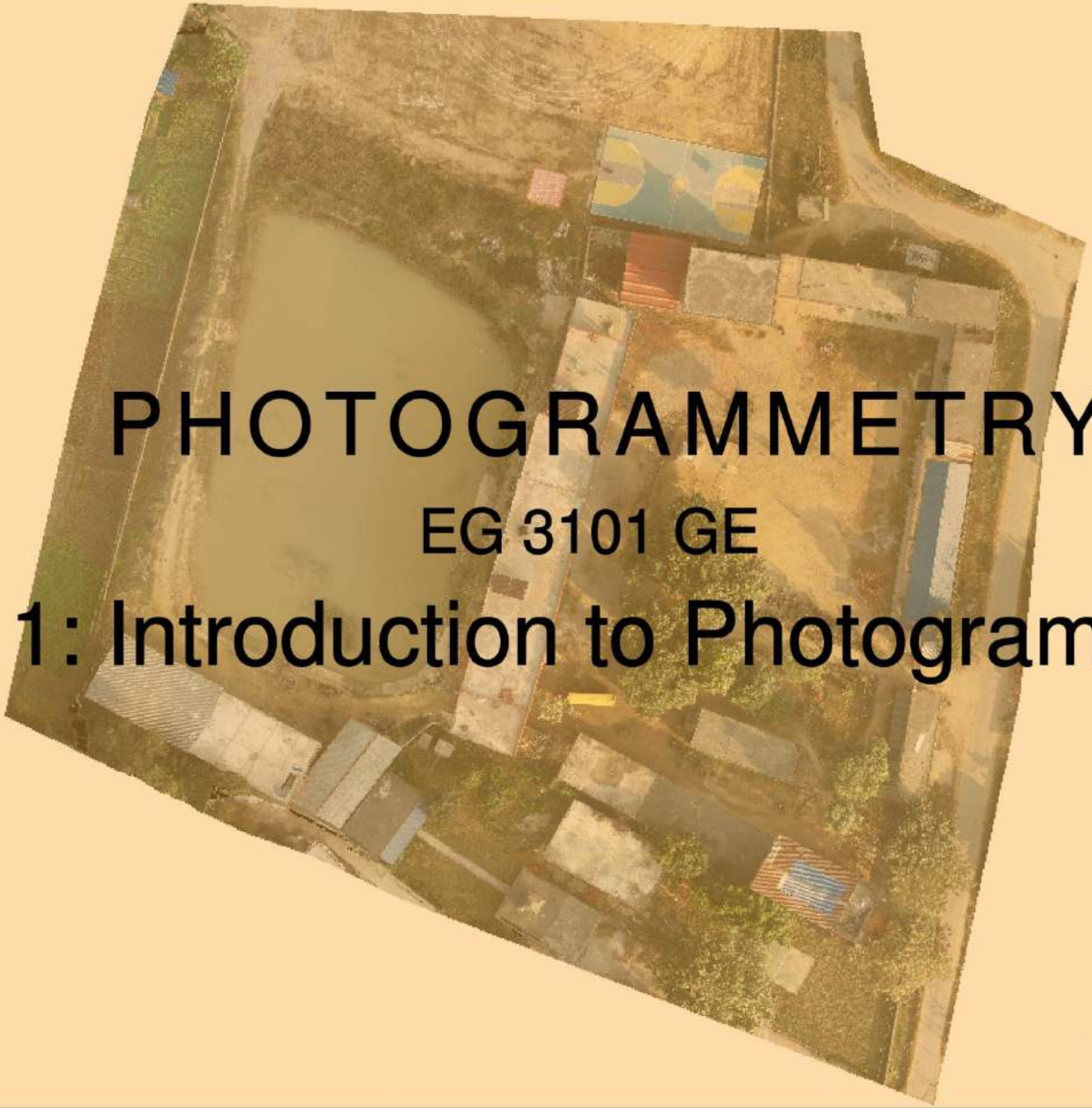

PHOTOGRAMMETRY

EG 3101 GE

Unit 1: Introduction to Photogrammetry

Lecture by

Er. Keshav Raj Bhusal

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1.1. Definition of Photogrammetry

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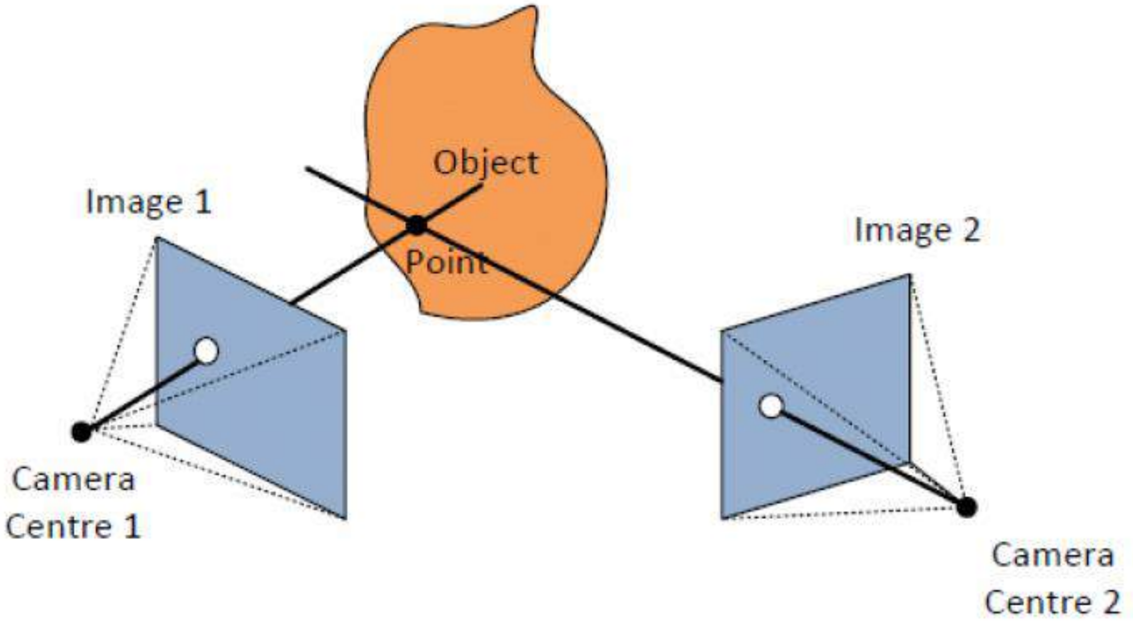
1.1 Definition of Photogrammetry

What is Photogrammetry?

- Photogrammetry: photo(picture) + grammetry(measurement). It is simply the science of measurement from photographs.
- ASPR definition: “Art, science and technology of obtaining reliable information about the physical objects and environment through the process of recording , measuring; and interpreting photographic images and patterns of recorded radiant electromagnetic energy”.
- The most important feature of photogrammetry is the fact the objects are measured/interpreted without actually being touched.
- Photogrammetry is a technique that allows for the reconstruction of 3D models by analyzing photographs taken from different angles.

Principle of Photogrammetry

- The fundamental principle used by Photogrammetry is triangulation or more specifically called Aerial Triangulation. By taking photographs from at least two different locations, socalled “lines of sight” can be developed from each camera to points on the object.
- These lines of sight (sometimes called rays owing to their optical nature) are mathematically intersected to produce the 3-dimensional coordinates of the points of interest.



Source: https://www.gim-international.com/content/article/dense-image-matching-2

1.3 Classification of Photogrammetry

Types of Photogrammetry

❖ In General (according to ASPR)

1. Metric Photogrammetry (Semantic)

- It deals with obtaining measurements from photographs from which ground positions, elevations, distances, area and volumes can be computed.
- The most common applications of metric photogrammetry are the preparation of planimetric and topographic maps from photographs.

2. Non-metric Photogrammetry (Interpretative)

- It deals with evaluation of existing features in a qualitative manner such as vegetation cover, water pollution, soil erosion, geological formation, crop identification, military intelligence, etc.
- Information is usually obtained by interpreting the recorded data.
- Key semantic elements include size, shape, tone, texture, pattern, site/location, shadows, stereoscopic appearance, association, etc.

1.3 Classification of Photogrammetry

Types of Photogrammetry

❖ Based on platform

1. Aerial Photogrammetry (Semantic)

- Platform is in air.
- Series of photographs of terrain at an angle are captured in sequence using camera.
- Examples of such photogrammetric platforms are: Airplane, Unmanned platform

like kite, birds, ballon, UAV etc.

- The advantage of aerial photogrammetry is data collection of inaccessible/difficult environments and fast data collection speed.
- It’s application includes topographic mapping, urban planning, heritage documentation, forestry, agriculture etc.

1.3 Classification of Photogrammetry

Types of Photogrammetry

❖ Based on platform

2. Terrestrial Photogrammetry

- Platform is usually earth based and is mounted on a tripod.
- Examples of such photogrammetric platforms are: Handheld camera, camera mounted on tripods etc.
- Terrestrial photogrammetry dealing with object distance less than 300 m is also termed close-range photogrammetry.
- It’s application include accident investigation, archaeology for documentation of ancient buildings, medical science for measuring sizes and shapes of body parts, recording tumor growth etc.

1.4 History and Development of Photogrammmetry

1. Invention of photography by Niepce and Daguerre in 1839.

First photograph taken

Source: http://www.close-range.com/docs/History_of_Photogrammetry--Dermanis.pdf

2. In 1849, French military topographer Aime Laussedat('Father of Photogrammetry') used terrestrial photographs for topographic map compilation for the first time.

3. In 1855, Nadar (Gaspard Felix Tournachon) used a balloon at 80- meters to obtain the first aerial photograph. Later he also took photographs from balloons for military interpretation purposes in the battle of Solferino in 1859.

Nadar capturing photographs from ballon

Source: http://www.close-range.com/docs/History_of_Photogrammetry--Dermanis.pdf

4. In 1858, the German architect A. Meydenbauer introduced measurements on photos for the documentation of public buildings.

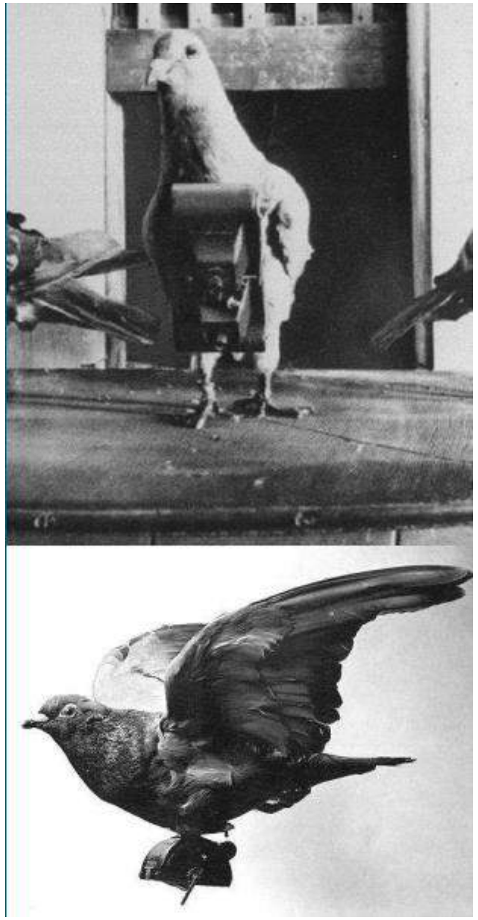
5. The English meteorologist E. D. Archibald was among the first to take successful photographs from kites in 1882. In France M. Arthur Batut took an aerial photographs using a kite, over Labruguiere, France, in May 1888.

Source: http://www.close-range.com/docs/History_of_Photogrammetry--Dermanis.pdf

6. Stereo measurement principle developed around 1900.

1.4 History and Development of Photogrammmetry

7. In 1903, Julius Neubranner, photography enthusiast, designed and patented a breast-mounted aerial camera for carrier pigeons.

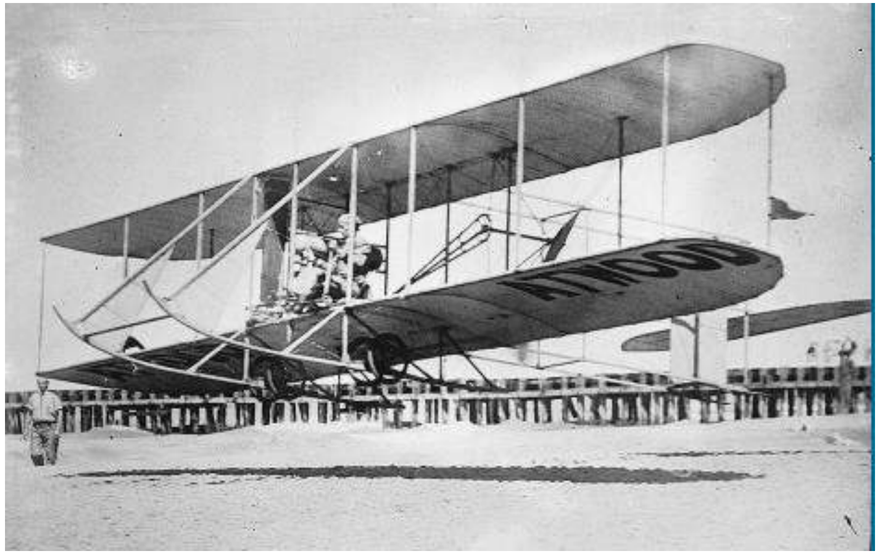


Source: http://www.close-range.com/docs/History_of_Photogrammetry--Dermanis.pdf

History and Development of Photogrammmetry

8. In 1903: Wright brothers invented Airplane; In 1909: the Wright brothers took the first photograph from a plane over Centocelli, Italy.

- More general use of photogrammetry was introduced after the availability of controllable aerial platforms and the motorized airplane of the Wright brothers (from 1903) soon became an accepted photogrammetric platform, which was used extensively for interpretive purposes during World War.



Source: http://www.close-range.com/docs/History_of_Photogrammetry--Dermanis.pdf

9. Oskar Messter in 1915 developed the aerial survey camera, which permitted a systematic survey of the terrain by near vertical aerial photographs.

History and Development of Photogrammmetry

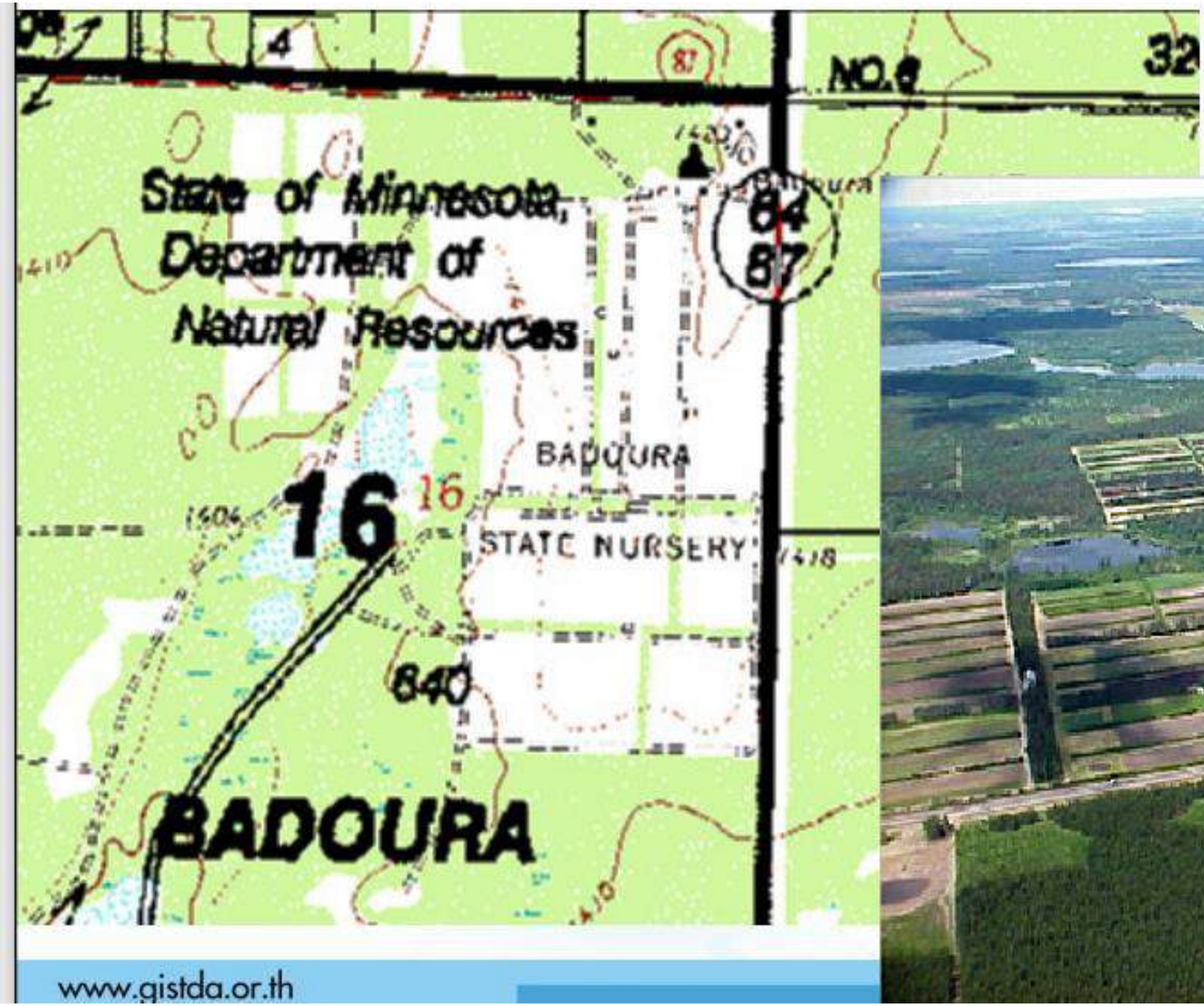
10. After the end of World War I, the optical industry in Europe began to construct optical and mechanical devices for the stereo reconstruction of overlapping images.

11. In the period between World War I and World War II, aerial photogrammetry for topographic mapping progressed to the point of mass production of maps.

12. In the 1950s, computer systems became available for analytical solution that permitted a rigorous photogrammetric treatment, the first of which is point measurement in images or stereo model by a human operator.

- Not only automated many steps of the photogrammetric process but also made photogrammetry more accurate and more reliable by use of least square adjustment and statistical testing included in the computer solutions.

Comparison of Aerial Photograph and Map



Comparison of Aerial Photograph and Map (Optional)

Map

1. It has orthogonal projection.
2. Map has a uniform scale.
3. Terrain relief without distortion (contour lines).
4. Non visible object like district, ward boundary etc. are also represented along with visible objects.
5. It is an abstract representation of the earth surface.
6. Representation geometrically correct.

Comparison of Aerial Photograph and Map (Optional)

Photograph

1. It has central perspective projection.
2. Photograph has variable scale.
3. Relief displacement in the image.
4. Only visible objects are represented.
5. It is a real representation of the earth surface, no legend needed.
6. Representation geometrically not correct.

Advantage/Disadvantage of Photogrammetry (Optional)

Advantage of Photogrammetry/Importance of Photogrammetry

- The major advantage of photogrammetry is the ease and speed at which the data can be collected.
- It is useful in any locations that are difficult, unsafe, or impossible to access.
- Data can be used for multiple use it offers a broad view of the mapped area by utilizing both topographic and cultural features of the land surface.
- It is cheap/cost effective for large area and in a long run.
- It is easy to re-process data for new information without the need for expensive fieldwork to re-survey the area.
- The road surveys can work without disturbing the traffic by closing lanes, or risking the field team.

Disadvantage of Photogrammetry

- The major disadvantage is that the photogrammetric survey is not possible in the absence of light.
- It is a complex system and requires highly trained human resource.
- It is weather dependent. Winds, clouds, haze etc. affect the aerial photogrammetry process and the image quality.
- It is costly at the time of installation/initiation as it needs heavy and complex equipments.
- Administrative procedure for getting fly permission is tedious/time-consuming.
- The accuracy of the measurement depends highly on the flight height.
- It cannot be used for accurate measurements when there are visibility restrictions such as trees, vegetation or any other obstacles.

Applications/Uses of Photogrammetry/Scope

1. Mapping

- The earliest applications of photogrammetry were in topographic mapping, and it is still the most common of photogrammetric activities.

2. Civil engineering

- It is used in road survey, cut-fill estimation, monitoring progress work of construction sites etc,.

Source: https://uavcoach.com/drones-in-construction/

Applications/Uses of Photogrammetry/Scope

3. Archaeology

- It helps to capture the landscape and finest details of buildings, sculptures, bas-reliefs, archaeological sites and excavations
- It is used in heritage documentation of ancient buildings through 3D models/Mesh, DSM etc.

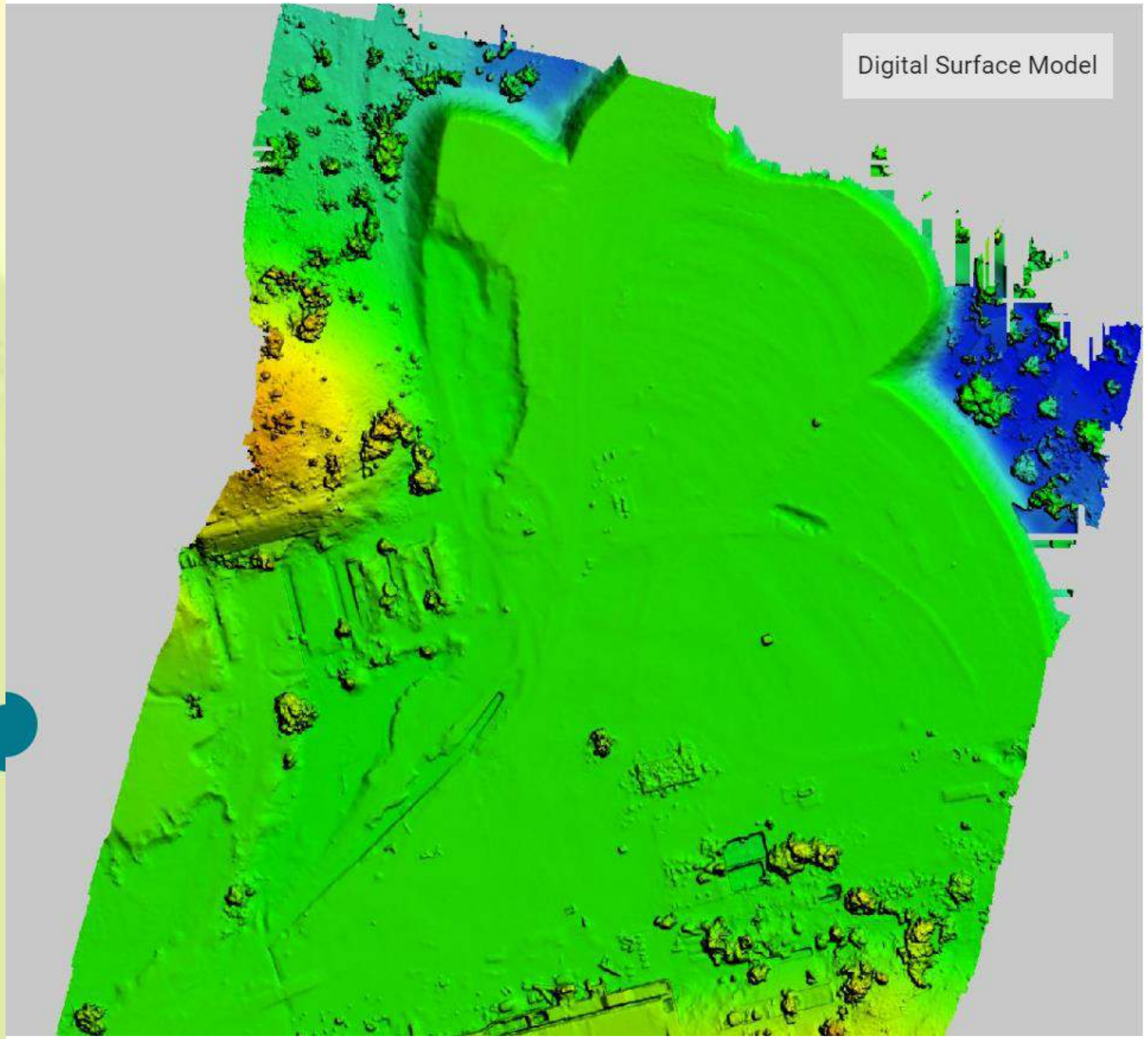
Drone used in documentation of heritage site: https://youtu.be/QztdRKS8xg0

Source: https://gistda.or.th/home.php

Applications of Photogrammetry

Applications/Uses of Photogrammetry/Scope

3. Archaeology



DSM (a photogrammetry product) giving insight about heritage site.

Source: https://geonadir.com/drone-mapping-heritage-sites/

Applications/Uses of Photogrammetry/Scope

4. Medicine

- It is also used in the fields of medicine and dentistry, measurements from X-ray and other photographs and images have been useful in diagnosis and treatment.

5. Highway planning

- Altitude photos or satellite images are used to assist in area and corridor studies and to select the best route; topographic maps are prepared for use in preliminary planning.
- DEMs are used in final design; and earthwork cross sections are taken to obtain contract quantities.

6. Real estate

- With the help of drone and photogrammetric techniques real estate agents are able to get the photographs taken from various angles with maximum accuracy within a short span of time.
- It's a cost-effective method to allow the buyer to view and decide.

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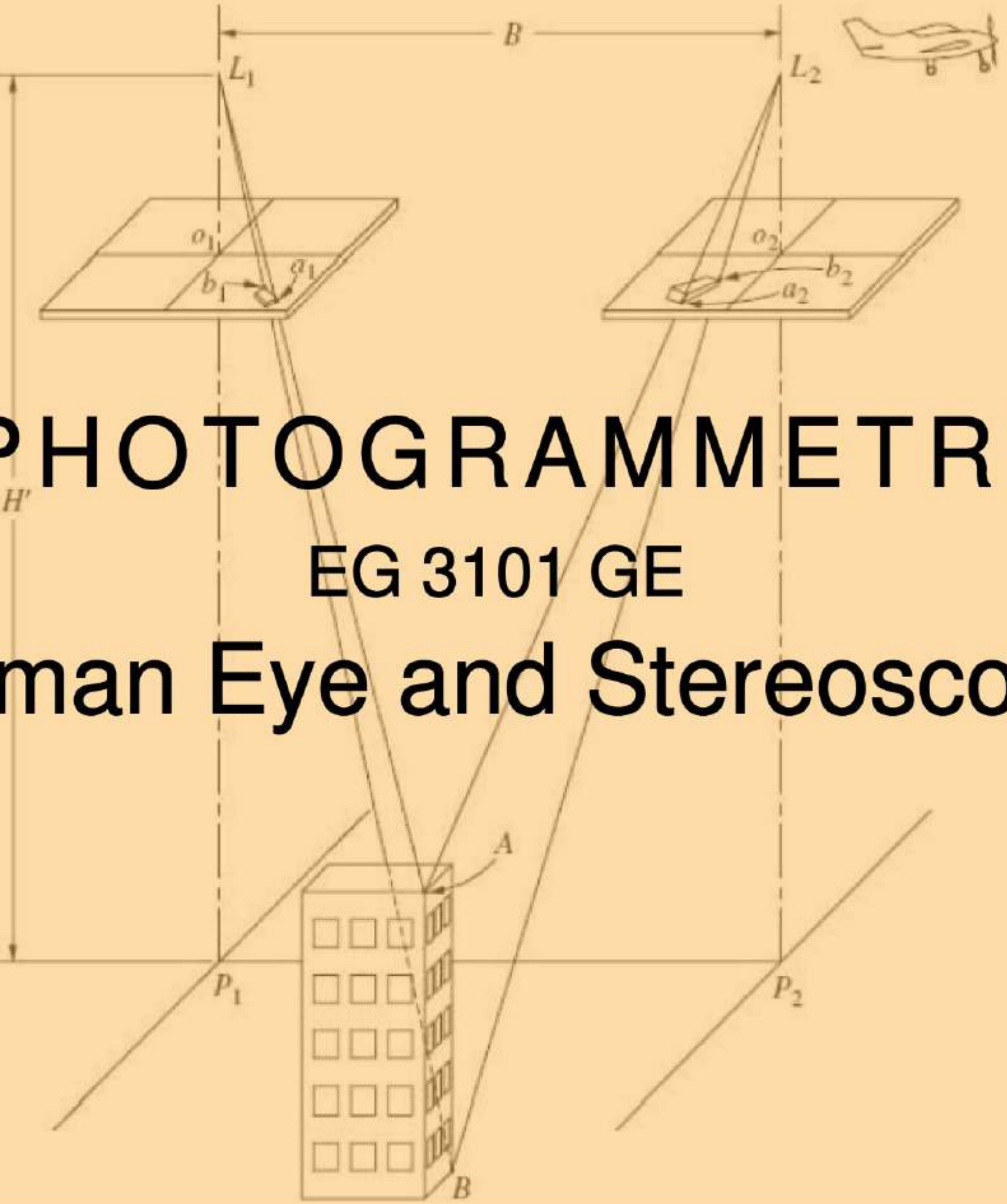

PHOTOGRAMMETRY

EG 3101 GE

Unit 2: Human Eye and Stereoscopic Vision

Lecture by

Er. Keshav Raj Bhusal

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Unit 2: Human Eye and Stereoscopic Vision

2.1. Human eye and its characteristics

2.2. Stereoscopic vision

2.3. Parallax

2.4. Application of stereovision and parallax in photogrammetry

Stereoscopic Vision

Depth Perception

- In our normal process of vision, consciously or unconsciously, we perceive depth to objects around us with the help of our eyes.
- Depth perception is the ability to perceive the world in three dimensions (3D) and to judge the distance of objects.
- Depth perception can be classified as either monoscopic or stereoscopic.

1. Monoscopic or monocular vision is the term which refers to viewing with only one eye and judging distance.

- Depth perception is poor with monoscopic vision and distance estimation can be different.

2.2 Stereoscopic Vision

Stereoscopic Vision

- Stereoscopic vision is a characteristic, possessed by most persons of normal vision (those capable of viewing with both eyes simultaneously; binocular vision) to conceive objects in three dimensional effects and to judge distances.
- With stereoscopic viewing, a much greater degree of accuracy in depth perception and distance estimation can be achieved.
- Stereoscopic vision is the basic prerequisite for photogrammetry and photo interpretation.
- The concept of stereoscopic vision can also be applied to view stereo pair (overlapping pair of photographs) by viewing the left photograph with the left eye, and the right photograph with the right eye, a 3D view of the terrain can be obtained. Here, the third dimension is obtained by using the principle of parallax.
- Stereoscopic viewing makes it possible to measure elevations and plot contours and planimetric features from the photographs oriented in stereoscopic plotting instruments.

Stereoscopic Vision

- With binocular vision, when eyes are focused on a certain point, the optical axes of the two eyes converge on that point intersecting at an angle called parallactic angle.

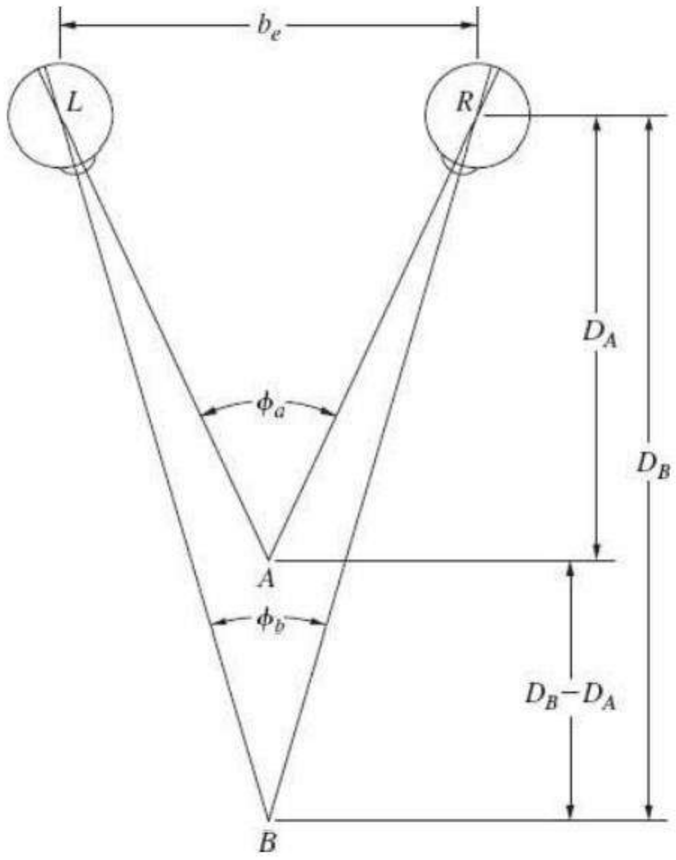


Fig: The depth between objects A and B is $D_B - D_A$ and is perceived from the difference in these parallactic angles; optical centers of the eyes L and R separated by a distance b_e, called the eye base.

2.2 Stereoscopic Vision

Types of Stereoscopic Vision

Stereoscopic vision can be of two types:

1. Natural Stereoscopic Vision

- Binocular Vision is responsible for perception of depth. Two slightly different images, seen by two eyes simultaneously are fused into one by brain, giving the sensation of a ‘model’ with three dimensions.
- The three dimension effect is reduced beyond viewing distance of one meter.
- The distance between two eyes, called ‘Eye base, affects stereoscopic vision. Wider the eye base, better is the three dimensional effect.

2. Artificial Stereoscopic Vision

- Stereoscopic Vision obtained from stereo model.

Stereo Model

- It is the phenomenon of creating the three-dimensional or stereoscopic impression of objects by viewing identical images of the objects photographically.
- This requires photographs of the objects to be taken from 2 positions. (Image overlap)

Let's suppose a pair of photographs is taken from exposure stations L1 and L2 so that a building appears on both photographs. In the figure flying ht. above the ground is H and the distance between 2 exposure stations is B, called air base.

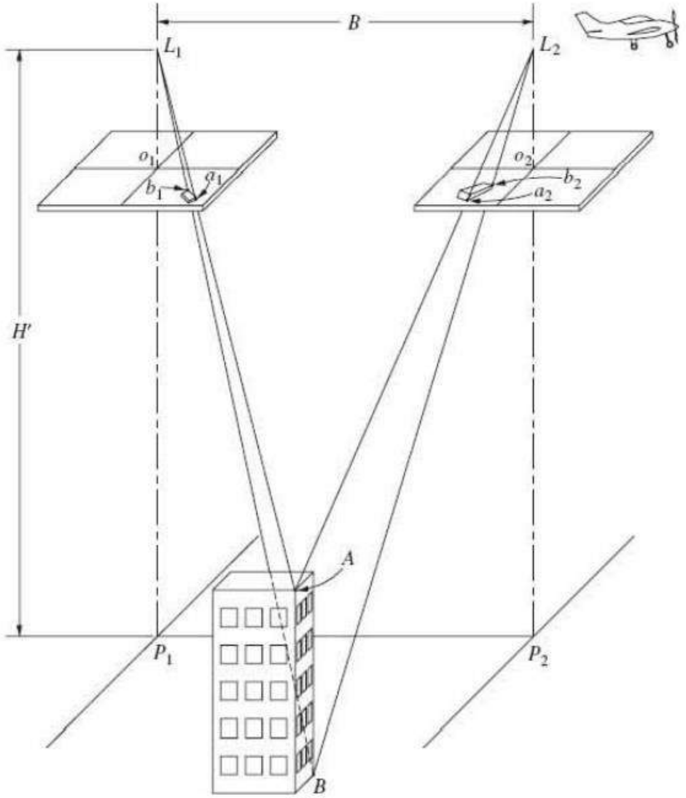


Fig: Photographs from two exposure stations with building in common overlap area.

Stereo Model

- Now if the photos are laid on the table and viewed so that the left eye sees only the left photo and the right eye sees only the right photo, a 3D impression of the building is achieved.

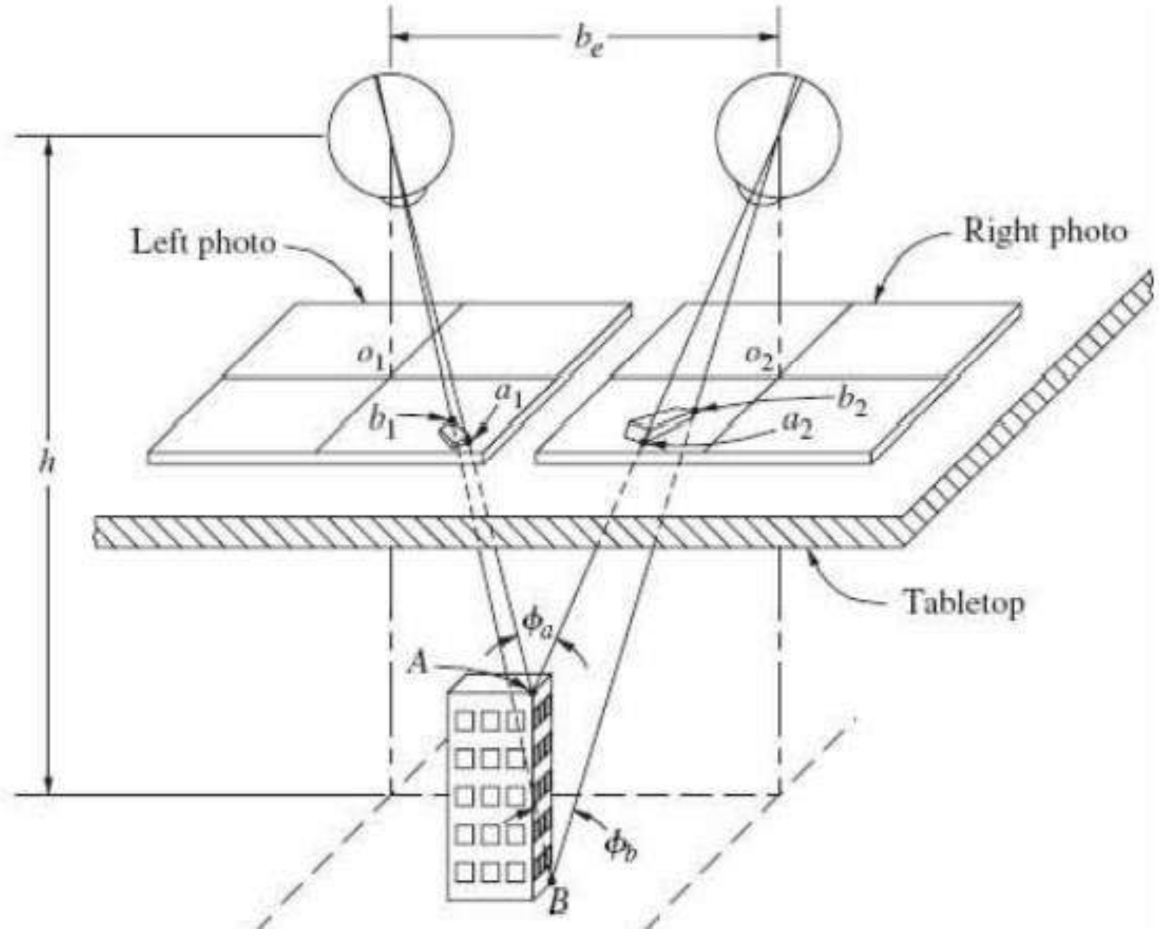


Fig: Viewing the building stereoscopically.

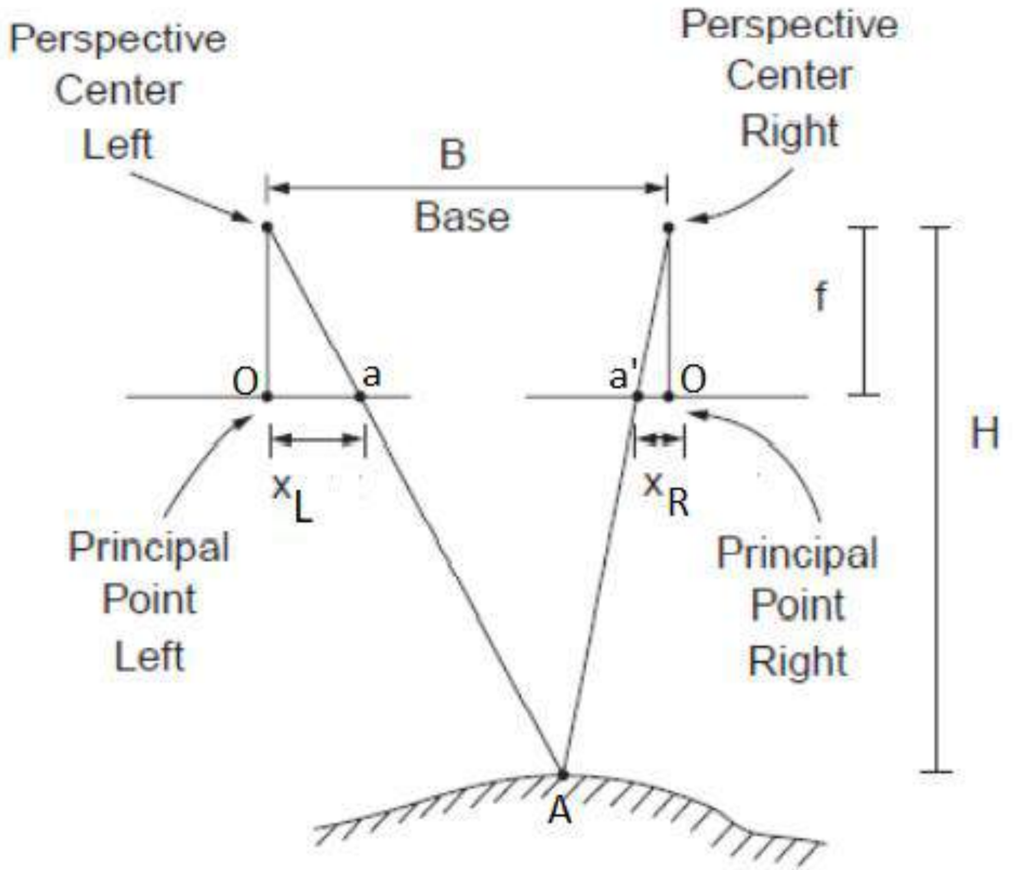
Parallax

- Parallax is the apparent shift in the position of an object caused by a shift in the position of observation.
- To demonstrate parallax hold finger in front of your eyes, while gazing at the finger, alternately close one eye and then the other. The finger will appear to move from side to side. This apparent shift of the finger is parallax, and it is caused due to the shift in the position of observation.
- Nearby objects have a larger parallax than more distant objects when observed from different positions.

Parallax bar

- In photogrammetry, a parallax bar is a tool used to measure the amount of parallax in a pair of overlapping photographs.

Parallax



- Referring to the figure, two vertical overlapping photographs are taken at the same altitude 'H'. For a given image point 'a', the parallax is defined as,

$$p = x_{\mathrm{L}} - x_{\mathrm{R}}$$

where, x_L = measured photo distance of the point on the left image

x_R = measured photo distance of the point on the right image

Stereoscopic parallax

Stereoscopic parallax

- The change in position of an image from one photograph to another caused by the aircraft's motion is termed as stereoscopic parallax or x-parallax or simply parallax.
- Parallax occurs for all image points appearing on successive overlapping photographs.
- The parallax of any point is directly related to the elevation of the point, and parallax is greater for high points(close to camera) than for low points (far from camera).
- Variation of parallax with elevation provides the fundamental basis for determining elevations of points from photographic measurements.

