A= L1 x L2 = 20 km x 16 km = 20000 m x 16000 m, Longitudinal overlap (OL) = 60% = 0.6, Side overlap (OS) =30% = 0.3, Scale 1: 15000, Photograph size = 23 cm x 23 cm = 0.23 m x 0.23 m = (L x L)
N1 = Number of photographs per flight line = [L_1 / {(1 – OL) scale * L}] + 1
= [20000 / {(1 – 0.6) 15000 * 0.23}] + 1
= 14.49 + 1 = 16 (taking round figure to cover entire area)
N2 = Number of flight lines = [L_2 / {(1 – OS) scale * L}] + 1
= [16000 / {(1 – 0.3) 15000 * 0.23}] + 1
= 6.62 + 1 = 8 (Taking whole no of flight lines)
Total number of photograph required = N1 x N2
= 15 x 8 = 120 No

Example 4.11:
The distance from the principal point of a photograph to the image of the top of a tower is 6.44 cm and the elevation of the tower above the above datum is 250 m. What is the relief displacement of the tower if the scale is 1:10,000 above datum and the focal length of the camera is 20 cm?

Solution:
r = 6.44 cm, h = 250 m, scale =1:10000, f = 20 cm
d = r h / H
and S = f / H or H = f / S
So, d = r h S / f
d = (6.44 / 100) * 250 / (0.20 * 10000)
= 6.44 / 800
= 0.00805 cm

Example 4.12:
The vertical photograph of a flat area having an average elevation of 250 m above datum was taken with a camera of 20 cm focal length. A line PQ, 250 m long, measures 8.50 cm on the photograph. A tower TQ appears on the photograph, and the distance between the images of top and bottom of the tower TQ measures 0.46 cm on the photograph. If the distance of the image of the top of the tower from principal point of the photograph is 6.46 cm, determine the height of tower TQ above datum.

Solution:
Ground distance = 250 m, map distance = 8.50 cm, f = 20 cm, r = 6.46 cm, d = 0.46 cm
S = f / H = 0.20 / H
[(8.50 / 100) / 250] = 0.20 / H
So , H = 0.20 * 25000 / 0.085
H = 588.24 m
d = r h / H
(0.46 / 100) = (6.46 / 100) * h / 588.24
h = 0.46 * 588.24 / 6.46
h = 41.90 m

Example 4.13:
The tower AB 50 m high above the ground, appears in a vertical photograph, was taken at a flying height of 2500 m above *msl*. The distance of the image of the top of the tower from principal point of the photograph is 6.35 cm. Determine the displacement of the image of the

top of the tower with respect to the image of its bottom. The elevation of the bottom of the tower is 1250 m above *msl*.

Solution:
r = 6.35 cm= 0.0635 m, h = 50 m
H = Flying height above the bottom of tower = 2500 – 1250 = 1250 m
The displacement of the image of the top of the tower with respect to the image of its bottom = d = r h / H
d = 0.0635 * 50 / 1250
d = 0.254 cm = 2.54 mm

A stereopair of vertical photographs is taken from a flying height of 1233 m above *msl*, with a 152.4-mm focal length camera, and air base as 390 m. With the stereo-photos properly oriented along the flight line, the coordinates of two points *a* and *b* were measured on left photo and right photo as x_a = 53.4 mm, y_a = 50.8 mm, x_b' = –7.1 mm, y_b' = –46.7 mm , and x_a' = –38.3 mm, y_a' = 50.9 mm, x_b = 88.9 mm, y_b = –46.7 mm, respectively. Find out the elevations of ground points A and B and the horizontal length of line AB.

$P_a = x_a - x_a'$
$P_b = x_b - x_b'$
P_a = 91.7 mm
P_b = 96.0 mm

$h_a = H\ B\ f / P_a$
$h_b = H\ B\ f / P_b$
h_a = 585 m
h_b = 614 m

$X_a = B\ x_a / P_a$
$Y_a = B\ y_a / P_a$
$X_B = B\ x_b / P_b$
$X_B = B\ x_b / P_b$

X_A = 227 m
Y_A = 216 m
X_B = 361 m
Y_B = -190 m

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

Example 4.14:
A stereopair of vertical photographs is taken from a flying height of 1233 m above *msl*. With the stereo-photos properly oriented along the flight line, the coordinates of two points *a* and *b* were measured on left photo and right photo as x_a = 53.4 mm, y_a = 50.8 mm, x_b' = –7.1 mm, y_b' = –46.7 mm, and x_a' = –38.3 mm, y_a' = 50.9 mm, x_b = 88.9 mm, y_b = –46.7 mm, respectively. Further, coordinates of a control point C are measured as x_c = 14.3 mm and x_c' = –78.3 mm. If the elevation of point C is 591 m above *msl*, calculate the elevations of points A and B, using parallax differences.

