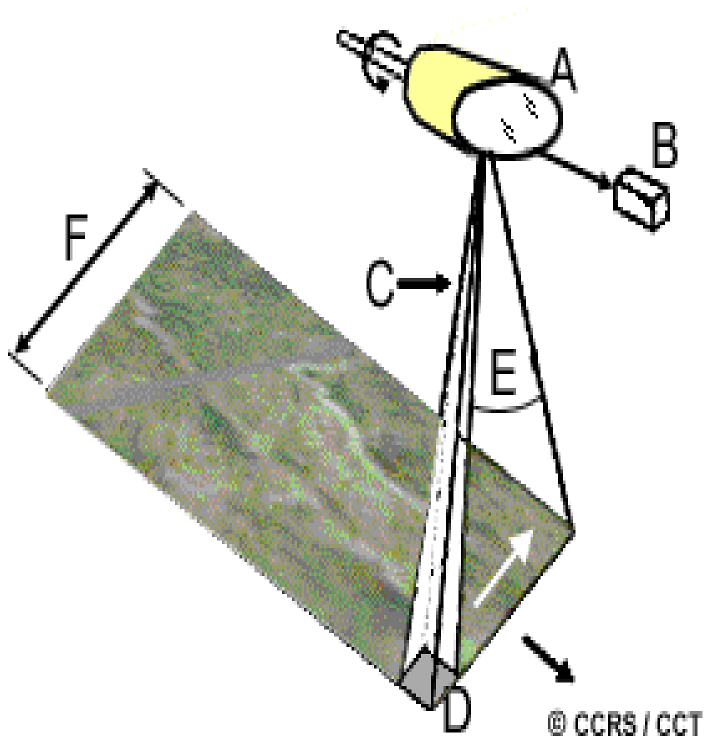


Figure 1.10 Multispectral Scanner Using a Scanner Mirror

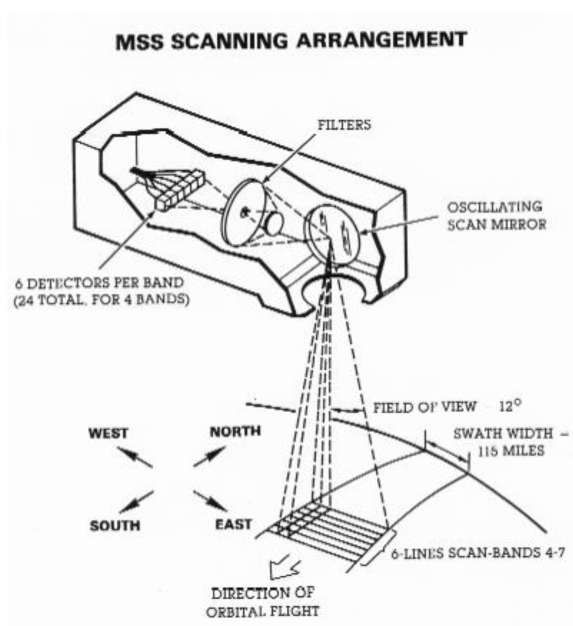


Figure 1.11 Oscillating mirror scanner used in Landsat satellites

- Satellite systems, such as a number of Landsat satellites, are usually based on an oscillating mirror as shown in Figure 1.11. The swath width of an oscillating mirror scanner can be limited to 100 km or so, based on small rotations of the mirror, and hence is preferred over a rotating mirror which would record a very large part of the globe from space.

1.7 Radar Sensors

Airborne or spaceborne imaging radar sensors are active microwave remote sensing systems which emit radiation from an antenna, and record the time of transmission for the radiation to be returned to the antenna. They primarily measure angles and distances based on the time of travel the reflected radiation, T. The radar beam is emitted sideways from the platform, approximately normal to the direction of flight, at an inclination to the horizontal, as shown in Figure 1.12.