Stereoscopic parallax

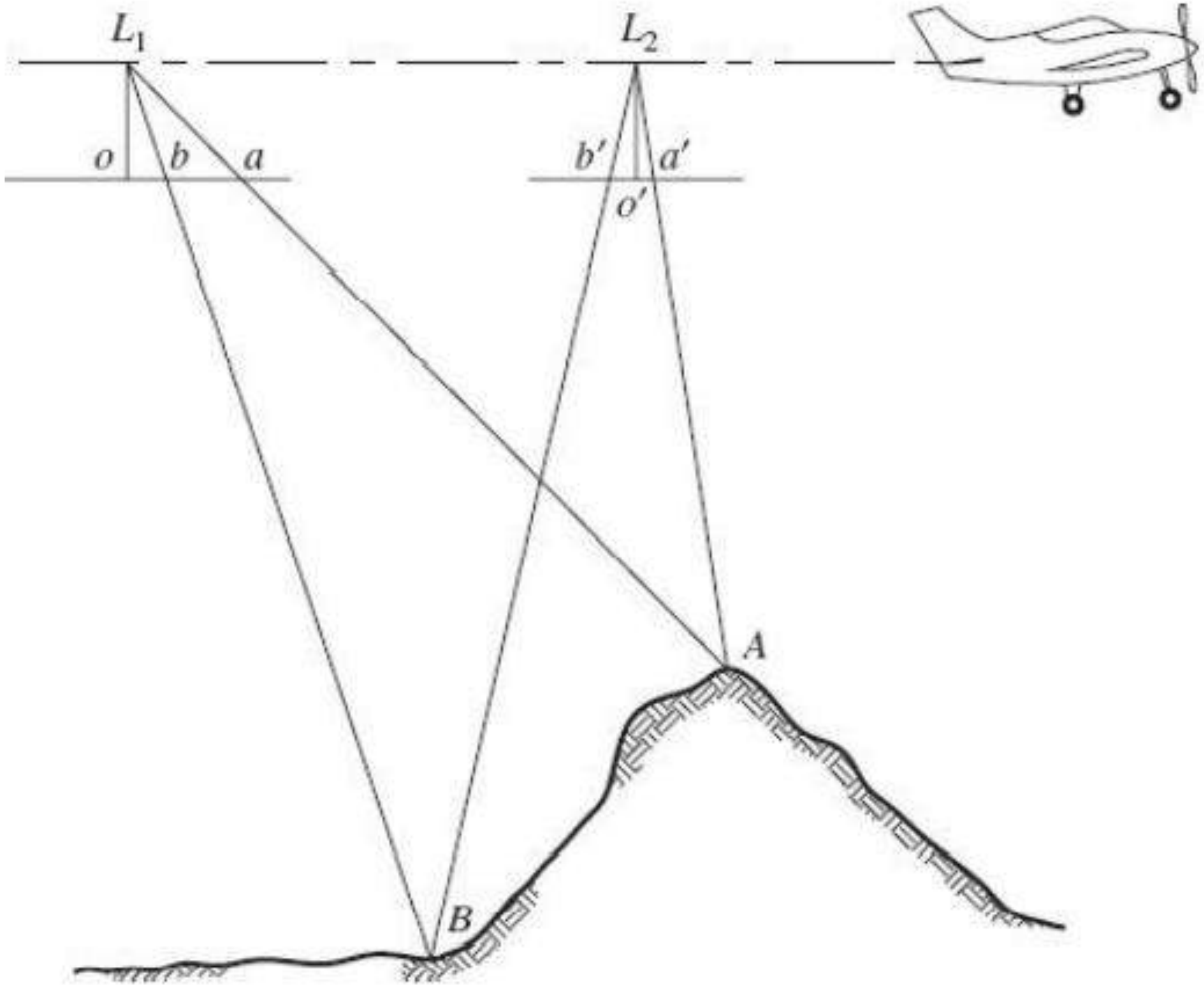
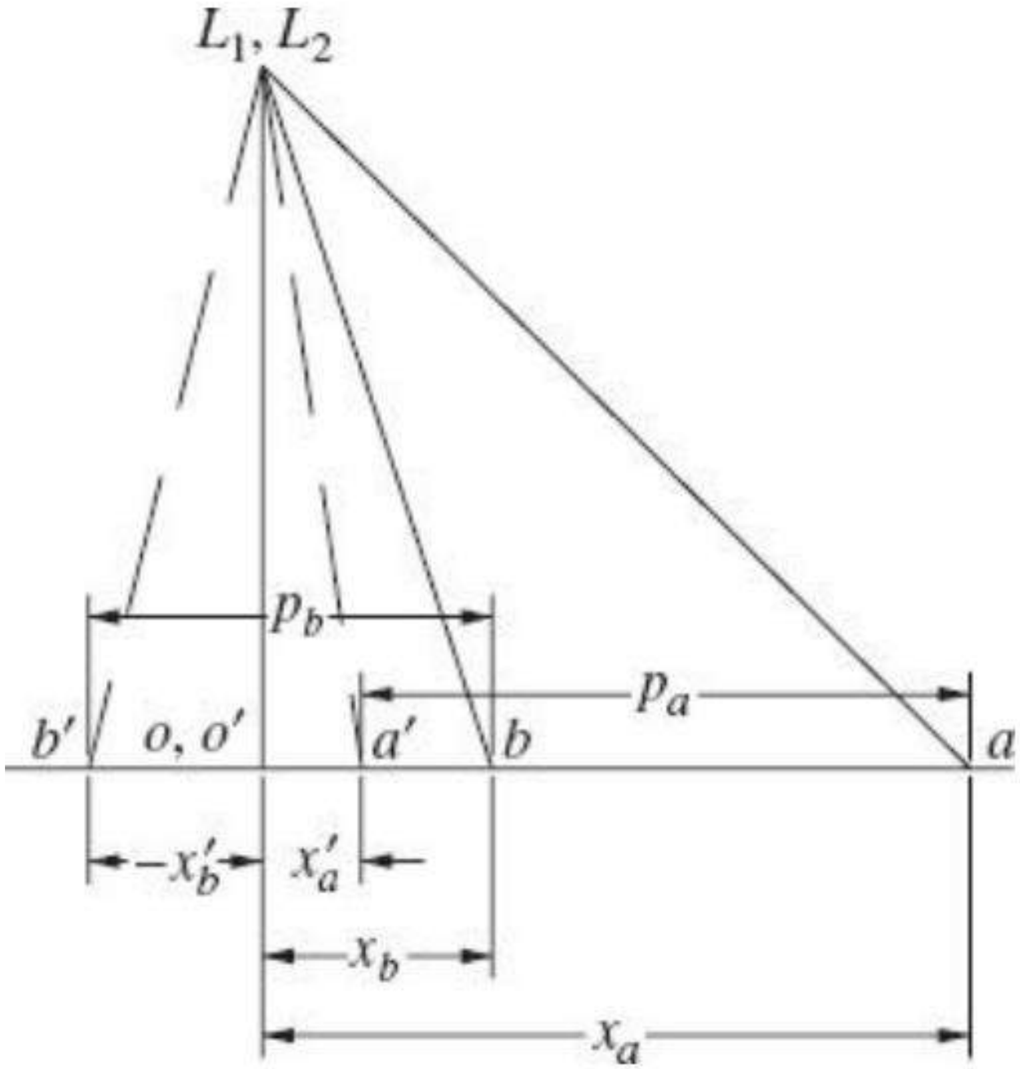


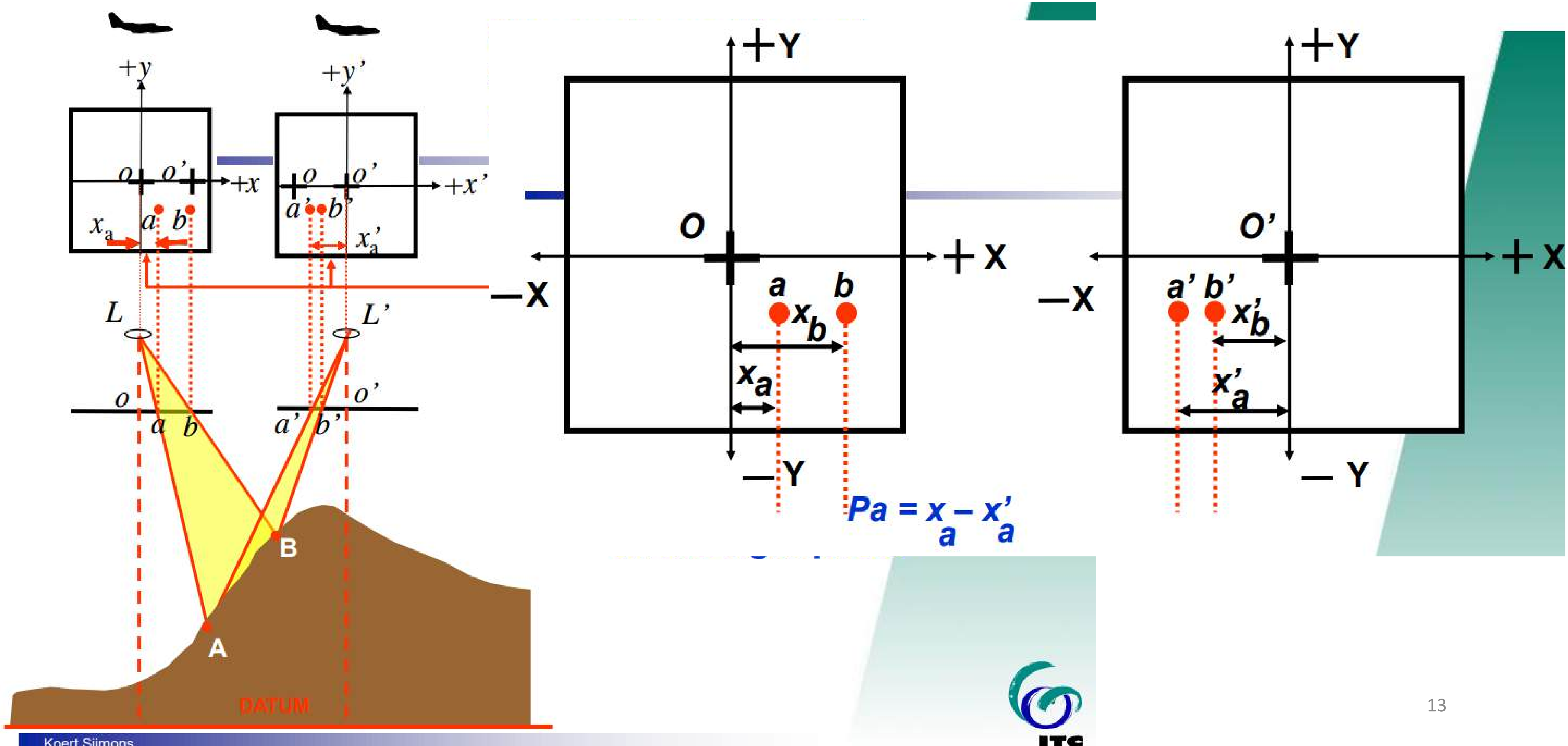
Fig: Stereoscopic parallax of vertical aerial photographs.



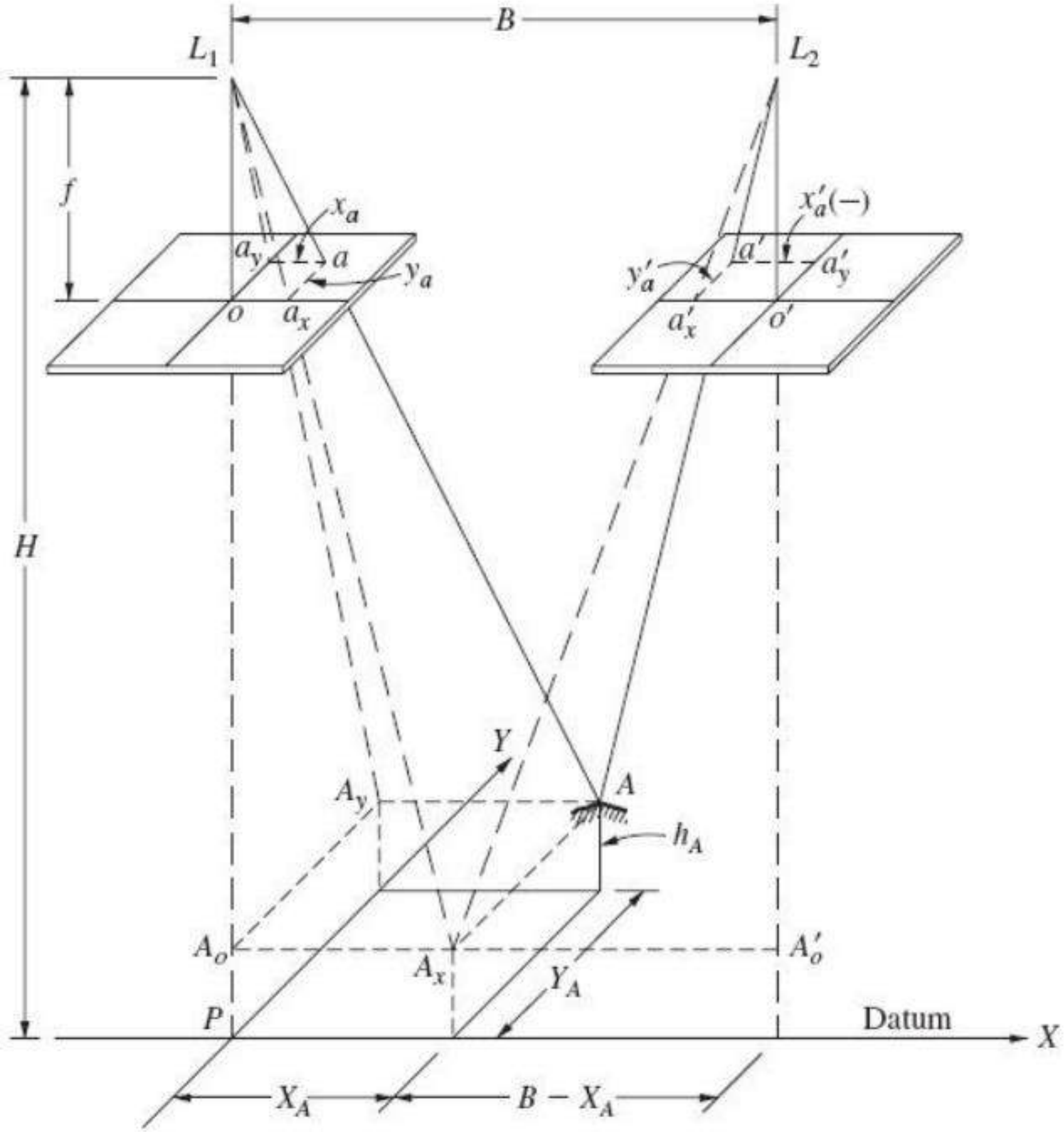
Parallax for point A = $x_a - x'_a$

Fig: The two photographs of Fig. 8-1 are shown in superposition.

Stereoscopic parallax



Stereoscopic parallax equation



Stereoscopic parallax

Stereoscopic parallax equation

Suppose two successive vertical overlapping photographs of a ground point ‘A’ having elevation of h_A is taken from two positions L_1 and L_2 repectively at a flying height ‘H’ from datum. Let the distance between two exposure station be ‘B’ (airbase). Also let ground Point ‘A’ appears on the left image as ‘a’ and right image as ‘a’’. If Ground coordinates of point ‘A’ is (X_A , Y_A) then repective image coordinates on left image is (x_a , y_a) and (x'_a , y'_a) on right image.

From similar triangles L_1oa_y and $L_1A_oA_y$,

$$(oa_y / A_oA_y) = (L_1o/L_1A_o)$$

$$\text{or, } (f/ H- h_A) = (y_a / Y_A)$$

$$\text{or, } Y_A = \frac{y_a (H- h_A)}{f} \quad \ldots\ldots\ldots\ldots\text{(i)}$$

Stereoscopic parallax

Stereoscopic parallax equation

From similar triangles L_1oa_x *and* $L_1A_oA_x$ *,*

$$(oa_x / A_oA_x) = (L_1o/L_1A_o)$$

$$\text{or, } (f/ H- h_A) = (x_a / X_A)$$

$$\text{or, } X_A = \frac{x_a (H- h_A)}{f} \ldots\ldots\ldots\ldots(ii)$$

Also from similar triangles $L_2o'a'_x$ and $L_2A'_oA_x$,

$$(o'a'_x / A'_oA_x) = (L_2o'/L_2A'_o)$$

$$\text{or, } (f/ H- h_A) = (-x_a / B-X_A)$$

$$\text{or, } X_A = B+ \frac{x'_a(H- h_A)}{f} \ldots\ldots\ldots(iii)$$

Stereoscopic parallax equation

From eq. (ii) and (iii),

$$h_A = H - \frac{Bf}{x_a - x'_a}$$ ....(iv)

Substituting p_a for $x_a - x'_a$

$$h_A = H - \frac{Bf}{p_a}$$ ....(v)

Now substituting Eq. (v) into each of Eqs. (ii) and (i) and reducing gives

$$X_A = B\frac{x_a}{p_a}$$ ....(vi)

$$Y_A = B\frac{y_a}{p_a}$$ ....(vii)

Equations (v), (vi) and (vii) are the parallax equations.

Assignment

Numericals related to Stereoscopic parallax

1. A pair of overlapping vertical photographs was taken from a flying height of 1233 m above sea level with a 152.4-mm-focal-length camera. The air base was 390 m. With the photos properly oriented, flight-line coordinates for points a and b were measured as x_a = 53.4 mm, y_a = 50.8 mm, $x_a{}'$ = –38.3 mm, $y_a{}'$ = 50.9 mm, x_b = 88.9 mm, y_b = –46.7 mm, x'_b = –7.1 mm, y'_b = –46.7 mm. Calculate the elevations of points A and B and the horizontal length of line AB. (Ans: 585m, 614m above sea level, 427m)

Solution By Eq. (8-1)

$$p_a = x_a - x'_a = 53.4 - (-38.3) = 91.7 \text{ mm}$$

$$p_b = x_b - x'_b = 88.9 - (-7.1) = 96.0 \text{ mm}$$

By Eq. (8-5),

$$h_A = H - \frac{Bf}{p_a} = 1233 - \frac{390(152.4)}{91.7} = 585 \text{ m above sea level}$$

$$h_B = H - \frac{Bf}{p_b} = 1233 - \frac{390(152.4)}{96.0} = 614 \text{ m above sea level}$$

By Eqs. (8-6) and (8-7),

Assignment

Numericals related to Stereoscopic parallax

$$X_A = B\frac{x_a}{p_a} = 390\left(\frac{53.4}{91.7}\right) = 227 \text{ m}$$

$$Y_A = B\frac{y_a}{p_a} = 390\left(\frac{50.8}{91.7}\right) = 216 \text{ m}$$

$$X_B = B\frac{x_b}{p_b} = 390\left(\frac{88.9}{96.0}\right) = 316 \text{ m}$$

$$Y_B = B\frac{y_b}{p_b} = 390\left(\frac{-46.7}{96.0}\right) = -190 \text{ m}$$

The horizontal length of line *AB* is

$$AB = \sqrt{(X_B - X_A)^2 + (Y_B - Y_A)^2} = \sqrt{(361 - 227)^2 + (-190 - 216)^2} = 427 \text{ m}$$

Assignment

Numericals related to Stereoscopic parallax

2. Overlapping vertical photograph with an airbase 650m. If the elevation of a point within the overlapping area is 283m, and the parallax of the point is 89.40mm, what is the flying height above sea level for this stereo pair? (f=152.4) [Ans:1391m above sea level]

Assignment

Numericals related to Stereoscopic parallax

3. Images of the endpoints of ground line AB, whose horizontal length is 650.47 m, appear on a pair of overlapping vertical photographs. Photo coordinates measured with respect to the flight axis on the left photo were xa = 33.3 mm, ya = 13.5 mm, xb = 41.8 mm, and yb = –95.8 mm. Photo coordinates measured on the right photo were xa ′ = –52.3 mm and xb ′ = –44.9 mm. Calculate the air base for this stereopair.

[Pa = 85.6 mm, Pb = 86.7 mm, B = 514 m]

PHOTOGRAMMETRY

EG 3101 GE

Unit 3: Basic Photogrammetry

Lecture by

Er. Keshav Raj Bhusal

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3.4. Terms used in Photogrammetry

3.5. Principle of perspective geometry, bundle of rays, collinearity condition, forward and side overlaps, concept of model

3.6. Scale of a vertical aerial photograph

3.7. Distortion in a photograph

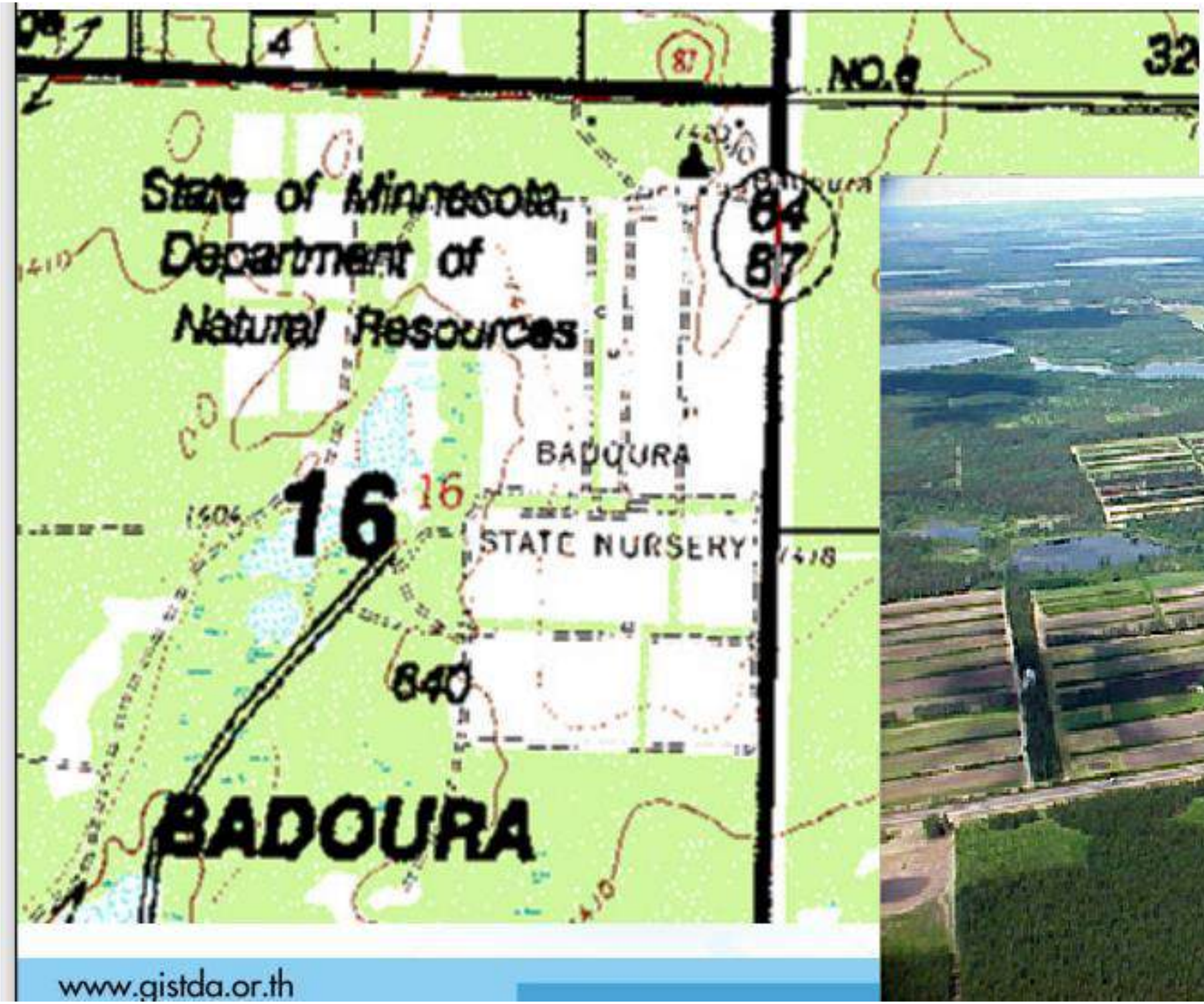
3.8. Effect of relief and tilt displacement

3.9. Rectification

3.10. Oblique photography

3.11. Photo mosaics and photo maps

3.1 Aerial photographs vs Maps



3.1 Aerial photographs vs Maps

Aerial photographs

1. It has central perspective projection.
2. Photograph has variable scale.
3. Relief displacement in the image.
4. Only visible objects are represented.
5. It is a real representation of the earth surface, no legend needed.
6. Representation geometrically not correct.

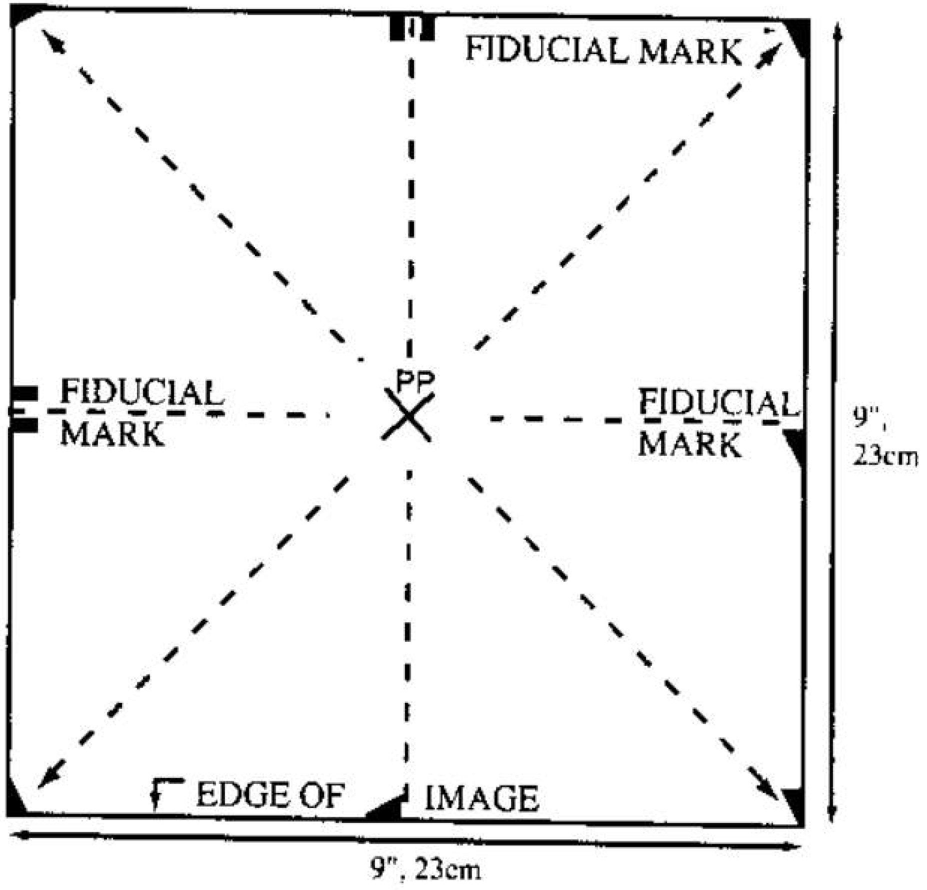
Maps

1. It has orthogonal projection.
2. The scale of the map is uniform throughout the map extent.
3. Terrain relief without distortion (contour lines).
4. Non visible object like district, ward boundary etc. are also represented along with visible objects.
5. It is an abstract representation of the earth surface.
6. Representation geometrically correct.

3.4 Terms used in Photogrammetry

1. Fiducial Marks

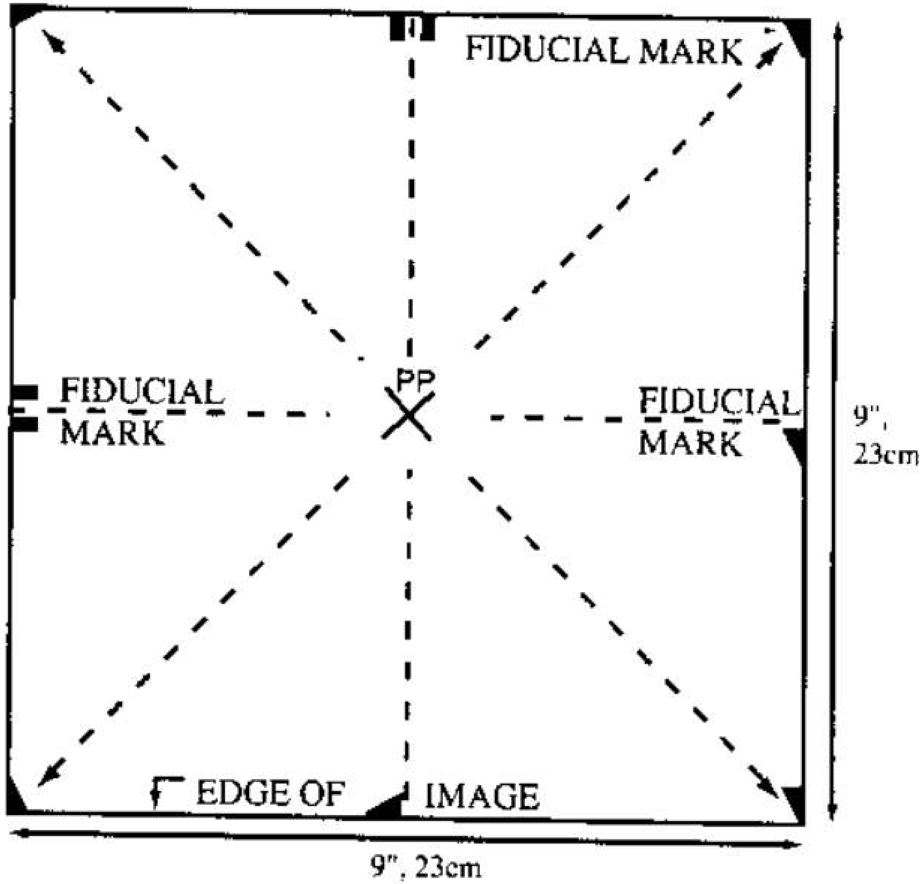
- Fiducial marks are small crosses or small V-shaped indents located precisely on each of the four corners or exactly midway along the four sides of a scanned-film photograph.



Fiducial marks and fiducial axis

2. Fiducial Axis

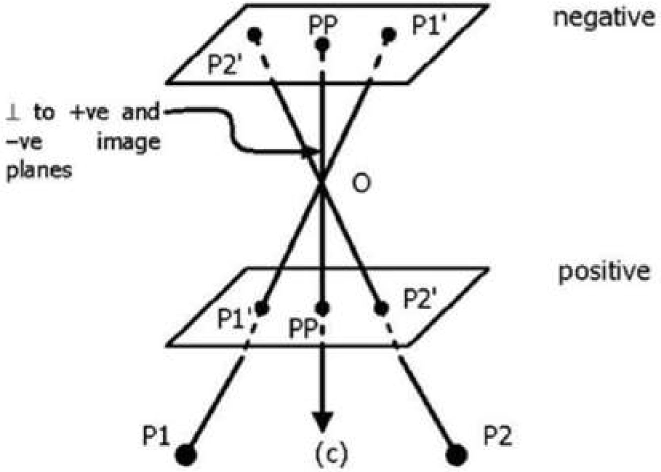
- The line joining opposite fiducial marks on a photograph.



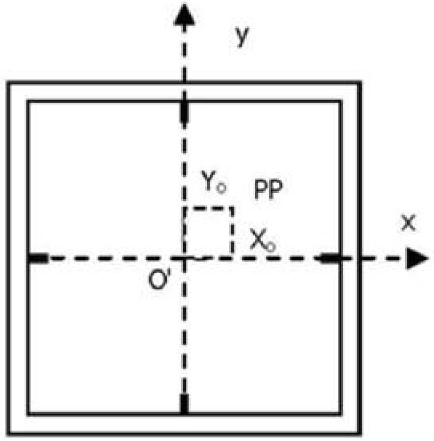
Fiducial marks and fiducial axis

3. Principal point

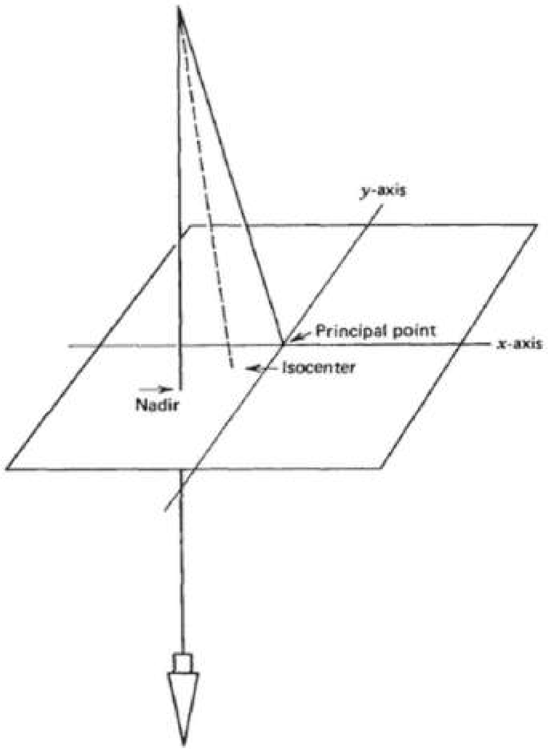
- It is the point of intersection of the optical axis of the aerial camera with the plane of the photograph see fig2 being represented as PP)



(c)



(d)



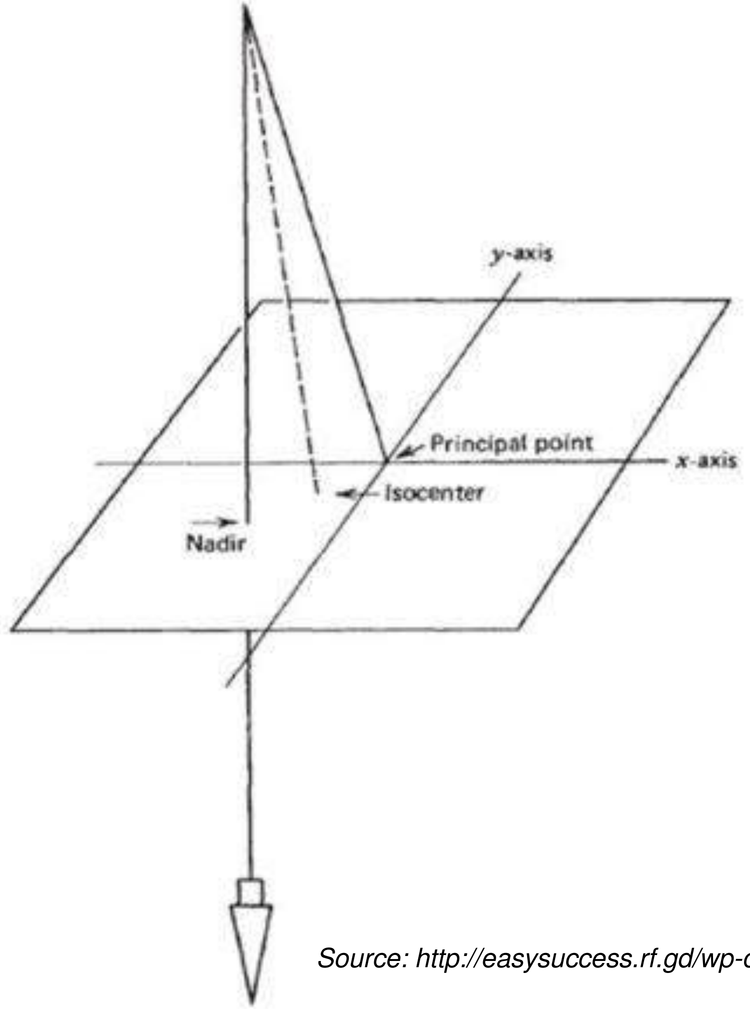
3.4 Terms used in Photogrammetry

4. Focal Length

- It is the distance from the middle of the camera lens or the perspective centre to the focal plane (i.e., the film).

4. Nadir Point

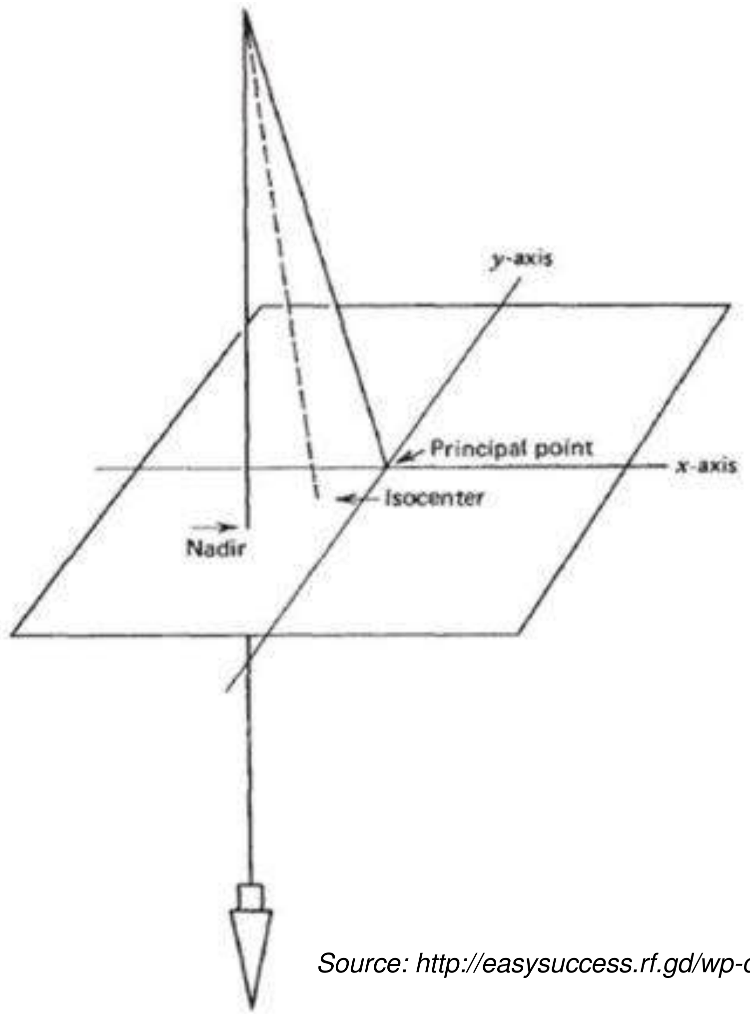
- It is the point vertically beneath the camera lens at the time of exposure where a plumb line extended from the camera lens to the ground intersects the photo image.



Source: http://easysuccess.rf.gd/wp-content/uploads/2016/10/Basic-Geometry-of-the-Metric-Photograph.pdf?i=1

4. Isocenter

- The isocenter is the point on the photo that falls on a line approximately halfway between the principal point and the nadir.



Source: http://easysuccess.rf.gd/wp-content/uploads/2016/10/Basic-Geometry-of-the-Metric-Photograph.pdf?i=1

3.4 Terms used in Photogrammetry

5. Tilted photograph

- Unavoidable aircraft tilts cause photographs to be exposed with the camera axis tilted slightly from vertical, and the resulting pictures are called tilted photographs.

6. Exposure Station

- The space position of the front nodal point (perspective centre) at the time of exposure, as the point L in the Figure 1.

3.4 Terms used in Photogrammetry

7. Tilt

- The angle formed between the optical axis of the camera and the plumb line, as the angle oLn in the Figure 1. It is also the angle which the plane of tilted photograph makes with the plane of vertical photograph.

9. Principal Plane

- The vertical plane containing the optical axis, as the plane Lno in the Figure 1.

10. Homologous Points

- The pairs representing ground points and their photo points, are called homologous points.

3.4 Terms used in Photogrammetry

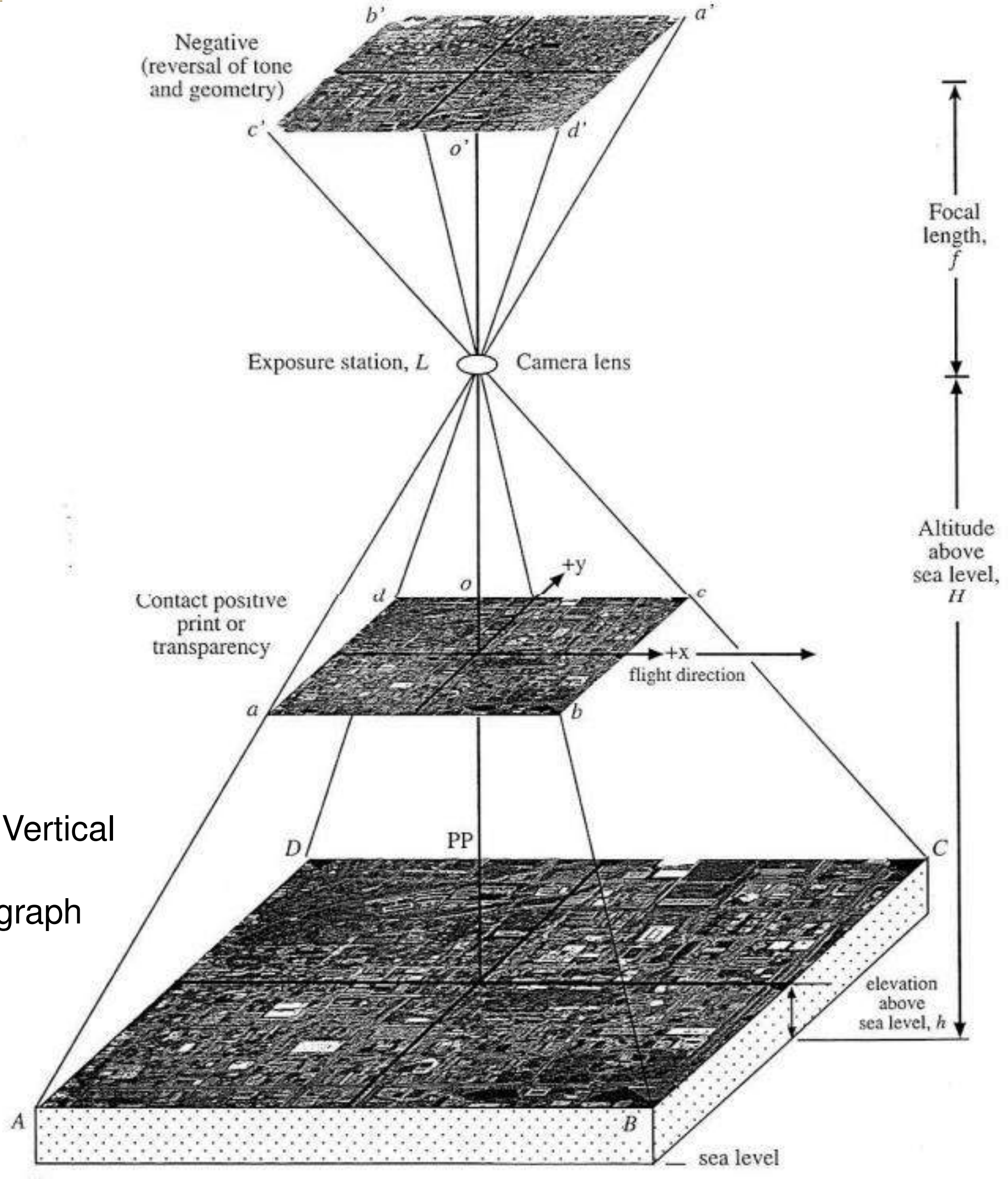


Figure 6-6 The geometry of a vertical aerial photograph obtained over flat terrain (Columbia, SC).