$P_c = x_c - x_c' = 14.3 - (-78.3) = 92.6$ mm
$\Delta p_{ac} = P_a - P_c = 91.7 - 92.6 = -0.9$ mm
$h_a = h_c + [(H - h_c)\, \Delta p_{ac} / P_a]$
$h_a = 591 + [(1233 - 591)(-0.9) / 91.7]$
$h_a = 585$ above *msl*

Similarly, $h_b = h_c + [(H - h_c)\, \Delta p_{bc} / P_b]$
$\Delta p_{bc} = P_b - P_c = 96.0 - 92.6 = 3.4$ mm
$h_b = 591 + [(1233 - 591)(3.4) / 96]$
$= 614$ m above *msl*

Example 4.15:
On a stereopair, the parallax difference between the top and bottom images of a tree is measured as 1.3 mm. The photographs were taken at 915 m height above ground. If the average photo base is 88.2 mm, determine the height of the tree?

Solution:
$h_a = \Delta p\, H / (b + \Delta p)$
$h_a = 1.3 * 915 / (88.2 + 1.3)$
$h_a = 13$ m

Example 4.16:
In a pair of overlapping photographs (mean photo base length 89.84 mm), the mean ground level is 70 m above the datum. Two nearby points are observed and the following information is obtained.

Point	Height above datum (m)	Parallax bar reading (mm)
X	55	7.34
Y		9.46

If the flying height was 2200 m above datum and the focal length of the camera was150 mm, find the :(i) Air base (ii) The height of Y above datum,(iii) The difference in height between point X and Y.

Solution:
$f / (H-70) = 89.84 / B = 150 / (2200-70)$
$B = 1275.728$m
$P_x / f = B / (H-h_x)$
$7.34 / 150 = 1275.728 / (2200-55)$
$P_x = [1275.728 / (2200-55)] \times 150$
$P_x = 89.22$ mm
$P_y - P_x = \Delta P$
$(9.46-7.34) = P_y - 89.22$
$P_y = 91.33$mm
$P_y = f\, B / (H-h_y)$
$91.33 = 150 \times 1275.728 / (2200-h_y)$
$(2200-h_y) = 150 \times 1275.728 / 91.33$
$(2200-h_y) = 2095.25$
$h_y = 104.75$m

Difference in height between X and Y= 104.75- 55= 49.75 m

Example 4.17:
On the overlap of a pair of vertical aerial photographs taken at a height of 2500 m above mean sea level with a 152 mm focal length camera are shown two points A and B. Point B is a point on a pass through a range of hills, while point A is the center of a bridge in a valley. In order to estimate the amount of rise between these points, parallax bar measurements were made as follows:

Point A: mean reading 5.90 mm
Point B: mean reading 11.43 mm

The mean level of the valley containing the principal points of the two photographs is 82.00 m above mean sea level, while a BM on the bridge near A was 74.55 m above mean sea level. If the respective photo bases are 89.1 mm and 91.4 mm, calculate the height of B above A.

Solution:

$$p = \frac{fB}{H - h} = \frac{bH_o}{H - h}$$

H_o = 2500-82.0 =2418 m above mean sea level, and elevation of A is 74.55m above mean sea level.

$$P_a = \frac{bH_o}{H - h_a} \qquad b = \frac{b_1 + b_2}{2} = \frac{89.1 + 91.4}{2} = 90.25mm$$

$$\therefore p_a = \frac{90.25 * 2418}{2500 - 74.55} = 89.97mm$$

From the parallax bar readings, the difference in parallax is found as

$dp_{ab} = p_b - p_a$ =11.43 -5.90 =5.53 mm

$\therefore p_b = p_a + dp_{ab}$ =89.97+5.53= 95.50 mm

$$\Rightarrow p_b = \frac{bH_o}{H - h_b} \Rightarrow h_b = H - \frac{bH_o}{p_b} = 2500 - \frac{90.25 * 2418}{95.50} = 214.93m$$