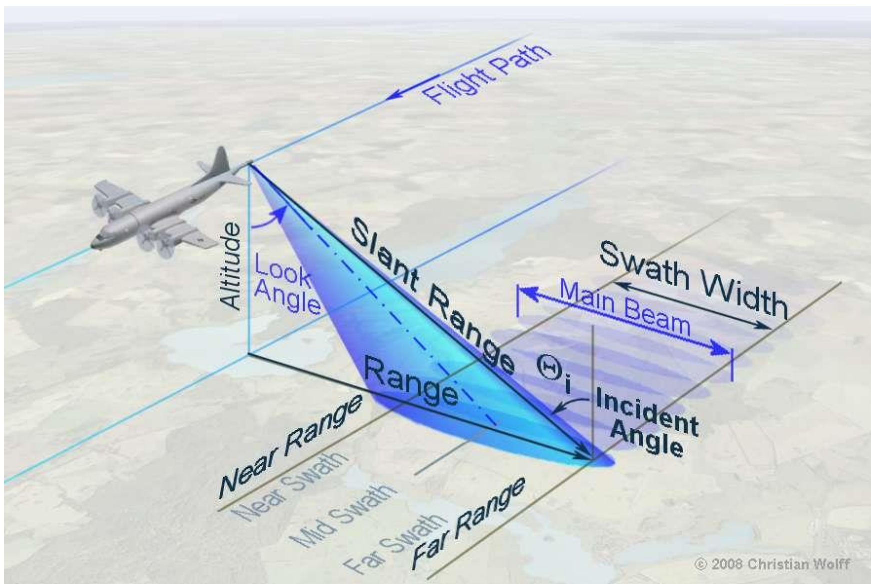


Figure 1.12 Data Acquisition by Radar System

The range, R, is therefore derived from the formula:

$$R=cT/2 \qquad (1.2)$$

where c is the velocity of the electro-magnetic radiation in the atmosphere. The range resolution, at right angles to the flight direction, is a function of the *pulse repetition frequency* (PRF) of the radar signal transmission. The azimuth resolution, in the direction of flight, is a function of the length of the antenna. To achieve a small azimuth resolution of the image, it is necessary to use an extremely long antenna (several km). A *synthetic aperture radar*, or SAR, overcomes this problem of achieving a suitable spatial resolution in the azimuth direction by synthesising a very long antenna, by processing the reflected signals that are acquired as the platform progresses. The azimuth resolution of SAR images can be shown to be approximately equal to d/2, where d is the actual length of the antenna on the platform. This means that the resolution of the images will decrease ie, improve as the antenna decreases in size. In addition, the azimuth resolution is independent of the elevation of the platform and the frequency of propagation. The limits of azimuth resolution are constrained, because the complexity of the radar system. Data storage and processing requirements all increase with increasing range and wavelength, while power requirements increase sharply as the antenna decreases in length.

Radar images are affected by geometric errors, which are functions of the combination of the elevation angle of the signal and variations in the elevations in the terrain. These errors are layover, foreshortening and shadow, as shown in Figure 1.13. Layover is caused by the imaging characteristics of radar, since ranges (distances) are measured from the antenna to the terrain. Elevated points are closer to the antenna than points below them and these points will therefore be imaged closer to the nadir point in the image. This effect will increase as the elevation or look angle of the emitted radiation decreases. Foreshortening will occur when slopes in the terrain facing the antenna are compressed in size due to the effects of layover. Shadows are image voids caused by certain areas being hidden from the radar beam, because of the intervening terrain features. In addition to errors caused by terrain elevations, the continuous process of data acquisition of SAR data will result in geometric distortions caused by variations in the platform attitude during flight.