Fig 2: Vertical aerial Photograph

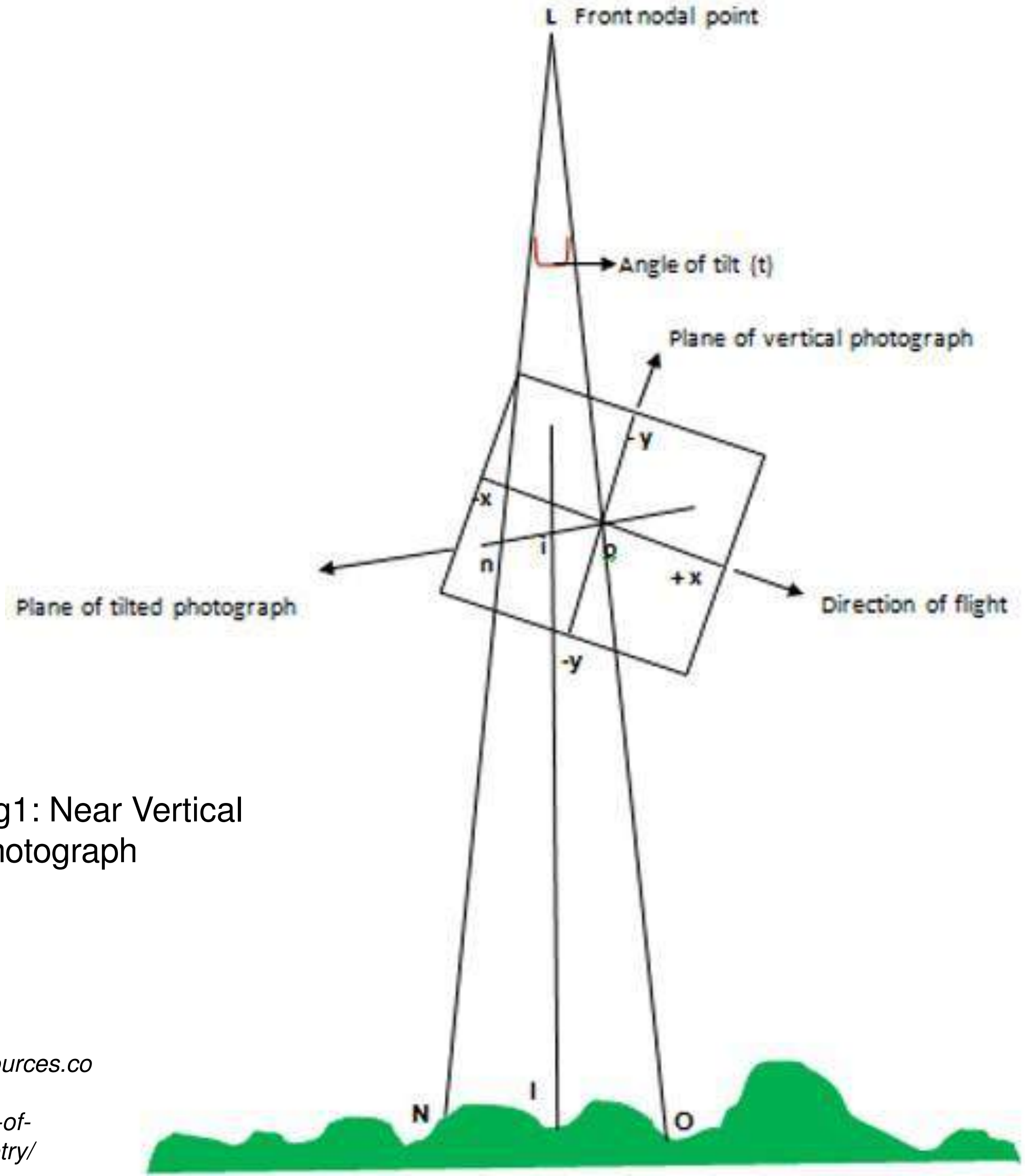


Fig1: Near Vertical Photograph

Source: https://gisresources.com/important-terminologies-of-photogrammetry/

3.4 Terms used in Photogrammetry

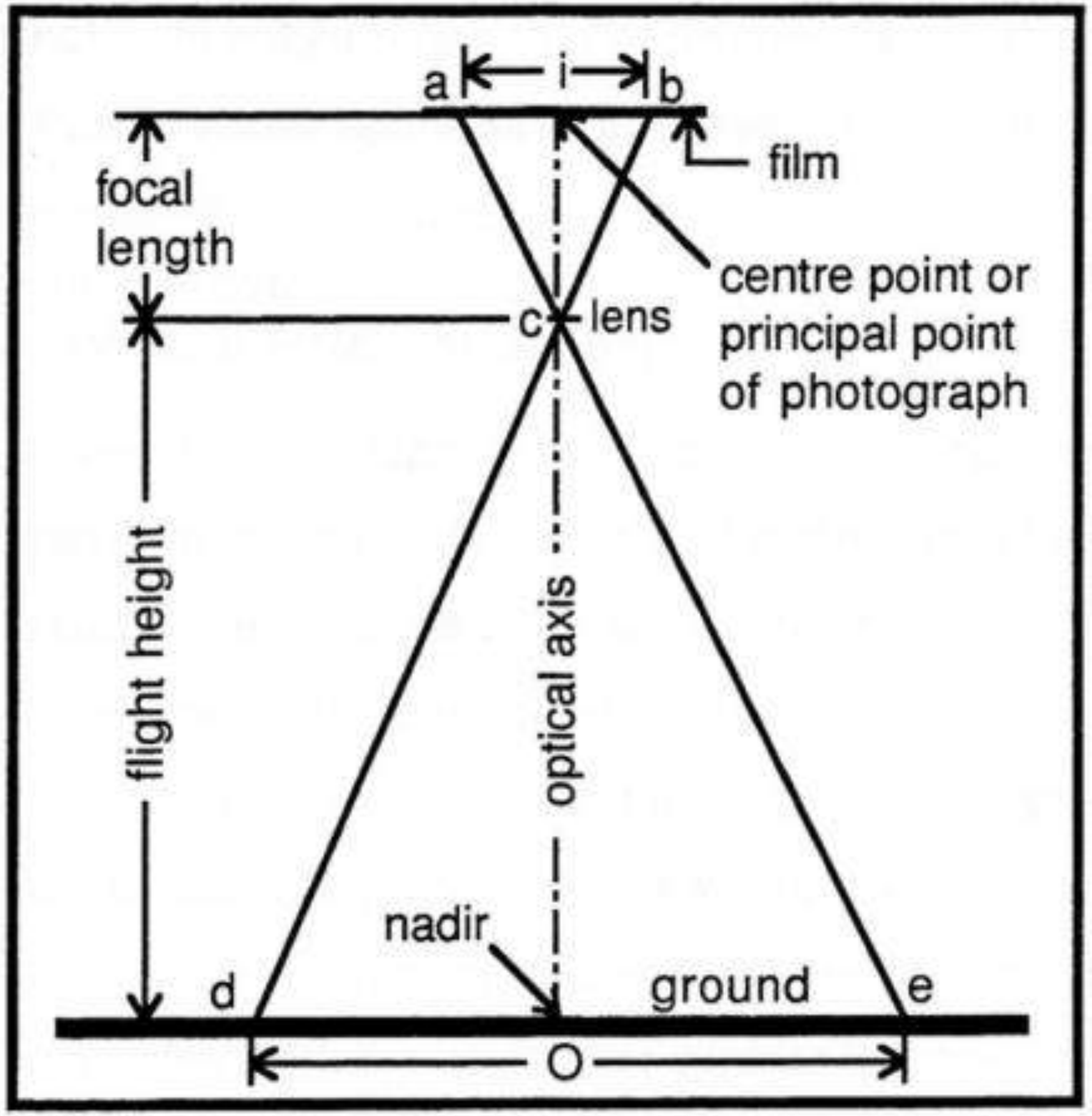


Fig: Geometry Vertical aerial Photograph

Source: https://www.uou.ac.in/sites/default/files/slm/GEOG-504.pdf

Classification of Aerial Photographs

Aerial Photographs can be classified on the basis of parameters:

A. Scale
B. Camera orientation
C. Angular coverage
D. Film

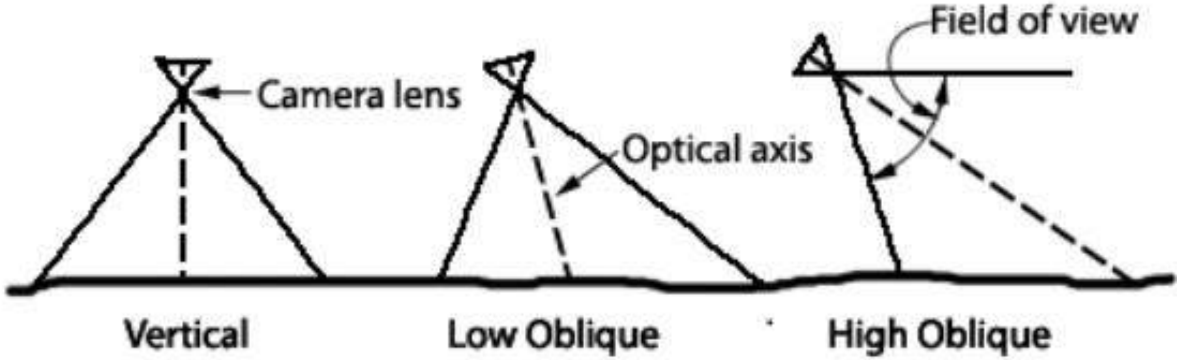
Fig: Aerial image of Bindhyabasini site

Source: https://keshavrajbhusal.com.np/

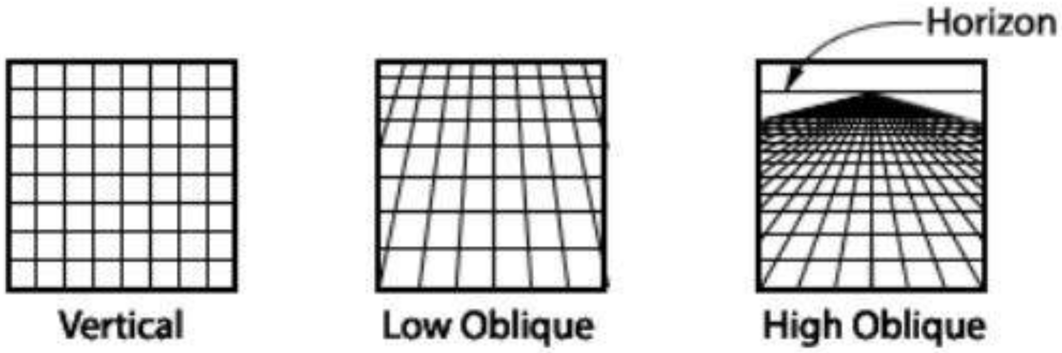
Types of Aerial Photographs

On the basis of camera orientation(Mainly two types)

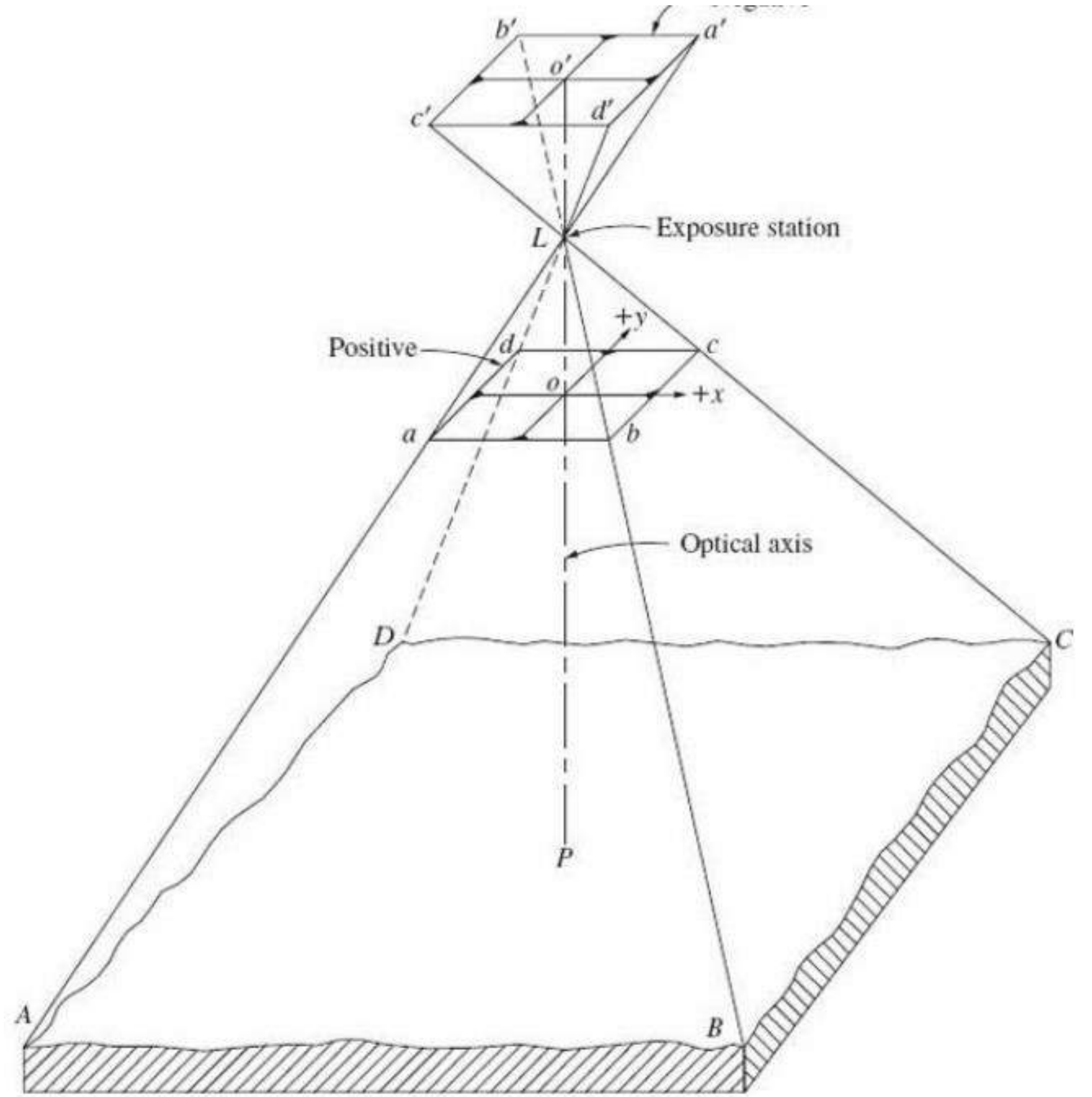
1. Vertical
2. Oblique



Camera orientation for various types of aerial photographs



How a grid of section lines appears on various types of photos.



6-1 The geometry of a vertical photograph.

Types of Aerial Photographs

On the basis of camera orientation

Vertical

- A vertical photograph is taken with the camera pointed as straight down as possible.

A vertical photograph has the following characteristics:

a. The lens axis is perpendicular to the surface of the earth.

b. It covers a relatively small area.

c. The shape of the ground area covered on a single vertical photo closely approximates a square or rectangle.

d. Tilt is within 3°.

* Useful in topographical Survey and thematic mapping.

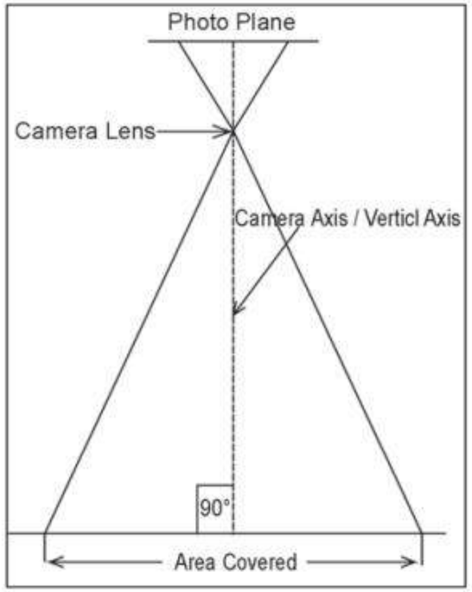


Figure 6.3 Vertical Aerial Photograph

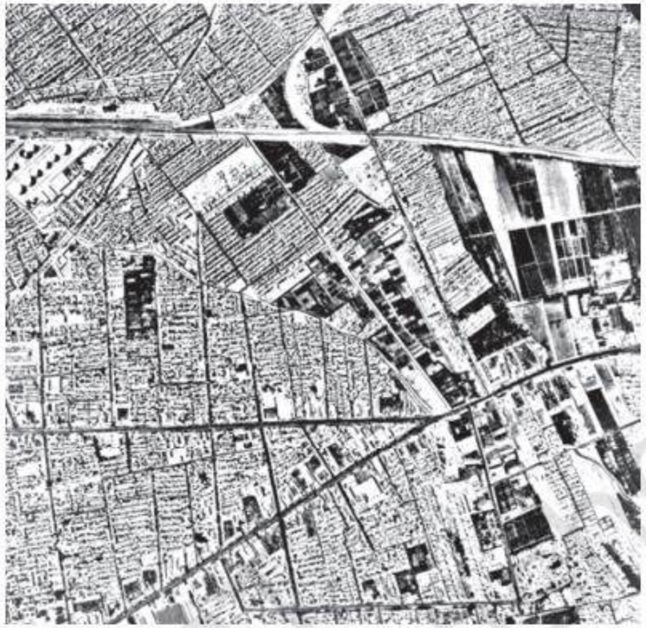


Figure 6.4 Vertical Aerial Photograph of Arneham,

Source: https://ncert.nic.in/textbook/pdf/kegy306.pdf

On the basis of camera orientation

Oblique

a. Low oblique

- This is a photograph taken with the camera inclined about 30° from the vertical.

A low oblique has the following characteristics:

i. It covers a relatively large area.

ii. The ground area covered is a trapezoid, although the photo is square or rectangular.

- It is used in reconnaissance survey.

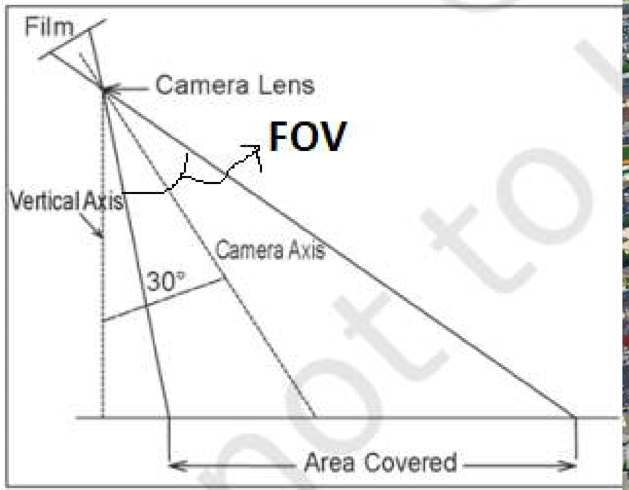


Figure 6.5 Low-Oblique Photograph

Source: https://ncert.nic.in/textbook/pdf/kegy306.pdf

Types of Aerial Photographs

On the basis of camera orientation

b. High oblique

- The high oblique is a photograph taken with the camera inclined about 60° from the vertical.

A high oblique has the following characteristics:

i. It covers a very large area.

ii. The ground area covered is a trapezoid, but the photograph is square or rectangular.

- It is also useful in Reconnaissance surveys.

Source: https://ncert.nic.in/textbook/pdf/kegy306.pdf

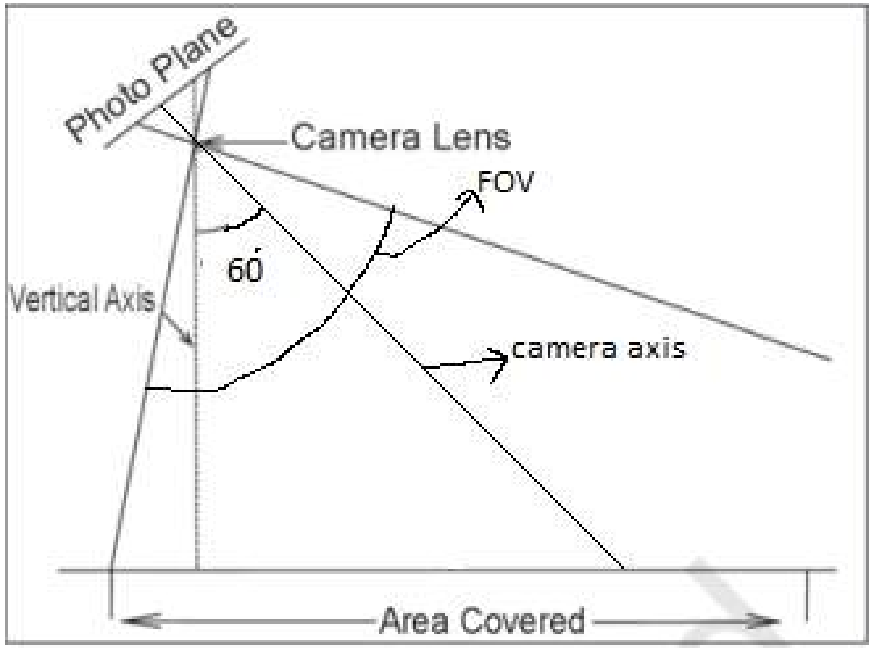


Figure 6.7 High Oblique Photograph

Types of Aerial Photographs

On the basis of scale

The aerial photographs may also be classified on the basis of the scale of photograph into three types. They are:

i. Large scale photograph

ii. Medium scale photograph

iii. Small scale photograph

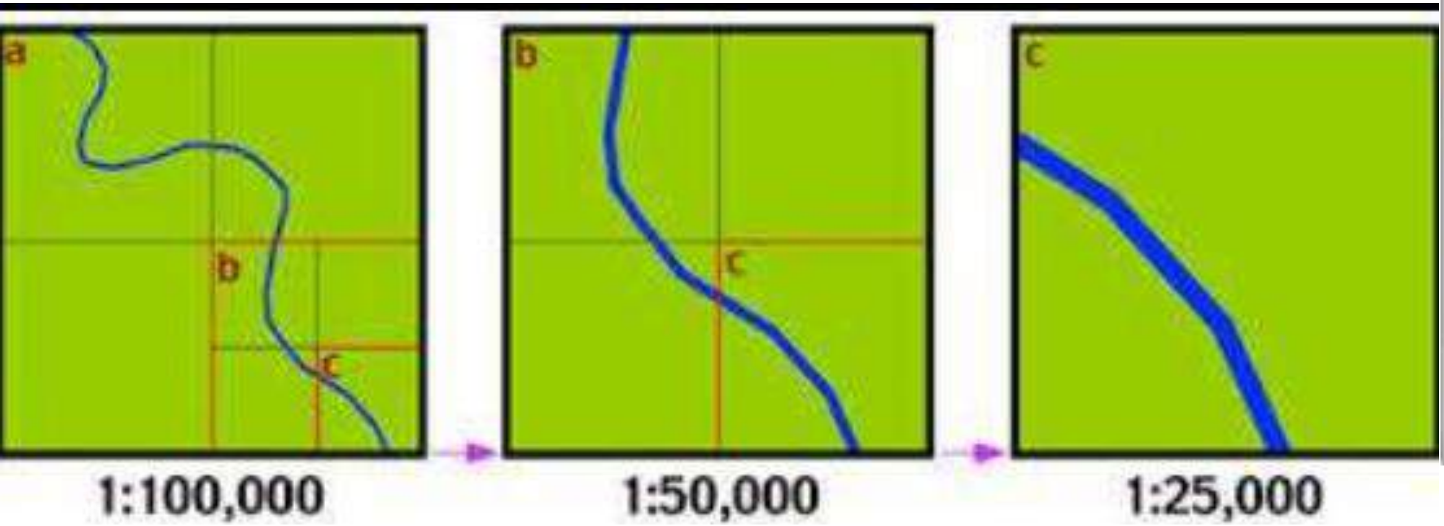


Fig: small, medium and large scale map respectively

Source: https://giscommons.org/chapter-2-input/

Types of Aerial Photographs

On the basis of scale

1. Large scale photograph

- When the scale of an aerial photograph between 1:5,000 and 1:20,000, the photography is classified as large-scale photograph.

2. Medium scale photograph

- The aerial photographs with a scale ranging between 1:20,000 and 1:50,000 are usually classified as medium-scale photograph.

3. Small scale photograph

- The photographs with the scale being smaller than 1:50,000, are referred to as small scale photographs.

Types of Aerial Photographs

On the basis of scale

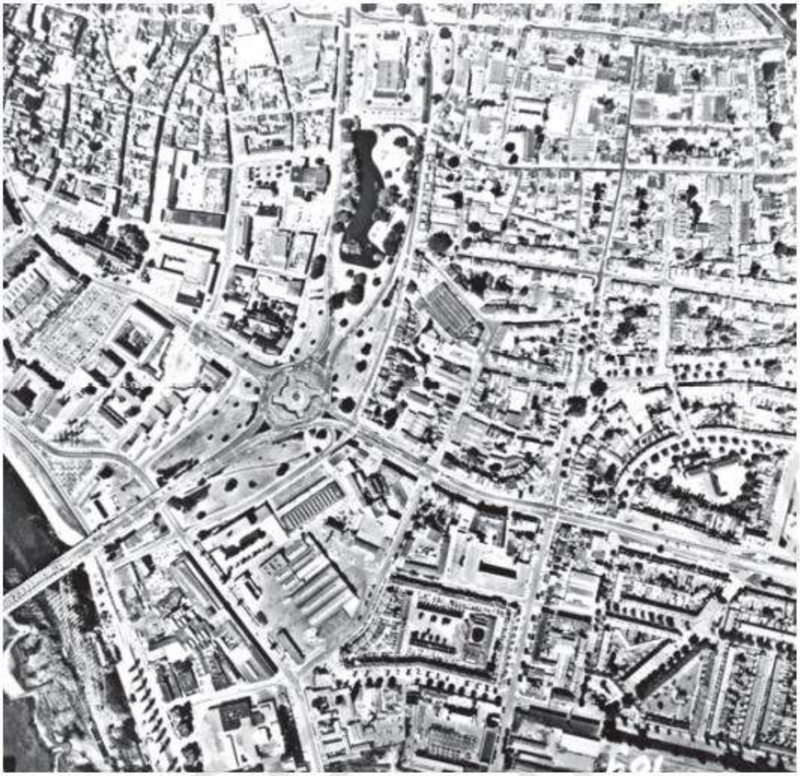


Figure 6.8 1 : 5000 Photograph of Arnehem

Figure 6.9 1 : 20,000 Photograph of Arnehem

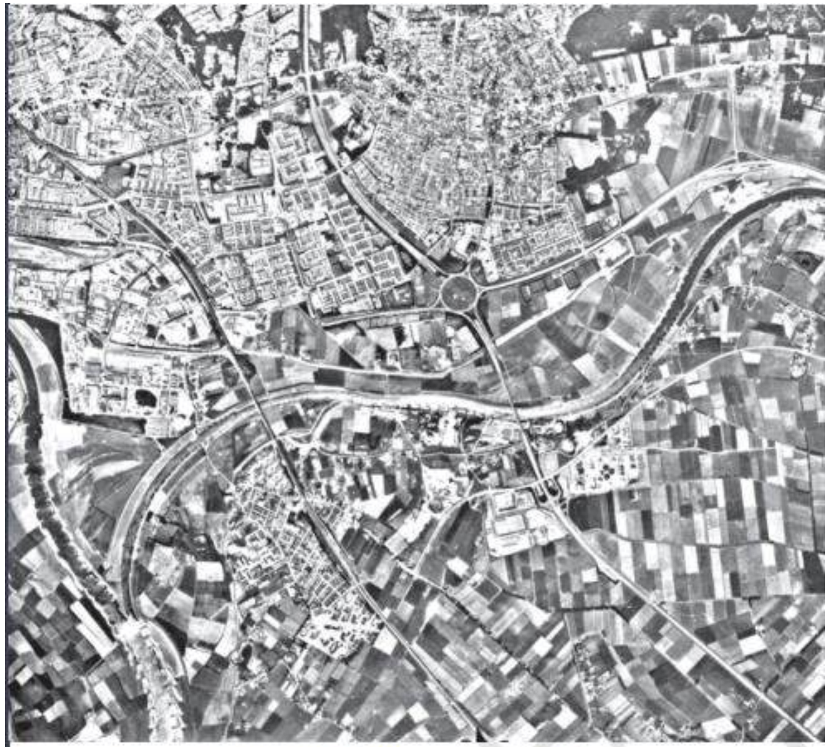


Figure 6.10 1 : 40,000 Photograph of Arnehem

Fig: showing large, medium and small scale photograph respectively

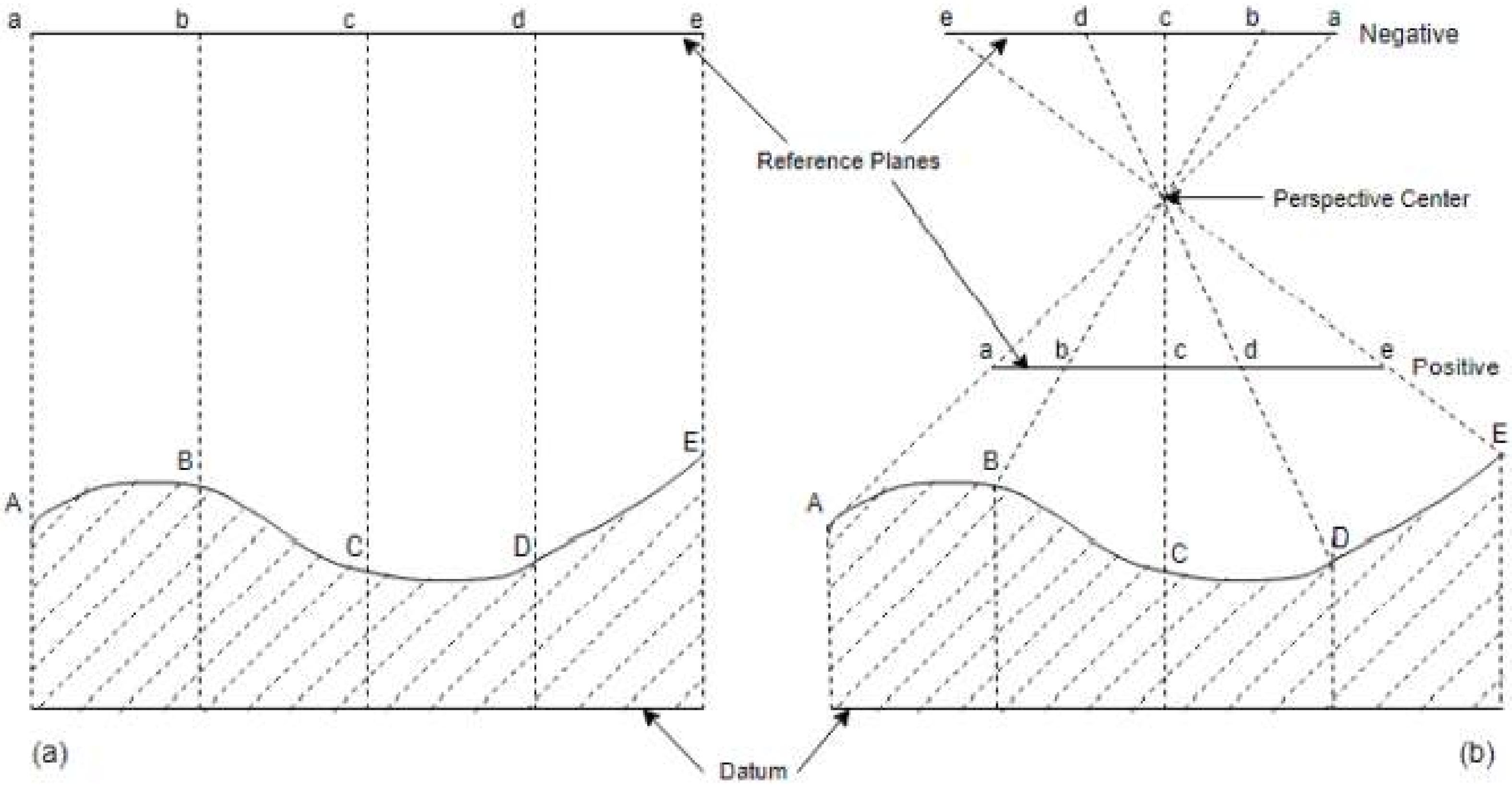
Projection and the properties of Orthogonal and Perspective Projections

Projection

- It is the transformation of higher dimensional space (usually 3d in object) into a lower dimensional space (2D in photographs).
- There are mainly two types of projection. They are:

1) Orthogonal Projection

2) Perspective Projection



Projection of Terrain Points in Orthographic vs Perspective Projection

Projection and the properties of Orthogonal and Perspective Projections

Orthogonal Projection

- Points are projected onto a plane in a certain uniform scale by rays perpendicular to that plane. The plane is usually parallel to a predetermined reference or datum plane.
- Points are projected in their planimetrically correct position.
- In this projection there is no displacement.
- Reference datum in orthographic projection are usually horizontal.

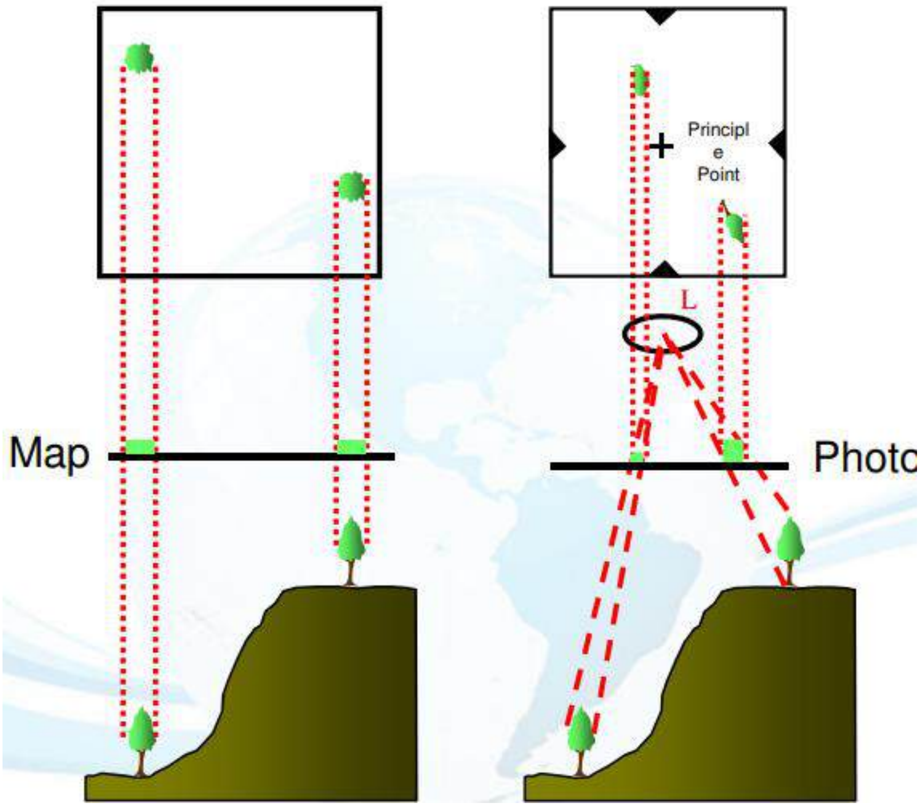
E.g Map

3.5 Principle of perspective geometry

Perspective Projection (Central Perspective Projection)

- It is also called central projection in which all rays pass through a common point called the projection center or perspective center.
- Image points displaced from their planimetrically correct positions either due to terrain relief (elevation) or due to tilt (object plane and image plane not in parallel).
- Varying scale.
- Reference datum may be horizontal, vertical or tilted.

E.g Photograph



3.5 Collinearity Condition

Collinearity Condition

- Fundamental condition in analytical photogrammetry.
- It is the condition in which the exposure station of any photograph(perspective center), any object point in the ground and its photographic image all lie on a straight line in 3D space.
- This condition hold true irrespective of the angular tilt of a photograph.
- The equations that express the collinearity condition are referred to as collinearity equation.
- They describe the relationships among image coordinates, ground coordinates, the exposure station position and angular orientation of a photograph as

3.5 Collinearity Condition

Collinearity Condition

$$x_a - x_o = (z_a - z_o)\left[\frac{m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right]$$

$$y_a - y_o = (z_a - z_o)\left[\frac{m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right]$$

where,

(x_a, y_a) = image coordinates, (x_o, y_o, z_o) = principal point coordinates (usually known from camera calibration); X_A, Y_A and Z_A are ground coordinates of the corresponding object point; X_L, Y_L and Z_L are ground coordinates of the exposure station; and the m’s are functions of three rotation angles omega, phi, kappa.

- Thus, if the location of the exposure station is known along with the rotation angles, then for any position on the ground, the associated image point can be computed through collinearity equations.
- This is how DEMs are used to generate digital orthophotos.

Collinearity Condition

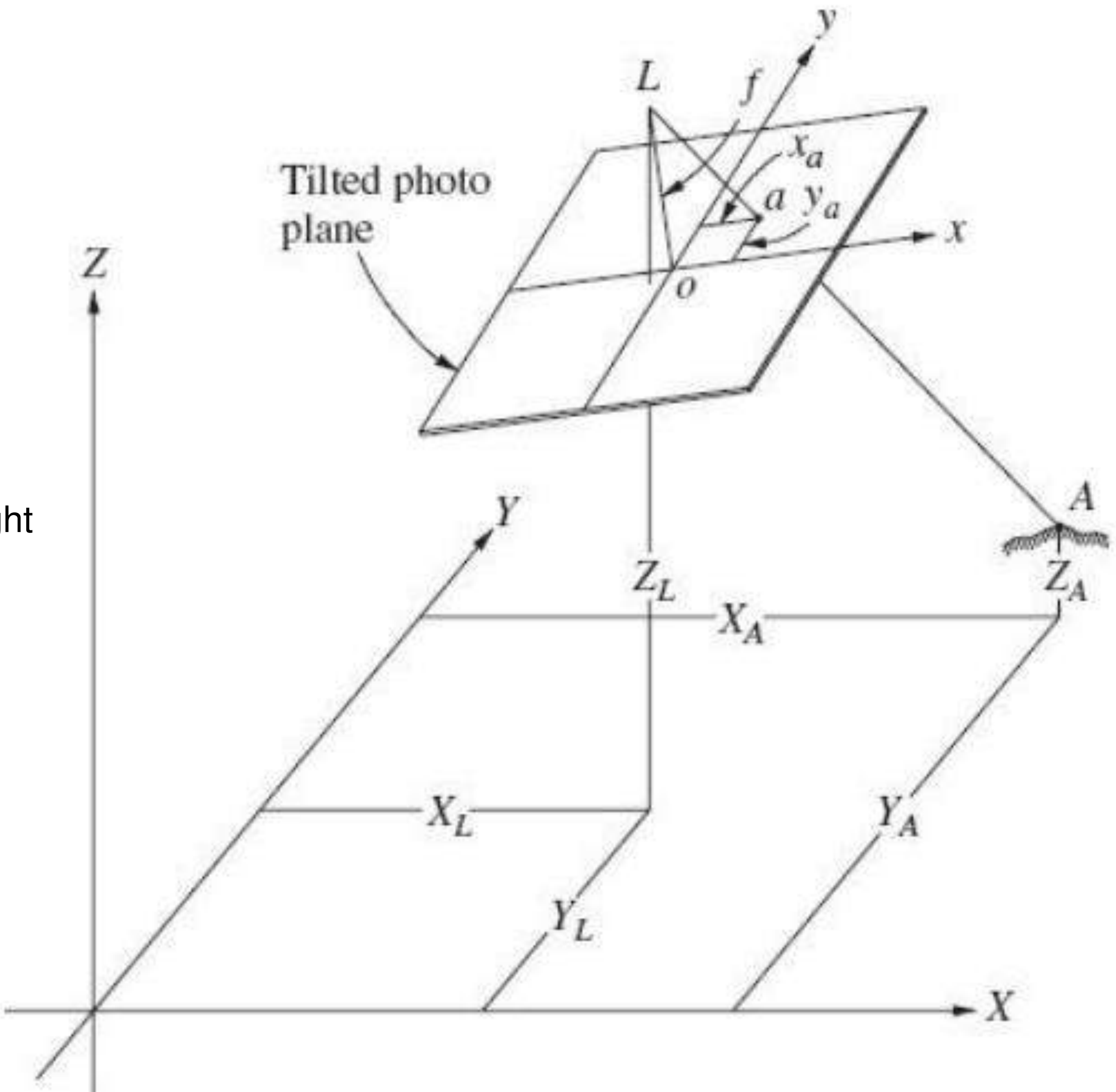


Fig: ‘L’, ‘a’, and ‘A’ all lie in a straight line; showing collinearity condition

3.6 Scale of a vertical aerial photograph

Scale of the photograph

- Ratio of a distance on the photo to the corresponding distance on the ground .

Mathematically,

$$\text{Scale of the photograph} = \frac{\text{distance on the photo}}{\text{distance on the ground}}$$

- A aerial photograph is a perspective projection and its scale varies with variations in terrain elevation.
- Scales may be represented as unit equivalents, unit fractions, dimensionless representative fractions, or dimensionless ratios.

3.6 Scale of a vertical aerial photograph

Scale of the photograph

Representation of scale

1. Unit equivalents: 1 in = 1000 ft
2. Dimensionless Unit fraction: 1 in/1000 ft
3. Representative fraction: 1/12,000
4. Dimensionless ratio: 1:12,000

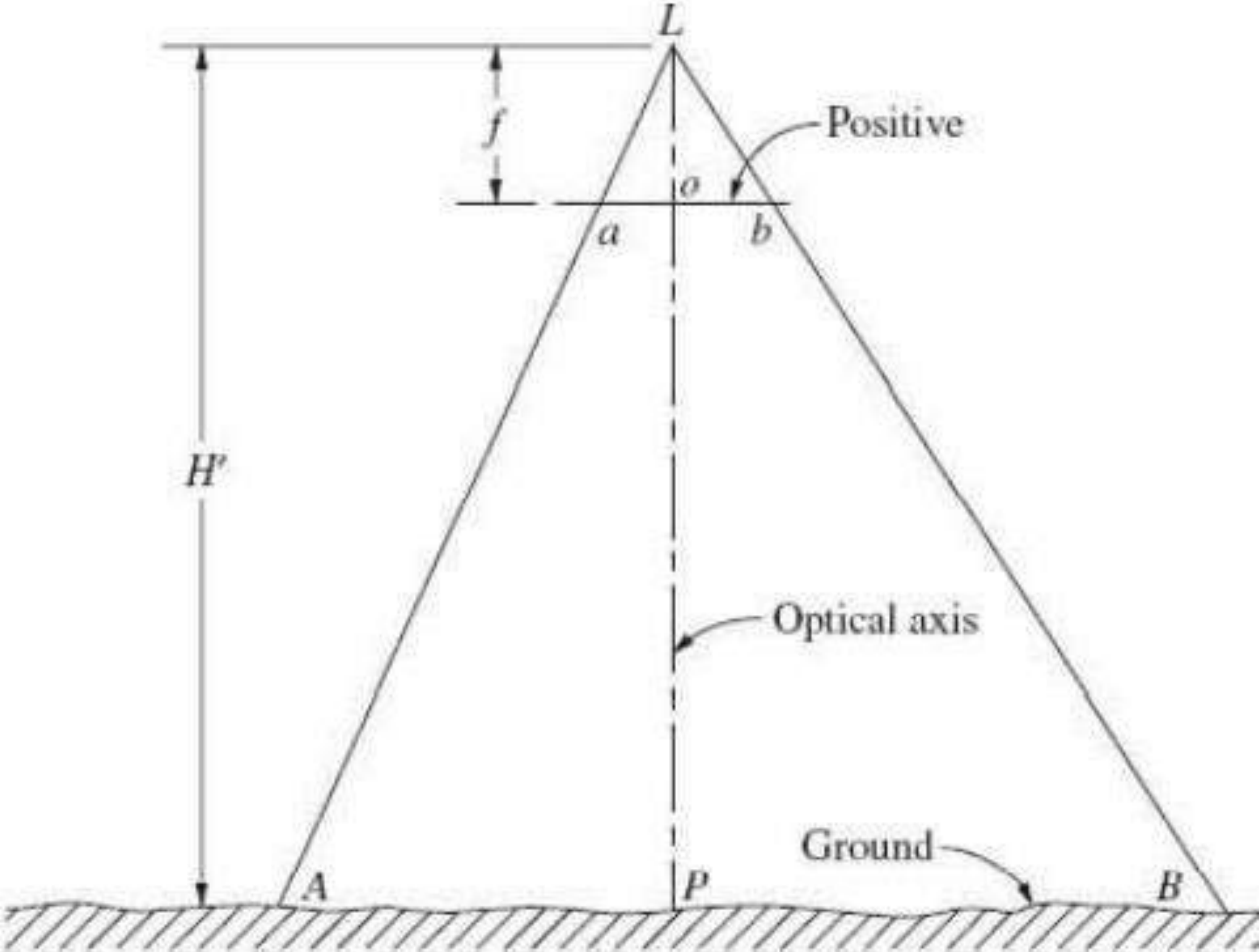
3.6 Scale of a vertical aerial photograph

Derivation of the formula for Scale of Vertical Aerial Photograph

Case I: (if terrain is flat)

- The scale of a vertical photograph over flat terrain is simply the ratio of photo distance ab to corresponding ground distance AB.
- That scale may be expressed in terms of camera focal length f and flying height above ground H′ by equating similar triangles Lab and LAB as follows:

$$S = \frac{ab}{AB} = \frac{f}{H'} \quad \text{.......................(i)}$$



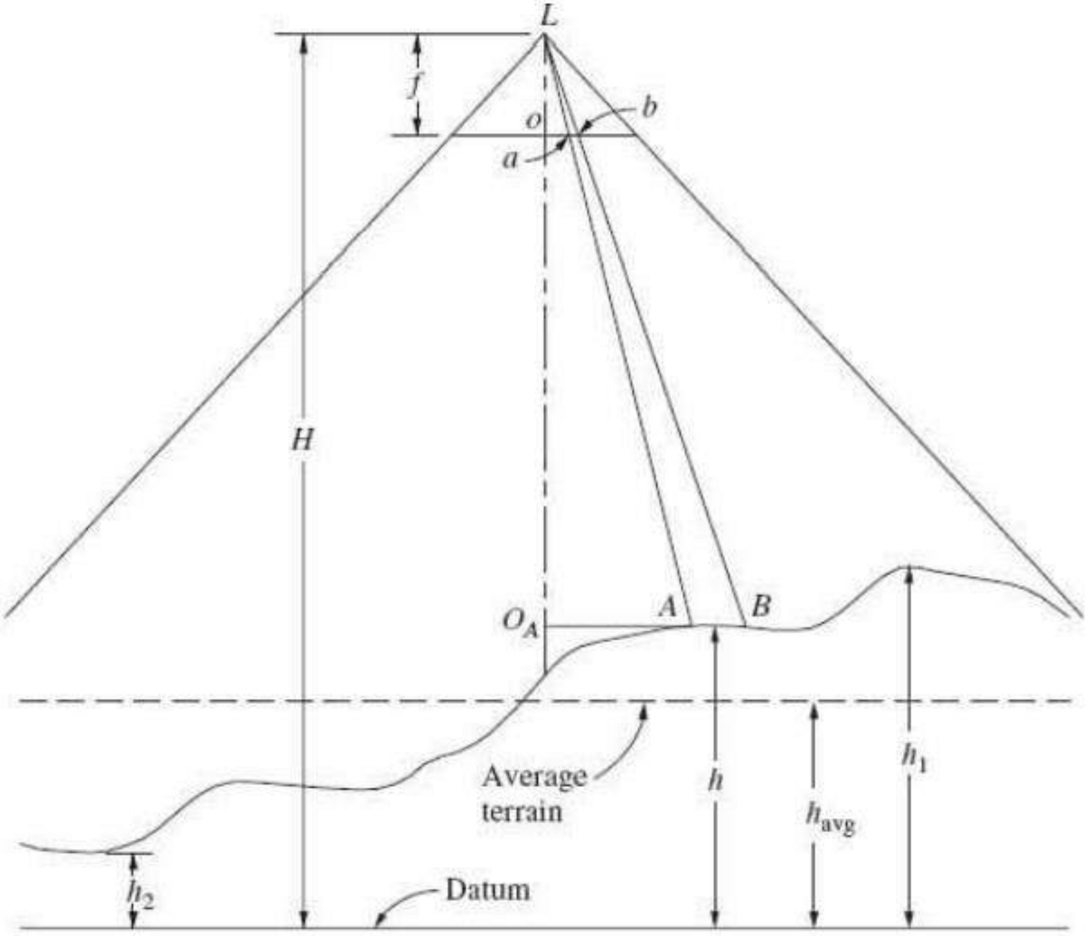
- It is seen that the scale of a vertical photo is directly proportional to camera focal length (image distance) and inversely proportional to flying height above ground (object distance).

3.6 Scale of a vertical aerial photograph

Derivation of the formula for Scale of Vertical Aerial Photograph

Case II: (if terrain is Variable)

- If the photographed terrain varies in elevation, then the object distance—or the denominator of Eq. (i)—will also be variable and the photo scale will likewise vary.
- For any given vertical photo scale increases with increasing terrain elevation and decreases with decreasing terrain elevation.



