Chapter 4

Image Measurements and Refinements

Elements of Photogrammetry with Applications in GIS

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1. Introduction

- Rectangular coordinates of imaged points are the most common type of photographic measurements which are usually made on positives printed on paper, film, glass, or digital images.
- Equipment used for photographic measurements varies from simple scales to complex machines.

2. Coordinate Systems for Image Measurements

- The rectangular coordinate system has positive x axis in flight direction.

- The origin of the system is the intersection of fiducial lines often called the indicated principal point which is very near the true principal point for a precise mapping camera.

- Rectangular coordinates can be used to calculate the photo distances by using simple analytic geometry:

$$ab = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2}$$

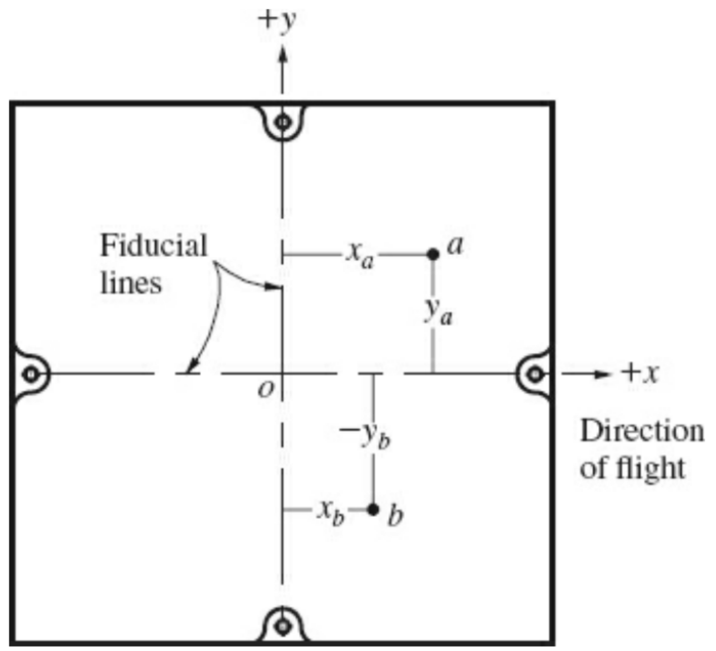


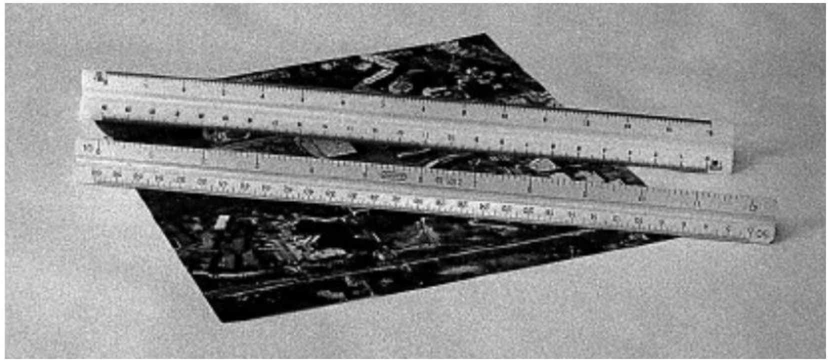
Figure 4-1 Photographic coordinate system based on side fiducials

3. Simple Scales for Photographic Measurements

- Engineer's scale may prove satisfactory for cases where a low accuracy is acceptable.

- Precision can be enhanced by using a magnifying glass and the finest set of graduations.

- Greater accuracy can be obtained by using a device such as the glass scale with magnifying eyepieces which can slide along the scale.