Therefore, the height of B above A is 140.40 m

Exercises for Practices

(A) Short questions

4.18 Explain in types of aerial photo based on the alignment of optical axis.

4.19 Discuss some of the principal uses of terrestrial photogrammetry. Draw the diagram to explain the Exposure station, focal length, flying height, and optical axis of aerial photograph.

4.20 Draw the diagram to explain the fiducial marks, principal point, conjugate principle point, superlap, mosaic.

4.21 What are the different methods of scale determination?

4.22 State any four advantages that an aerial photograph offers over ground based mapping.

4.23 What is the relevance of base-height ratio in aerial photogrammetry? Write the relationship to determine the (i) average scale of a photograph, (ii) relief displacement, (iii) absolute parallax of a point.

4.24 What is a relief displacement? On what factors, it depends? Why relief is not present at the principal point a truly vertical photograph.

4.25 Define stereovision. What are the essential conditions to create a stereovision?

4.26 Draw line diagrams to see the stereo-vision from a stereo-pair using (i) Lens stereoscope, and (ii) Mirror and lens stereoscope.

4.27 Draw a line diagram of Parallax Bar, and show various components.
4.28 What do you understand by Digital photogrammetry? What is the difference between an ortho-photo and normal photo?
4.29 Define interior orientation in aerial photogrammetry.
4.30 What is isocentre in a tilted photograph? What is the utility of tilted photographs?

(B) Long questions

4.31 Establish a relationship to determine the scale of an aerial photograph in an undulating terrain. Why the scale of a photograph is not uniform throughout?
4.32 What do you understand by relief displacement? Derive a relationship to compute the relief displacement from a vertical photograph.
4.33 Briefly explain about image parallax and its relation with stereoscopic viewing of aerial photographs.
4.34 Discuss the salient features of (i) Lens stereoscope, and (ii) Mirror and lens stereoscope.
4.35 Describe the base lining procedure from a stereo-pair.
4.36 Discuss the use of a Parallax Bar to determine the height of points in a stereo-pair.
4.37 Explain in brief the concept of digital ortho-photo. Write down the steps involved in the generation of an ortho-photo. List some of the applications of ortho-photo.
4.38 Establish a relationship to derive the scale of a tilted photograph.

Unsolved numerical questions

4.39 A vertical photograph is taken at an altitude of 1200 m above mean sea level of a terrain lying at an elevation of 80 m. The focal length of camera is 15 cm find out the approximate scale of the photograph.

(Ans: 1:7467)

4.40 Compute the scales (maximum, minimum, and average) of a photograph, if the highest terrain, average terrain, and lowest terrain heights are 610, 460, and 310 m above mean sea level, respectively. The flying height above mean sea level is 3000 m and the camera focal length is 152.4 mm.

(Ans: S_{max} = 1:15,700, S_{min} = 1: 17700, and S_{avg} = 1:16,700)

4.41 The length of an airport runway is 160 mm on a vertical photograph. On a map at a scale of 1:24,000, the runway length is measured as 103 mm. Determine the scale of the photograph at runway.

(Ans: 1:15,400)

4.42 A camera with a focal length of 152.35 mm and a photo size 230 mm* 230 mm is used to photograph an area from a height of 2400 m above *msl*. The average ground elevation is 420 m above *msl*, determine the average scale of the photographs. Also, determine the ground area covered by a single photograph.

(Ans: 1:13,0008, 940,100m^2)

4.43 A vertical aerial photograph was taken from a flying height of 1385 m above datum with a 152.4 mm focal length camera. Two ground points A and B appear on the photograph, as *a* and *b*, and their measured photo-coordinates are x_a = –52.35 mm, y_a = – 48.27 mm, x_b = 40.64 mm, and y_b = 43.88 mm. Determine the horizontal length of line AB if the elevations of points A and B are 204 and 148 m above datum, respectively.