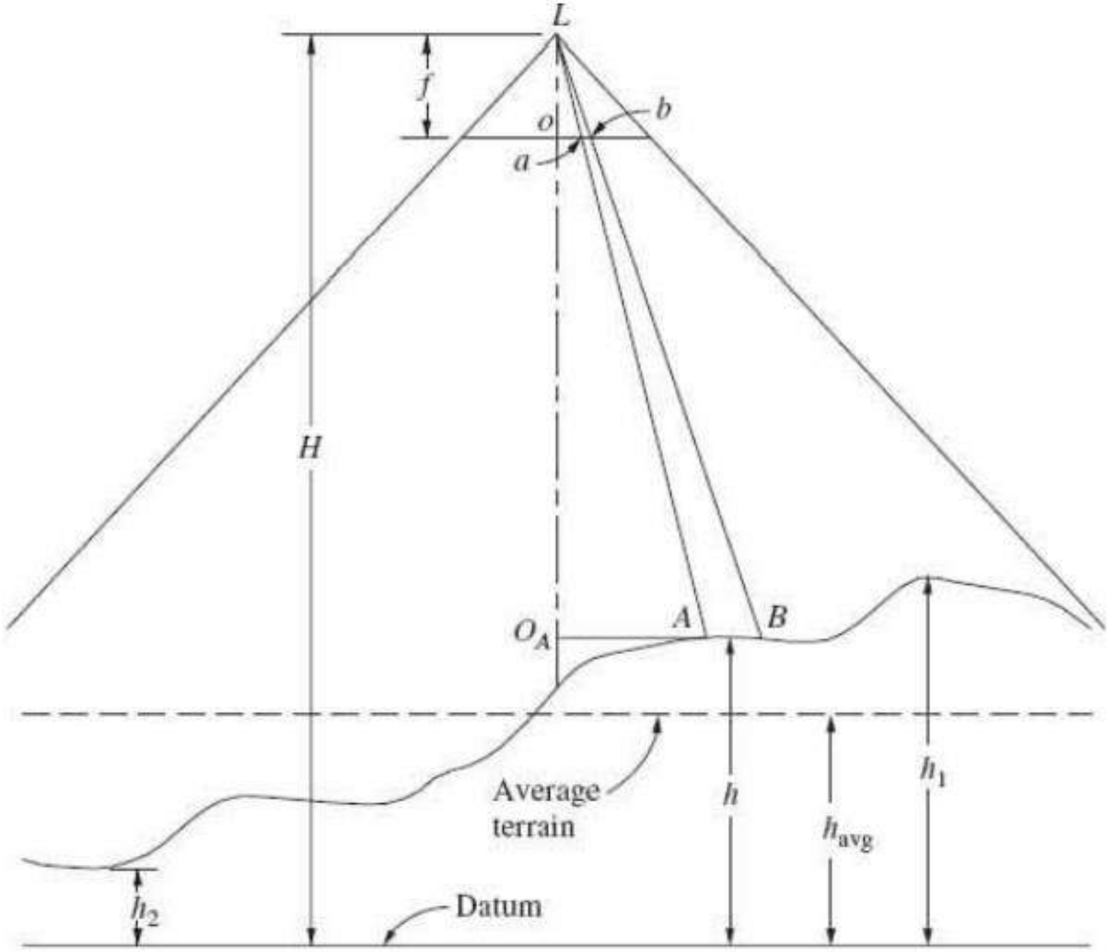
Derivation of the formula for Scale of Vertical Aerial Photograph

Case II: (if terrain is Variable)

- Suppose a vertical aerial photograph is taken over variable terrain from exposure station L of. Ground points A and B are imaged on the positive at a and b, respectively. Photographic scale at h, the elevation

of points A and B, is equal to the ratio of photo distance ab to ground distance AB. By similar triangles Lab and LAB, an expression for photo scale S_{AB} is

$$S_{AB} = \frac{ab}{AB} = \frac{La}{LA} \qquad \text{......................(a)}$$



Derivation of the formula for Scale of Vertical Aerial Photograph

Case II: (if terrain is Variable)

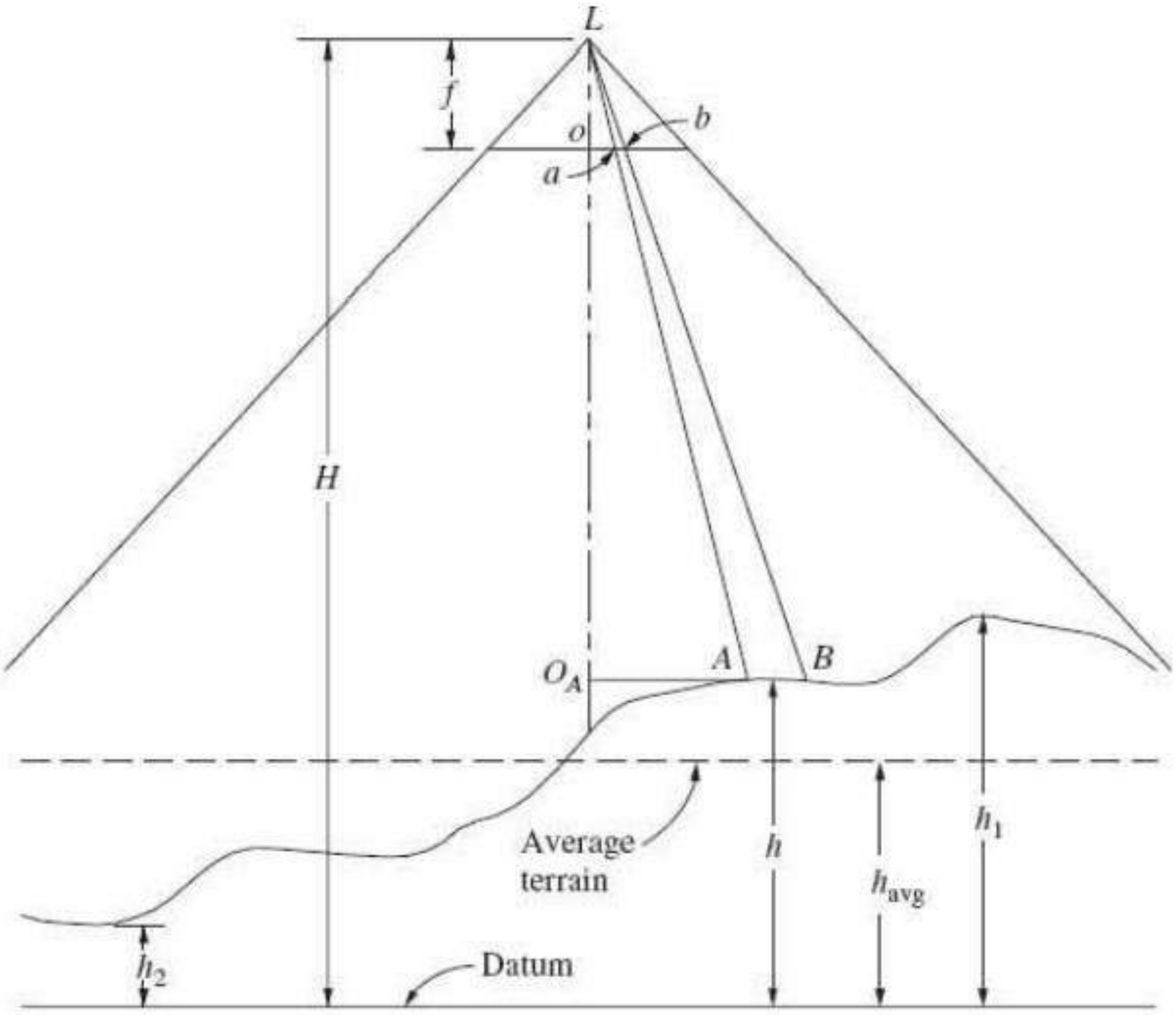
Also, by similar triangles LO_AA and Loa,

$$\frac{La}{LA} = \frac{f}{H-h} \qquad \text{......................(b)}$$

Equating equation (a) and (b)

$$S_{AB} = \frac{ab}{AB} = \frac{La}{LA} = \frac{f}{H-h} \qquad \text{......................(c)}$$

Here the denominator H - h is the object distance. In this equation as in Eq. (c), scale of a vertical photograph is seen to be simply the ratio of image distance to object distance.



3.6 Scale of a vertical aerial photograph

Derivation of the formula for Scale of Vertical Aerial Photograph

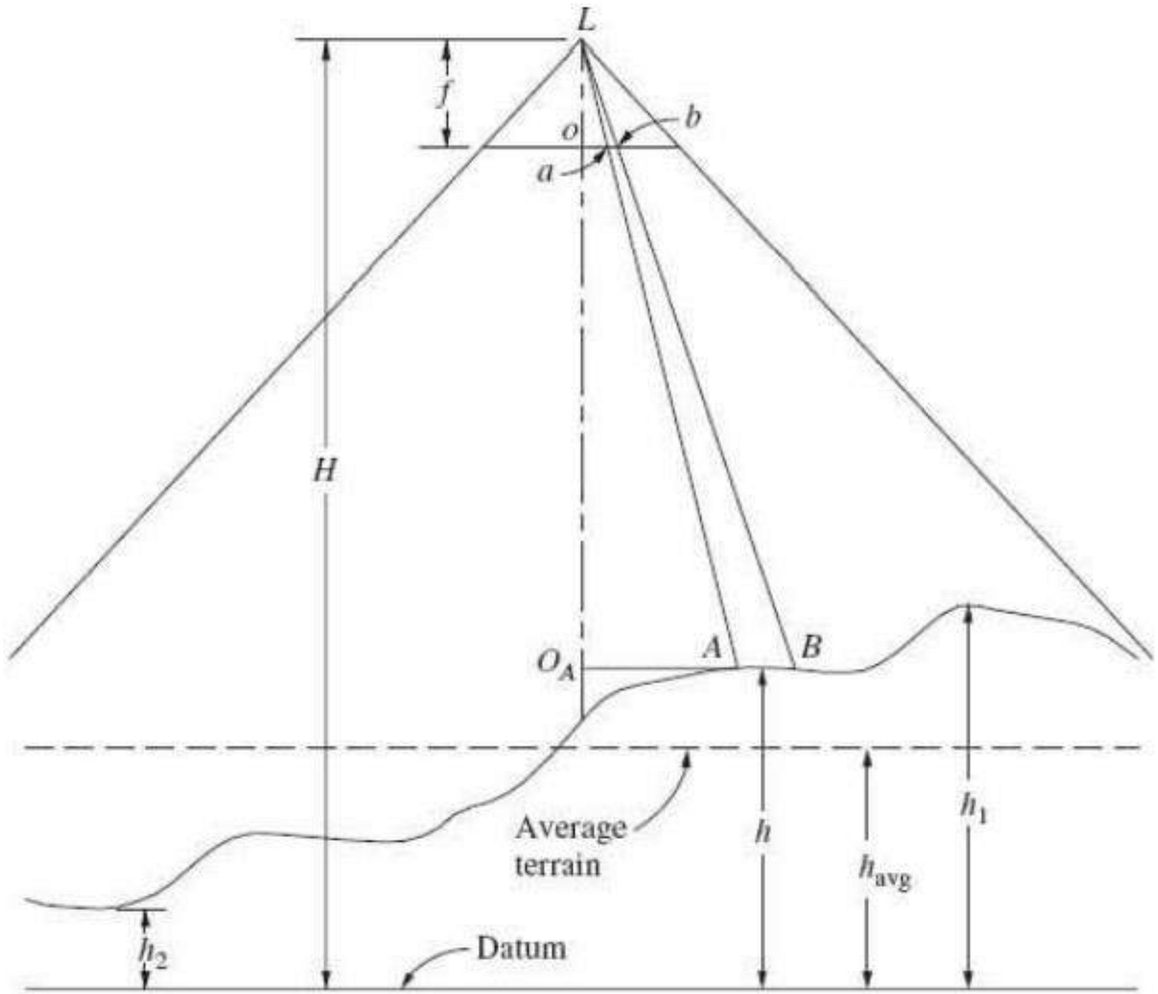
Case II: (if terrain is Variable)

- The shorter the object distance, the greater the photo scale, and vice versa. For vertical photographs taken over variable terrain,

there are an infinite number of different scales.

This is one of the principal differences between

a photograph and a map.



Derivation of the formula for Scale of Vertical Aerial Photograph

Case II: (if terrain is Variable)

Average Photo Scale:

- Average scale is the scale at the average elevation of the terrain covered by a particular photograph and is expressed as

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

3.6 Scale of a vertical aerial photograph

There are several methods for calculating the scale of an aerial photo. Some of them are:

a. Feature of Known Size:

- The scale of an aerial photo can also be determined if an object of a known ground size appears in the image.
- One method is to find a feature of a known size (e.g. football field or standard event field) in the photograph to calculate the scale. The scale can be determined by measuring the distance or length of the feature on the photo and comparing it to the real-life or ground distance.

For eg: If a 1 km stretch of highway covers 4 cm on an air photo, the scale is

calculated as follows:

$$Photo\ distane/\ Ground\ distance = 4\ cm/1\ km = 4\ cm/100000\ cm = 1/25000$$

So the scale is: 1/25000

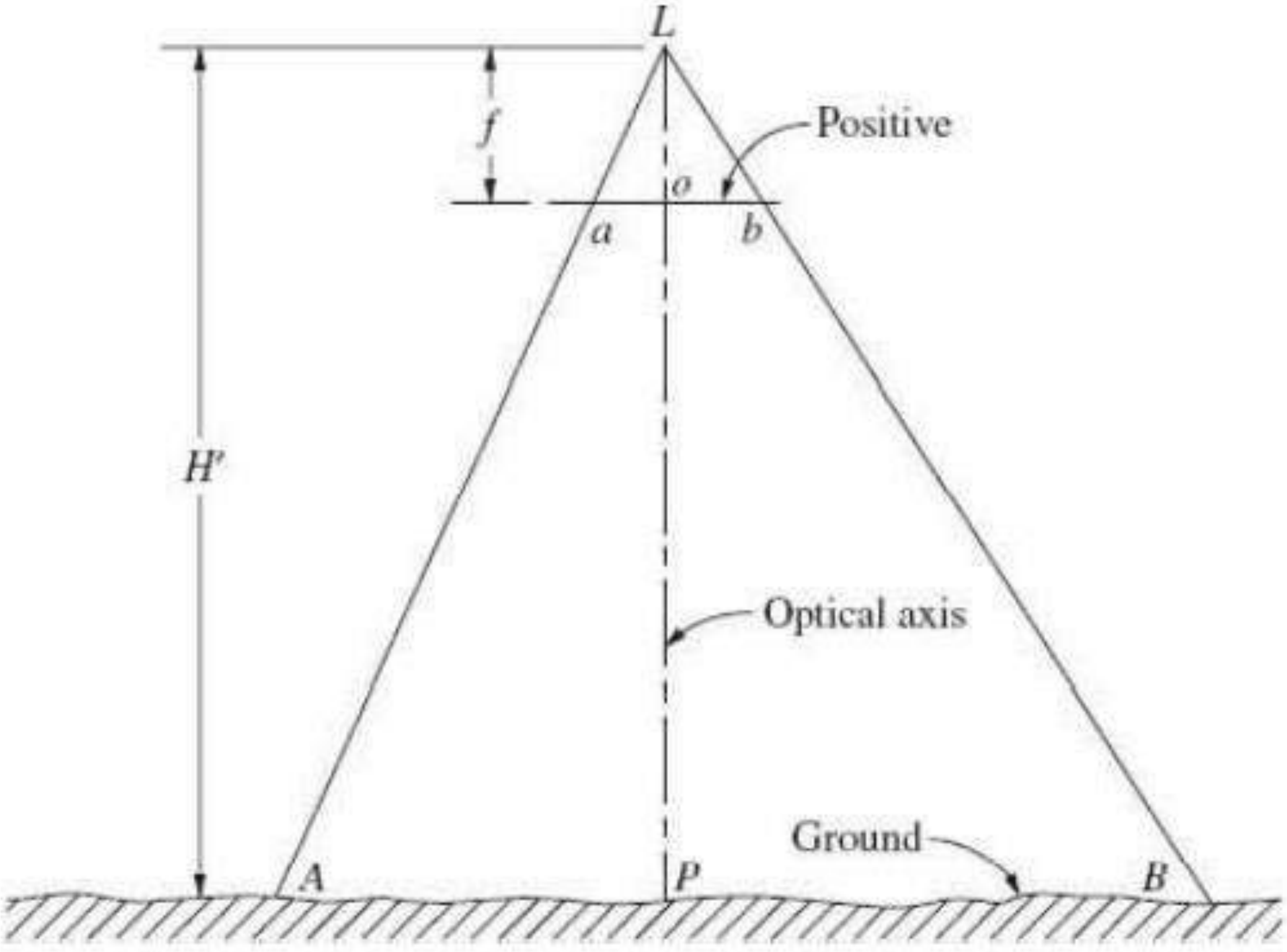
3.6 Scale of a vertical aerial photograph

There are several methods for calculating the scale of an aerial photo. Some of them are:

b. Focal length of the camera and the flying height

- If the focal length and flying altitude above the surface is known, the scale can be calculated using the following formula:

$$S = \frac{f}{H'}$$



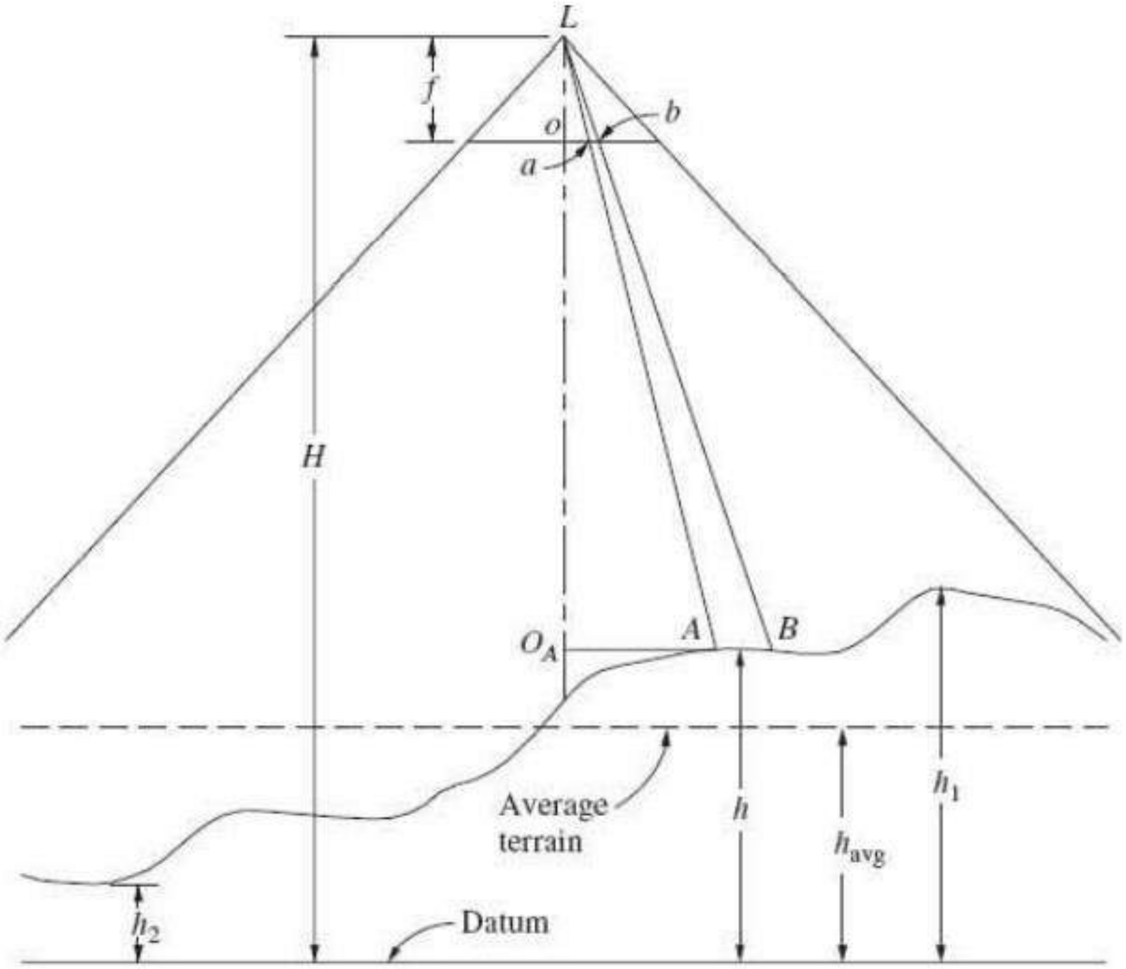
3.6 Scale of a vertical aerial photograph

There are several methods for calculating the scale of an aerial photo. Some of them are:

c. Focal length of the camera, flying height and altitude above sea level or MSL

- If the focal length and flying altitude above the surface is known, the scale can be calculated using the following formula:

$$S_{AB} = \frac{f}{H-h}$$



3.6 Scale of a vertical aerial photograph

1. A vertical aerial photograph is taken over flat terrain with a 152.4 mm-focal-length camera from an altitude of 1830 m above ground. What is the photo scale? (Ans: 1/12000)
2. On a vertical photograph the length of an airport runway measures 160mm. On a map that is plotted at a scale of 1:24,000, the runway is measured as 103 mm. What is the scale of the photograph at runway elevation? (Ans: 1:15,400)
3. A vertical photograph was exposed with a 150mm focal length camera at a flying height of 5000m above the sea level. (a)What is the scale at a point if the elevation of a point a on the ground level is 800 m above datum? (b)What is the scale if the elevation of point B in the ground is 1250 m above datum? (c) For this photo if the average terrain is 950 m above datum, what is the average photo scale? (Ans: 1:28000, 1:25000, 1:27000)

3.7 Distortion in an aerial photograph

Distortion

- Distortion in aerial photographs refers to any deviation from the true position, shape, size, or orientation of objects as they appear in the image compared to their actual position on the ground.
- Distortion affects the entire image uniformly and is typically a systematic error that can be mathematically modeled and corrected.
- **Cause**: It is caused primarily due to lens characteristics, atmospheric effects, and camera movement.

3.8 Displacement in an aerial photograph

Displacement:

- It is the shift in the position of object in the photograph due to object height, camera tilt and other factors.
- Displacement is not uniform across the image and depends on the geometry of the scene and the position of objects relative to the camera.
- **Cause**: Due to the geometry of the scene, including object height (relief), camera tilt, and varying aircraft altitude.
- **Correction**: Corrected through geometric corrections using ground control points, digital elevation models (DEMs), and orthorectification.

3.4 Terms used in Photogrammetry

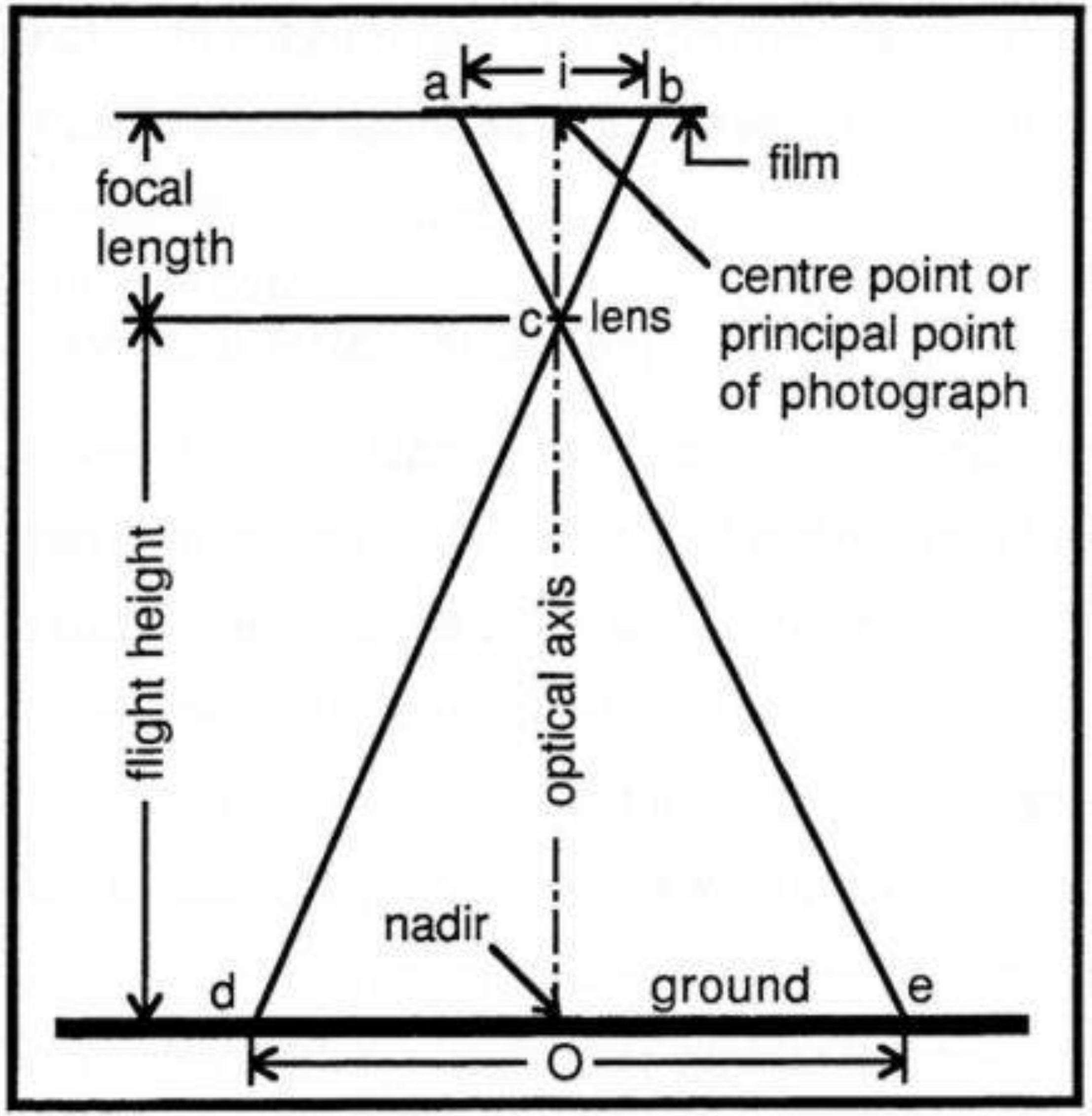
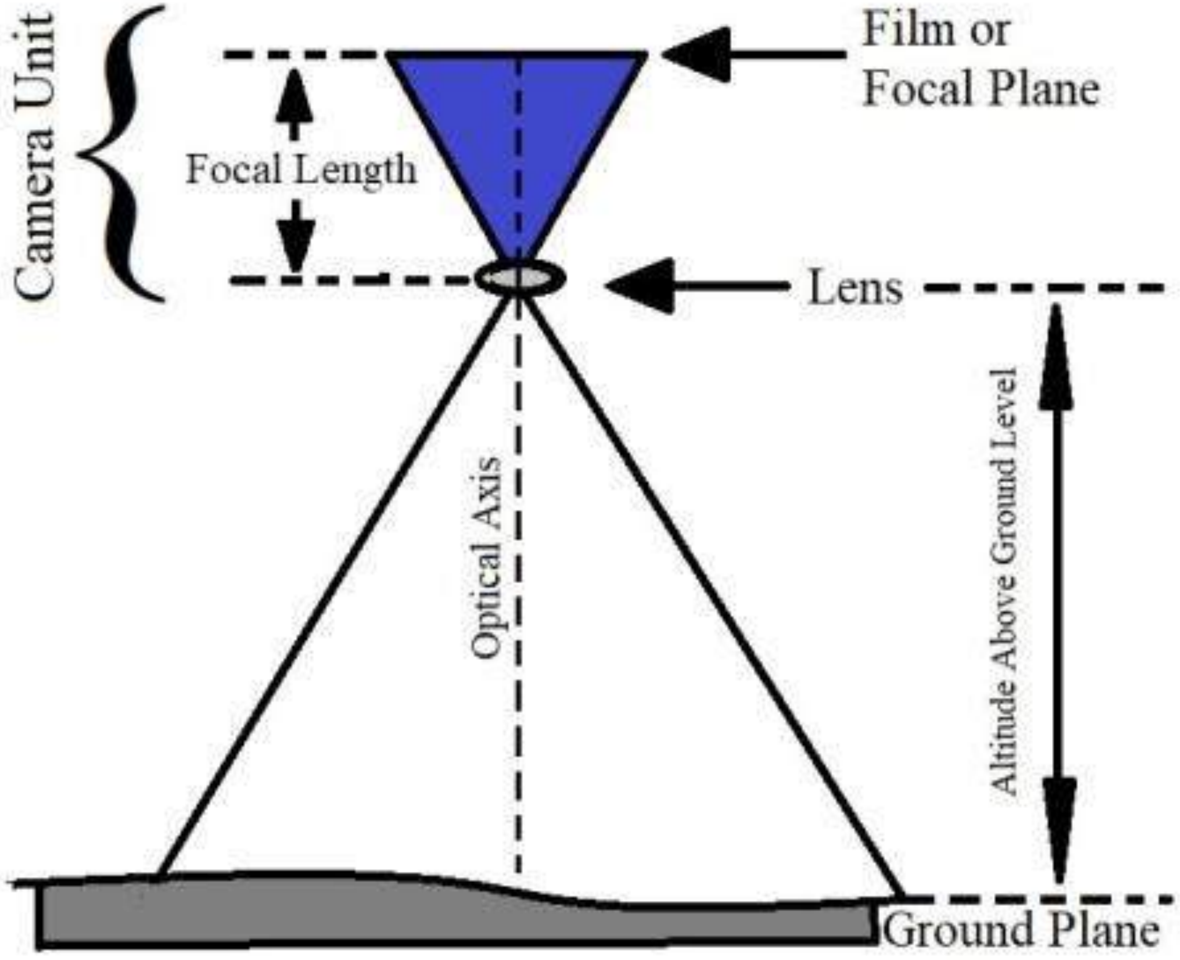


Fig: Geometry Vertical aerial Photograph

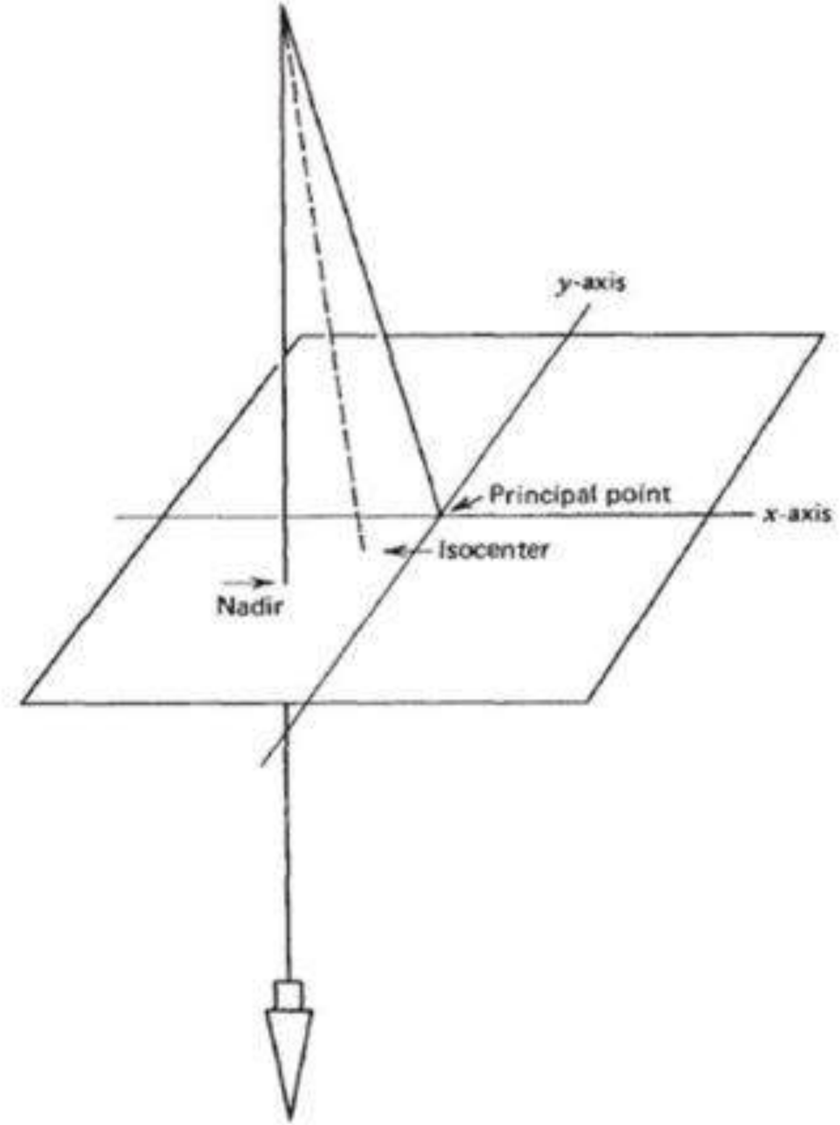
Source: https://www.uou.ac.in/sites/default/files/slm/GEOG-504.pdf

Geometrical Properties of aerial Photographs



Source: https://pangeography.com/geometry-of-aerial-photography/

3.3 Geometrical Properties of aerial Photographs



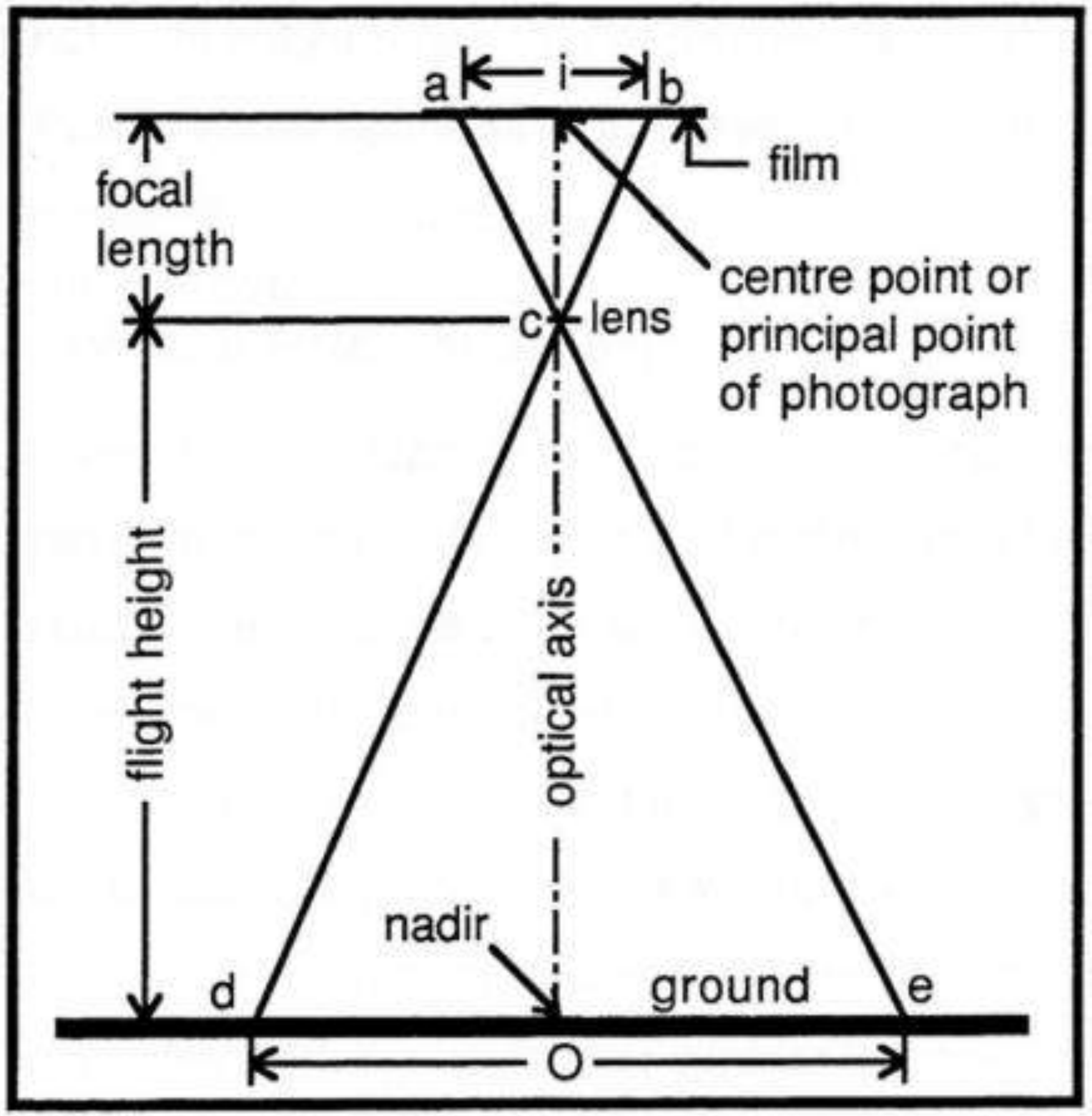


Fig: Geometry Vertical aerial Photograph

Source: http://easysuccess.rf.gd/wp-content/uploads/2016/10/Basic-Geometry-of-the-Metric-Photograph.pdf?i=1

3.3 Geometrical Properties of aerial Photographs

Geometrical Properties of aerial Photographs

1. Film Plane or Focal Plane:

- Film plane or focal plane is the surface in the camera on which the captured photo is imprinted. It is also known as the negative or focal plane.

2. Principal point:

- The point where the optical axis intersects the photograph is termed the centre point or principal point of the photograph.

3. Lens

- The lens is transparent part of the camera which captures the light coming from the ground and focusses it on the negative or film of the camera.
- There are two types of cameras i.e. single lens cameras and multi-lens cameras.
- Single lens camera can provide mosaic photos while the multi-lens camera can provide composite aerial photo.

3.3 Geometrical Properties of aerial Photographs

Geometrical Properties of aerial Photographs

4. Focal Length

- Focal length refers to the distance between the film plane and the camera lens.
- Different lenses have different focal lengths.
- The lenses with greater focal length have narrower view but more clarity while the lenses with lesser focal length captures wider view but with lesser clarity than the greater focal length lenses.

5. Ground Plane

- The ground plane is the earth surface which is being captured by the camera.
- It is also known as positive.

3.3 Geometrical Properties of aerial Photographs

Geometrical Properties of aerial Photographs

6. Optical Axis

- Optical axis is the line joining the center of the film plane with the center of the lens of the camera and touches the ground plane.
- The angle of the optical axis in relation to ground determines the shape of the objects in the aerial photographs.

7. Scale:

- Aerial photographs have a scale, which indicates the ratio between distances on the photograph and corresponding distances on the ground.
- It varies across the image due to terrain relief and camera parameters.

3.3 Geometrical Properties of aerial Photographs

Geometrical Properties of aerial Photographs

8. Nadir Point

- It is the photographic position representing the point on the earth's surface vertically beneath the camera lens at the time of exposure.

9. Flying height:

- It is the distance between the camera lens and the ground represents the flight height of the aircraft.

10. Overlap:

- It is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage.

3.5 Overlap

Overlap

- Overlap is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage.
- The photo survey is designed to acquire 60% forward overlap (between photos along the same flight line) and 30% lateral overlap (between photos on adjacent flight lines).
- When an area is to be a mapped, vertical aerial photograph are taken along a series of parallel passes called flight stripes.

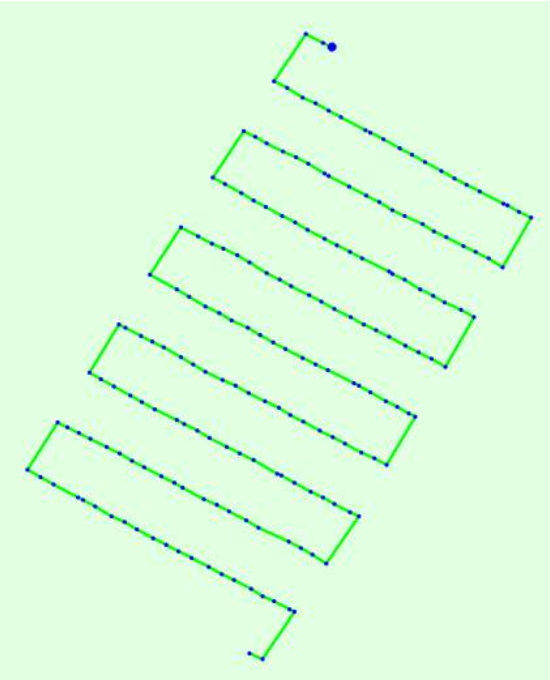
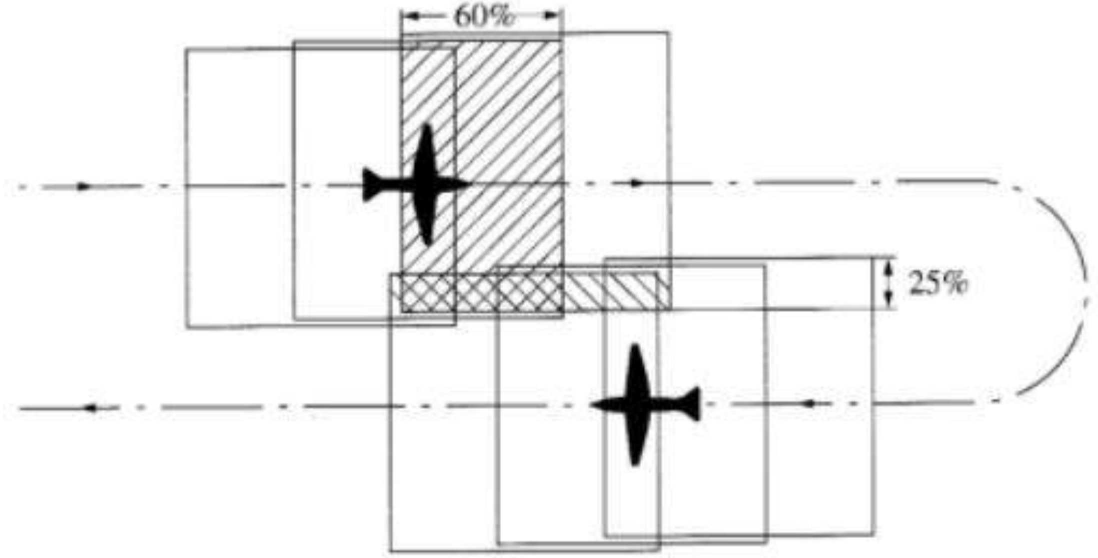


Fig: showing flight stripes with green color; blue showing camera position where photo was taken.

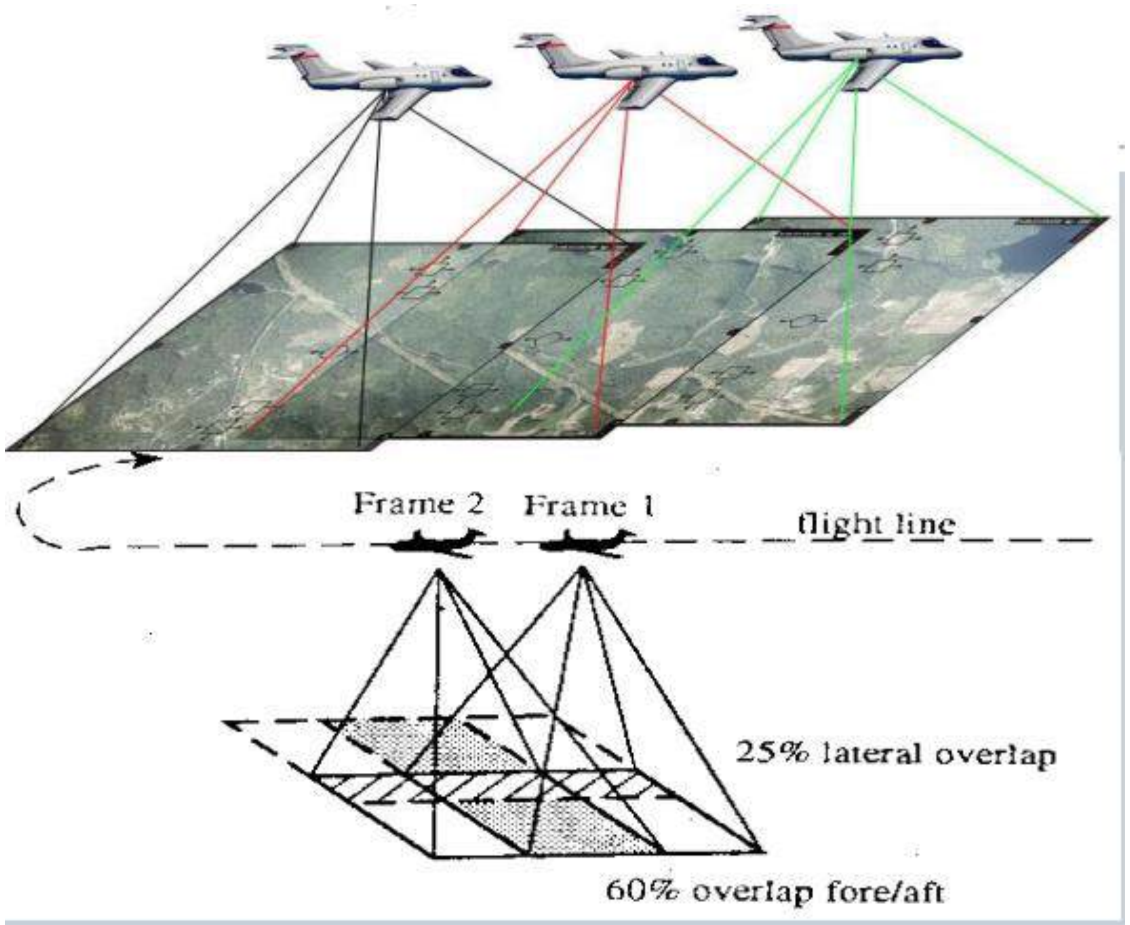


Source: https://www.geavis.si/en/2018/09/typical-causes-for-anomalies-in-the-overlap-of-aerial-photo-stereo-pairs/#:~:text=Drift%20is%20the%20lateral%20shift,between%20adjoining%20strips%20of%20photographs.

3.5 Overlap

Reasons for overlap

1. Arrangement of Mosaic.
2. Remove errors due to distortion , displacement & tilt.
3. For view in stereoscope-3D vies.
4. Avoid repetition of Aerial survey.