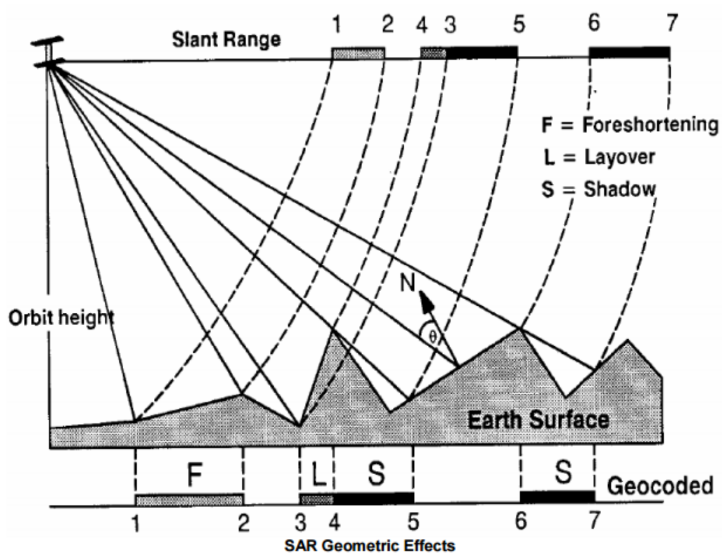


Figure 1.13 Geometric Distortions in SAR Data

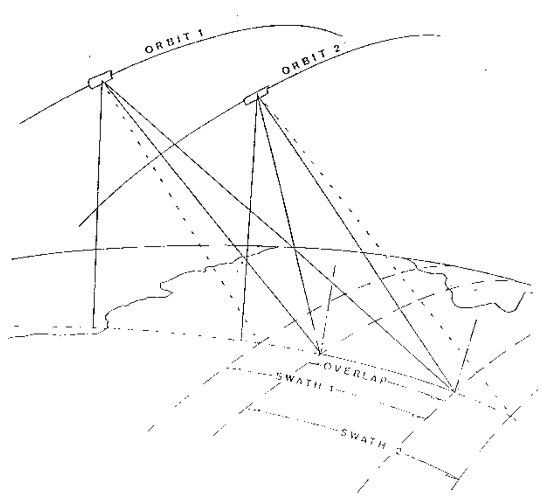


Figure 1.14 Same–side data acquisition for stereo observation of radar images

1.7.1 Overlapping Radar Images

Overlapping images for elevation computations are derived by the acquisition of two parallel passes as show in Figure 1.14, which demonstrates the so-called 'same-side' stereo configuration. That is, the antennas view the terrain from the same side of the platform. Opposite side configuration is also possible but there are limitations in the suitability of this configuration for computation of elevations because of the large geometric distortions as described above. The accuracy of elevation computation from overlapping radar images is usually poor. A more accurate method being developed is referred to as interferometric radar.

1.7.2 Interferometric SAR (InSAR and also referred to as IfSAR)

A SAR image of a scene comprises amplitude and phase information. In Figure 1.15, two antennas A_1 and A_2 with a baseline length B, record the echoes of the signal emitted by one of the antennas. The range distance from an illuminated point on the ground to antenna A_1 is r, while $r + \delta r$ is the distance to antenna A_2 from the same point. The difference in phases in wavelengths, between the signals received at the two antennas can be used to determine the difference in range δr and hence terrain elevations with high accuracy. After registering the two images, the phases are calculated and differenced on a pixel by pixel basis, resulting in a phase difference image or interferogram.

Accuracies of elevations determined by interferometric SAR depend on the parameters of the radar system and can be better than 0.5 metre for low wavelength airborne radar systems. Accuracies of the order of several metres are achievable with spaceborne systems. An approach called differential InSAR is based on the acquisition of SAR images in two or more epochs and can be used for monitoring small changes in elevation, such as those that occur due to earthquakes and mine subsidence. Accuracies of differential InSAR can be of the order of 1 cm, even when the images are recorded from space.

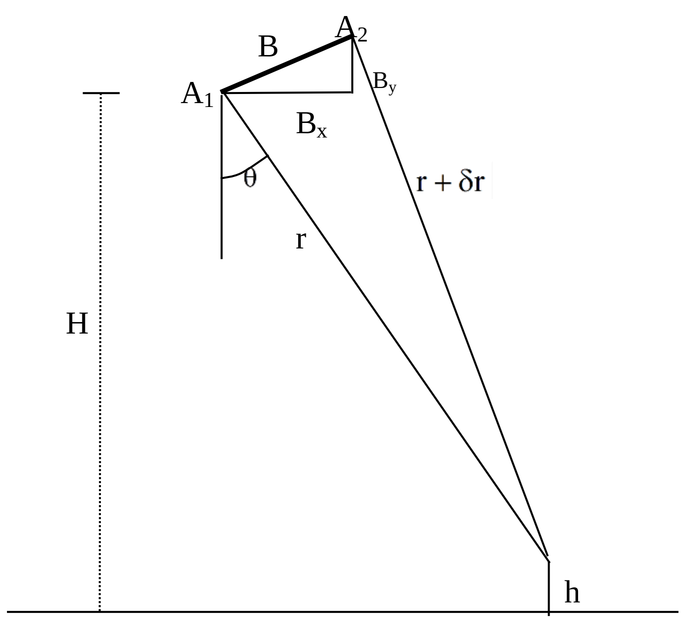


Figure 1.15 A schematic diagram of InSAR.

1.8 Airborne Lidar or Airborne Laser Scanning (ALS)

In airborne lidar (**Li**ght **D**etection **A**nd **R**anging also written as LiDAR) or airborne laser scanning (ALS), a laser scans the terrain surface normal to the flight direction of an aircraft AS SHOWN IN Figure 1.16. The measured distance from the aircraft to visible points on the terrain surface will enable the position and elevation of points to be determined. A lidar system includes the following equipment:

- The laser scanning normal to the flight direction for which the range to the object and rotation angle of the scanner are determined
- GNSS equipment to determine the location of the aircraft based on kinematic measurements
- IMU to continuously determine the tilts of the aircraft.