(Ans: AB = 1036 m)

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

(Ans: 1:10,00)

4.45 A road segment of length 1 km measures 6 cm on a vertical photograph. The focal length of the camera is 150 mm. If the terrain is nearly plain, determine the flying height of the aircraft.

(Ans: 2500 m)

4.46 If the length covered by each photograph is 1.5 km with 60% overlap, and length of the strip is 18 km, determine the number of photographs in the strip.

(Ans: 30)

4.47 A rectangular area 130 km x 120 km with average height as 160 m above *msl* is to be mapped from aerial photographs at a scale of 1:20000. The focal length of the camera lens to be used is 152 mm and each print size will be 23 cm square. A 60% overlap between successive photographs and a 25% lateral overlap is to be kept. Find (a) the average height above *msl* at which the aircraft must operate; (b) the time interval between two successive exposures in a strip if the operating speed of the aircraft is 200 km/h; and (c) minimum total number of photographs required to cover the entire area.

(Ans: (a)3200 m, (b) 33.12 sec, and (c) 2485)

4.48 If the height of a tower is 50 m, flying height of the aircraft above the base is 5000 m and the image of the top of the tower is 20 cm, from the principal point, what will be the relief displacement?

(Ans: 0.2 cm)

4.49 On an aerial photograph taken at an altitude of 1500 m above ground, the relief displacement of the image of a flagpole was measured as 1.6 cm. The distance from the center of the photograph to the image of the top of the flagpole is 11.0 cm. If the base of the flagpole is at an elevation of 200.0 m above msl, determine the height of the flagpole above ground.

(Ans: 18 m)

4.50 An overlapping pair of vertical photographs taken with a 152.4 mm focal length camera has an air base of 548 m. The elevation of control point A is 283 m above *msl*, and the parallax of point A is 92.4 mm, determine the flying height above *msl*.

(Ans: 1187 m)

4.51 A vertical photograph taken from 535 m above *msl* was used to determine the height of a tower. The elevation at the base of the tower is 259 m above *msl*. Determine the height of the tower, if the relief displacement of the tower is measured as 54.1 mm, and the radial distance to the top of the tower from the photo center is 121.7 mm.

(Ans: 123 m)

References and Suggested Readings

1. Aber, James S.; Marzolff, Irene and Ries, Johannes B. (2010), Small-Format Aerial Photography: Principles, Techniques and Geoscience Applications, Elsevier Science.
2. ASPRS, (1980), Manual of Photogrammetry, ASPRS publication, 4th Ed., p. 1056.