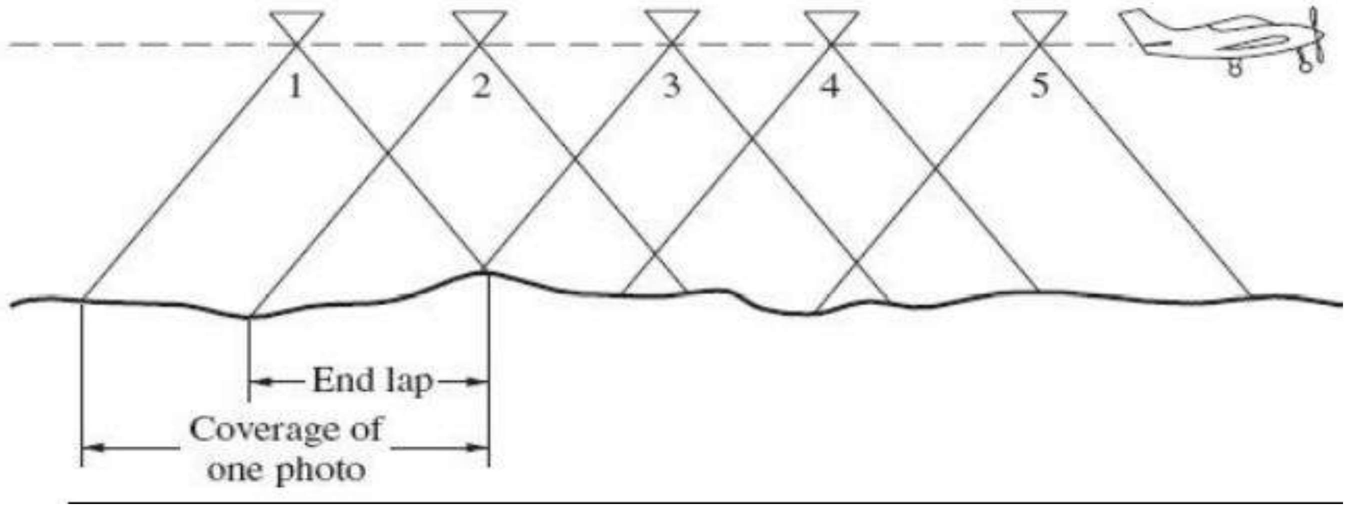


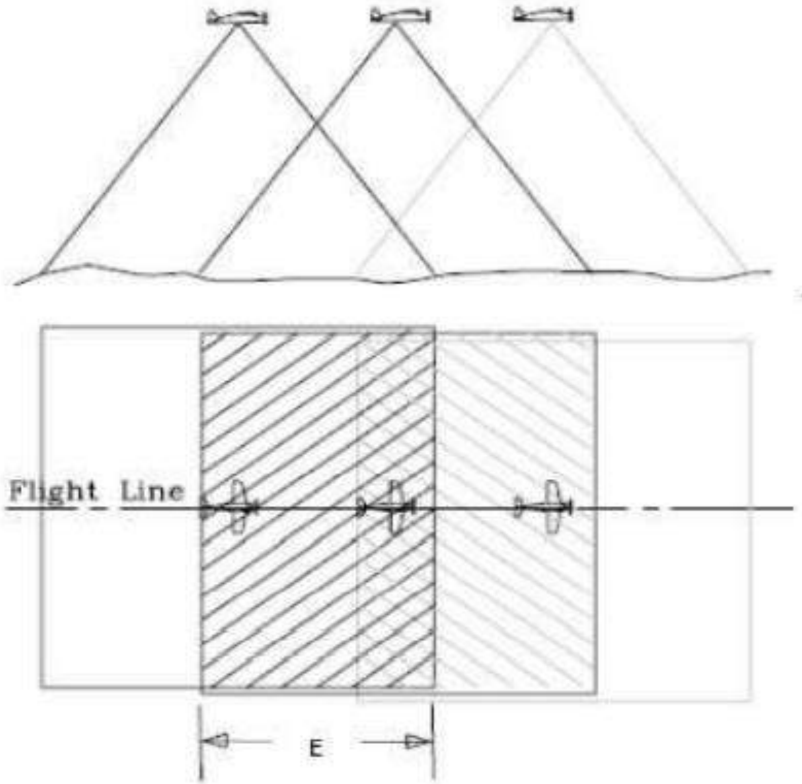
Source: https://arts.nprcolleges.org/site/download?file=unit+2-aerial+surveying.pdf

3.5 Overlap

Forward Overlap(End lap)

- Forward overlap is the amount by which one photograph includes the area covered by another photograph along the same flight line.
- In order to prevent gaps due to terrain variation, flying height variations, tilt crab; end laps greater than 50% are used.
- Sometimes aerial photographs are required with more than 80% endlap in mountainous terrain.

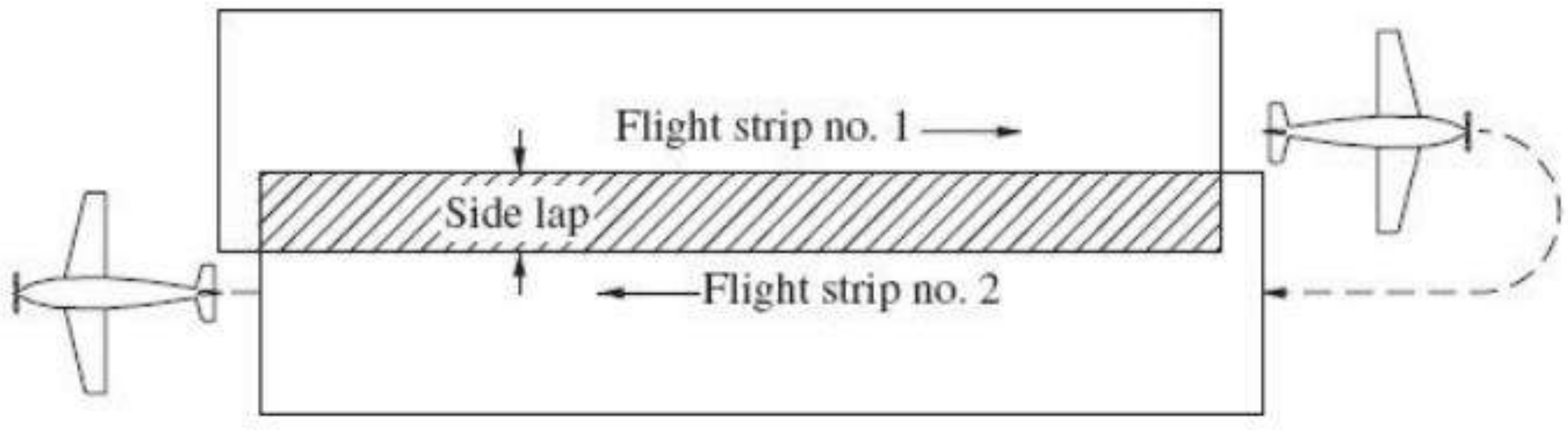




3.5 Overlap

Lateral Overlap(Side lap)

- Side overlap is the amount by which one photograph includes the area covered by another photograph on adjacent flight lines.
- Sidelap is required in aerial photography to prevent gaps from occurring between flight strips as a result of drift, crab, tilt, flying height variation and terrain variations.



3.5 Concept of model

Lateral Overlap(Side lap)

- Side overlap is the amount by which one photograph includes the area covered by another photograph on adjacent flight lines.
- Sidelap is required in aerial photography to prevent gaps from occurring between flight strips as a result of drift, crab, tilt, flying height variation and terrain variations.

3.8 Relief Displacement

Relief Displacement

- Relief displacement is the shift or displacement in the photographic position of an image due to object's elevation above or below datum.
- With respect to a datum, relief displacement is outward for points whose elevations are above datum and inward for points whose elevations are below datum.

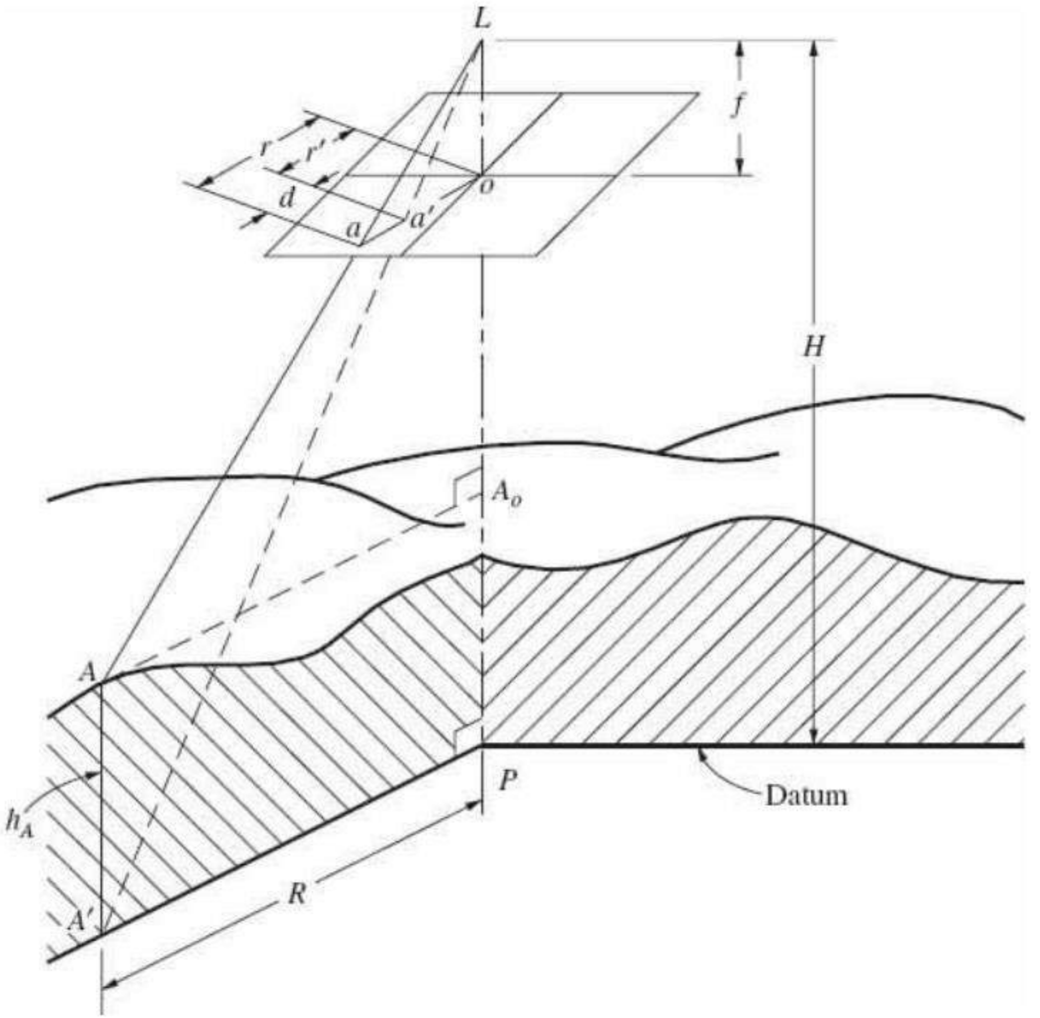
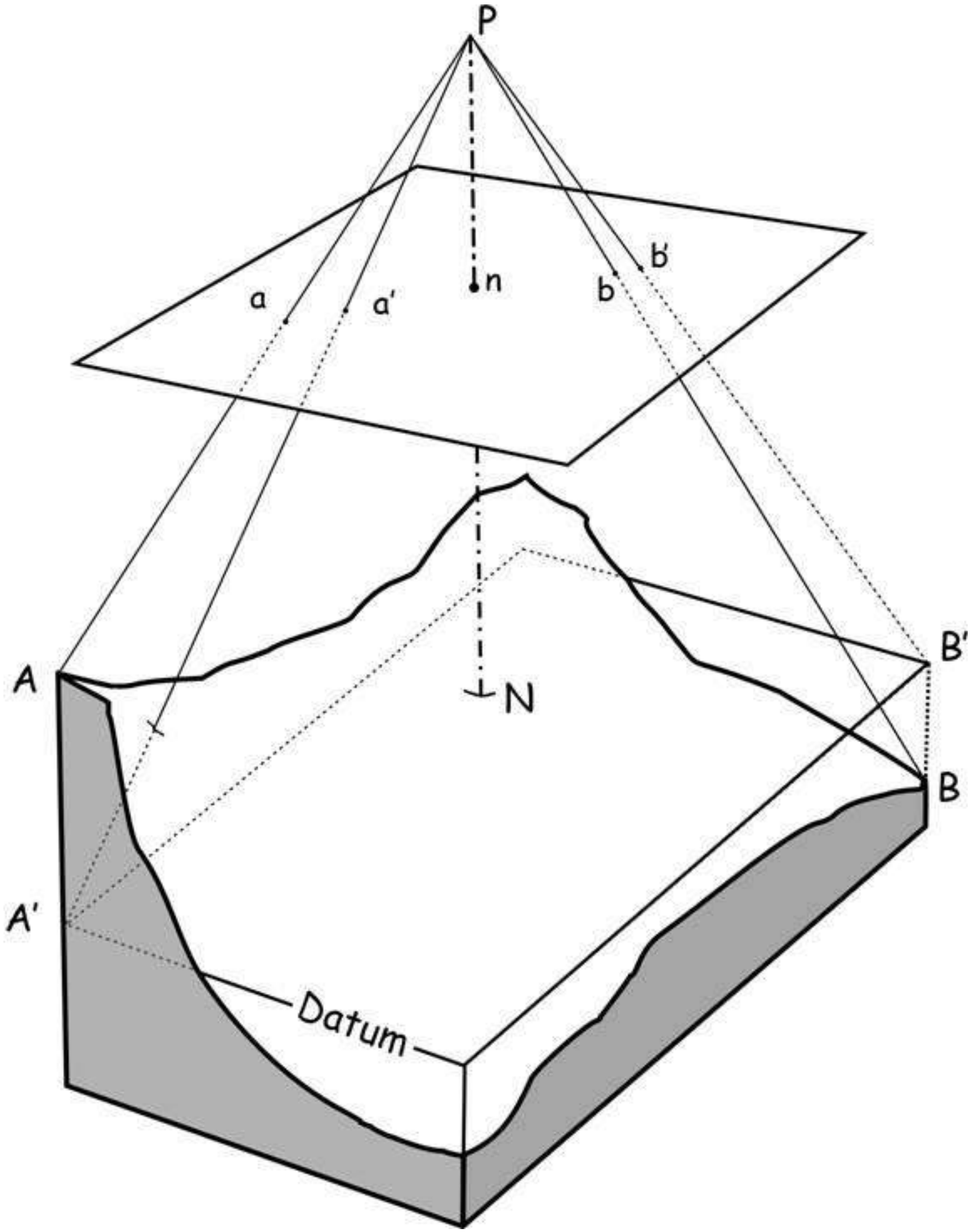


Fig: showing Relief displacement on a vertical photograph

Relief Displacement

Here, A, B: location on the ground surface; will be shown in a and b on the aerial photo and A', B': location on the reference datum surface; will be shown in a' and b' on the aerial image



Source: https://gis.depaul.edu/shwang/teaching/geog258/lec7.htm#:~:text=Geometric%20Distortions%20of%20Aerial%20Photograph&text=Distortion%20in%20aerial%20photographs%20comes,camera%20tilt%20and%20terrain%20variation.&text=Objects%20in%20the%20higher%20elevation,a)%20in%20the%20aerial%20photo.

Relief Displacement

- An increase in the elevation of a feature causes its position on the photograph to be displaced radially outward from the principle point.
- Hence, when a vertical feature is photographed, relief displacement causes the top of the feature to lie farther from the photo center than its base. As a result, vertical features appear to lean away from the center of the photograph.

Fig: showing cooling towers at the edge of photo with greater radial displacement

Relief Displacement

- The relief displacement occurs radially from the center of the photograph (principal point).

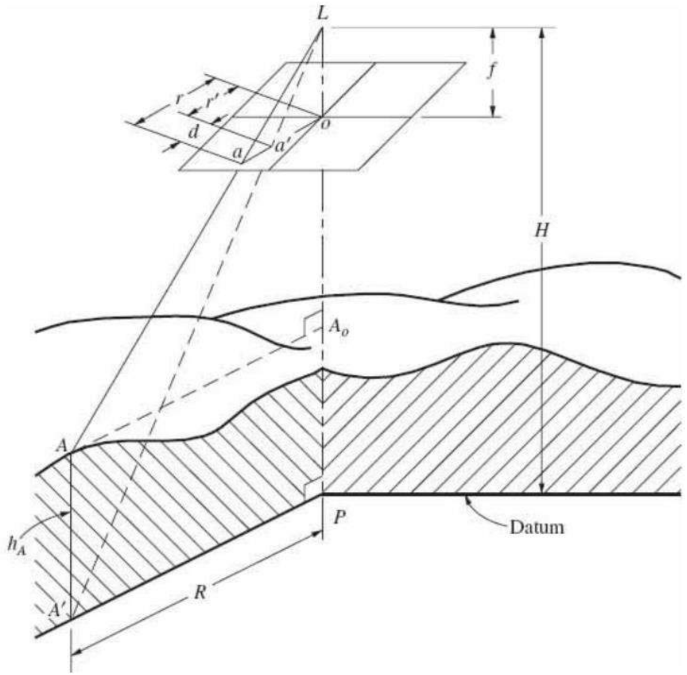
Fig: showing Vertical photograph of Tampa, Florida, illustrating relief displacements

Source: https://ocw.snu.ac.kr/sites/default/files/NOTE/chapter06.%20Vertical%20Photographs.pdf

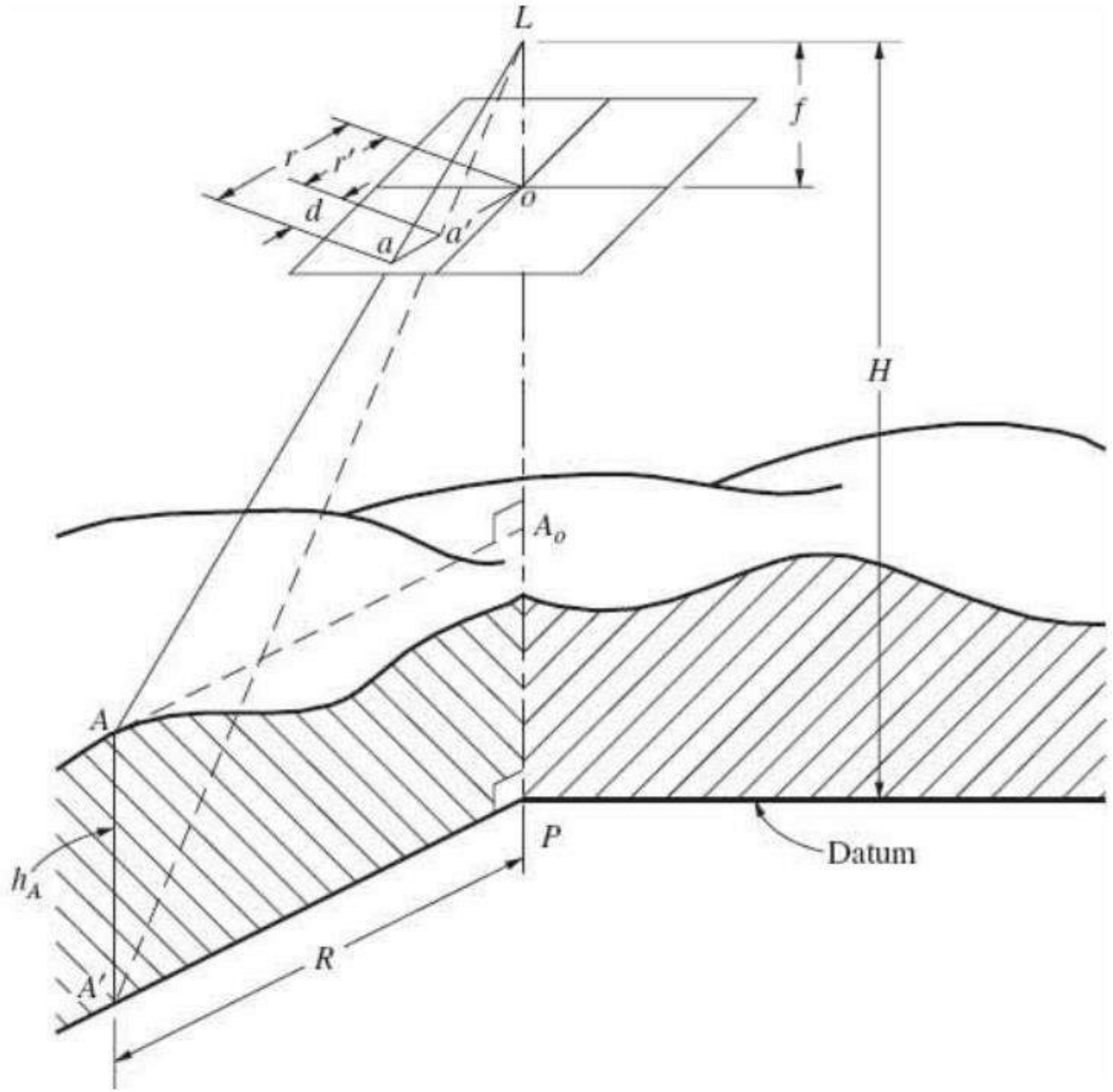
Derivation of formula of relief displacement

Let us consider a vertical photograph is taken from flying height H above datum with a camera having focal length f with photograph with the principal point o. The image of terrain point A, which has an elevation h_A above datum, is located at on the photograph. An imaginary point A′ is located vertically beneath A in the datum plane, and its corresponding imaginary image position is at a′.

On the figure, both A′A and PL are vertical lines, and therefore A′AaLoP is a vertical plane. Plane A′a′LoP is also a vertical plane which is coincident with A′AaLoP. Since these planes intersect the photo plane along lines oa and oa′, respectively, line aa′ (relief displacement of point A due to its elevation h_A) is radial from the principal point.



Derivation of formula of relief displacement



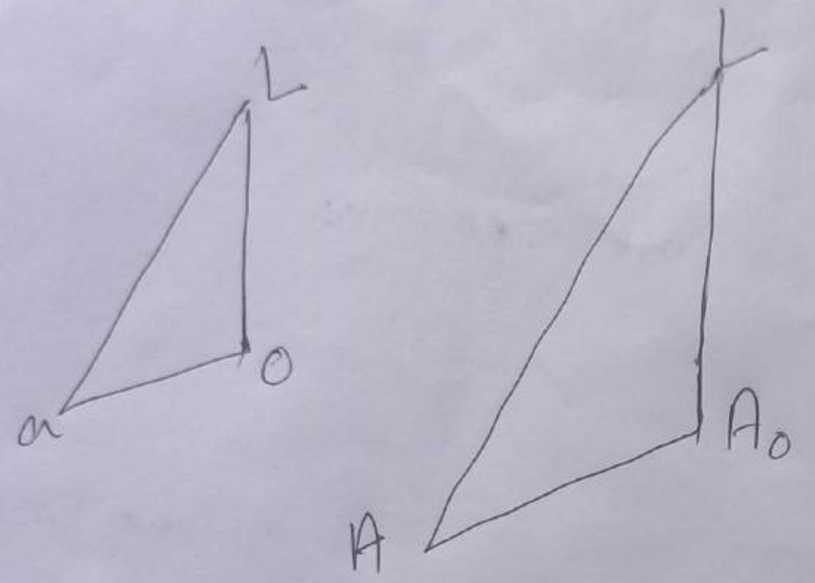
3.8 Relief Displacement formula derivation

Derivation of formula of relief displacement

For similar triangles Lao and LAA_o

Here (ao=image distance and

LAA_o = object distance)



Using concept of similar triangles

$$\frac{ao}{AA_o} = \frac{aL}{AL} = \frac{LO}{LA_o}$$

~~Also~~, or, $\frac{f}{H-h_A} = \frac{r}{R}$

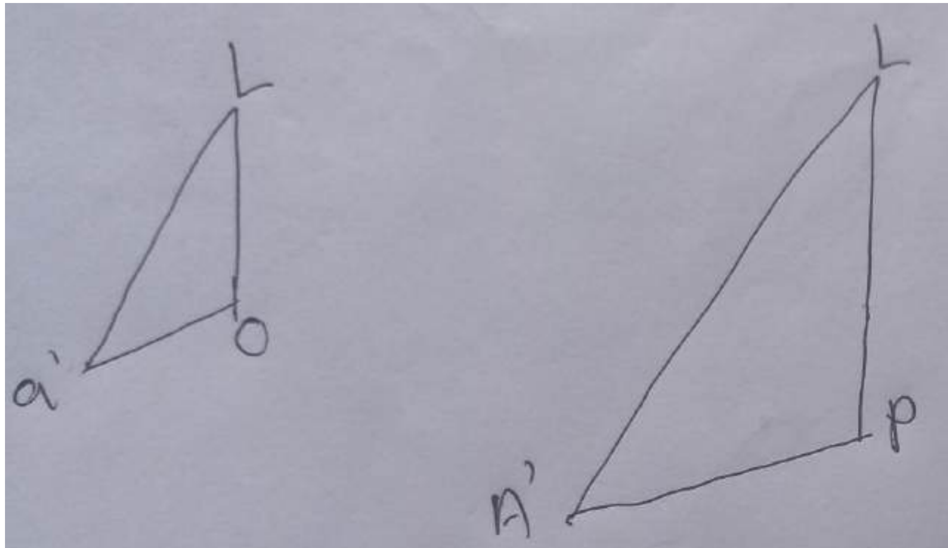
or, $fR = r(H-h_A)$ ... (a)

Derivation of formula of relief displacement

For similar triangles La′o and LA′P

Here (a’o=image distance and

A’P = object distance)



From similar triangles

$$\frac{a'o}{A'P} = \frac{a'L}{A'L} = \frac{Lo}{LP}$$

or, $\dfrac{f}{H-o} = \dfrac{r'}{R}$ or, $fR = r'H$ ... (b)

3.8 Relief Displacement formula derivation

Derivation of formula of relief displacement

From equation (a) and (b)

$$r(H-h_A)=r'H$$

Rearranging the above equation, dropping subscripts, and substituting the symbol d for r - r′ gives

d= (rh/H) ……………..(d)

where, d = relief displacement

h = height above datum of object point whose image is displaced

r = radial distance on photograph from principal point to displaced image; here of point A (The units of d and r must be the same.)

H = flying height above same datum selected for measurement of h

Thus, equation (d) gives the basic relief displacement equation for vertical photos.

3.8 Numericals: Relief displacement

1. A vertical photograph taken from an elevation of 535 m above mean sea level (MSL) contains the image of a tall vertical radio tower. The elevation at the base of the tower is 259 m above MSL. The relief displacement d of the tower was measured as 54.1 mm, and the radial distance to the top of the tower from the photo center was 121.7 mm. What is the height of the tower? (Ans: 123m)

Solution Select datum at the base of the tower. Then flying height above datum is

$$H = 535 - 259 = 276 \text{ m}$$

By Eq. (6-12),

$$h = \frac{54.1(276)}{121.7} = 123 \text{ m} \quad \blacktriangle$$

3.8 Numericals: Relief displacement

1. Radial distances to the top and bottom of a chimney are 63.57mm and 60.83mm respectively. If the flying height above the datum is 1500m and the ground elevation is 450m, what is the height of the chimney above the ground? (45.26 m above ground)

$\Rightarrow$ *Relief displacement of the top of the chimney,*

$d = r_t - r_b$

$= 63.57 - 60.33$

$= 2.74mm$

Also $d = \frac{rh}{H}$

Here $r = r_t \Rightarrow$ *radical displacement of chimney top*

h = *relative height (chimney height above ground)*

H = *Flying height above ground = local datum*

$\therefore \quad h = \frac{dH}{r} = \frac{2.74(1500-450)}{63.57}$

$= 45.26$ *m above ground #*

3.8 Tilt displacement

Tilt displacement

- Tilt displacement in aerial photography refers to the geometric distortion that occurs when the camera axis is not perfectly vertical at the moment of exposure.
- Some of the causes of tilt displacement includes aircraft movement and stability (pitch, roll & yaw), Improper Camera Mounting, Wind and Turbulence and so on.
- It results linear features (roads, railways) appear curved or angled, scale variation from one part to another etc.
- It can be corrected through use of Ground Control Points (GCPs), orthorectification and other photogrammetric software.

3.9 Rectification

Rectification

- Rectification involves correcting geometric distortions in an aerial image to align it with a specific map coordinate system.
- The process adjusts the image to correct distortions caused by camera angles and movements, but it does not take into account terrain variations due to which rectification is suitable for flat areas or applications where high precision is not critical.
- It can be done by relating pixels of unrectified image with a geocorrected image or coordintates of some vector data.
- It has got lower accuracy compared to orthorectification.
- It is used in scenarios where the terrain is relatively flat or where high precision is not required.

3.9 Rectification

Rectification

(a) (b)

(a) Digital image of an oblique, nonrectified photograph. (b) Image after digital recification

3.9 Orthorectification

Orthorectification

- Orthorectification is a more advanced process that corrects both geometric distortions and terrain-induced distortions of aerial image.
- It uses a DEM to correct for terrain variations, ensuring accurate representation of the Earth's surface.
- It has got higher accuracy compared to rectification.
- It is used in high-precision mapping, geographic information systems (GIS), land use planning, and any application requiring accurate spatial measurements.

3.10 Oblique photography

Oblique aerial photograph

- Oblique aerial photograph is one which has been taken with the camera axis directed at an inclination to the ground.
- It involves taking images at an angle, rather than directly overhead.
- Oblique imagery allows users to observe ground features from multiple angles, which more realistically shows the actual conditions of the features.
- It can obtain more information about ground features, especially the building facades, by tilting the camera and helps to prepare better 3D models of given study area.

3.10 Oblique photography

Oblique aerial photograph

- It is particularly suited for

a. visualizing topography and terrain features

b. assessing land use and environmental impacts and

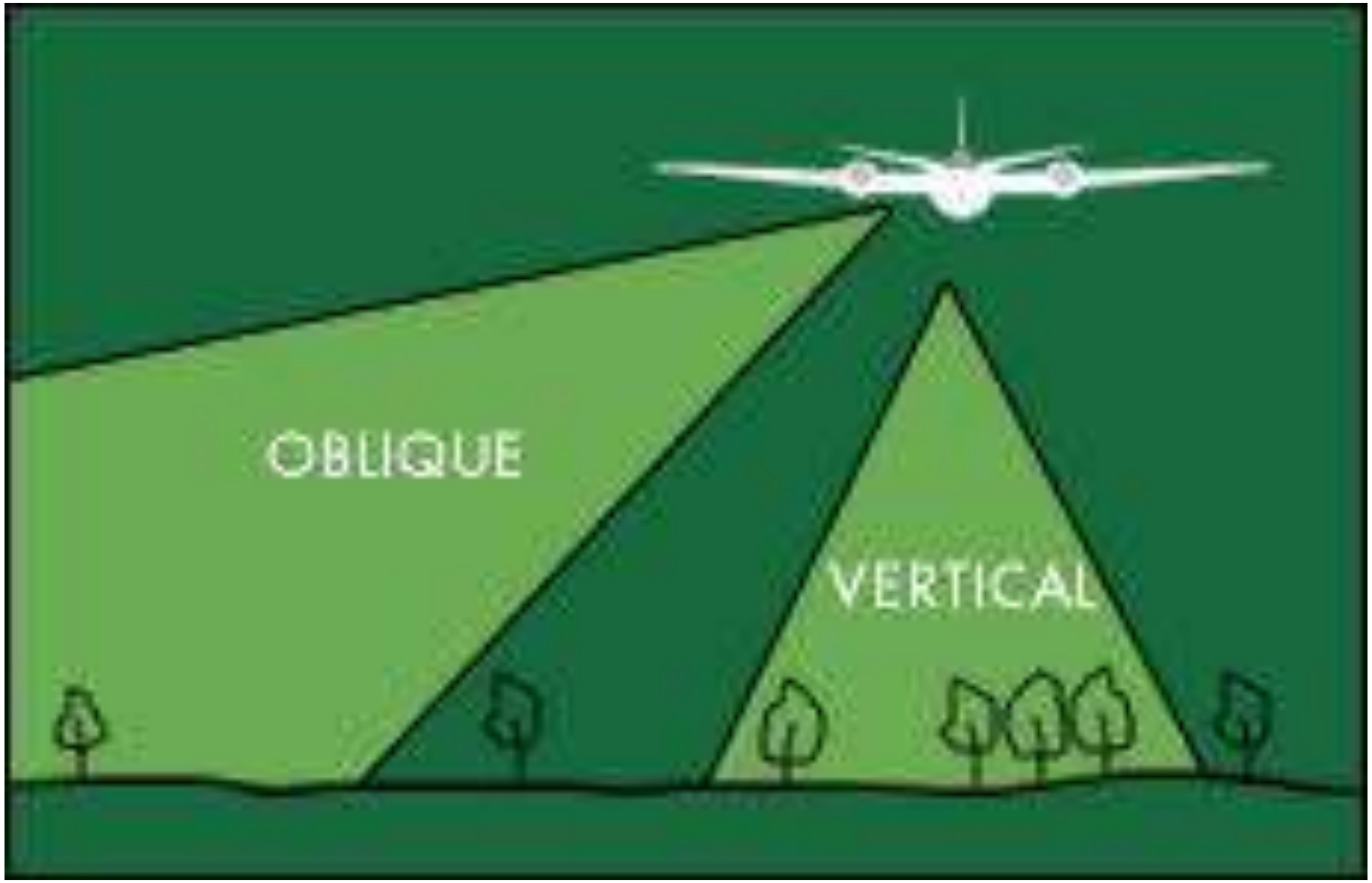
c. Providing visual context for maps and geographic information systems (GIS).

It is mainly divided into two types. They are:

a. High-oblique

b. Low-oblique

Oblique aerial photograph



Source: https://ncap.org.uk/feature/vertical-and-oblique-aerial-photography

Fig: showing difference oblique and vertical photograph

Oblique aerial photograph

Source: https://keshavrajbhusal.com.np/

Fig: showing oblique photograph

3.11 Photo maps

Photo maps

- Photomaps are simply aerial photos that are used directly as planimetric map substitutes.
- Title information, place names, and other data may be superimposed on the photos in the same way that it is done on maps.
- Photomaps may be prepared from single aerial photos, or they may be made by piecing together two or more individual overlapping photos to form a mosaic.

Advantages

a. Photo maps show relative planimetric locations of a virtually unlimited number of objects, whereas features on maps—which are shown with lines and symbols—are limited by what was produced by the map maker.

b. Photo maps of large areas can be prepared in much less time and at considerably lower cost than maps.

c. Photomaps are easily understood and interpreted by people without photogrammetry backgrounds due to which they are very useful in describing proposed construction or existing conditions to members of the general public, who may be confused by the same representations on a map.

3.11 Photo maps

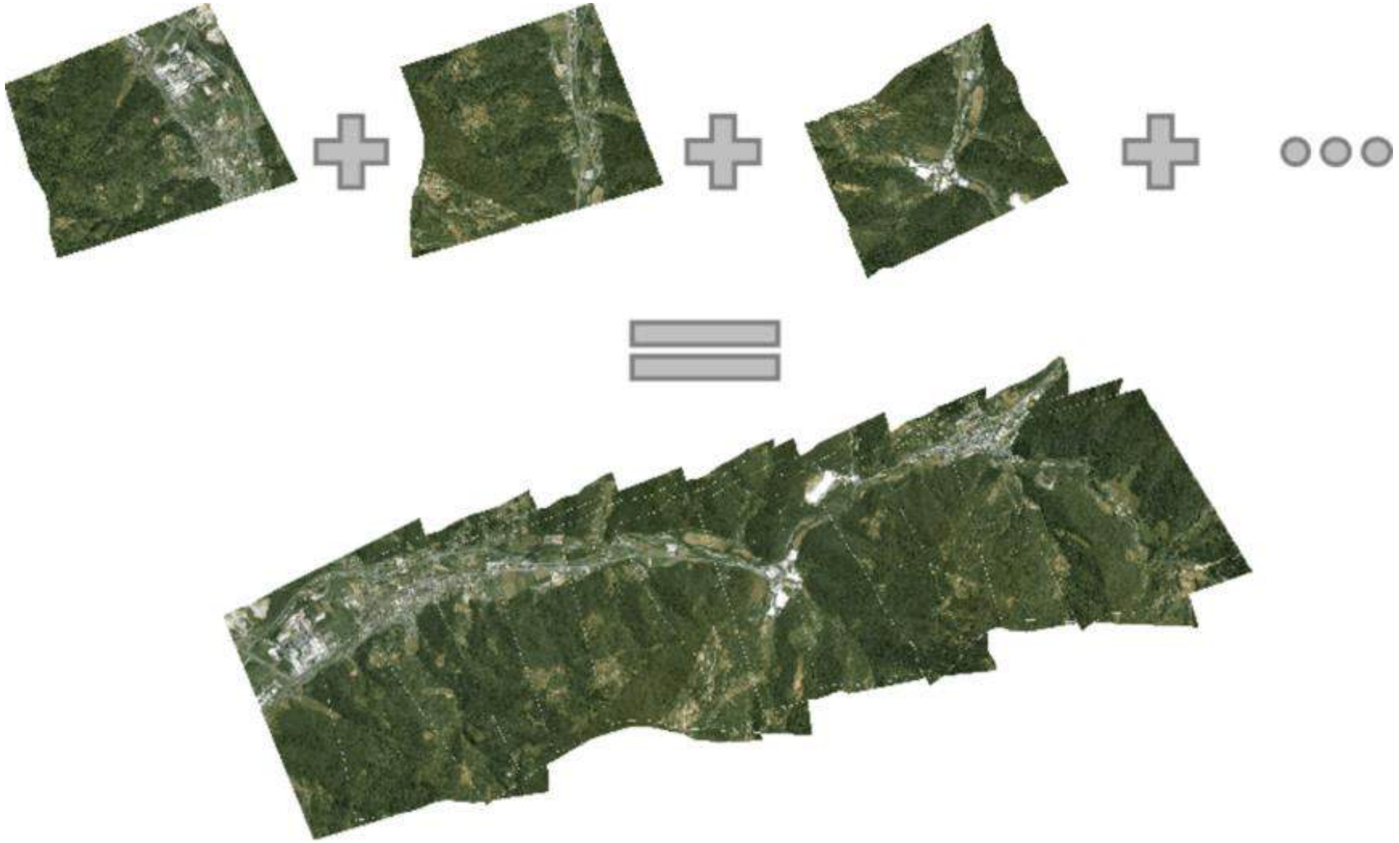
Disadvantages

a. Photomaps have one serious disadvantage—they are not true planimetric representations. Rather, they are constructed from perspective photographs, which are subject to image displacements and scale variations.

Mosaic

- A mosaic is an assesmbly of series of aerial photographs put together in such a way that the detail of one photograph matches the detail of all adjacent photographs.
- While assembling, the edge have been cut and matched and fitted together systematically to form a continuous photographic representation of a portion of the Earth's surface.
- It consist of three main types:

i. uncontrolled mosaics
ii. semi-controlled mosaics
iii. controlled mosaics.



3.11 Mosaic

Uncontrolled mosaics

- An uncontrolled mosaic is prepared by simply matching the image details of adjacent photos.
- There is no groundcontrol, and aerial photographs that have not been rectified are used.
- Uncontrolled mosaics are more easily and quickly prepared than controlled mosaics.
- They are not as accurate as controlled mosaics, but for many qualitative uses they are completely satisfactory.

Semi-controlled mosaic

- Semicontrolled mosaics are assembled by utilizing some combinations of the specifications for controlled and uncontrolled mosaics.
- A semicontrolled mosaic may be prepared, for example, by using ground control but employing photos that have not been rectified or ratioed.
- The other combination would be to use rectified and ratioed photos but no ground control.

3.11 Mosaic

Controlled mosaics

- If aerial photographs have been properly rectified, i.e., enlarged or reduced and fitted on adequate ground control the mosaic is said to be a controlled mosaic.
- A controlled mosaic is the most accurate of the three classes.

3.11 Concepts of Orthophoto, Orthomosaic

Orthophoto, Orthophotograph or Ortho image or Ortho map

- It is an aerial photograph which is geometrically corrected ("orthorectified") with all the distortions removed such that the scale is uniform.

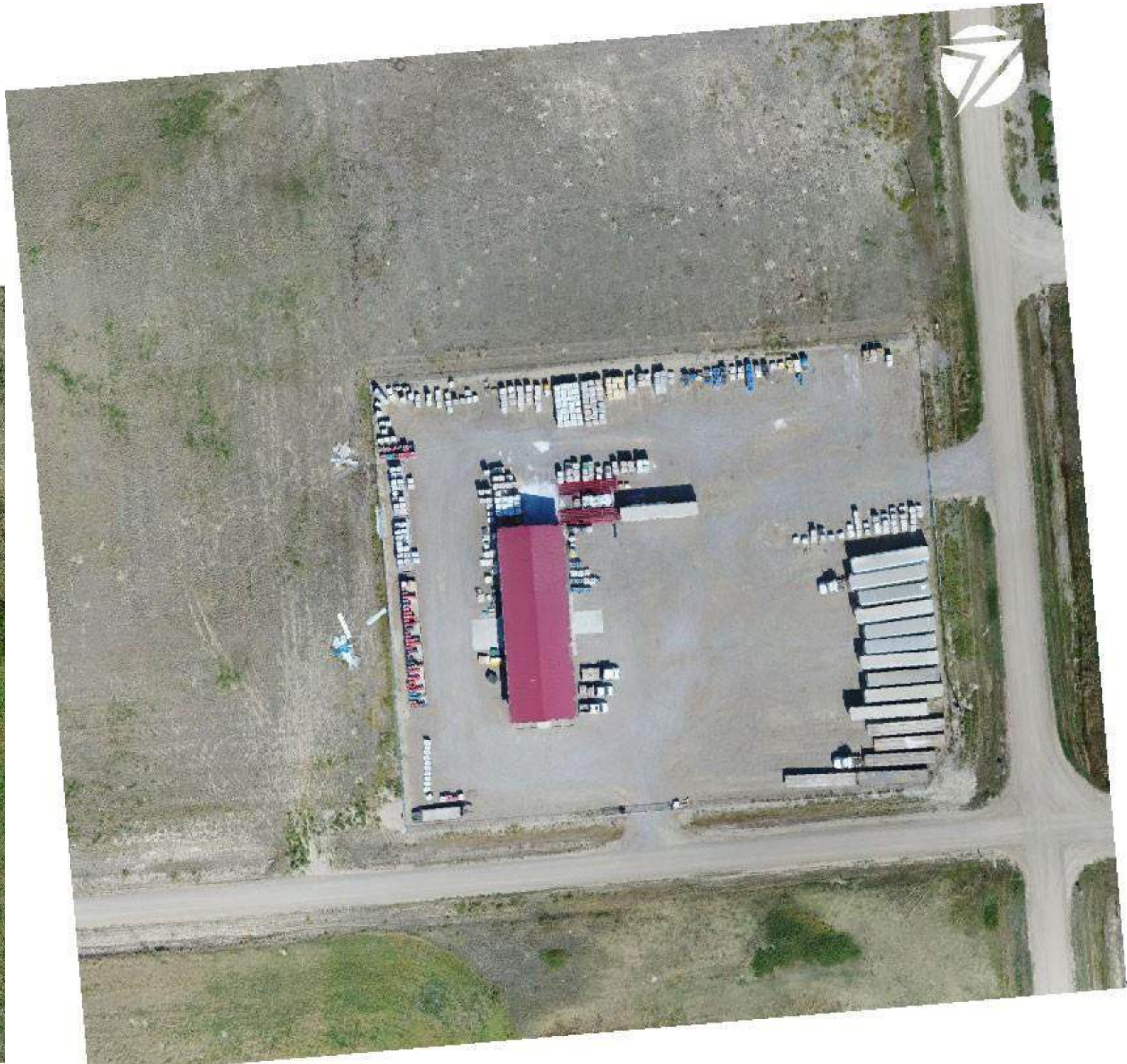
Orthomosaic

- Ortho — meaning straightened or aligned
  Mosaic — piecing things together
- Orthomosaic is the final product after stitching together all the individual orthophotos.

Aerial photo vs Orthophoto

Aerial photo	Orthophoto
1. Aerial photo contains errors due to terrain relief, sensor, satellite/aircraft motion, ens distortion etc.	Orthophoto is free from such errors as it passess through orthorectification process.
2. Ground features are not in planimetrically true position.	Ground features are in planimetrically true position.
3. It has non-uniform scale. 4. It has perspective projection. 5. It is obtained from aerial cameras fixed in aircraft, UAV and other vehicle.	It has uniform scale. It has orthogonal projection. It is obtained by processing (orthorectification) aerial photos.

Aerial photo vs Orthophoto



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Oblique photography

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PHOTOGRAMMETRY

EG 3101 GE

Unit 4: Aerial Camera

CTEVT 1989

Public Secondary School

Lecture by

Er. Keshav Raj Bhusal

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4.1. Structure of aerial camera and their functions

4.2. Different types of analogue and digital camera

Aerial camera

- Aerial mapping camera is the traditional imaging device used in photogrammetry.
- They are referred to as "passive sensors" because they detect and capture the natural light reflected from objects.
- It is designed for obtaining aerial photographs of the earth's surface from an airplane or other type of aircraft.
- Aero-camera differs from ordinary camera and has specific features like fully automatic operation, shock absorbing support frame, large picture format, photographing from great distance, rapid movement and vibration during exposure etc.