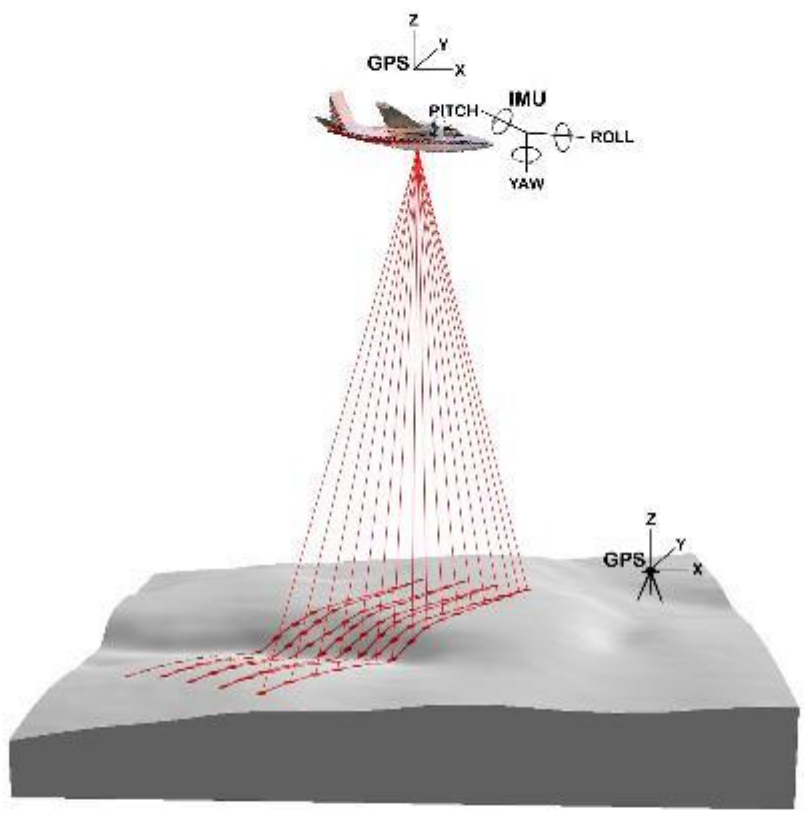


Figure 1.16 Airborne lidar system

Lidar systems acquire a dense set of elevation posts (XYZ coordinates), referred to as a *point cloud*, at a separation typically of 1 m or less for modern lidar systems, that represent a digital surface model (DSM) of the visible terrain, that is, objects such as buildings and trees, but also the terrain surface if the laser beam penetrates the vegetation. The accuracy of the elevation posts is of the order of 10-20 cm, although tests have shown that accuracies of interpolated hard surfaces better than 5 cm are achievable. The separation of the posts will depend on the configuration of the lidar equipment and the scanning frequency, which is increasing as the systems are developed further. This technology is also referred to as 'linear lidar' to differentiate them from single photon lidar (SPL) and Geiger systems as described below.

Some lidar systems can register multiple returns or echoes of the laser beam, but most systems will register, as a minimum the *first* and the *last pulses*. For example, if the laser beam hits a tree, a part of the laser beam will be reflected by the canopy, resulting in the returned signal being registered by the sensor as the *first pulse*. The rest of the beam may penetrate the canopy and, thus be reflected from further below the top of the tree, maybe even by the soil. The *last pulse* registered by the sensor corresponds to the lowest point from which the signal was reflected. In certain cases, the difference in elevation between the first and last pulses can be assumed to measure the heights of trees or buildings.

Along with the time of transmission of the signal from the sensor to the terrain and back to the sensor, the *intensity* of the returned laser beam is also registered by lidar systems. Lidar systems typically operate in the infrared part of the electromagnetic spectrum and therefore the intensity can be interpreted as an infrared (IR) image. However, this intensity image is usually under-sampled and thus very noisy, because the footprint of the lidar is about 0.3 m-0.5 m and the average sampling point distance is 0.3 m to 1 m apart. As well as the laser data, images of the terrain surface may also be recorded by a separate medium or high resolution digital camera. These images may be used to identify the location of points on the terrain surface. The combination of colour and the IR as multi-spectral images can provide valuable information for information extraction of the terrain surface. Multi-spectral lidar systems have now been developed incorporating 2 or 3 lidar beams with different wavelengths.

Technological advances have resulted in new systems being developed, referred to as single photon lidar (SPL) and Geiger systems, which enable the collection of data with much higher point densities. They offer better use of the photons generated by the laser source, resulting in a dense point cloud from the same or a less efficient laser source. These systems are not available on the market year, but they are likely to be available in a year or so.

Typical applications of lidar data may include:

- DEMs of the bare earth surface
- Beach erosion studies
- Infrastructure analysis
- Flood risk analysis, flood simulation, and drainage design
- Ground subsidence
- Visibility analysis
- Telecommunications planning
- Noise propagation studies
- Volume change monitoring
- Buildings extraction for 3D city models
- Forest analysis

The economics of lidar equipment require it to be used over large areas, and hence GBytes of data are likely to be acquired in a single mission (250,000 points may be recorded in a few seconds). Therefore, it is essential that automatic processes are developed that enable the extraction of information from the lidar data. There are described in more details later in these notes.