3. ASPRS, (1983), Multilingual Dictionary of Remote Sensing and Photogrammetry, ASPRS publication, p. 343.
4. Balenovic, I., Seletković, A., Pernar, R., Marjanović, H., Vuletić, D., Paladinić, E., Kolic, J., and Benko, M. (2011). Digital Photogrammetry – State of the Art and Potential for Application in Forest Management in Croatia. South-east European forestry, 2, 81-93.
5. Ebner H, Heipke C, Mayer H, and Pakzad, K., (2003) Photogrammetric Image Analysis, ISPRS Conference on "Photogrammetric Image Analysis" (PIA '03), Munich, Sept. 17-19, 2003.
6. Egels, Yves and Kasser, Michel, (2001), Digital Photogrammetry, CRC Press.
7. Formlabs (2021), Photogrammetry: Step-by-Step Guide and Software Comparison, https://formlabs.com/asia/blog/photogrammetry-guide-and-software-comparison/
8. Faig, W. (1979), Canadian Experiences in the Adjustment of Large Photogrammetric Blocks with Auxiliary Vertical Control, International Symposium on Current Trends in Aerial Triangulation, Brisbane, Queensland
9. Garg, P K (2019), Principles and Theory of Geoinformatics, Khanna Book Publishers Ltd., New Delhi.
10. Grave, Cliff, (1996) Digital Photogrammetry: An Addendum to Manual of Photogrammetry, ASPRS Publication.
11. Henderson, Scott, (2010), Sausage Finger, Cooloptical illusions, Trick, https://coolopticalillusions.com/sausage-finger-trick/
12. Hassani, Mahmoud and Carswell, James, (1992), Transition from Analogue to Digital Photogrammetry, Journal of Advances in Remote Sensing, Vol I. No. 3 –VII.
13. JARS, (1996) Stereoscopes, Japan Association of Remote Sensing, http://sar.kangwon.ac.kr/etc/rs_note/rsnote/cp7/cp7-3.htm.
14. Jenson, J R (2013), Remote Sensing of the Environment: An Earth Resource Perspective, Pearson Education India.
15. Kellie, Andrew and Valentine, Wayne Valentine, (1987), Photogrammetry, In: Brinker, R.C., Minnick, R. (eds) The Surveying Handbook. Springer, Boston, MA. https://doi.org/10.1007/978-1-4757-1188-2_18
16. Kraus, K., (1994), Photogrammetry, Verd. Dümmler Verlag, Bonn.
17. Leh, Mansoor; Bajwa, Sreekala; Chaubey, Indrajeet and Cothren, Jackson, (2008), A remote sensing based methodology of delineating stream channel morphology. 10.13031/2013.25124.
18. Manugula, S S and Bommakanti, Veeranna Bommakanti (2018) Photogrammetry, GIS & Remote Sensing, Ebooks2go Inc.
19. Mikhail, Edward M, Bethel, James S and McGlone, J Chris (2001) Introduction to Modern Photogrammetry, John Wiley & Sons.
20. Moffit, F.H. and Mikhail, E., (1980), Photogrammetry, 3rd Ed., Harper & Row Publishers, New York.
21. Nam, Kyoung; Park, Jeongyun; Kim, In and Kim, Kwanggi (2012), Application of Stereo-Imaging Technology to Medical Field. Healthcare informatics research. 18. 158-63. 10.4258/hir.2012.18.3.158.
22. Quirós Rosado, Elia. (2018). Introduction to Applied Photogrammetry and Cartography for Civil Engineering
23. Phillipson, Warren R. (1996) Manual of Photographic Interpretation, ASPRS Publication.
24. Samson, A. A., (2003), M. Tech. Thesis, Dept. of Civil Engineering, IIT Kanpur, India.
25. Schenk, T. (2005), Introduction to Photogrammetry, Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University 2070 Neil Ave., Columbus, OH 43210.
26. Sijmons, Koert, Introduction on Photogrammetry, ITC, Netherland. https://www.scribd.com/ document/277243918/Introduction-on-Photogrammetry-by-Koert-Sijmons.
27. Su, Yuan-Fong; Lin, Yan-Ting; Jang, Jiun-Huei and Han, Jen-Yu. (2022), High-Resolution Flood Simulation in Urban Areas Through the Application of Remote Sensing and Crowdsourcing Technologies. Frontiers in Earth Science. 9. 1-11. 10.3389/feart.2021.756198.
28. Thomas, Robson, S.O., Kyle, Stephen and Boehm, Jan, (2014) Close Range Photogrammetry and 3D Imaging, Walter de Gruyter, GmbH, Berlin.
29. Wilkinson, Benjamin E., DeWitt, Bon A. and Wolf, Paul R.(2014), 4th Ed, Elements of Photogrammetry with Application in GIS, McGraw-Hill Education India Pvt.Ltd - New Delhi
30. Wolf, P., 1980. Elements of Photogrammetry, McGraw Hill Book Co, NY.
31. Wolf, P.R. and Dewitt, B.A. (2000) Elements of Photogrammetry with Applications in GIS. 3rd Ed., McGraw-Hill Education, New York.
32. Wróżyński, R., Pyszny, K., Sojka, M., Przybyła, C. and Murat-Błażejewska, S. (2017) Ground Volume Assessment using 'Structure from Motion' Photogrammetry with a Smartphone and a Compact Camera, Open Geosciences formerly Central European Journal of Geosciences, Vol 9, Issue1.
33. http://www.durban.gov.za/City_Services/engineering%20unit/Surveying_Land_Information/Documents/AerialPhotogrammetry.pdf
34. http://www.state.nj.us/transportation/eng/documents/survey/Chapter7.shtm#7.3 Introduction to Photogrammetry by T. Schenk, Autumn Quarter 2005

35. http://professionalaerialphotographers.com/content.aspx?page_id=22&club_id=808138&module_id=158950, History of Aerial Photography
36. file:///C:/Users/user/Downloads/8435637.pdf