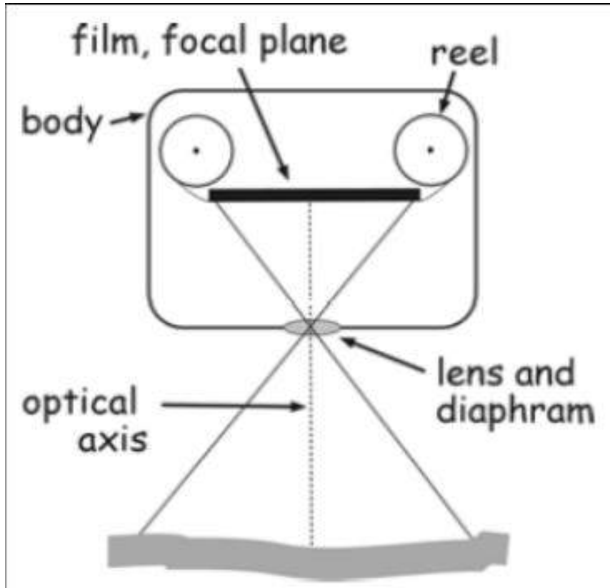


Fig: showing simple aerial camera

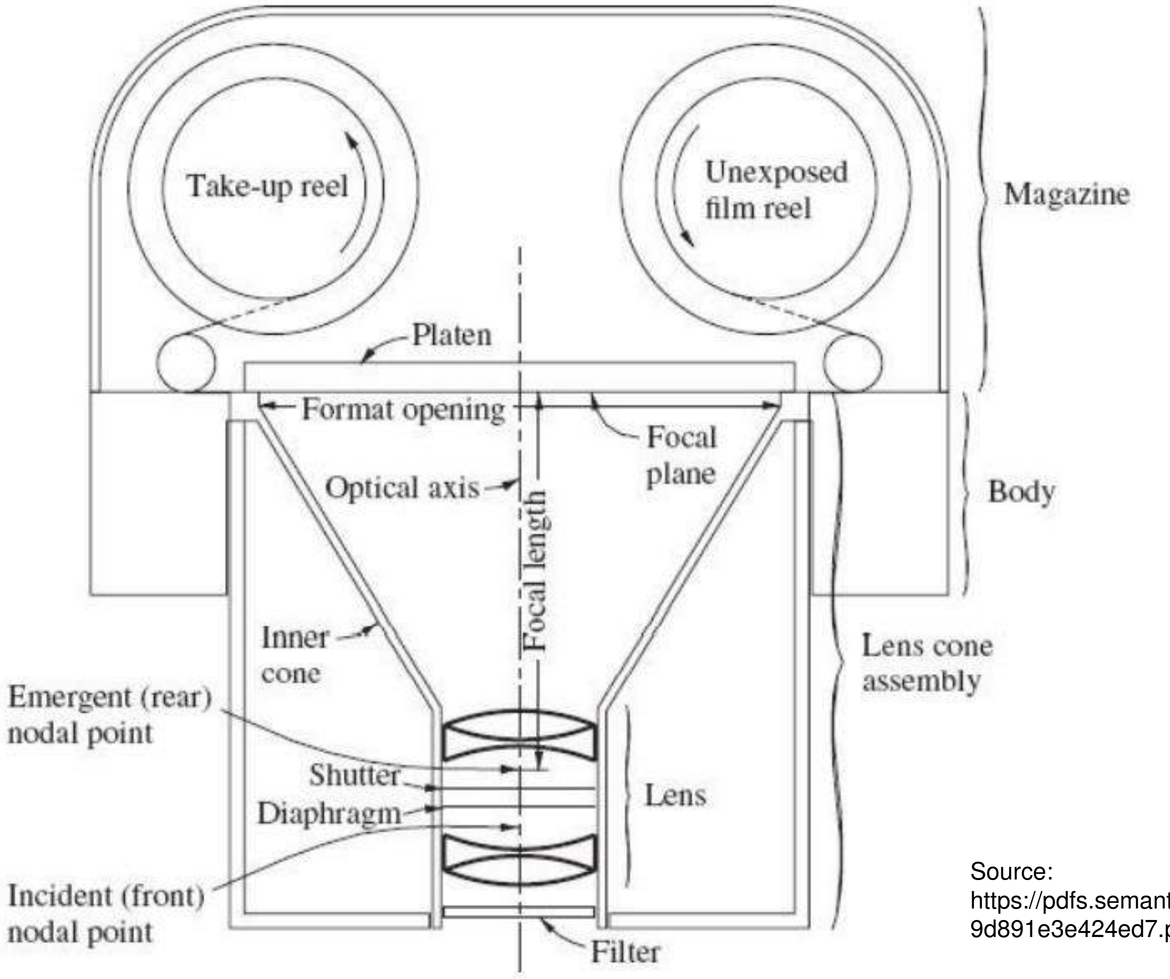
Source: https://www.shivajicollege.ac.in/sPanel/uploads/econtent/72c481f85b187d903efb91bbcb3402d3.pdf

4.1. Structure of aerial camera and their functions

Essential parts of an aerial camera

There are three basic components of aerial camera. They are:

1. Magazine
2. Camera body
3. Lens cone assembly



Source: https://pdfs.semanticscholar.org/9d9a/63a99f78285d3ada4464c79d891e3e424ed7.pdf

Fig: Components of Aerial camera

4.1. Structure of aerial camera and their functions

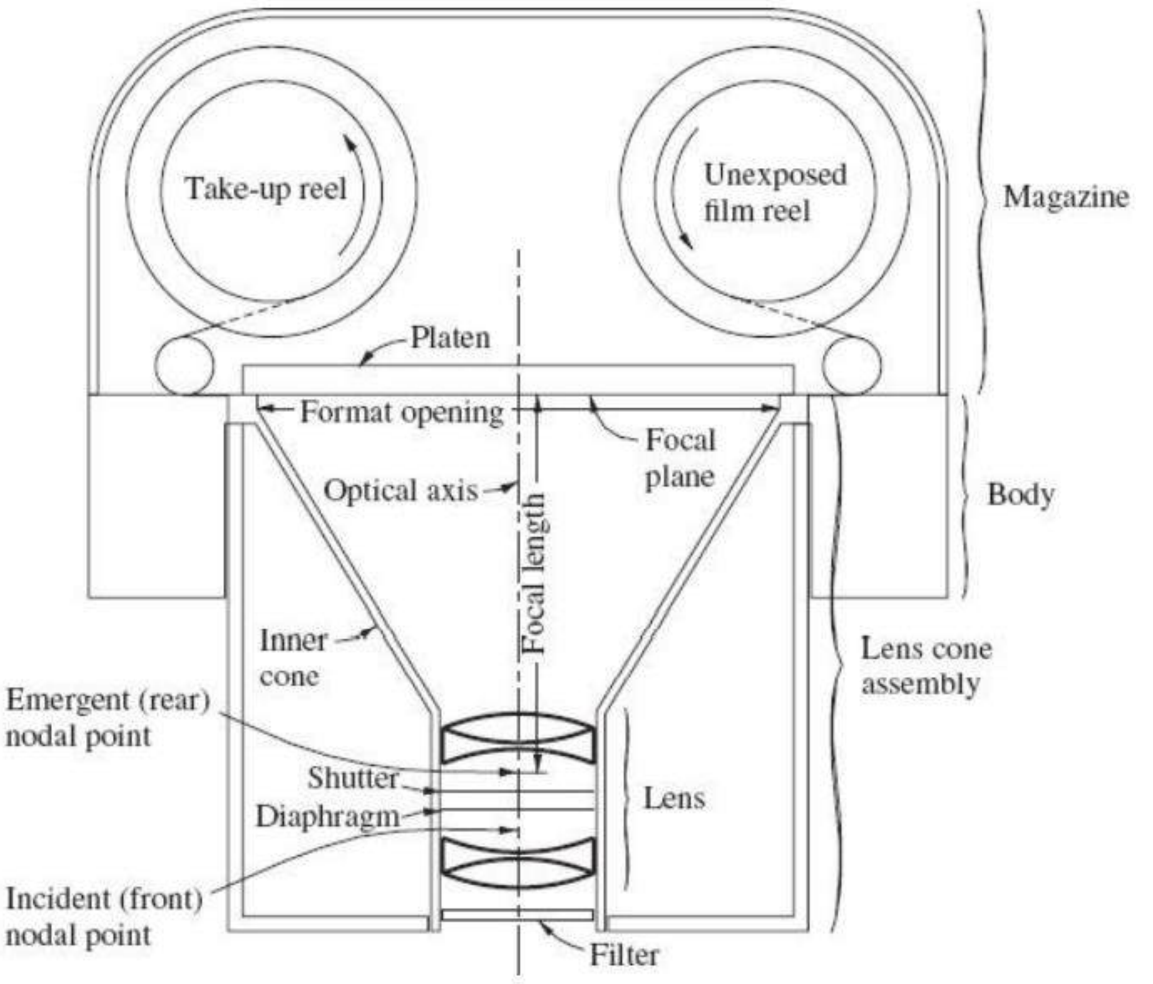
Essential parts of an aerial camera

Magazine consists of following parts:

i. Take-up reel
ii. Unexposed film reel
iii. Platen

Lens Cone Assembly consists of following parts

i. Filter
ii. Lens
iii. Shutter
iv. Diaphragm



Source:
https://pdfs.semanticscholar.org/9d9a/63a99f78285d3ada4464c79d891e3e424ed7.pdf

Fig: Components of Aerial camera

4.1. Structure of aerial camera and their functions

a. Lens Cone Assembly

1. The lenses :

- The camera lens is the most important (and most expensive) part of an aerial camera.
- Helps in gathering the bundle of light rays and passes through it in order to record the feature from the real ground.
- Most aerial cameras use compound lenses, formed from many separate lenses of varied sizes, shapes, and properties. To correct for the errors that may be present in any single component, so the whole unit is much more accurate than any single element.

2. Shutter:

- The shutter controls the length of time that light is permitted to pass through the lens.
- Shutters are designed to operate efficiently so that they open instantaneously, remain open the required time, and then instantaneously close, thus enabling the most uniform exposure possible over the format.
- The shutter speeds of aerial cameras typically range from about to 1/100 to 1/1000 S.

4.1. Structure of aerial camera and their functions

a. Lens Cone Assembly

3. Diaphragm

- It controls the amount of light passing through the lens by varying the size of the aperture.

4. Filter

Consists of a piece of colored glass placed in front of the lens.

The filter serves three purposes:

1. It reduces the effect of atmospheric haze.
2. It helps provide uniform light distribution over the entire format.
3. It protects the lens from damage and dust.

4.1. Structure of aerial camera and their functions

b. Camera Body

The camera body is a one-piece casting which usually houses the drive mechanism.

- The drive mechanism advances the film after each exposure, using electric motors activated in coordination with the shutter and the motion of the plane.
- The camera body also contains carrying handles, mounting brackets, and electrical connections.

c. Magazine

- The camera magazine houses the reels which hold exposed and unexposed film, and it also contains the film-advancing and film-flattening mechanisms.
- Operate through the drive mechanism.
- It is detachable, allowing to interchange magazines during a flight mission.

Platen

- At the time exposure the film must lie flat in the camera's focal plane. The function is performed by the platen, a small, spring-mounted, metal plate positioned to hold the film flat at the instant of exposure.

4.2 Different types of analogue and digital camera

Analog aerial camera

Different types of analog aerial camera are as follows:

1. Film-based Aerial Cameras:

- These cameras use traditional photographic film to capture images.
- They captured images on light-sensitive film, which then had to be developed and processed in a darkroom.
- Film cameras have been widely used in aerial photography for decades but are becoming less common with the rise of digital technology.

2. Optical-Mechanical Aerial Cameras:

- These cameras use a combination of lenses, mirrors, and film to capture images.
- They often have precision mechanical systems for controlling exposure, aperture, and focus.

4.2 Different types of analogue and digital camera

Analog aerial camera

Different types of analog aerial camera are as follows:

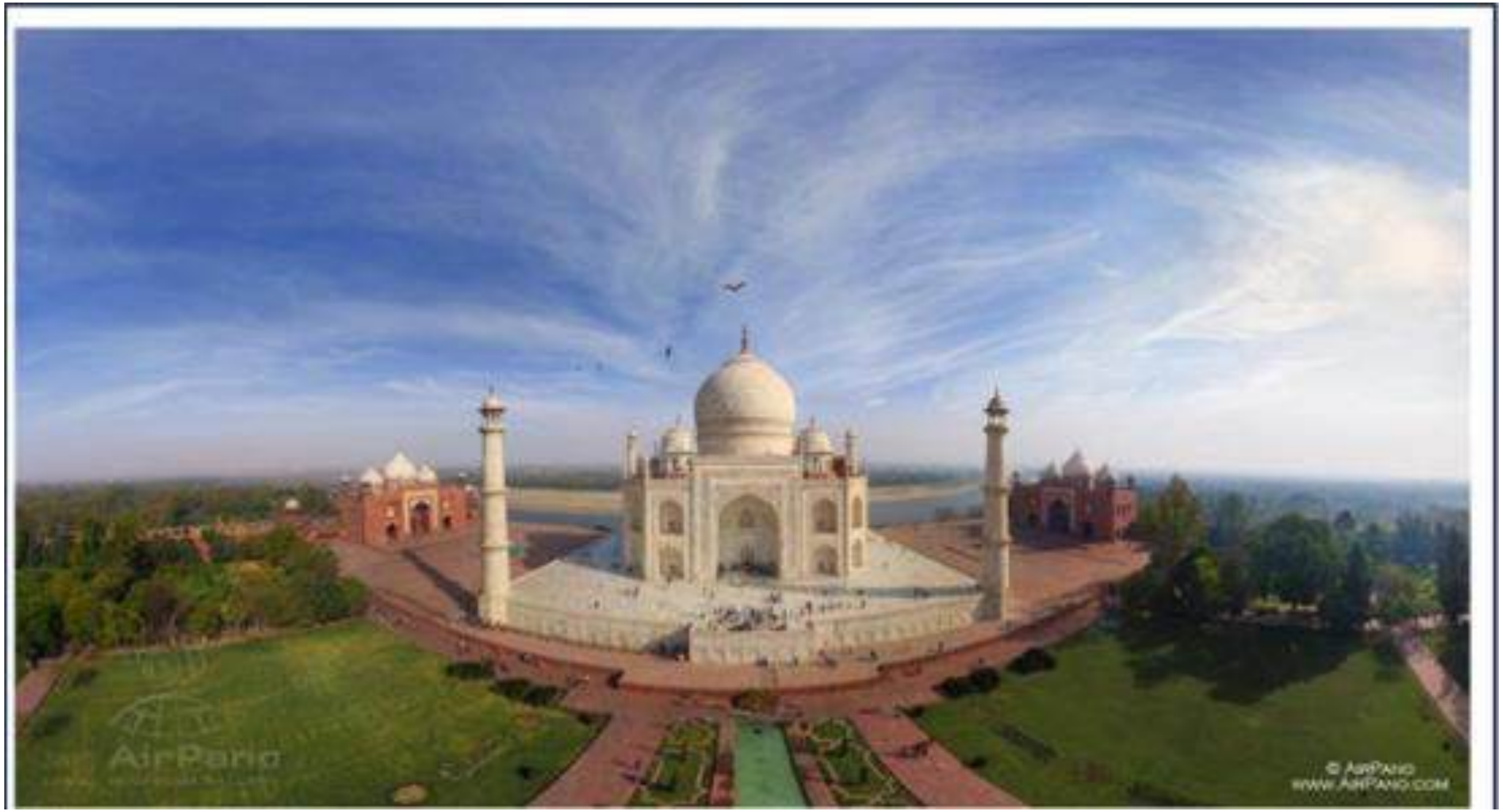
3. Panoramic Cameras:

- Panoramic cameras are used to capture wide-angle or 360-degree views in a single exposure.
- They are often used for capturing images in confined spaces or for creating immersive visualizations.

Analog aerial camera

Different types of analog aerial camera are as follows:

3. Panoramic Cameras:



Source: https://pdfs.semanticscholar.org/9d9a/63a99f78285d3ada4464c79d891e3e424ed7.pdf

4.2 Different types of analogue and digital camera

Digital camera

- Advantage with digital camera is that it records and store photographic images in digital form. These images can be stored directly in the camera or can be uploaded onto a computer or printer later on.

E.g camera used in drones

4.2 Different types of analogue and digital camera

Digital aerial camera

Different types of analog aerial camera are as follows:

1. Thermal Infrared Cameras:

- These cameras detect infrared radiation emitted by objects to create thermal images.
- They're valuable for applications like search and rescue, environmental monitoring, and building inspections.

2. Multispectral Cameras:

- These cameras capture images in multiple spectral bands, allowing for analysis beyond what the human eye can perceive.
- They're commonly used in applications like agriculture, environmental monitoring, and resource management.

Digital aerial camera

Different types of analog aerial camera are as follows:

3. Hyperspectral camera

- Hyperspectral aerial cameras are specialized imaging systems used in photogrammetry for capturing imagery across hundreds or even thousands of narrow spectral bands.
- Unlike traditional RGB cameras that capture imagery in three spectral bands (red, green, and blue), hyperspectral cameras capture data across a much broader range of the electromagnetic spectrum, providing detailed spectral information about the Earth's surface.

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- https://staff.ui.ac.id/system/files/users/dodi.sudiana/material/ch.03-photographicsensors.pdf : Parts of aerial camera

PHOTOGRAMMETRY

EG 3101 GE

Unit 5: Aerial Photography Planning

Lecture by

Er. Keshav Raj Bhusal

Public Secondary School

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5.5. Indexing of aerial photographs on a map

5.1 Extension of control for photogrammetry

Ground Control Points (GCP)

- Ground Control Points or simply Ground Controls refers to physical points on the ground with known coordinates with respect to some horizontal coordinate system and/or vertical datum.
- These points shall be identifiable in the images as well.
- In GCPs position, generally some large flags and symbols are kept in grounds so that they can be recognized clearly in aerial photographs and georeferencing can be done easily.
- They are used to increase the accuracy of photogrammetric products.
- GCPs can be natural or artificial features, such as road intersections, building corners, or distinct landscape features that are easily identifiable in the imagery.
- They are typically collected using high-precision Global Positioning System (GPS) receivers or derived from other accurate sources, such as survey data or existing maps.

5.1 Extension of control for photogrammetry

Ground Control Points (GCP)

They are generally classified as either horizontal control or vertical control.

a. **Horizontal control**: It is the known planimetric position of point in object space in some XY coordinate system.

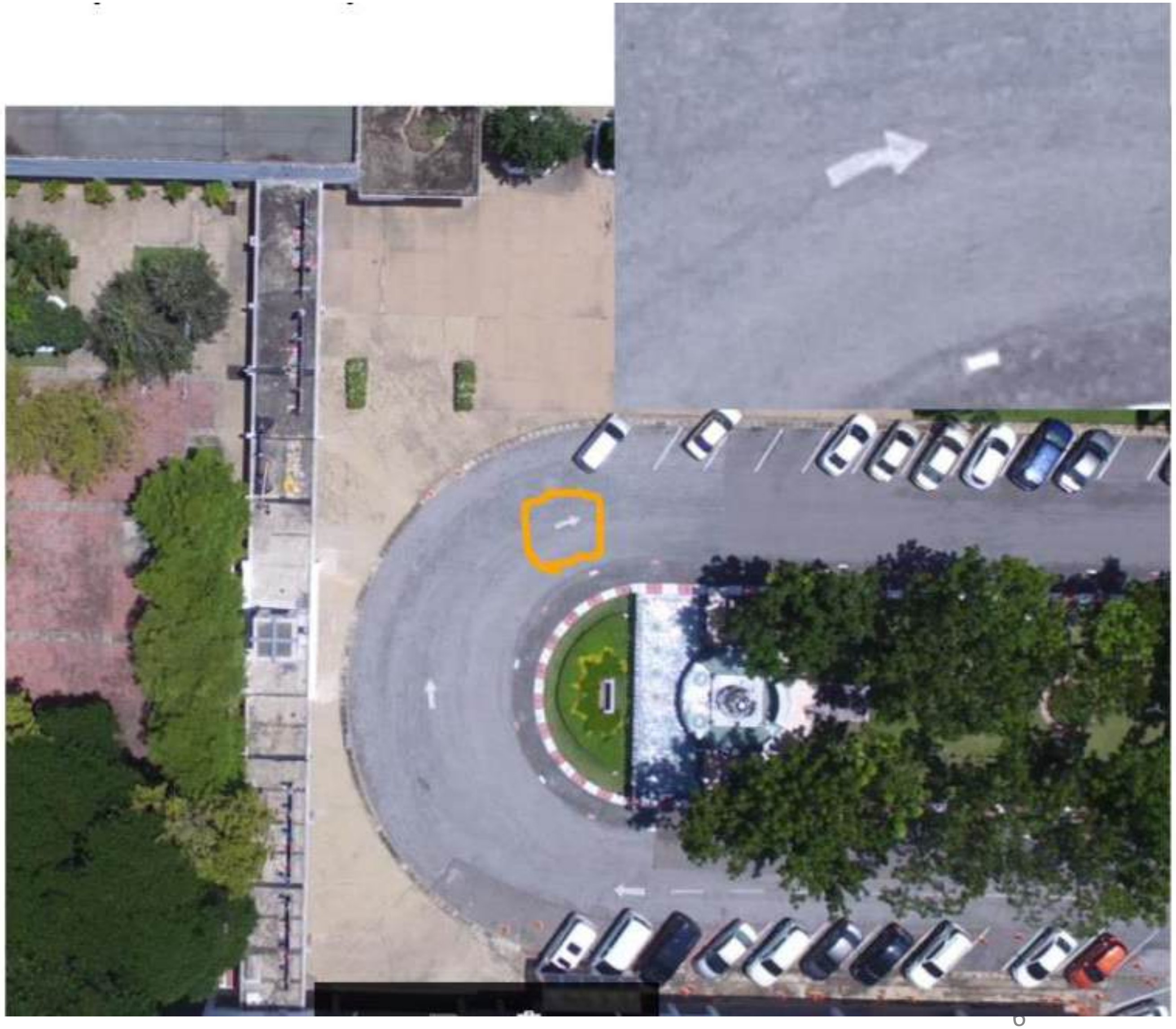
b. **Vertical control**: It is the known elevation of the point with respect to a vertical datum.

5.1 Extension of control for photogrammetry

Ground Control Points (GCP)

Source: https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2018/Drones-in-agriculture/asptraining/A_ground_control_for_UAV_mapping.pdf

Ground Control Points (GCP)



Source: https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2018/Drones-in-agriculture/asptraining/A_ground_control_for_UAV_mapping.pdf

Extension of control

- It refers to the process of expanding the network of control points or ground control points (GCPs) to cover a larger area or to improve the accuracy and reliability of the photogrammetric results.
- These additional GCPs serve to improve the spatial distribution and density of control points, thereby minimizing errors and distortions in the final orthophoto or digital surface model (DSM).

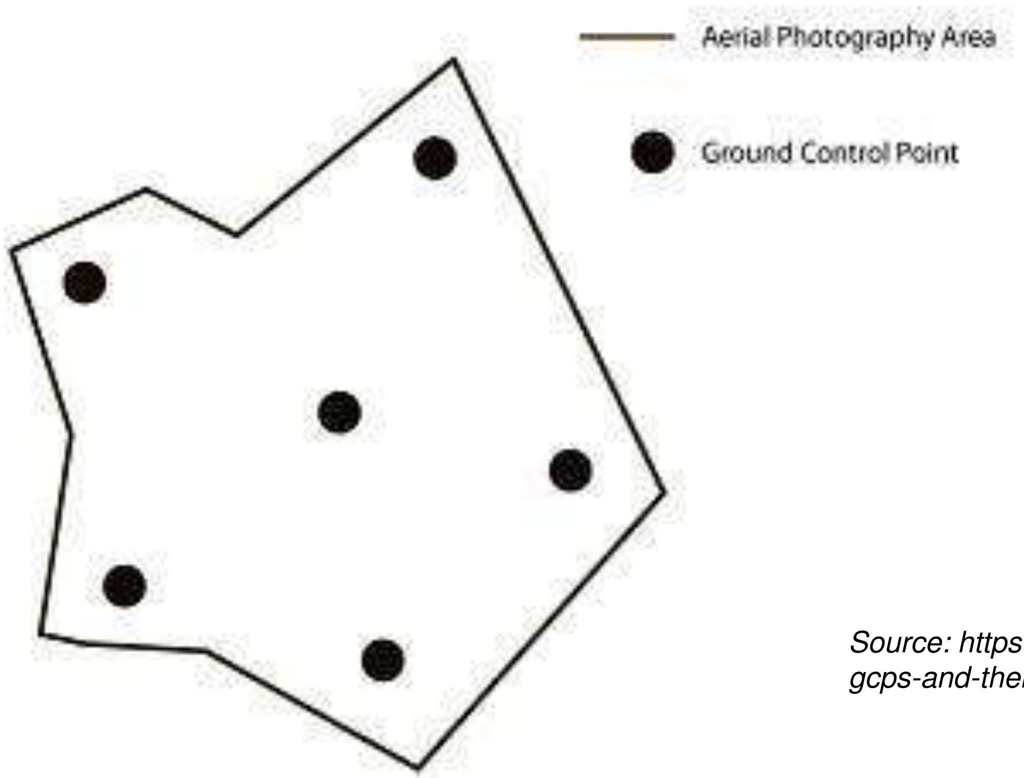


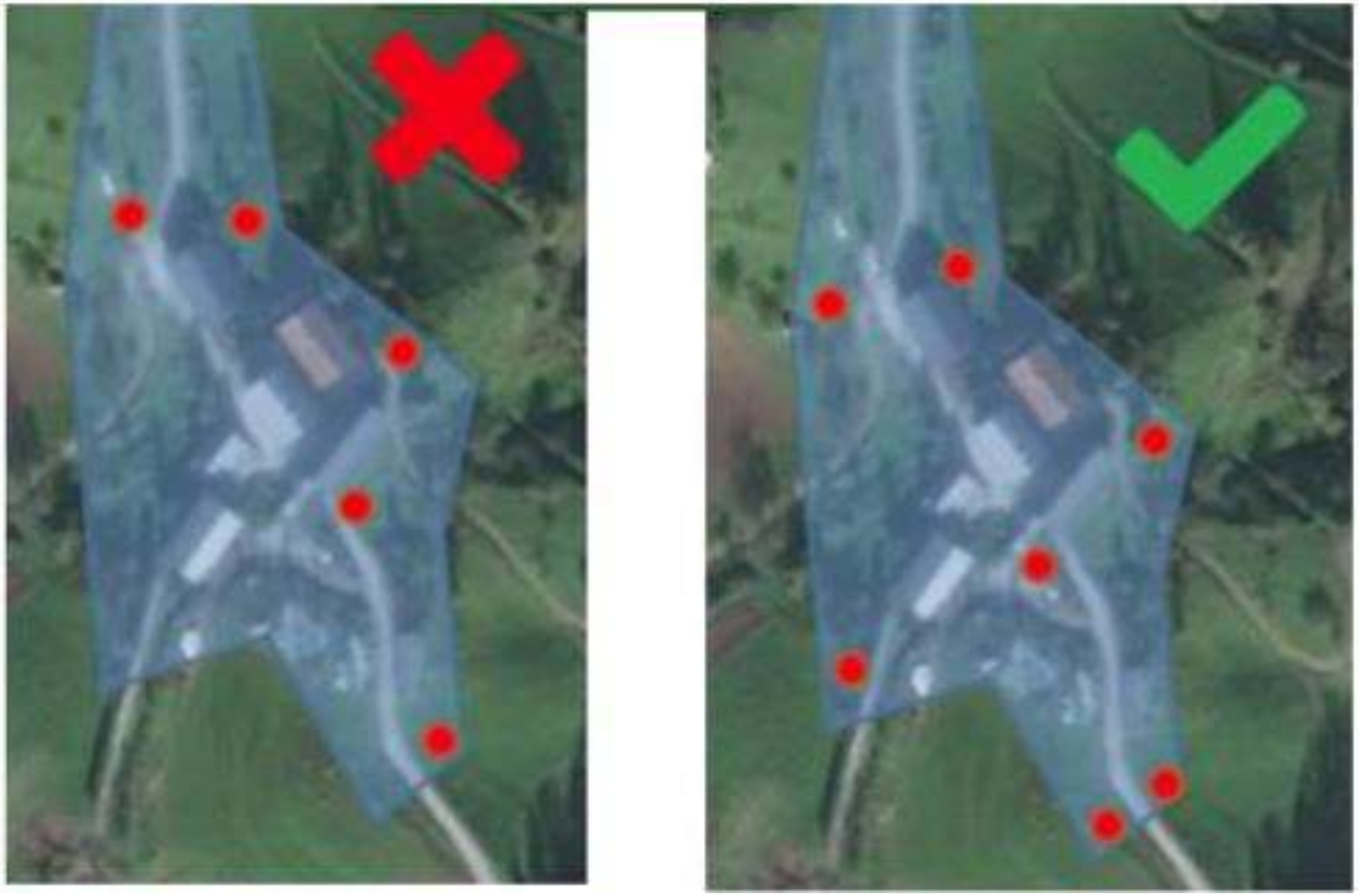
Fig: showing spatial distribution of GCPs around project area.

Source: https://medium.com/@dinesh.neupane5/ground-control-points-gcps-and-their-distribution-pattern-32aa248e8130

5.1 Extension of control for photogrammetry

Extension of control

- Control points should be extended uniformly for a given study area for better quality of photogrammetric products.



Source: https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2018/Drones-in-agriculture/asptraining/A_ground_control_for_UAV_mapping.pdf

5.1 Extension of control for photogrammetry

Extension of control

- Some of the field survey method for extension of control are:

a. Traditional Methods

- Traversing (through total stations and theodolite) for horizontal control and levelling for vertical control.

b. GNSS

- It includes using RTK receiver for extending control.

5.2 Pre pointing and post pointing

Pre-pointing

- In pre-pointing, ground control points are established on the ground before the aerial or satellite imagery is captured.
- These points are surveyed using traditional surveying techniques, such as GPS or total stations. and their coordinates of these points are precisely determined and recorded.
- During the flight the aircraft is oriented and positioned in a way that these ground control points are visible and can be identified in the imagery. By matching the known ground coordinates of these points with their corresponding locations in the imagery, the entire image is accurately georeferenced.

5.2 Pre pointing and post pointing

Post-pointing

- Post-pointing involves establishing ground control points after the aerial or satellite imagery has been captured.
- This method is often used when it's not feasible to pre-point due to factors such as inaccessible terrain or time constraints.
- Post-pointing typically involves identifying distinguishable features in the imagery that can be matched to known ground features or targets. These features are then surveyed using ground-based methods to determine their precise coordinates. The coordinates of these points are then used to georeference the imagery after it has been captured.

5.3 Properties of ideal GCP

Some of the properties of ideal GCP are as follows:

a. Identifiable and visible:

- A good GCP should be easily identifiable in the images or datasets being processed.
- It should be a distinct and recognizable feature, such as a road intersection, a building corner, or a unique natural feature.
- The GCP should be visible in multiple images if you are working with a set of images for mosaicking or change detection.

b. Well-distributed:

- To achieve optimal accuracy, GCPs should be well-distributed across the entire area of interest, ideally located at the corners and the center of the image.

5.3 Properties of ideal GCP

Some of the properties of ideal GCP are as follows:

b. Well-distributed:

Fig: showing spatial distribution of GCPs around project area.

Source: https://www.toolsforforesters.co.nz/__data/assets/pdf_file/0006/84804/TFF-SOP_GCP-Use_20221110.pdf

5.3 Properties of ideal GCP

Some of the properties of ideal GCP are as follows:

c. Stable and permanent:

- A good GCP should be a stable and permanent feature that remains unchanged over time, ensuring that it remains reliable for multiple temporal datasets or long-term studies.

d. Uniform shape:

- GCPs with uniform shapes, such as circular or rectangular objects, can be more accurately pinpointed in images, leading to better georeferencing results.
- Irregularly shaped objects can be harder to locate precisely.

e. Unambiguous location:

- A good GCP should have a clearly defined location, such as the center of a road intersection or the corner of a building.
- The coordinates of GCPs should be collected using high-precision GPS receivers or derived from reliable sources such as accurate maps, survey data, or other trustworthy datasets.

5.4 Planning for aerial photography

Planning for aerial photography

- Planning for aerial photography involves several critical steps to ensure successful outcomes, including understanding your objectives, selecting the right equipment, complying with regulations, considering environmental factors, and planning the actual flight

Some of the factors that are to be considered for flight or mission planning of aerial photography are as follows:

a) Purpose of photography
b) Photographic Scale
c) Overlap
d) Flying height
e) Crab and Drift
f) Weather conditions
g) Season of the year

.

5.4 Factors to be considered for flight planning

Some of the factors that are to be considered for filght or mission planning of aerial photography are as follows:

a. Purpose of photography

- In planning aerial photographic missions, the first and foremost consideration is the purpose for which the photography is being taken. Only with the purpose defined can optimum equipment and procedures be selected.
- If the purpose is topographic mapping or quantitative photogrammetric measurements are required then aerial photographs should have good metric qualities for which wide- or super-wide-angle (short-focal length) camera is needed.

.

5.4 Factors to be considered for flight planning

Some of the factors that are to be considered for filght or mission planning of aerial photography are as follows:

b. Photographic Scale

- It is the ratio of focal length to the flying height (f/H).
- Average photographic scale is one of the most important variables that must selected in planning aerial photography and is generally fixed within certain limits by specific project requirements.
- For topographic mapping, photo scale is usually dictated by the map’s required scale and/or horizontal and vertical accuracy and for other purposes depending upon the requirements different lens/focal length/film/filter combination can be used.

.

5.4 Factors to be considered for flight planning

Some of the factors that are to be considered for filght or mission planning of aerial photography are as follows:

c. Flying height

- As the altitude increases, the ground sample distance (GSD) increases, which means each pixel in the image represents a larger area on the ground which results in lower image resolution. So, flying height is an important factor during aerial mission planning.
- It's value is automatically fixed in accordance with value of focal length and scale of aerial photograph.

d. Overlap:

- It is the amount by which one photograph includes the area covered by another photograph, and is expressed as a percentage.
- It is essential for an aerial photograph to have enough side and end overlap for good mosaic, removal of errors due to distortion , displacement & tilt and overall good photogrammetric products.

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5.4 Factors to be considered for flight planning

Some of the factors that are to be considered for filght or mission planning of aerial photography are as follows:

d. Overlap:

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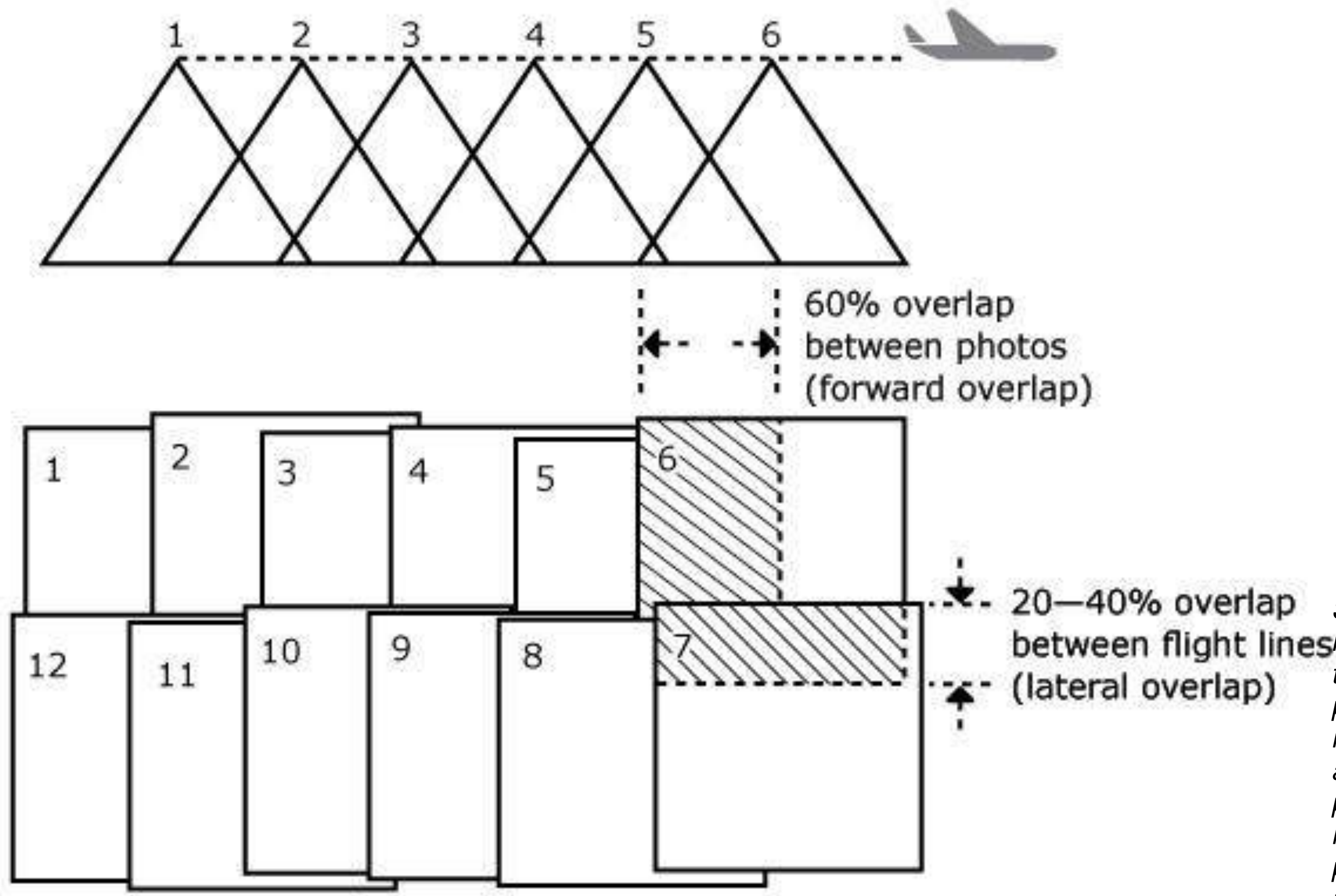


Source: https://natural-resources.canada.ca/maps-tools-and-publications/satellite-imagery-elevation-data-and-air-photos/air-photos/national-air-photo-library/about-aerial-photography/concepts-aerial-photography/9687

5.4 Factors to be considered for flight planning

Some of the factors that are to be considered for filght or mission planning of aerial photography are as follows:

e. Weather conditions

- For flight planning, it's essential to have good visibility i.e clear skies with minimal cloud cover.
- A sunny day with low winds is ideal for aerial photography. The sun provides a natural light source for the camera, which can improve the quality of the images and low winds also makes it easier to control the aerial vehicle and keep it stable.

f. Season of the year:

- The season of the year is a limiting factor in aerial photography because it affects ground cover conditions and the sun’s altitude.
- If photography is being taken for topographic mapping, the photos should be taken when the deciduous trees hold leaves, so that the ground is not obscured by leaves.
- Aerial photography is not taken when the ground is snow-covered. Heavy snow not only obscures the ground but also causes difficulties in interpretation and in stereoviewing.

End lap

- The amount of end lap of a stereopair is commonly given in percent. Expressed in terms of G and B, it is

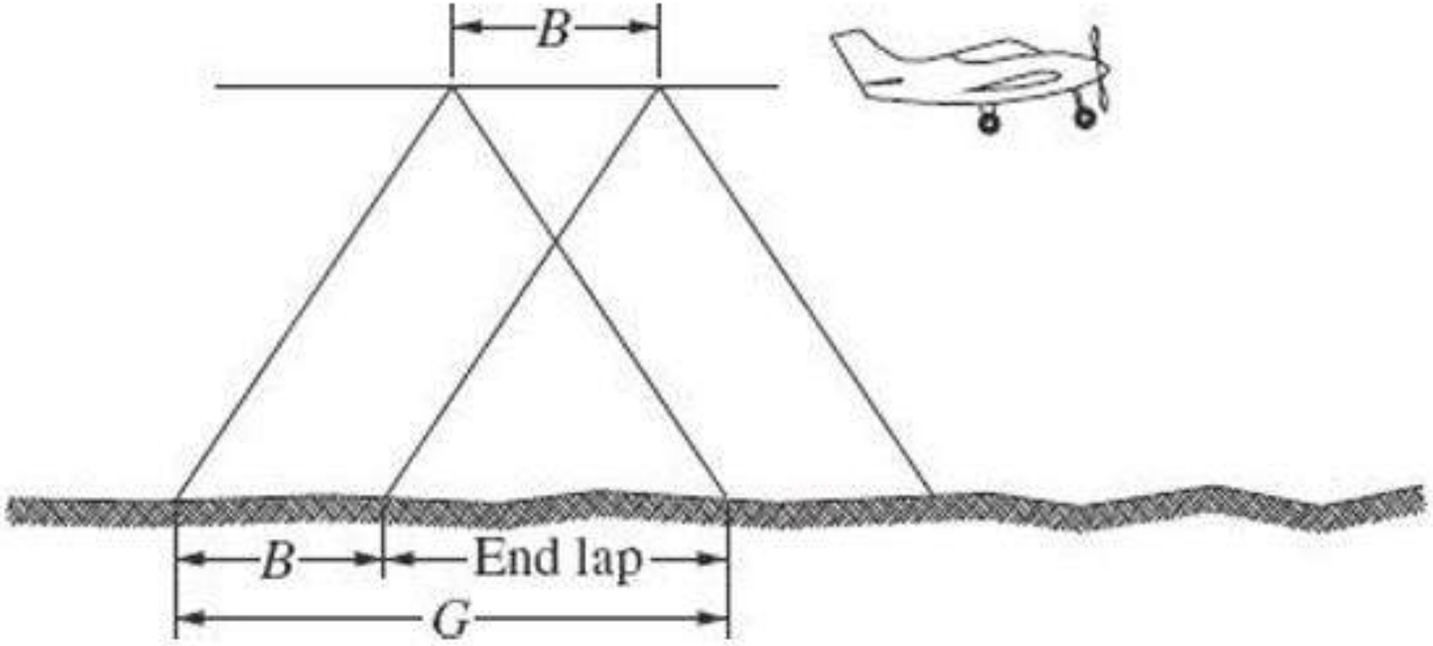
$$PE = \frac{G - B}{G} \times 100$$

Where,

G = dimension of the square of ground coverage of a single vertical photograph

B = airbase or distance between exposure stations of a stereopair.

PE = Percent end lap



Source: Elements of photogrammetry.

Side lap

- The amount of side lap of a stereopair is commonly given in percent. Expressed in terms of G and W, it is

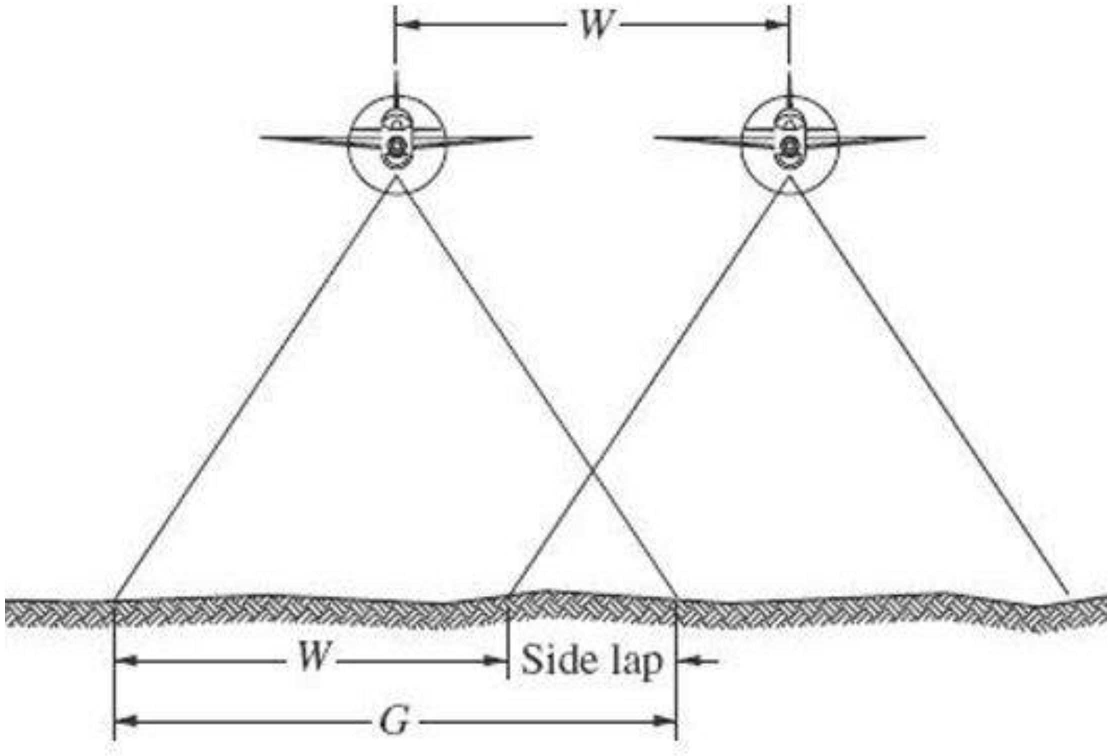
$$PS = \frac{G - W}{G} \times 100$$

Where,

G = dimension of the square of ground coverage of a single vertical photograph

W = spacing between adjacent flight lines

PS = Percent side lap



Source: Elements of photogrammetry.