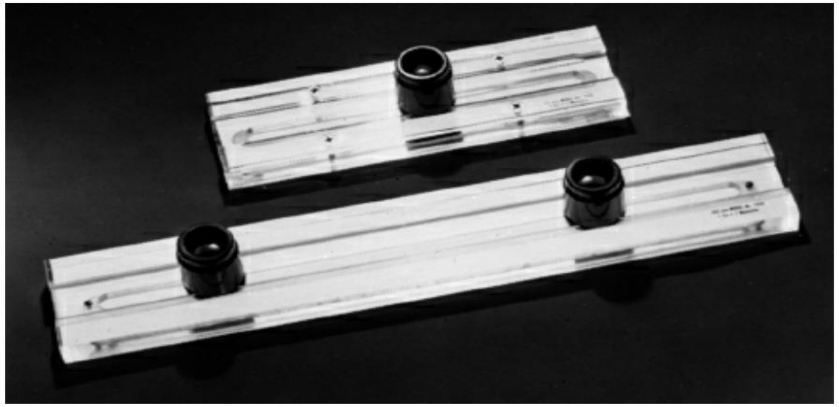


Figure 4-2 Metric (top and English (bottom) Engineer's scale
Figure 4-3 Glass scales for photographic measurements

4. Measuring Photo Coordinates with Simple Scales

- Marking the coordinate axes with a razor blade, pin, or sharp pencil are followed by obtaining coordinates through measuring the perpendicular distances from these axes.

- If the points on image are not clear enough for identification making a small pinprick can be helpful.

- It is important to affix the proper algebraic sign to the coordinates measured.

5. Comparator Measurement of Photo Coordinates

- Comparators can provide a high level of accuracy (2~3 μm) in coordinate measurements while no longer in common use.

- Two types of comparator exist: *monocomparators* and *stereocomparators* with which image positions are measured by simultaneously viewing an overlapping stereo pair of photographs.

- Analytical stereoplotter is commonly used to perform the function of both type of comparators

Figure. Mann Monocomparator
https://www.researchgate.net/figure/Mann-monocomparator_fig6_325425242

6. Photogrammetric Scanners

- Photogrammetric scanners are used to convert analog content of photograph to digital form from which coordinate measurement can take place in computer environment.

- High-quality photogrammetric scanners should be capable of producing digital images with minimum pixel sizes on the order of 5 to 15 μm

- These scanners are no longer popular due to increased use of digital cameras.

7. Refinement of Measured Image Coordinates

- The measured photo coordinates will contain systematic errors as bellows.

1) Film distortions due to shrinkage, expansion, and lack of flatness/ CCD array distortions due to electrical signal timing issues or lack of flatness

2) Failure of photo coordinate axes to intersect at the principal point/ Failure of principal point to be aligned with center of CCD array.

3) Lens distortions

4) Atmospheric refraction distortions

5) Earth curvature distortion

8. Distortions of Photographic Films and Papers

- Even though film is much more stable than paper it can be distorted as much of 0 to 0.2 percent by temperature and humidity in a storage room and affected by film type and thickness.

9. Image Plane Distortion

- Shrinkage or expansion of a photograph can be determined by comparing the measured (*m*) fiducial distances with their corresponding calibrated values (*c*):

$$x'_a = \left(\frac{x_c}{x_m}\right)x_a \qquad y'_a = \left(\frac{y_c}{y_m}\right)y_a$$

- [Example 4-1] Measured fiducial distances in x and y are 233.8 & 233.5 mm, respectively while calibrated fiducial distances are 232.604 & 232.621 mm.

$$x' = \left(\frac{232.604}{233.8}\right)x = 0.9949x$$

$$y' = \left(\frac{232.621}{233.5}\right)x = 0.9962y$$

	Measured Coordinates		Corrected Coordinates	
(a) Point no.	(*b*) *x*, mm	(c) *y*, mm	(*d*) *x′*, mm	(e) *y′*, mm
1	–102.6	95.2	–102.1	94.8
2	–98.4	–87.8	–97.9	–87.5
3	16.3	–36.1	16.2	–36.0
4	65.7	61.8	65.4	61.6
5	104.9	–73.5	104.4	–73.2

Figure 3-19 Resolution test pattern for camera calibration.

10. Reduction of Coordinates to an Origin at the Principal Point

- Lens distortions are most symmetric about the principal point which photo coordinates/photogrammetric equations are based on. The principal points, however, generally does not coincide with the intersection of fiducial lines or the CCD center.

- Normally (mapping) camera manufacturers attempt to make the principal point coincide with the intersection of fiducial lines within a few micrometers so that the correction can usually be ignored in work of coarse accuracy.

- For precise analytical photogrammetric work, the principal point coordinates, x_p and y_p are subtracted from the measured and transformed x and y coordinates.

11. Correction for Lens Distortions

- Lens distortions typically consist of symmetric radial distortion and decentering distortion which are normally less than 5 μm in modern aerial mapping cameras.

- Symmetric radial lens distortion is unavoidable and was significantly larger than decentering distortion which is primarily caused by imperfect assembly of lens elements.

- The radial distortion value (Δr) is the radial displacement from the ideal location to the actual image of collimator cross when the multicollimator is adopted.

- Correction procedure: coordinates relative to the principal point are calculated ($\bar{x}, \bar{y}$) and radial distortion (Δr) is obtained from a polynomial:

$$\Delta r = k_1 r^1 + k_2 r^3 + k_3 r^5 + k_4 r^7$$

, where $r = \sqrt{\bar{x}^2 + \bar{y}^2}$ and $\bar{x} = x - x_p, \bar{y} = y - y_p$.

11. Correction for Lens Distortions

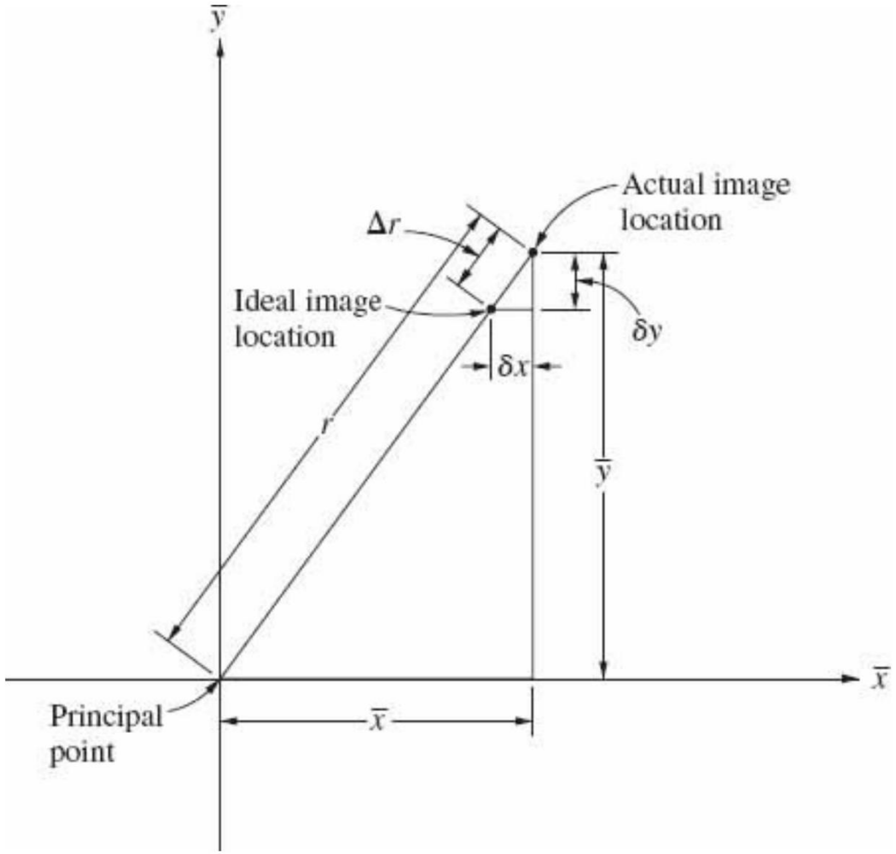


FIGURE 4-4 Relationship between radial lens distortion and corrections to *x* and *y* coordinates.