5.4 Factors to be considered numerical examples

Numericals

Overlap

1. The air base of a stereopair of vertical photos is 1400 m, and flying height above average ground is 2440 m. The camera has a focal length of 152.4 mm and a 23-cm format. What is the percent end lap? (Ans: 62%)

Flying height

2. Aerial photography having an average scale of 1:6000 is required to be taken with a 152.4 mm-focal-length camera over terrain whose average elevation is 425 m above mean sea level. What is required flying height above mean sea level? (Ans: 1340 m above sea level)

Coverage

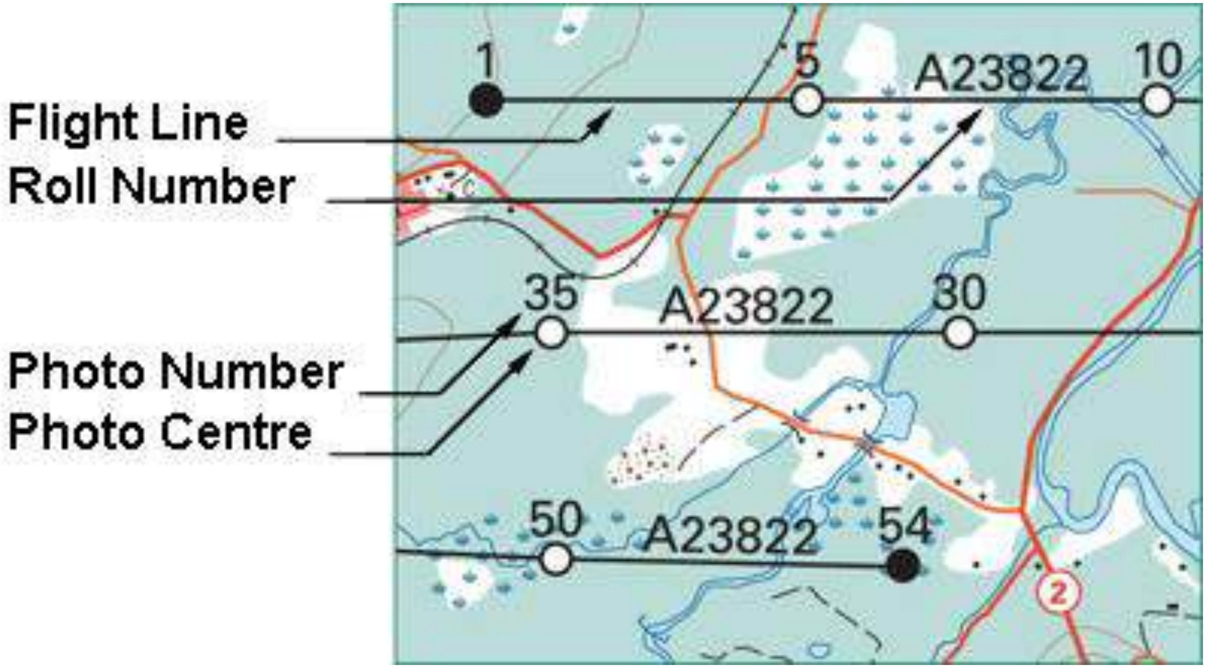
3. Aerial photography is to be taken from a flying height of 6000 ft above average ground with a camera having a 6-in (152.4-mm) focal length and a 9-in (23-cm) format. End lap will be 60 percent, and side lap will be 30 percent. What is the ground area covered by a single photograph

(Ans: 1900 acres)

5.5 Indexing of aerial photographs on a map

Photo index

- The photographs are laid in such a sequence as to allow photo number and flight number of each photograph to appear on the finished assembly. This assembly is called an index mosaic or photo index mosaic.
- They are prepared for the purpose of providing an index to the individual photographs.
- The margin of each photograph is clearly labeled so that the observer can quickly determine which piece covers a particular area.



Source: https://natural-resources.canada.ca/maps-tools-and-publications/satellite-imagery-elevation-data-and-air-photos/air-photos/national-air-photo-library/about-aerial-photography/concepts-aerial-photography/9687.

References

Control points:

https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2018/Drones-in-agriculture/asptraining/A_ground_control_for_UAV_mapping.pdf

Ideal properties of GCPs:

https://mapscaping.com/ground-control-points/

Flight planning

https://epgp.inflibnet.ac.in/epgpdata/uploads/epgp_content/S000017GE/P001788/M027029/ET/1517207018AERIALPHOTOGRAPHY(2.pdf

PHOTOGRAMMETRY

EG 3101 GE

Unit 6: Analogue/Analytical Photogrammetric Process

Public Secondary School

Lecture by

Er. Keshav Raj Bhusal

Table of contents

6.1. Orientation: Interior orientation, relative orientation, absolute orientation

6.2. Aerial Triangulation

6.3. Mapping : Concepts and photo interpretation elements, feature extraction and compilation

6. Concept of coordinate system

Relation between Camera, Ground and Image in coordinate system

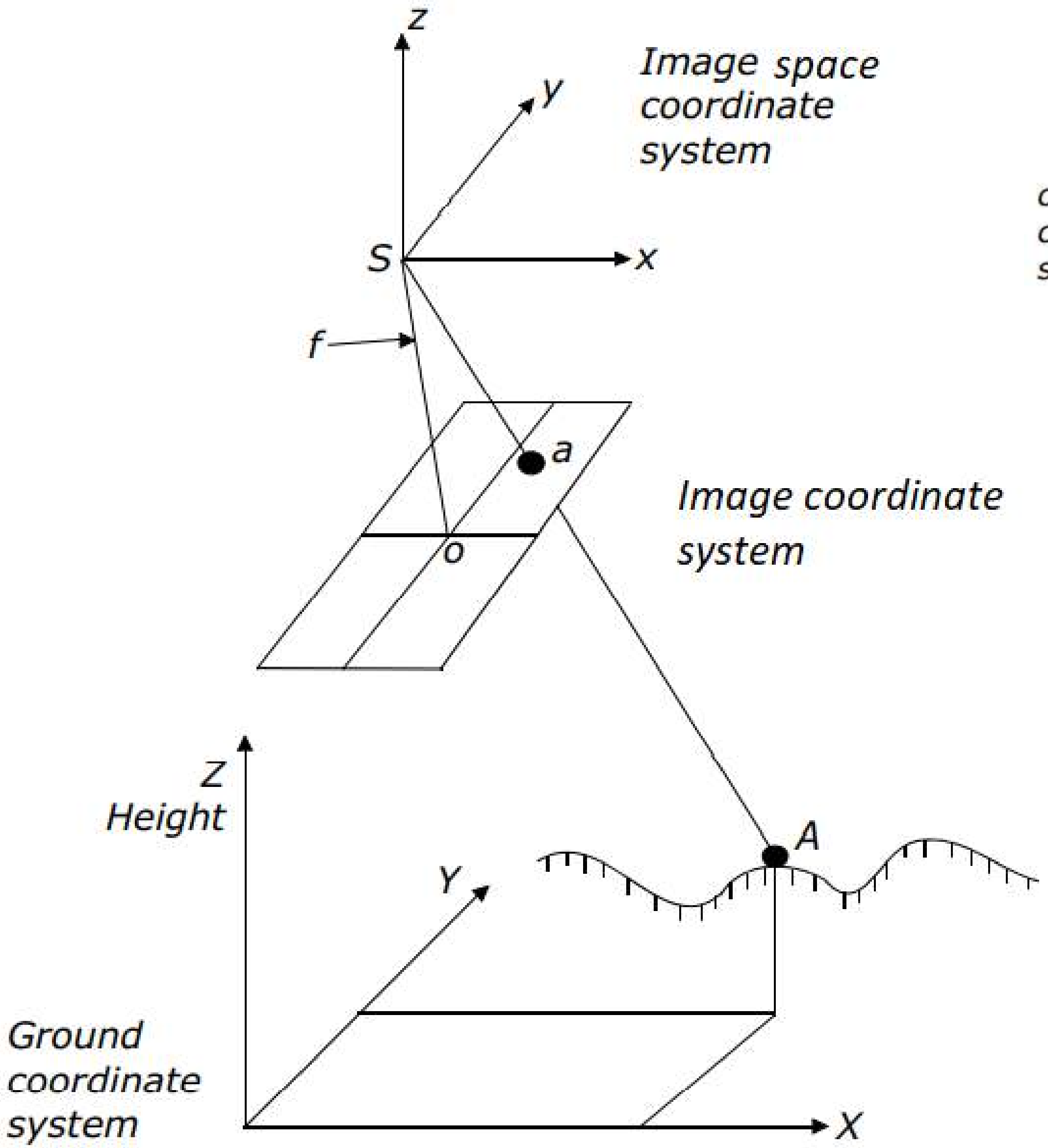


Fig1: showing relation between Camera, Ground and Image itself; here S is the lens(perspective center) of the camera, a is the position in image of ground object A

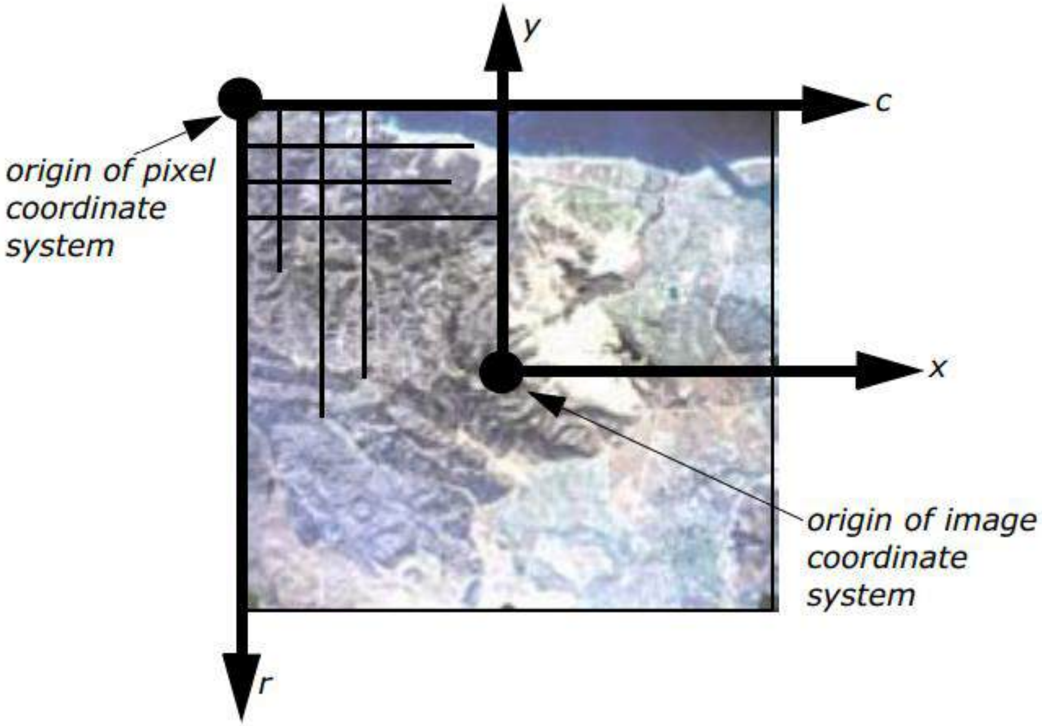


Fig 2: showing relation between pixel coordinate system and image coordinate system

6. Concept of coordinate system

Image space coordinate system (camera coordinate system or photo coordinate system)

- Identical to image coordinate system, except it adds a third axis: z-axis.
- The origin of this system is defined at the perspective center.
- x-axis and y-axis are parallel to the x-axis and y-axis in the image coordinate system, while the z-axis is the optical axis which means, z-value of an image point in this system is usually equal to the focal length (f) of the camera as shown in fig1.
- Describe positions inside the camera, and usually measured in millimeters or microns. Therefore, it is also known as camera coordinate system.
- It is a 3D Cartesian coordinate system.

6. Concept of coordinate system

Image coordinate system

- An image coordinate system or an image plane coordinate system is usually defined as a two-dimensional (2D) coordinate system occurring on the image plane with its origin at the image center.
- The origin of the image coordinate system is also referred to as the principal point.
- On aerial photographs, the principal point is defined as the intersection of opposite fiducial marks as illustrated by axes x and y in Figure 2.
- Image coordinates are used to describe positions on the film plane.

6. Concept of coordinate system

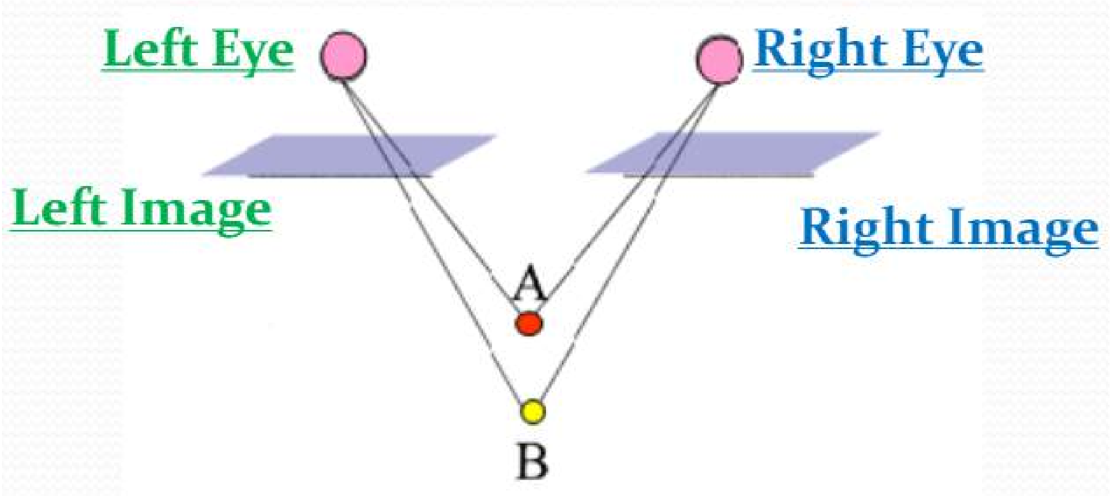
Ground coordinate system (*also called object space coordinate system*)

- A ground coordinate system is usually defined as a 3D coordinate system that utilizes a known geographic map projection.
- Ground coordinates (X,Y,Z) may be local or global system and are usually expressed in feet or meters. The Z value is elevation above mean sea level for a given vertical datum. See fig1
- When it is used as global system, the origin can be the Earth's center of mass (geocentric system) or some convenient local point with respect to known map projection (topocentric system).
- Photogrammetrically compiled data or the control point coordinates are usually available in <u>geocentric (Φ,λ,h)</u> or <u>topocentric (x, y, h)</u> coordinate system, but these have to be transformed into Cartesian system to serve as object space coordinate system for photogrammetry

6.1. Photogrammetric Orientations

Stereo restitution

- Stereo restitution in photogrammetry refers to the process of obtaining three-dimensional information about an object or scene by analyzing pairs of overlapping images captured from different angles.
- It involves the use of stereo vision, which is the ability to perceive depth by combining two slightly different views of the same scene.
- Stereo restitution in photogrammetry can be performed using a variety of techniques, including manual measurement, semi-automatic feature matching, and fully automatic algorithms. The choice of method depends on factors such as the complexity of the scene, the level of accuracy required, and the availability of software tools and hardware resources.



Source: https://www.kau.edu.sa/Files/0007183/Subjects/GEOM101%20_%20Lecture%205%20-%20%20Photogrammetry.pdf

6.1. Photogrammetric Orientations

Stereo restitution

The process comprises of the following:

i. Interior orientation

ii. Exterior orientation (Relative and Absolute orientation)

6. Photogrammetric Orientations

Theory of Orientation

- Orientation is the procedure through which transformation parameters from one coordinate system to a second coordinate system are determined.
- Fundamental operations in photogrammetry.
- It refers to the process of determining the position and orientation of the camera or sensor that captured an image relative to the objects being photographed.
- This is crucial for accurately reconstructing three-dimensional information from two-dimensional images.
- In photogrammetry, orientations are described as interior and exterior or relative and absolute.

6.1 Photogrammetric Orientations

Interior(Inner) orientation

- IO is the procedure whereby the geometric characteristics of an aerial photograph are mathematically related to the geometric characteristics of the camera.
- Interior orientation is primarily used to transform the image pixel coordinate system or other image coordinate measurement system to the image space coordinate system.
- Interior orientation defines the internal geometry of a camera or sensor (camera characteristics) as it existed at the time of image capture.
- For a frame camera, the internal geometry of the camera includes:

i. Focal length

ii. Location of fiducial marks

iii. Location of principal point in the image plane

iv. Description of lens distortion

- In case of digital metric camera, the camera characteristics include.

i. Focal length

ii. Pixel size

- These information are obtained from camera calibration report.

Interior(Inner) orientation

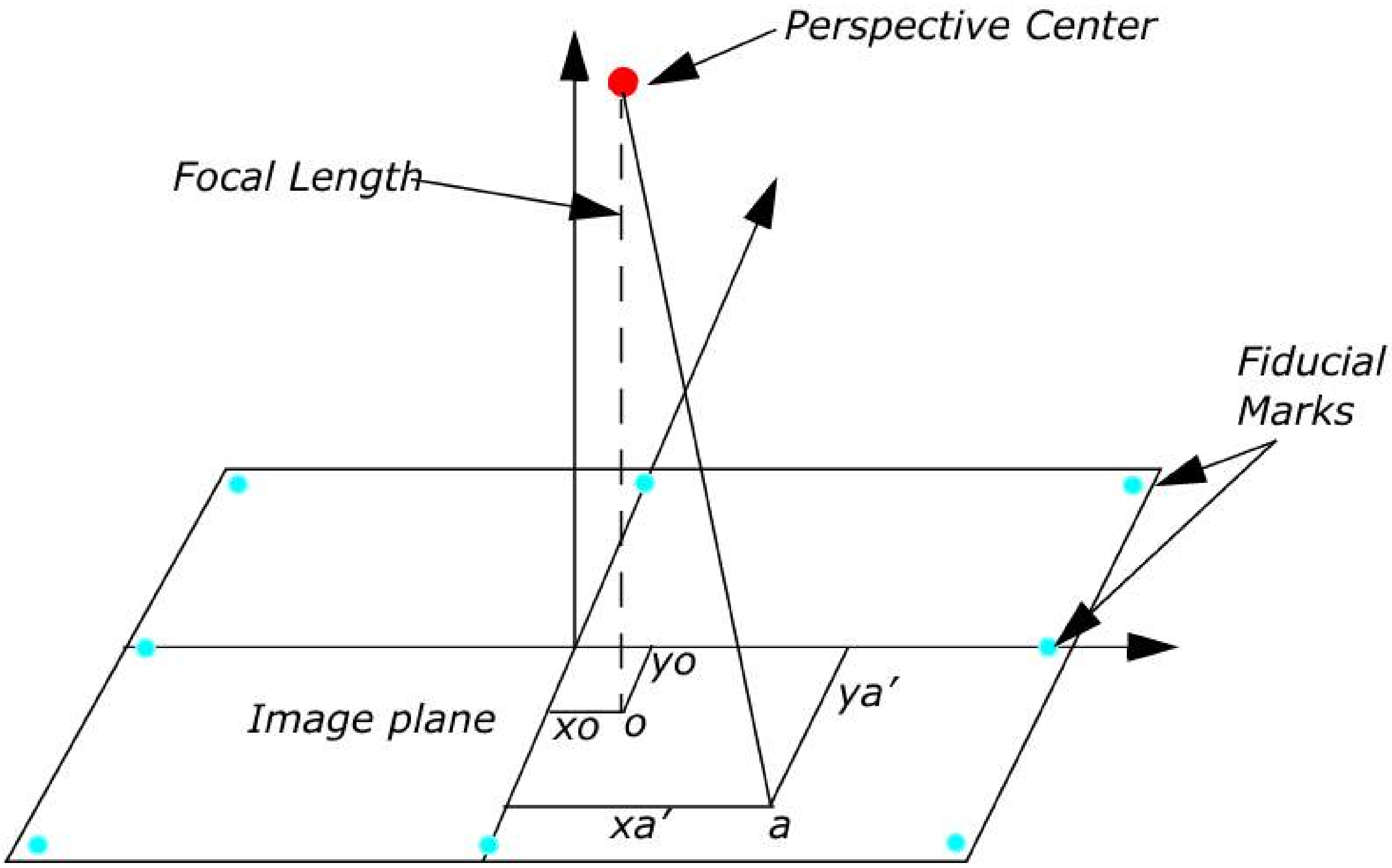


Fig: illustrates the variables associated with the internal geometry of an image captured from an aerial camera, where o represents the principal point and a represents an image point.

6.1 Photogrammetric Orientations

Exterior orientation

- EO determines the mathematical relationship between image coordinates (x, y, z) and real-world ground coordinates (X, Y, Z).
- It involves defining the position and angular orientation of the camera that captured the image.
- There are six parameters (3D coordinates of the perspective center wrt ground coordinate system and 3 rotations around the image space coordinate axes) of EO that express the spatial location and angular orientation of the image.
- The positional elements of exterior orientation include Xo, Yo, and Zo. They define the position of the perspective center (O) with respect to the ground space coordinate system (X, Y, and Z). Zo is commonly referred to as the height of the camera above sea level, which is commonly defined by a datum.
- The angular or rotational elements of exterior orientation describe the relationship between the ground space coordinate system (X, Y, and Z) and the image space coordinate system (x, y, and z). Three rotation angles are commonly used to define angular orientation. They are omega, phi , and kappa.

Exterior orientation

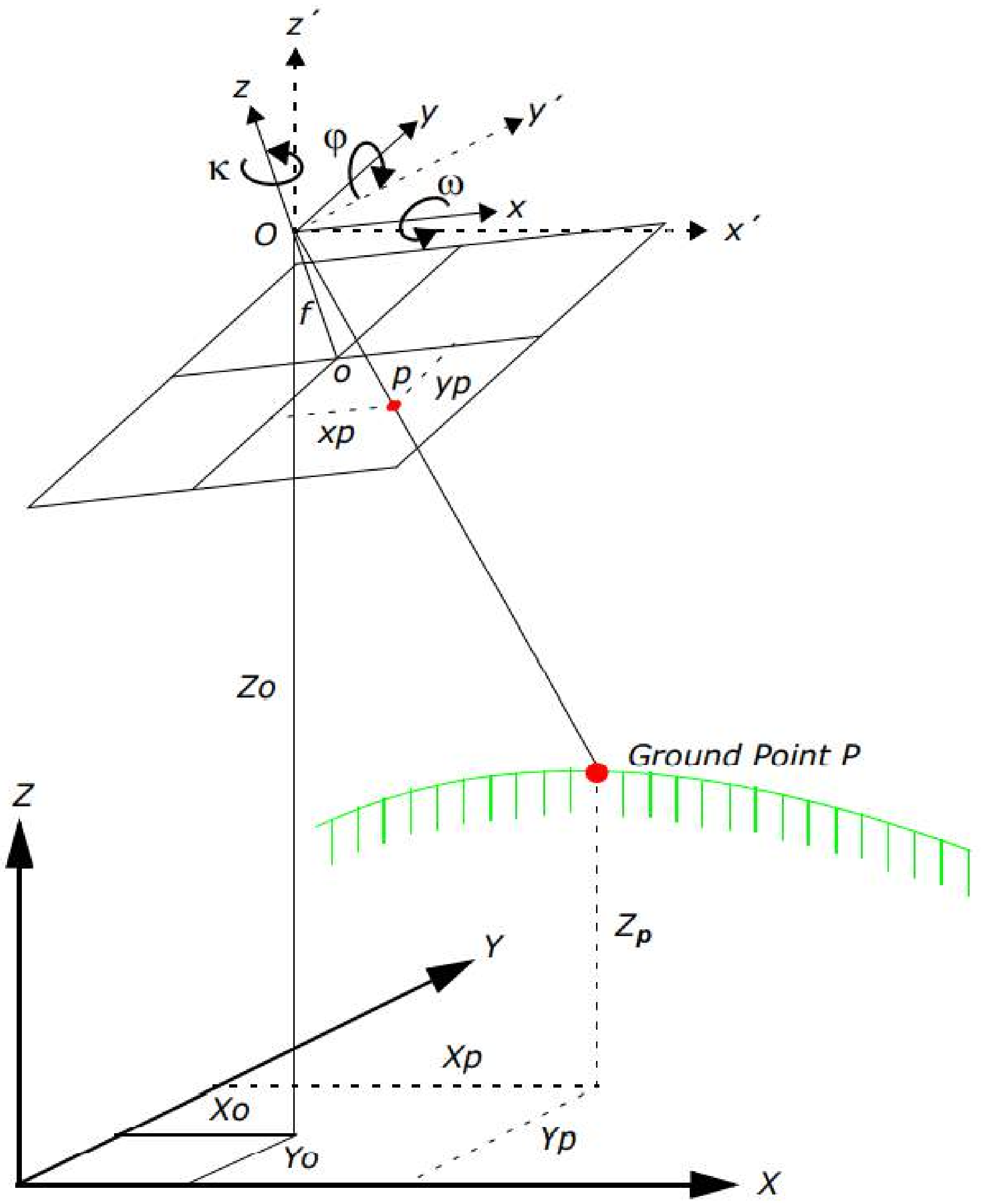


Fig: showing elements of exterior orientation; angular element: omega , phi , and kappa and positional element X_{O}, Y_{O}, Z_{O}

6.1 Photogrammetric Orientations

Exterior orientation

- Unlike interior orientation, EO requires that the control points to be located in both images of stereo pair.
- Exterior orientation parameters can be derived in one of three ways: (1) direct space resection (2) relative orientation followed by absolute orientation. (3) simultaneous orientation by bundle adjustment.
- For resection, at least 3 controls are required and shall be well distributed in each image.
- Knowing the six exterior orientation parameters for an image is necessary for any photogrammetric processing aimed at creating products from such an image. Whether you perform map compilation on a stereo plotter or generate an ortho image, the six exterior orientation parameters need to be computed before you start the production process.

6.1 Relative and Absolute orientation

Relative Orientation (RO)

- It is the process of establishing the relationship between two consecutive photographs or images at it existed at the time of exposure to form the stereo model.
- It involves the determination of the position and attitude of one of a pair of stereo images with respect to another.
- This process orients one image relative to another image.
- Can be performed with more than 2 images in a sequential procedure, once the 1st pair of images is relatively oriented. In this process each successive image is oriented to its preceding image.
- It is the basis of independent model block adjustment.
- Relative orientation is based on the coplanarity condition that two image points on a stereopair, the perspective centers of the two images, and the object point lie on the same plane.
- Relative orientation is an important process that must be performed before we scale the imagery to the ground datum through the process of absolute orientation. To form a cohesive block, all images in the block should be relatively oriented with respect to each other through the process of relative orientation.

6.1 Relative and absolute orientation

Absolute Orientation

- Absolute orientation in photogrammetry is the process of transforming a photogrammetric model, which is initially in an arbitrary coordinate system, into a real-world coordinate system.

6.1 Relative and absolute orientation

Absolute Orientation

- Absolute orientation is a 3-D conformal transformation that converts the model coordinates obtained during the relative orientation into correctly oriented mapping coordinates.
- There are seven parameters in this 3-D conformal transformation, including three rotation angles $R\omega$, $R\phi$, and $R\kappa$, three translation components T_X, T_Y, and T_Z, and a scale factor s.
- In this process at least three control points with known horizontal and vertical positions are necessary to achieve a result.
- The accuracy of absolute orientation depends on the quality of the relative orientation and the accuracy of the control points.
- Without performing the absolute orientation process, the generated map would not be specifically associated with a certain location in space. Generating maps that have geo-location information such as datum and coordinates systems can only happen after the process of absolute orientation is performed following relative orientation.

The relative and absolute orientations can be performed on an individual stereopair or on complete image blocks covering a large area. In the latter case, the term aerial triangulation is often used to describe the procedure.

Absolute Orientation

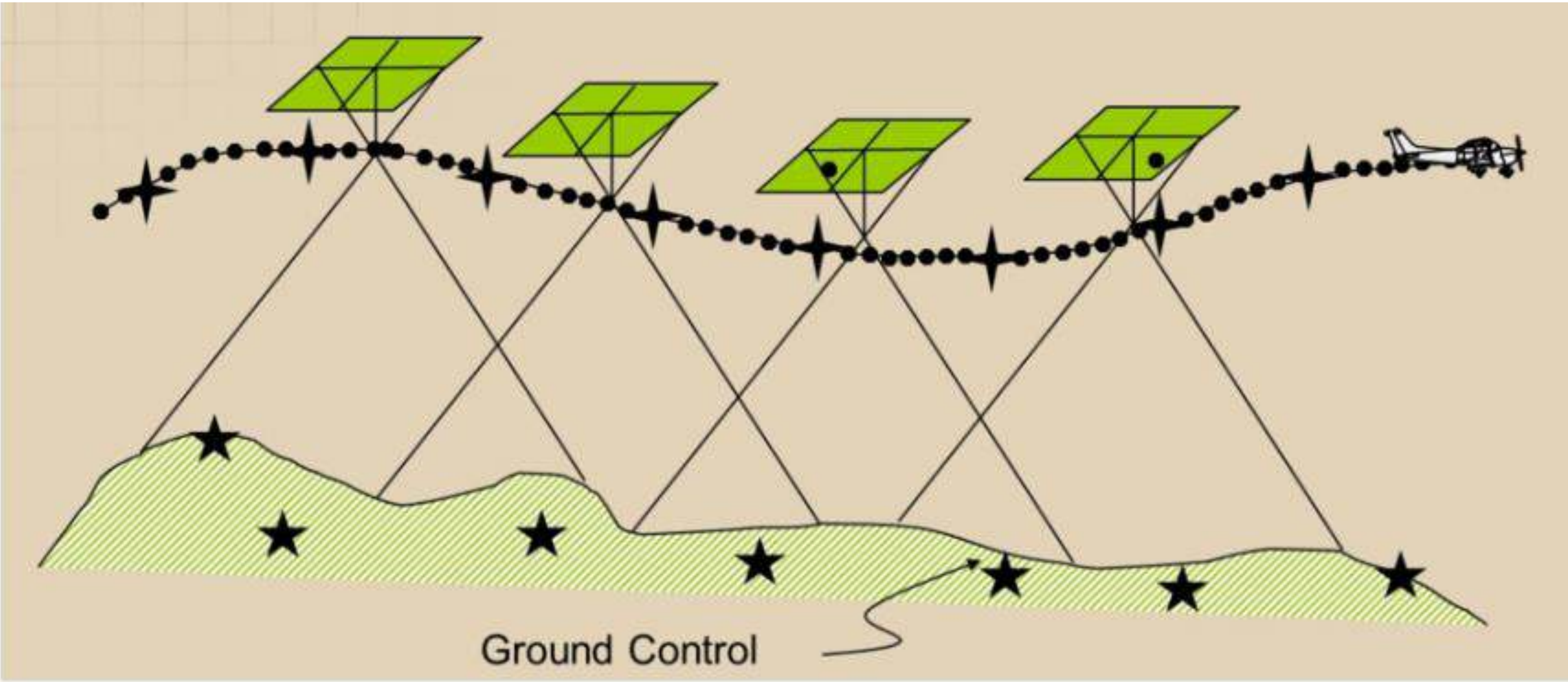
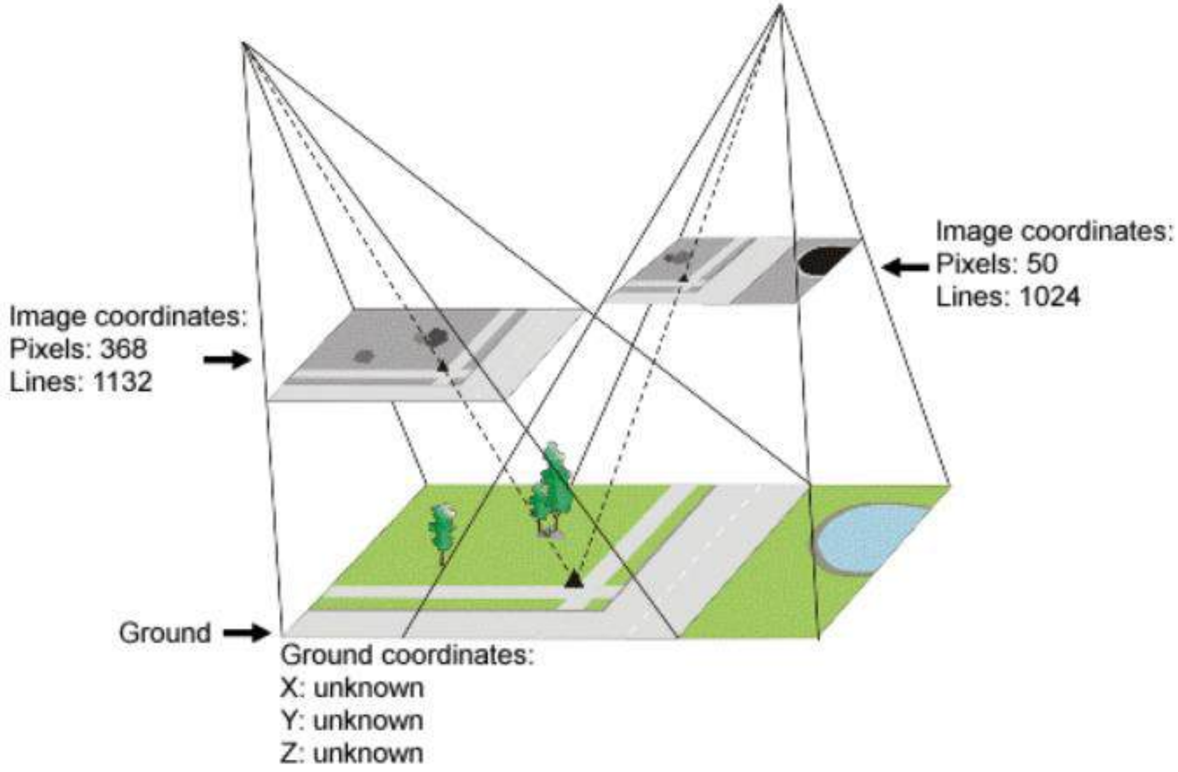


Fig: showing images being tied up to the ground with seven ground controls

Tie Points

- Points that appear in overlapping images which are used to establish the geometric relationship between the adjacent image.
- It is usually expressed as a pair, tie points can be used to link images and create mosaics.
- Tie points can be measured both manually and automatically.
- These are supplementary control points selected to connect strips of photographs together to form a block.



Source: https://catalyst.earth/catalyst-system-files/help/COMMON/concepts/TiePoint_explain.html

Tie Points

Fig 5.4: showing join of several images through tie points

6.2 Aerial triangulation

Aerial triangulation

- Aerial triangulation or aero-triangulation is the process of determining the real world(ground) X, Y and Z coordinates of individual points based on photo coordinate measurements.
- Photogrammetric triangulation or photo-triangulation is a more general term as it can be applied to terrestrial photos as well as aerial photos.
- One of the principal application lies in extending or densifying of a sparsely distributed horizontal and vertical control network through:

i. measurements performed on overlapping aerial photographs,

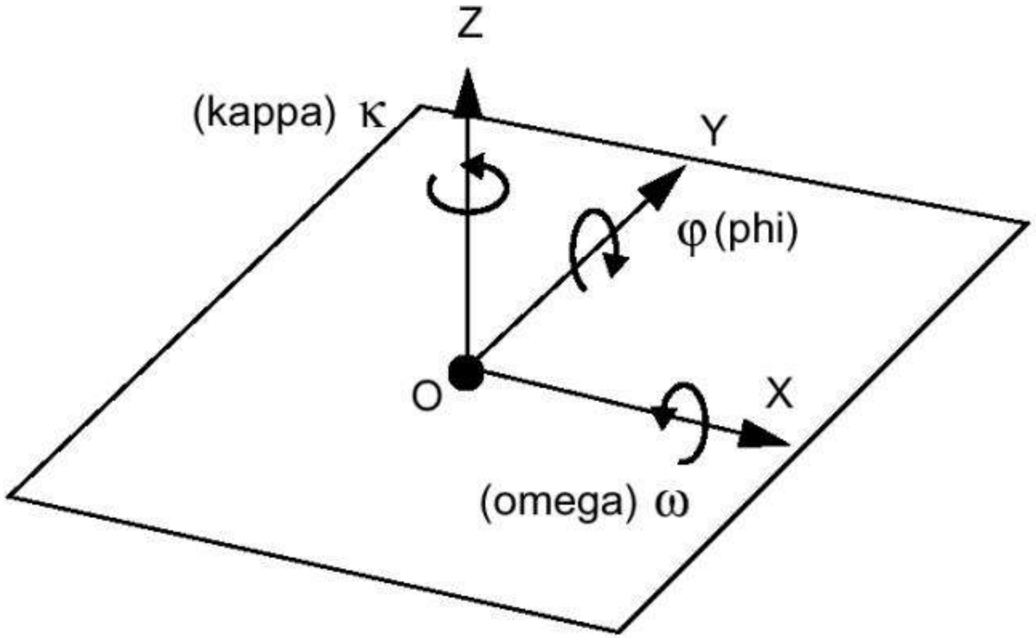
ii. known ground control points coordinates on the ground, and

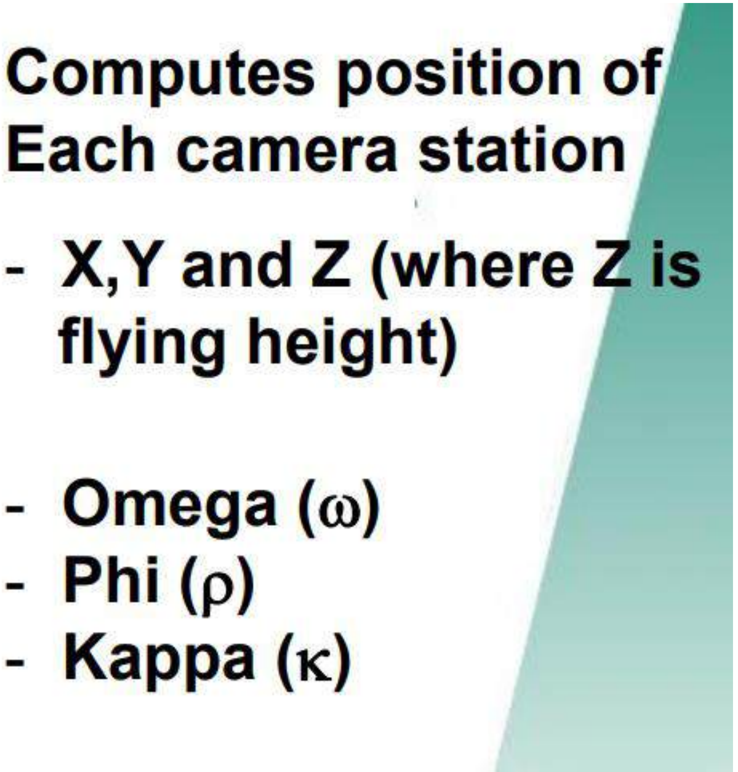
iii. mathematical modeling and solution

- The process of densification involves establishment of intermediate control points between the field surveyed control that exist in only a limited number of photos in a strip or block.
- Also called bridging in a sense a bridge of intermediate controls are developed.

What it does?

- Computes coordinate values for any point measured on two or more images (tie points).
- Computes positions and orientation for each camera station through exterior orientation.





Source: http://drm.cenn.org/Trainings/Generation%20of%20geodatabases%20using%20ARCGIS%20and%20ERDAS/Lectures/Introduction%20on%20Photogrammetry.pdf

6.2 Aerial triangulation

Why we need Aerial triangulation?

Advantages(Besides having cost advantage over field surveying, aero-triangulation has other benefits as well)

i. It minimizes delay and hardship due to adverse weather conditions as aerial triangulation is done in lab.

ii. Access to the property within a project area is not required.

iii. Surveying in difficult areas (like marshes, extreme slopes, and hazardous rock formations) minimized.

iv. Accuracy of field survey (ground control) can be checked with the help of controls generated through aero triangulation.

Why we need Aerial triangulation?

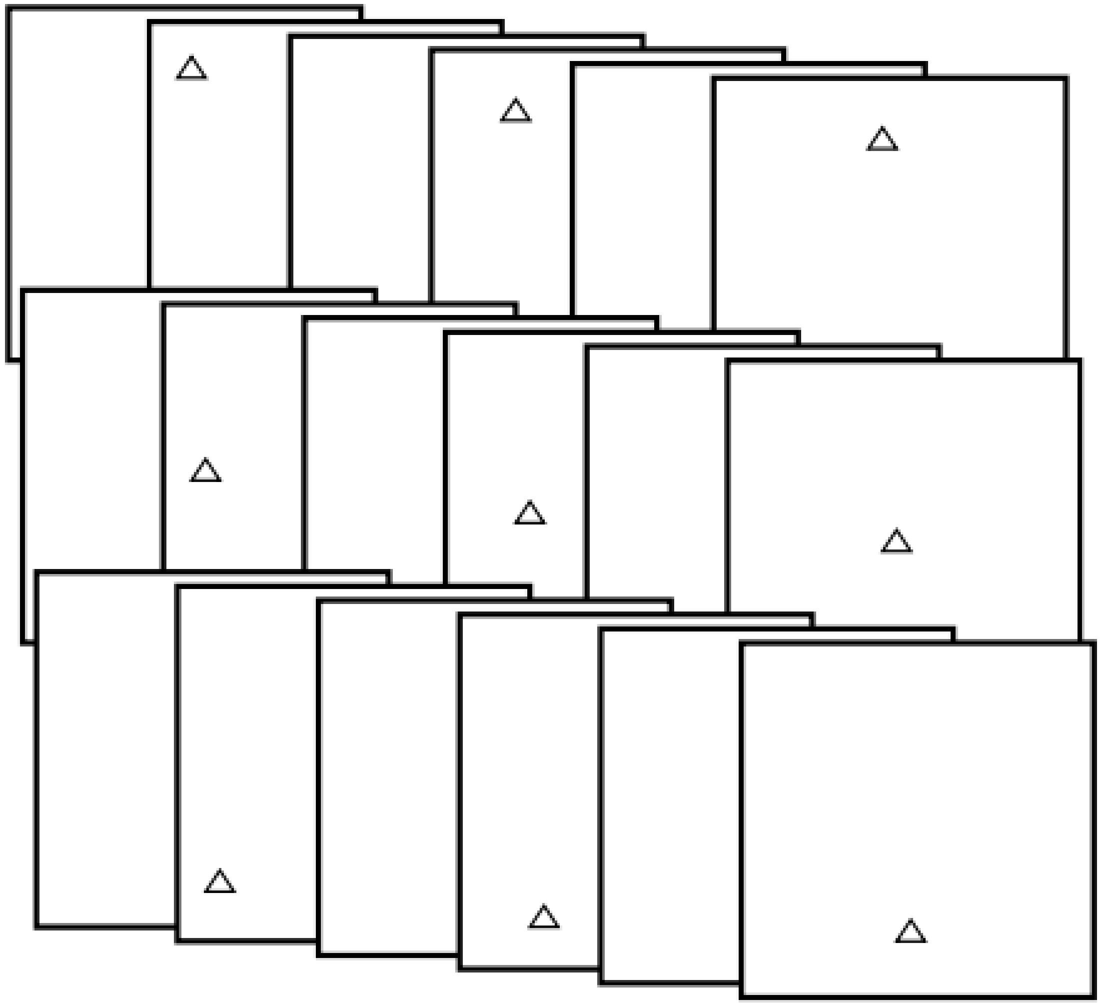


Fig 1: showing concept of strips and blocks. Triangles symbolize existing control point which are later densified through aero triangulation process.

Unit 6.3 : Photo interpretation elements

Photo/Image interpretation

- It is a process of examining and extracting useful information from aerial photographs.
- It involves studying and gathering the information required for identifying the various cultural and natural features and consists of points, lines, or polygons.
- Photo interpretation is easy in oblique photographs than the vertical photographs.
- The reliability of information collected from aerial photographs depends on the quality of aerial photographs, instruments used for interpretation, working conditions and personal experience with photo interpretation techniques.
- Preliminary knowledge of the area of interest which comprises of its geographic location, past and present climate conditions, vegetation and published literature are always useful for accurate identification of features.

Unit 6.3 : Photo interpretation elements

Factors affecting Photo/Image interpretation

- Training ,skills and experience of the interpreter possessed.
- Characteristics of the objects or features on the photographs to be studied.
- Quality of photographs being used.
- Proper selection of emulsion , scale of photographs, season of flight and time of day.

Unit 6.3 : Photo interpretation elements

Elements of Photo interpretation

1. Shape:

- Shape refers to general form, structure, or outline of individual objects.
- Regular geometric shapes are usually indicators of human presence and use.

✓ Agricultural areas tend to have geometric shapes like rectangles and squares.

✓ Streams are linear (line) features that can have many bends and curves.

✓ Roads frequently have fewer curves than streams.

- Some objects like buildings, playground, river etc. can be identified almost solely on the basis of their shapes.

2. Texture

- It refers to the "smoothness" or "roughness" of image features.
- It is caused by the amount of change of tone in photographs. Grass, cement, and water generally appear "smooth", while a forest canopy may appear "rough".

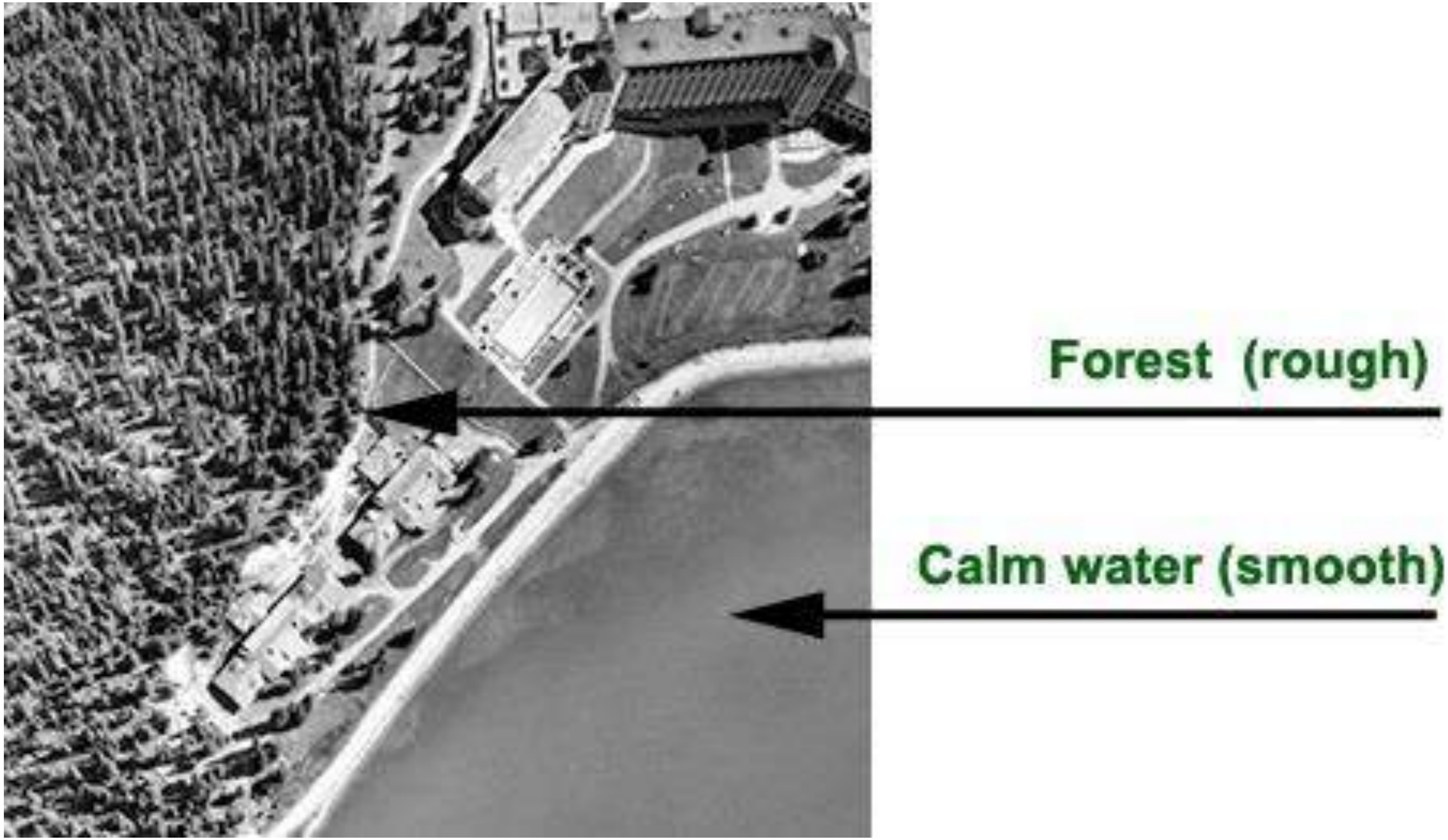
Elements of Photo interpretation

1. Shape:

Source:https://jimcoll.github.io/classes/geog111/labs/lab10/

Elements of Photo interpretation

2. Texture



Source:https://www.nrcan.gc.ca/maps-tools-publications/satellite-imagery-air-photos/air-photos/national-air-photo-library/about-aerial-photography/introduction-air-photo-interpretation/9689

Elements of Photo interpretation

3. Size:

- The size of objects must be considered in the context of the scale of a photograph.
- The scale will help you determine if an object is a small pond or a large lake. Major highways can be distinguished from smaller roads. Long rivers can be distinguished from smaller tributaries.

4. Tone

- Tone refers to the colour or relative brightness of an object in colour image and the relative and quantitative shades of gray in black and white image.
- The tonal variation is due to the reflection, transmission or absorption characteristic of an object.
- Tone is one of the most basic elements because it is difficult to recognize other elements without tonal differences.

Elements of Photo interpretation

4. Tone

Source: http://keshavraj bhusal.com.np/

Elements of Photo interpretation

5. Shadow:

- Shadow is an especially important clue in the interpretation of objects. the outline or shape of a shadow provides a profile view of objects, relative height of a target which aids in image interpretation.
- The disadvantage of shadow is objects within shadow reflect little light and are difficult to recognize on image, which hinders interpretation.

Unit 6.3 : Photo interpretation elements

Elements of Photo interpretation

6. Association:

- It refers to the occurrence of certain features in relation to others.
- Sometimes objects that are difficult to identify on their own can be understood from their association with objects that are more easily identified.
- It takes into account the relationship between other recognizable objects or features in proximity to the target of interest.
- For example a lake is associated with boats and adjacent recreational land, airport with planes, runway etc.

7. *Site*:

- It refers to location of object in relation to its geographic or topographic setting.
- For example, certain vegetations or tree species are expected to occur on well drained uplands or in certain countries), man made features may also be found on rivers (e.g. power plant) or on a hill top (observatory or radar facility) etc.

Elements of Photo interpretation

6. Association:

Source: https://speaklounge.files.wordpress.com/2013/09/f930f-flight-line-2010-04-24.jpg

Unit 6.3 : Photo interpretation elements

Elements of Photo interpretation

8. *Pattern*:

- Pattern is the spatial arrangement of objects.
- Typically orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern.
- Pattern can be either man-made or natural.
- Orchards with evenly spaced trees and urban streets with regularly spaced houses are good examples of pattern.

Elements of Photo interpretation

8. *Pattern*:

6.3 Feature extraction and compilation

Feature extraction

- Feature extraction is the process of extracting the required topographic or planimetric features from photograph.

Main Steps in Feature Extraction:

i. Image Interpretation
ii. Detail Classification
iii. Digitization (2D or 3D)

a. Image Interpretation:

i. Spontaneous recognition: It is the detail type which is familiar and can be identified easily e.g. building, river
ii. Logical inference: It is the detail which are not easily identified are interpreted by applying logical inference e.g. colour, shape, size, pattern, texture, orientation/location, association etc.

6.3 Feature extraction and compilation

Feature extraction

b. Detail Classification

- There may be different types of details on the photographs and can be classified according to their common characteristics:
- For example, different types of buildings like residential, commercial, industrial, school, hospitals can be put together in a class ”Building”. Similarly, highway, motorable, cycle track, foot trails can be categorised as ” Road”
- As these extracted information can be used as GIS layers, so this type of classification plays important role for further data management.

c. Digitization

- After classifying features digitizing rules should be followed for point, line and area features.
- The features should be digitized under the same feature classes.

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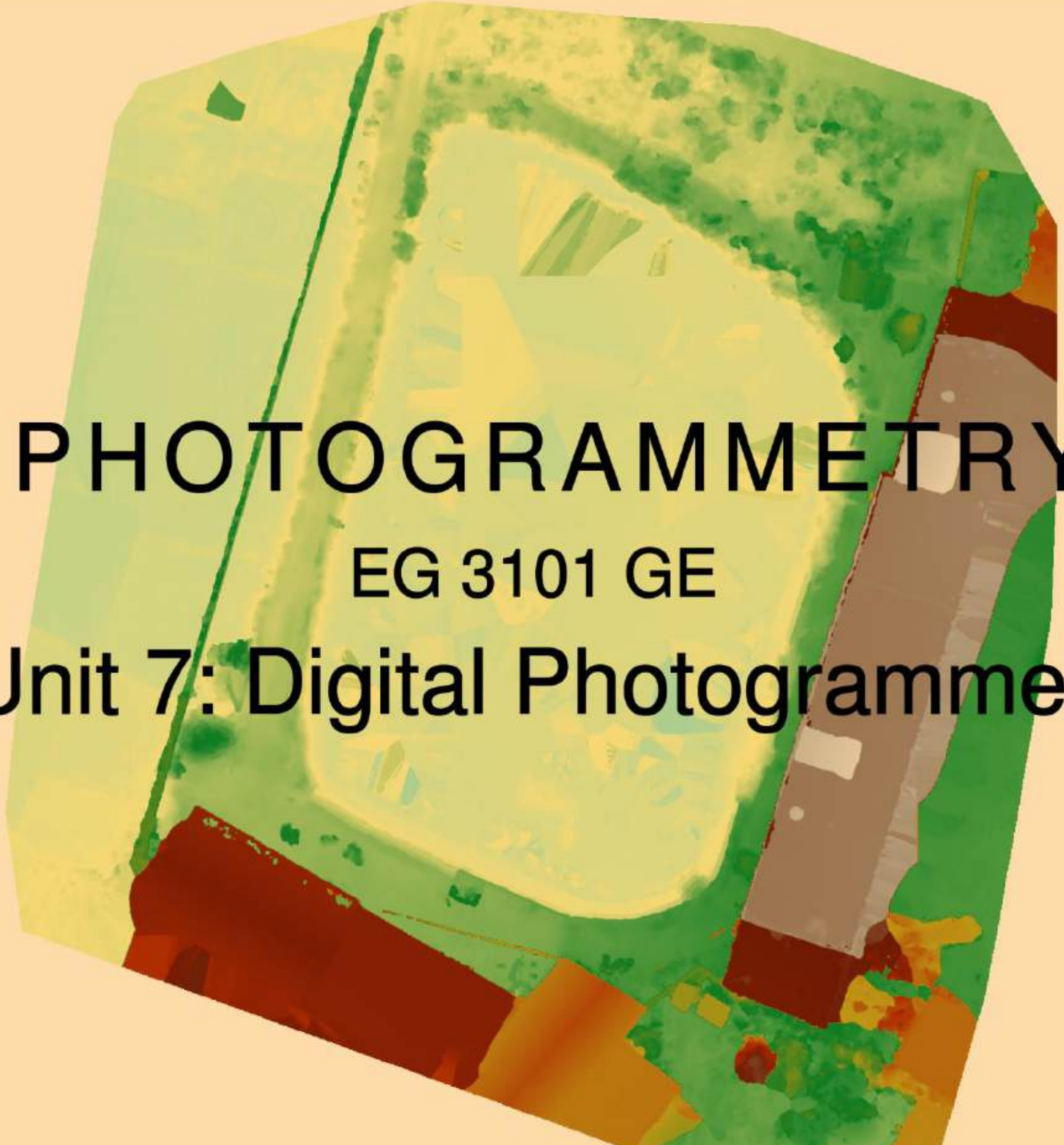

PHOTOGRAMMETRY

EG 3101 GE

Unit 7: Digital Photogrammetry

Public Secondary School

Lecture by

Er. Keshav Raj Bhusal

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7.9. 2D and 3D feature extraction

7.1. Digital Photogrammetry and its advantages

Digital photogrammetry

- It is a photogrammetry applied to digital images that are stored and processed on a computer. Digital images can be scanned from photographs or directly captured by digital cameras.
- Digital photogrammetry is sometimes called softcopy photogrammetry.
- In digital photogrammetry, softwares are used for photogrammetric tasks and is highly automated e.g automatic DEM extraction, digital orthophoto generation etc.
- The output products are in digital form, such as digital maps, DEMs, and digital orthoimages saved on computer storage media.

7.1. Digital Photogrammetry and its advantages

Advantages of Digital photogrammetry

a. Increased Accuracy:

- Digital photogrammetry allows for high precision and accuracy in measurements.
- Advanced software algorithms can process images to correct for distortions and improve the reliability of the data.

b. Efficiency and Speed:

- Processing digital images is much faster compared to traditional photogrammetry.
- Automated processes and powerful computers can handle large datasets quickly, reducing the time required for analysis.

c. Cost-Effectiveness:

- Digital methods can reduce costs associated with film, chemical processing, and manual labor.

7.1. Digital Photogrammetry and its advantages

Advantages of Digital photogrammetry

d. Ease of Data Storage and Management:

- Digital images and data can be easily stored, copied, and managed on various digital storage media. This facilitates better data organization, archiving, and sharing.

e. Enhanced Visualization:

- Digital methods provide superior visualization capabilities. 3D models, orthophotos, and digital terrain models (DTMs) can be created and manipulated easily, offering detailed and interactive representations of the surveyed area.

f. Integration with Other Technologies:

- Digital photogrammetry can be seamlessly integrated with other geospatial technologies such as GIS (Geographic Information Systems), LiDAR (Light Detection and Ranging), and remote sensing. This integration enhances data analysis and application.

7.2. Digital photogrammetric workstations

Digital photogrammetric workstations

- It is the combination of hardware (stereo viewing devices and a three dimensional mouse) and software to derive photogrammetric products from digital imagery.
- The core of a softcopy plotter is a set of computer software modules that perform various photogrammetric tasks.
- Besides the software, another essential component of a softcopy plotter is a computer with a high-resolution graphics display.

Components of DPW

i. Computer System supported by corresponding software

ii. Stereoscopic display device

iii. 3D measurements device

iv. I/O device

Digital photogrammetric workstations

Source: https://www.gim-international.com/content/article/digital-photogrammetric-workstations

7.4 Measurements of GCPs

Measurements of GCPs

- They are typically measured using field survey or derived from other accurate sources, such as survey data or existing maps.

Field survey techniques for GCPs are:

a. GNSS Surveying:

i. <u>Static GPS</u>: High-precision measurements using static GNSS receivers left on a point for a long period.

ii. <u>Real-Time Kinematic (RTK):</u> Provides high-accuracy positions in real-time by using a base station and a rover.

iii. <u>Differential GPS (DGPS):</u> Enhances the accuracy of standard GPS by using reference stations.

7.4 Measurements of GCPs

Measurements of GCPs

Field survey techniques for GCPs are:

b. Total Station Surveying:

- It is normally used to transfer GCPs through traversing and foresighting.

c. Levelling:

- It is used to transfer vertical control.

7.5 Image matching: Area based and Feature Based Image Matching

Image matching:

- Image matching refers to the automatic identification and measurement of corresponding image points (conjugate points) that are located on the overlapping areas of multiple images.
- This process is fundamental for generating 3D models, maps, and various spatial measurements.

The various image matching methods can be divided into three categories including:

a. Area-based matching

b. Feature-based matching

c. Relation-based matching

Image matching:

Area-based matching

- This method determines the correspondence between two image areas according to the similarity of their gray level values.
- It is based on the idea that grey values of pixels of conjugate points have similar radiometric characteristics.
- Area-based matching is also called signal based matching.
- The cross correlation and least squares correlation techniques are well-known methods for area-based matching.

7.5 Image matching: Area based and Feature Based Image Matching

Image matching:

Feature-based matching

- It is a technique of obtaining automatic tie-points in corresponding multiple images.
- It is used in digital photogrammetry is done with the use of photogrammetric softwares.
- The algorithm attempts to detect well-recognisable features – such as a road marking, a building edge or any other strong change in contrast – in each individual image. Once all the features have been found, the algorithm proceeds to detect corresponding features in multiple images. This results in highly reliable corresponding points that are very suitable as tie points.

7.7 Steps in DEM generation/Process of DEM generation

Major Steps in DEM generation

1. Orientation
2. Image matching
3. Editing/Filtering

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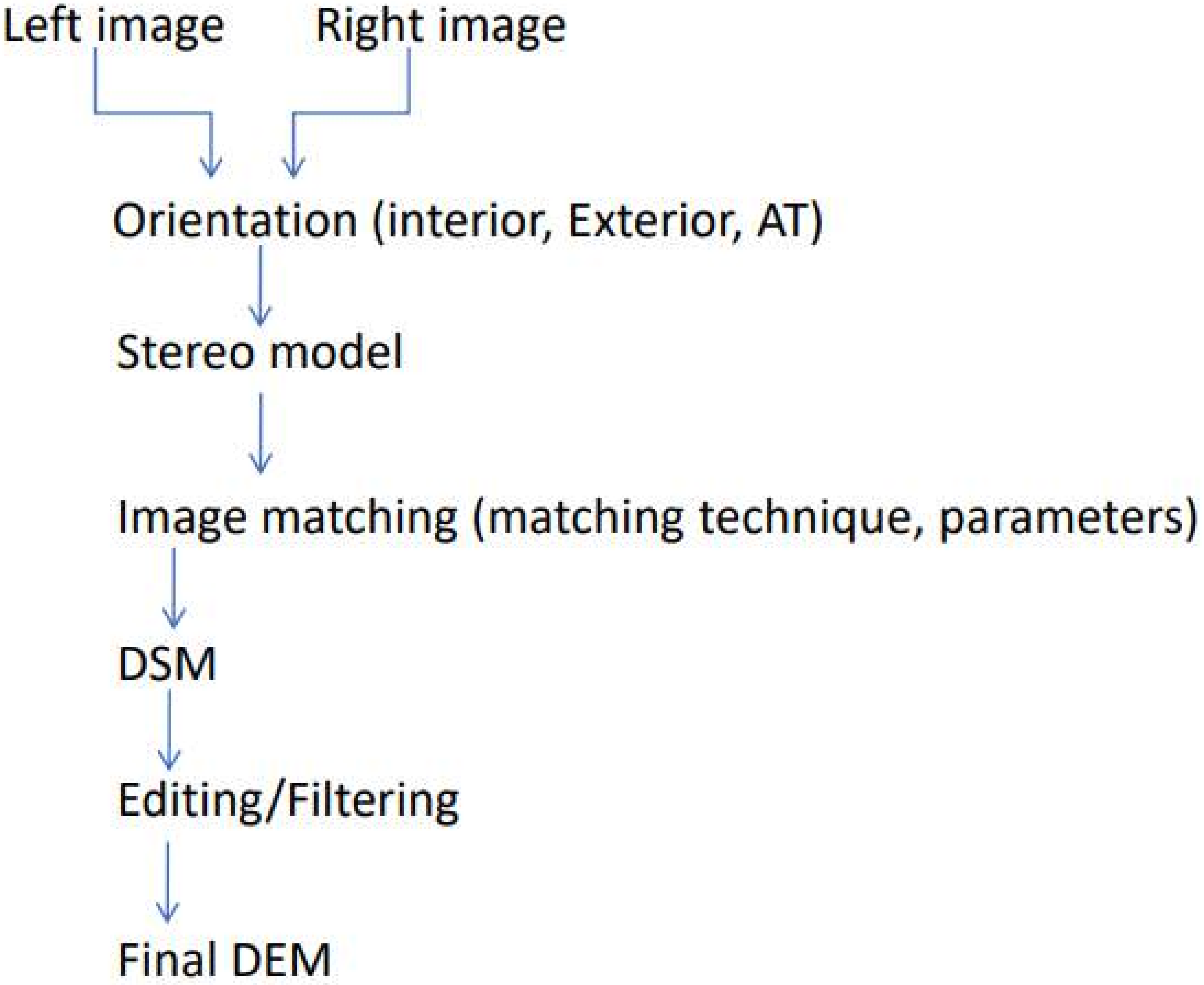

Process of DEM generation in digital photogrammetry

2. Image matching:

It includes:

i. Select a matching point in one image.

ii. Find its conjugate point in the other image.

iii. Compute 3D position of the matched point in object space.

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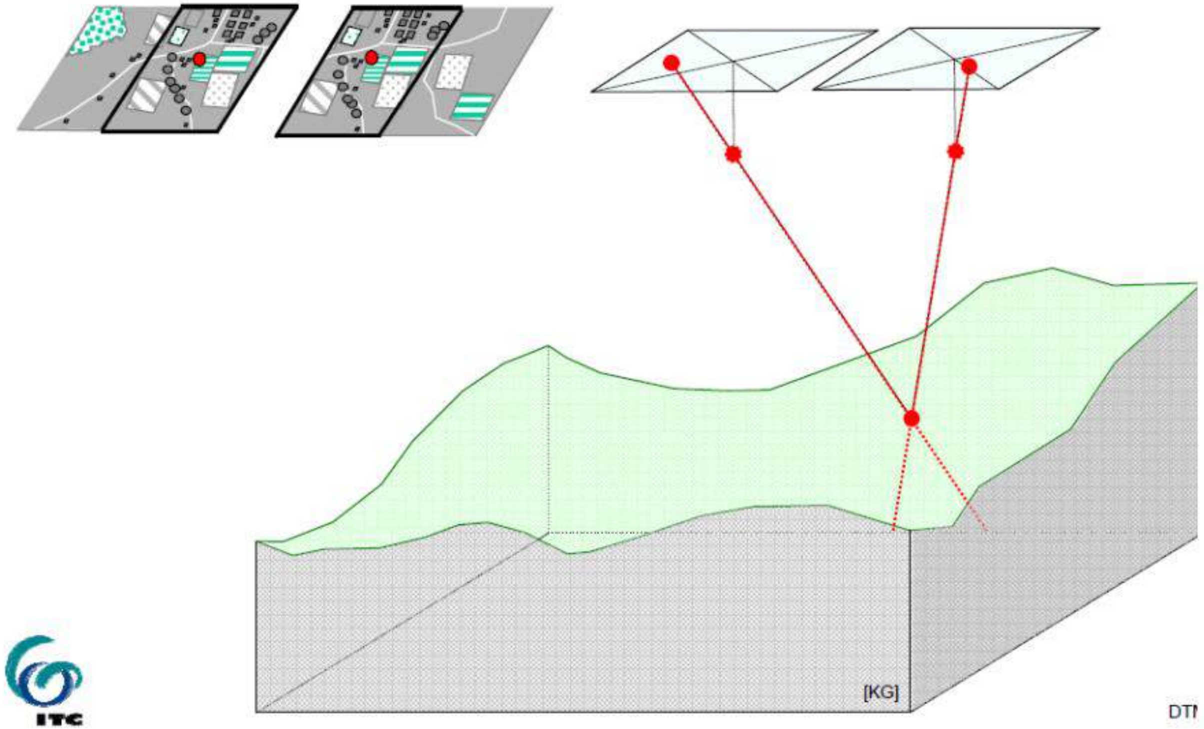


7.7 Steps in DEM generation/Process of DEM generation

Process of DEM generation in digital photogrammetry

3. Editing/Filtering

- Filtering process are applied for reducing the height point to the ground.

Different types of filtering is carried out while creating DEM from DSM which are as follows:

i. Morphological filters (eg: slope-based filtering)

ii. Surface based filters (eg: robust interpolation in addition with hierarchic extension)

iii. Progressive densification (eg: TIN densification)

iv. Segmentation based filters

.

7.8 Ortho Rectification and the process of orthophoto production

Ortho Rectification

- Orthorectification is the process of removing sensor, satellite/aircraft motion and terrain-related geometric distortions from raw imagery and creating a planimetrically correct image.
- It is the process to make orthophoto. This procedure is totally based on the computer technology in which orthophoto production is done using softwares.
- The resultant orthorectified image has a constant scale where in features are represented in their 'true' positions like in map. This allows for the accurate direct measurement of distances, angles, and areas.
- Required input for orthorectification:

i. Photographs
ii. camera calibration data
iii. ground control points
iv. DTM

Ortho Rectification

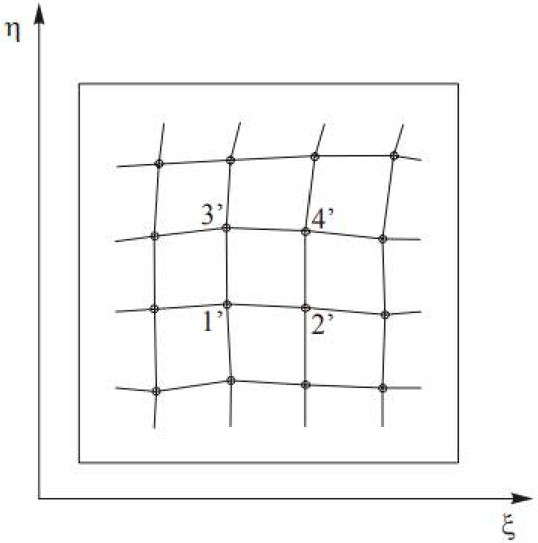
- The various ortho rectification techniques are:

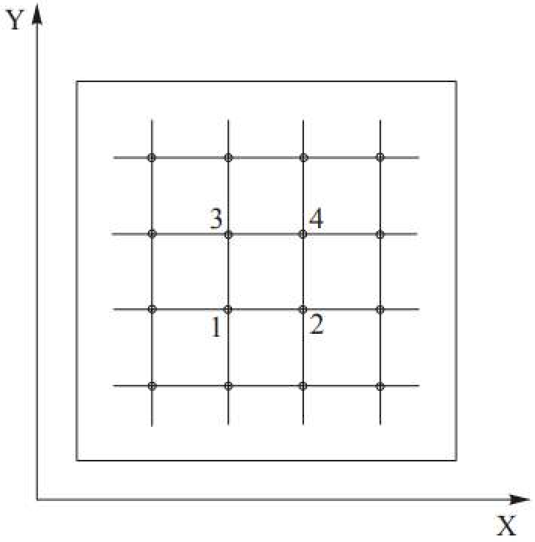
i. Polynomial rectification

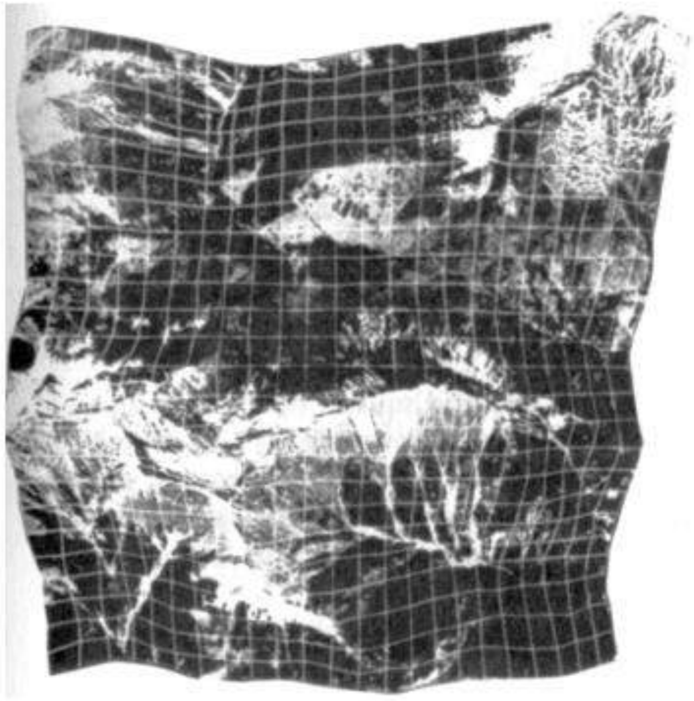
ii. Projective rectification

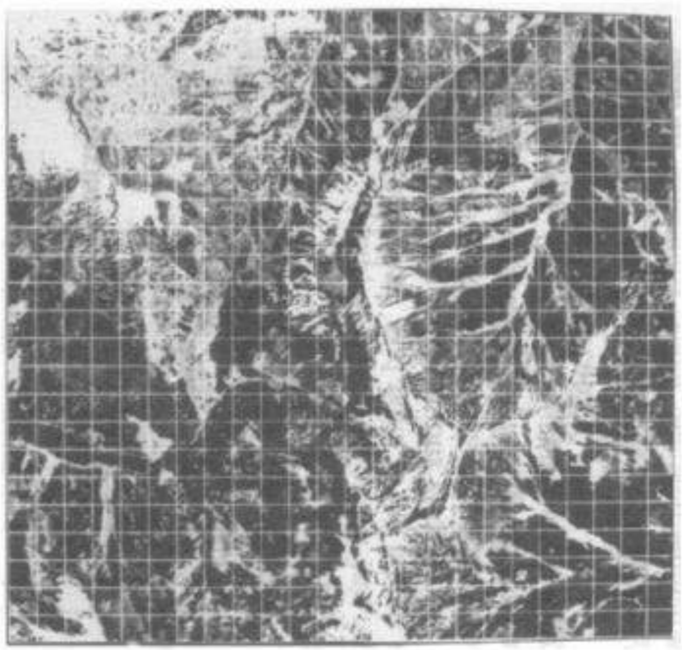
iii. Differential rectification

Ortho Rectification









7.8 Process of orthophoto production

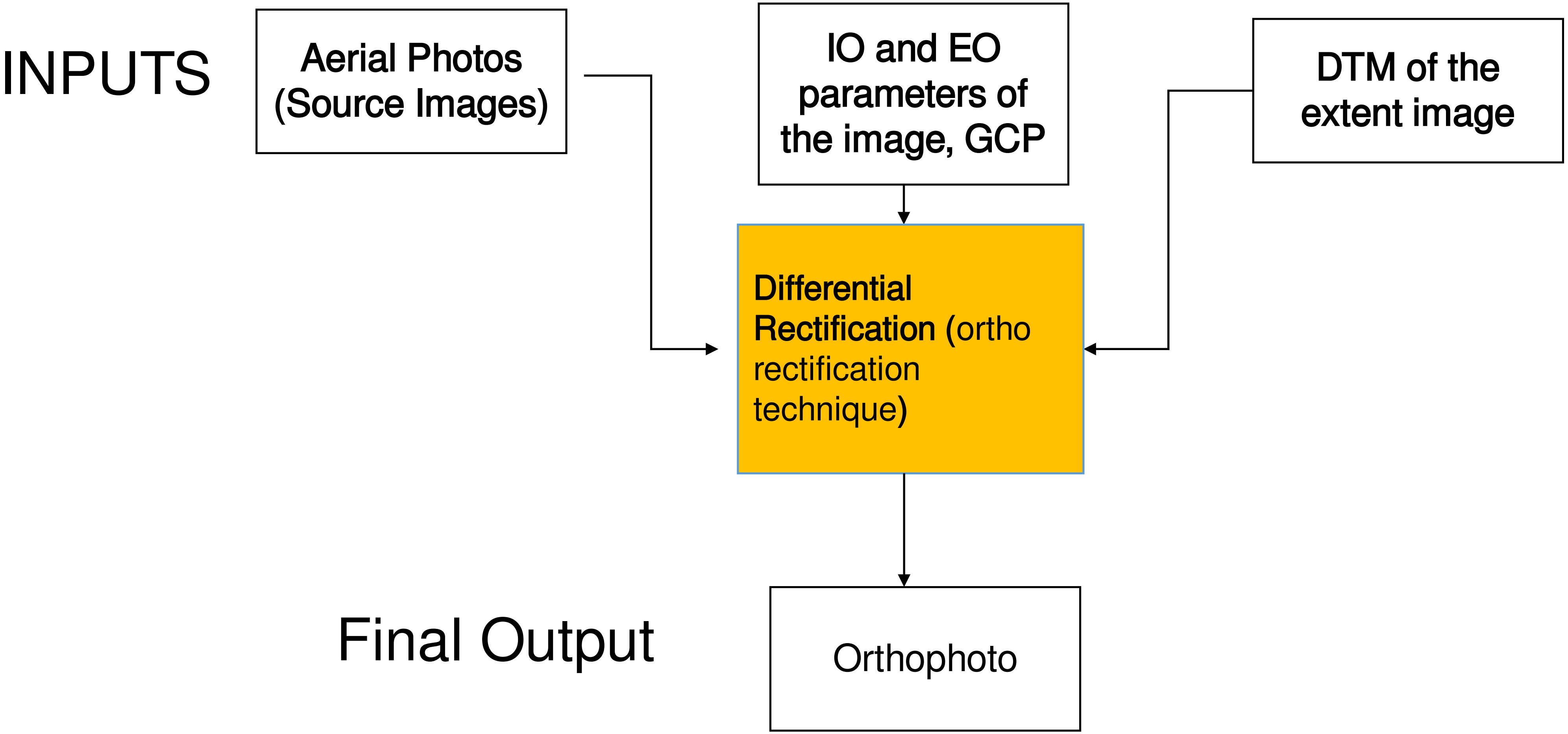


Diagram: Process of orthophoto Production

7.8 Process of orthophoto production

1. Aerial Images (Source Images)

- The images from which orthophoto are produced refers to the source image.
- These aerial images are distorted due to tilt, relief and other geometric errors.

2. IO and EO parameters of the image, GCP:

3. DTM:

- This is one of the main input during the production of the ortho photo
- The 3D information (X,Y,Z) are generated from the DTM.

7.8 Process of orthophoto production

4. Differential Rectification:

- It is an assignment of color intensity value(gray value) from the perspective image to each pixel of the DSM or DEM.
- To determine gray values, we follow this procedure:

i. Collinearity equations are applied to determine the intensity values as follows:

$$x - x_0 - \Delta x = -c\frac{r_{11}(X - Xc) + r_{12}(Y - Yc) + r_{13}(Z - Zc)}{r_{31}(X - Xc) + r_{32}(Y - Yc) + r_{33}(Z - Zc)} = f_x(X', y') \qquad (1)$$

$$y - y_0 - \Delta y = -c\frac{r_{21}(X - Xc) + r_{22}(Y - Yc) + r_{23}(Z - Zc)}{r_{31}(X - Xc) + r_{32}(Y - Yc) + r_{33}(Z - Zc)} = f_y(X', y') \qquad (2)$$

❖ The DSM coordinates (X, Y, Z) defined by the DSM pixel are transformed into the perspective image by (1) and (2).

ii. Then the color intensity value is interpolated by one of the resampling methods at the image position (x, y), and it is stored at the the x', y' position of the orthophoto, which is equal to the position of the DSM point.

4. Differential Rectification:

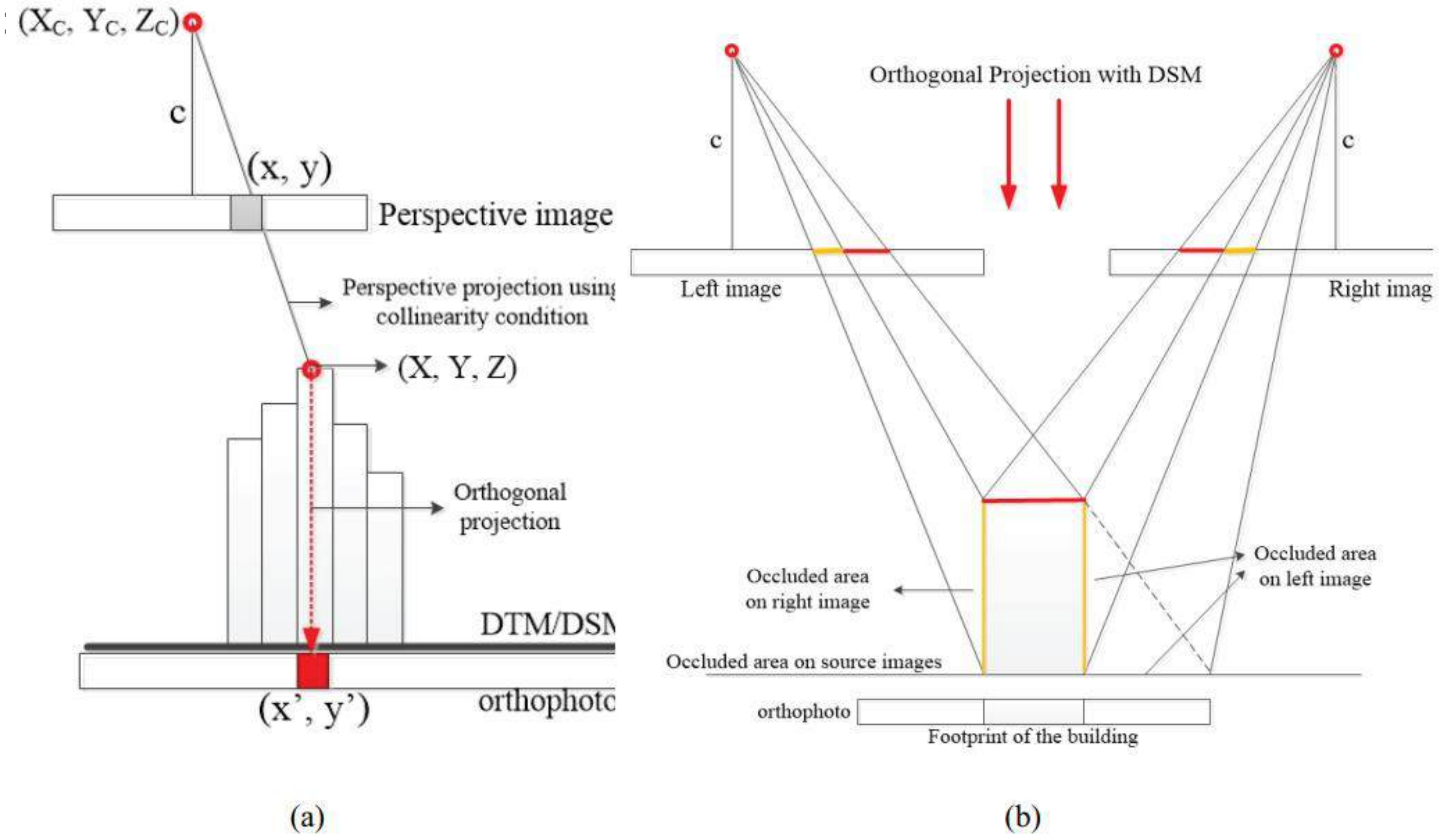


Fig7.2 showing Orthorectification process: (a), each 3D surface point defined as pixel of the DSM is transformed into the image the color intensity value from the source image. This value is assigned to the orthophoto raster at the same pixel location as the DSM point.

References

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Unit 8: UAV Photogrammetry

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UAV photogrammetry

- UAV photogrammetry refers to the process of using unmanned aerial vehicles (drones) to capture a series of high-resolution images from different angles which are then processed using specialized software to create accurate 2D maps and 3D models of the surveyed area.
- The technique combines the principles of photography and geometry to extract precise measurements and spatial data from the photographs.
- It is a relatively new technology with its roots in traditional photogrammetry and computer vision.
- Drone photogrammetry has made aerial photogrammetry faster and less expensive, putting it within reach of the budgets of many more people and organizations.

8.2 Field Procedure of UAV survey

General workflow of Photogrammetry/Field Procedure of UAV survey

1. Project Planning (recce, instruments etc.)
2. GCP establishment
3. Flight planning and image acquisition
4. Image processing (Orientation & Aerial Triangulation)
5. Production of Photogrammetric products (After Point cloud densification

DSM, Orthophoto, DTM and contour generation)

8.2 Field Procedure of UAV survey

Field Procedure of UAV survey

1. Project Planning

- This is the first stage where all the necessary decisions are taken and relevant documents are collected.
- Necessary decisions include the methodology, instruments, human resources, budget, mapping areas, product accuracy etc. Relevant documents include existing maps, mapping specification (Scale of map, Contour Interval, etc), flight permission etc.

2. GCP establishment

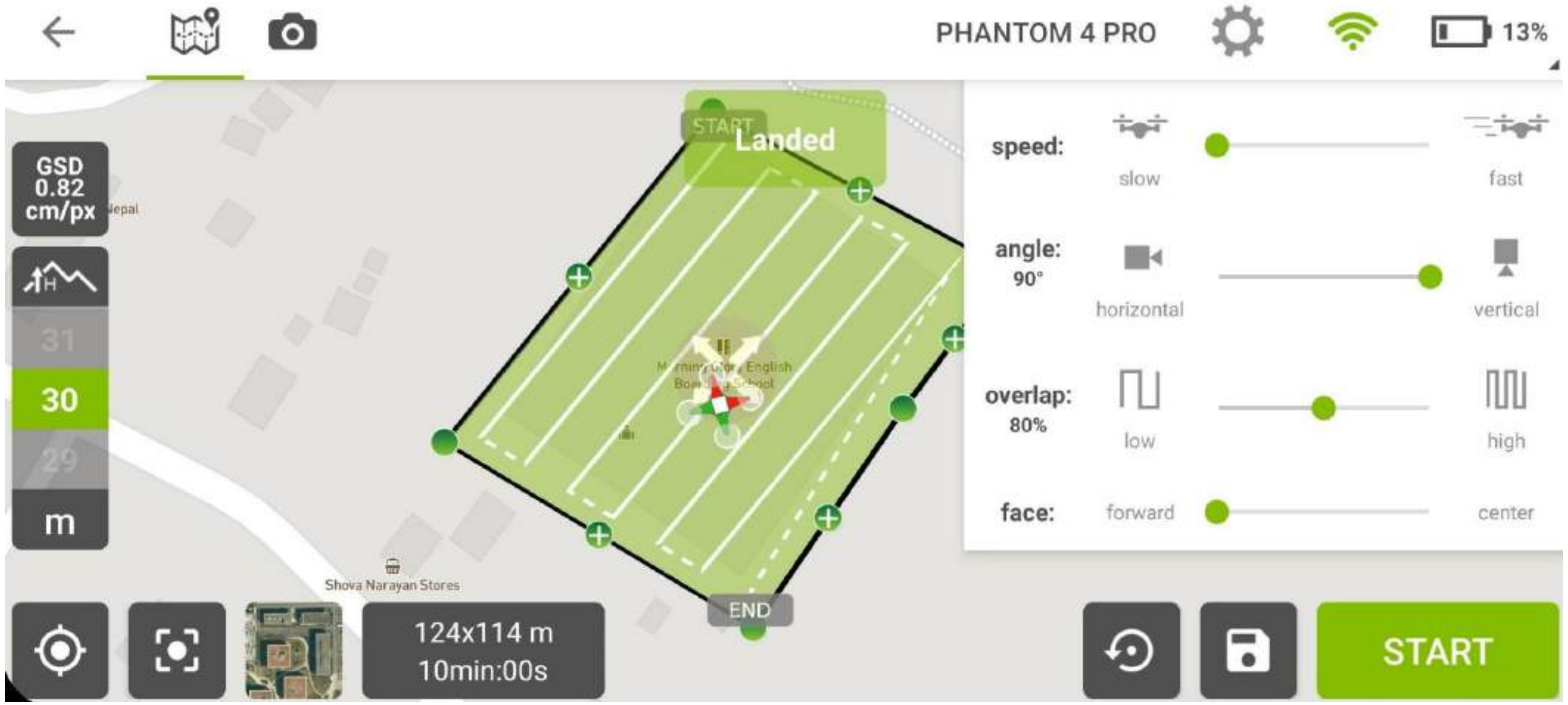
- Ground control points(GCP) increases the accuracy of photogrammetric products. At present GCPs are establish using DGPS, RTK and other survey grade receivers.
- It depends on client accuracy and budget.
- Cost of establishing ground control ranges between 20 to 50 % of total mapping cost.
- In GCPs position, generally some large flags and symbols are kept in grounds so that they can be recognized clearly in aerial photographs and georeferencing can be done easily.

2. GCP establishment

Source: https://www.pix4d.com/blog/why-ground-control-points-important

3. Flight planning and image acquisition

- In this stage, flight path for aircraft is planned and images along that respective path is taken .
- These days, flight planning is done using mobiles apps like Pix4d capture, DroneDeploy etc. We can adjust the settings like required overlap, speed of UAV, flying height and other various settings.
- Flight planning has become very easy with the technological development.



Source: http://keshavrajbhusal.com.np/

Fig7.2 : showing flight planning and settings adjustment in Pix4d capture.

8.2 Field Procedure of UAV survey

4. Image processing

- Once the image is captured they are to be processed. In modern photogrammetry, processing of such digital aerial images is done using softwares like Pix4d Mapper, Webodm etc.
- It involves orientation (interior and exterior orientation) and aerial triangulation (when orientation process is done in blocks). Aerial triangulation also enables densification of control points required to make mosaics.
- It also includes image matching(the determination of conjugate points in a stereo image pair), feature matching processes.

5. Production of Photogrammetric products

- Image processing results generation of point cloud. After point cloud densification DSM, Orthophoto, DTM and contour are generated.

8.3 Application area of UAV

Application area of UAV

1. Forestry:

i. Drone seeding: Tree seeds planting through drones.

ii. Tree health monitoring through NDVI and other indices.

iii. Stockpile calculation

iv. Monitoring rare animals, plant species and forest fires.

Application area of UAV

1. Forestry:

Source: https://www.undp.org/nepal/stories/flying-forests-nepal-can-seeding-drones-save-degraded-areas#:~:text=The%20UAV%20drone%20will%20also,a%20short%20period%20of%20time.

Fig: Drone carrying plant seeds for forest trees restoration.

Application area of UAV

2. Agriculture

i. Spraying pesticides, seeds etc. in field.

ii. Livestock monitoring through use of thermal sensor. We can also know the predators if they are around those livestocks.

iii. Mapping agricultural fields.

iv. Crop health monitoring through use of multispectral sensors fitted in drones.

Source: https://iotechworld.com/application-of-drones-in-indian-agriculture/.

Application area of UAV

3. Medical sector:

- Unmanned aerial vehicles are used to carry emergency medical supplies and goods to remote villages where there are no access to roads or difficult geography.
- It is also used to transport organs to transplant patients.

Source: https://vitalrecord.tamhsc.edu/drone-care-researchers-study-proposed-health-care-delivery-method//.

Application area of UAV

4. Shipping and Delivery

- Drones are being used to deliver goods and parcel packages to customer within few minutes.
- It is becoming quite popular these days and reduces individual manual labor and cost.

5. Post-disaster rescue

- Aerial photographs of disaster areas from UAV helps in dentification of crucial disaster relief areas, selection of safe rescue routes also site selection for post-disaster reconstruction.
- UAV can also monitor the situation in the disaster-stricken area in real-time and in all directions to prevent secondary disasters.

Application area of UAV

5. Post-disaster rescue

Source: https://www.pix4d.com/blog/mapping-nepal/

Application area of UAV

6. Forest fire

- Patrolling: Drone with video shooting or infrared lenses are used to identify the fire source through smoke detection, which significantly reduces the cost of forest patrol.
- It is also used in post fire damage assessment and research and rescue mission.

Source: https://www.unmannedsystemstechnology.com/wp-content/uploads/2019/06/Drone-based-forest-fire-detection.jpg

8.3 Application area of UAV

Application area of UAV

7. Recreational and cinematography

- Drones are used to capture aerial shots of landscapes, cityscapes, and scenes that makes films and TV shows more appealing.
- Drones are also used for live event coverage, aerial shots of concerts, sports events, and outdoor festivals.

8. Millitary

- Drones are used to gather intelligence, monitor enemy movements, and conduct battlefield surveillance.
- Combat drones are equipped with weapons and are used for targeted strikes and close air support.

8.4. UAV data processing

UAV data processing

- It is the process of converting raw data collected from drone into meaningful information.
- It involves the process of converting images acquired through drone into photogrammetric products like DEM, DSM, Orthomosaic etc.
- It can be done through photogrammetry software like Pix4Dmatic, Agisoft metashape, WebODM or cloud platform like Dronebox, Geonadir etc.

Major steps in UAV data processing are:

a. Initial processing

b. Point cloud and Mesh

c. DSM, orthomosaic and index

UAV data processing

Major steps in UAV data processing are:

a. Initial processing

In this stages the following tasks are done with the images:

I. Key Points extraction: Identify specific features as keypoints in the images.

II. Keypoints matching: Find which images have the same key points and match them.

III. Camera model optimization: Calibrate the internal (focal length,...) and external parameters (orientation,...) of the camera.

IV. Geolocation GPS/GCP: Locate the model if geolocation information is provided.

- Automatic Tie Points were created during this step. These are the basis for the next steps of processing.

8.4. UAV data processing

UAV data processing

Major steps in UAV data processing are:

b. Point cloud and Mesh:

I. Point Densification:

- Additional Tie Points are created based on the Automatic Tie Points that result in a Densified Point Cloud.

II. 3D Textured Mesh:

- Based on the Densified Point Cloud a 3D Textured Mesh can be created.

8.4. UAV data processing

UAV data processing

Major steps in UAV data processing are:

c. DSM, orthomosaic and index:

This step enabled the creation of:

I. Digital Surface Model (DSM):

- The creation of the DSM will enable the computation of Volumes, Orthomosaics and Reflectance Maps.

II. Orthomosaic:

- The creation of the Orthomosaic is based on orthorectification. This method removes the perspective distortions from the images.

Contours and various maps can also be created as per necessity.

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UAV photogrammetry

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