$$\frac{\Delta r}{r} = \frac{\delta x}{\bar{x}} = \frac{\delta y}{\bar{y}}$$

$$\delta x = \bar{x}\frac{\Delta r}{r}, \qquad \delta y = \bar{y}\frac{\Delta r}{r}$$

The corrected coordinates:

$$x_c = \bar{x} - \delta x$$

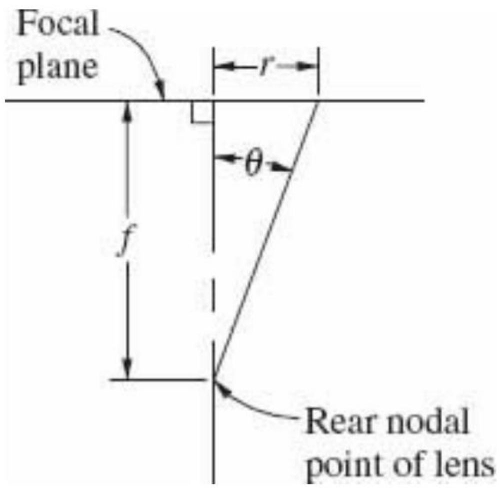
$$y_c = \bar{y} - \delta y$$

11. Correction for Lens Distortions

[Example 4-2]

- $f = 153.206\,mm, \quad (x_p, y_p) = (0.008, -0.001)$
- $(x, y) = (62.579, -80.916) \rightarrow (x_c, y_c)?$

Mean Radial Distortion		
(a) Field angle θ	(b) Δr, mm	(c) r, m
7.5°	0.004	0.0202
15°	0.007	0.0411
22.5°	0.007	0.0635
30°	0.001	0.0885
35°	–0.003	0.1073
40°	–0.004	0.1286



From the least squares method

$$k_1 = 0.2296, \; k_2 = -35.89$$
$$k_3 = 1{,}018, \quad k_4 = 12{,}100$$

$$\bar{x} = x - x_p = 0.062571 \text{ m}$$
$$\bar{y} = y - y_p = -0.080915 \text{ m}$$
$$r = \sqrt{\bar{x}^2 + \bar{y}^2} = 0.1023 \text{ m}$$
$$\Delta r = k_1 r^1 + k_2 r^3 + k_3 r^5 + k_4 r^7 = \text{-}0.0021 \text{ mm}$$

11. Correction for Lens Distortions

$$\delta x = \bar{x}\frac{\Delta r}{r} = 0.062571\left(\frac{-0.0021}{0.1023}\right) = -0.0013 \text{ mm}$$

$$\delta y = \bar{y}\frac{\Delta r}{r} = -0.080915\left(\frac{-0.0021}{0.1023}\right) = 0.0017 \text{ mm}$$

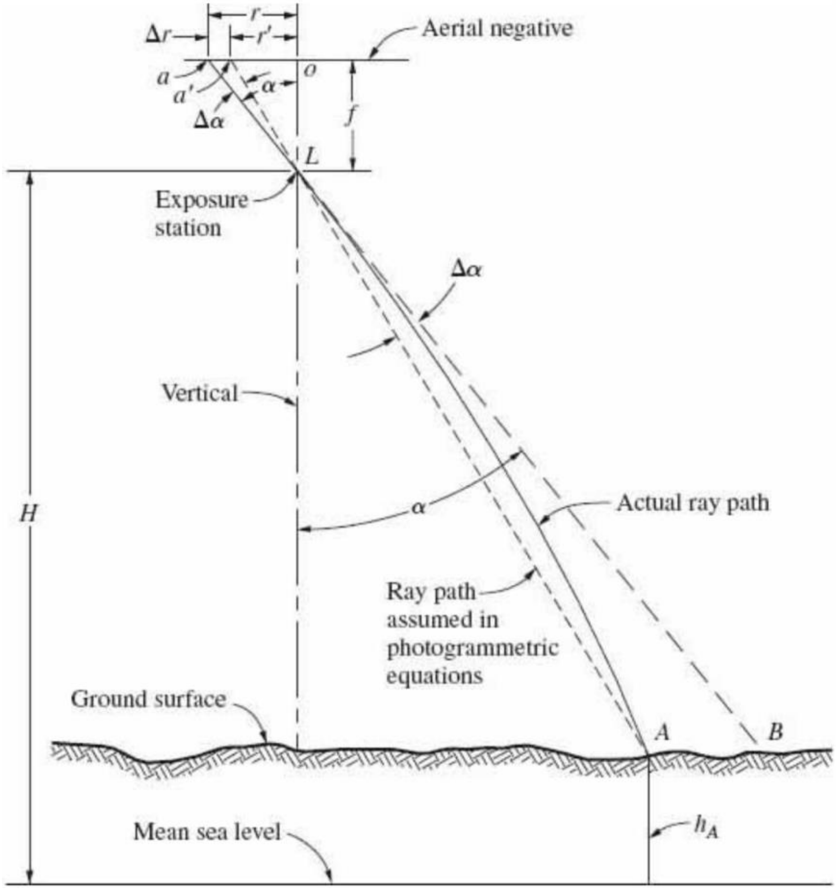
$$x_c = \bar{x} - \delta x = 62.571 - (-0.0013) = 62.572 \text{ mm}$$

$y_c = \bar{y} - \delta y$ =-80.915-0.0017 = -80.917 mm

- USGS adopted SMAC (Simultaneous Multi-camera Analytical Calibration) for the calibration procedure which computes both symmetric radial and decentering distortion parameters directly by least squares.

12. Correction for Atmospheric Refraction

- Air density decreasing with increasing altitude makes light rays bent according to Snell's law, which requires corrections for the image coordinates.



- Angular distortion due to refraction, Δα increases with increasing flying height and increasing incident angle α:

$$\Delta\alpha = K \tan \alpha$$

, where K is a function of H (camera elevation) and h (object elevation) (ex. $K = (7.4 \times 10^{-4})(H - h)[1 -$

12. Correction for Atmospheric Refraction

[Example 4-4]

Elevations of Camera with 153.099 mm of focal length and an object A are 3,500 m and 120 m, respectively. The image point a of A has fiducial system coordinates: $x_a = 73.287$ mm and $y_a = -101.307$ mm . Compute $x'$and y' corrected for atmospheric refraction

$$r = \sqrt{73.287^2 + (-101.307)^2} = 125.036 \text{ mm}$$

$$\tan\alpha = \frac{125.036}{153.099} \rightarrow \alpha = 39.2386°$$

$$K = (7.4 \times 10^{-4})(3.5 - 0.12)[1 - 0.02(2(3.5) - 0/12)] = 0.0022°$$

$$\Delta\alpha = K\,\frac{r}{f} = 0.0022°\left(\frac{125.036}{153.099}\right) = 0.0018°$$

$$r' = 153.099 \tan(39.2386° - 0.0018°) = 125.029 \text{ mm}$$

$$\Delta r = 125.036 - 125.029 = 0.008 \text{ mm}$$

12. Correction for Atmospheric Refraction

$$\delta x = 73.287\left(\frac{0.008}{125.036}\right) = 0.005\ \text{mm}$$

$$\delta y = -101.307\left(\frac{0.008}{125.036}\right) = -0.006\ \text{mm}$$

$$x' = x - \delta x = 73.287 - 0.005 = 73.282\ \text{mm}$$

$$y' = y - \delta y = -101.307 - (-0.006) = -101.301\ \text{mm}$$

13. Correction for Earth Curvature

- Earth curvature corrections has been recognized not to be theoretically correct but at the same time such correction generally leads to more accurate results than ignoring it.

- Correcting photo coordinates for earth curvature may degrade the accuracy of either *x*, or *y* coordinates depending upon the map projection used: For example, UTM (Universal Transverse Mercator coordinate system) projection with earth curvature corrections will yield more accurate elevation and *y* values while *x* values will be degraded because UTM projection does not curve in the *x* direction.

- Local vertical coordinate system can avoid the need of earth curvature correction which will be described in Sec.5-5.

13. Correction for Earth Curvature

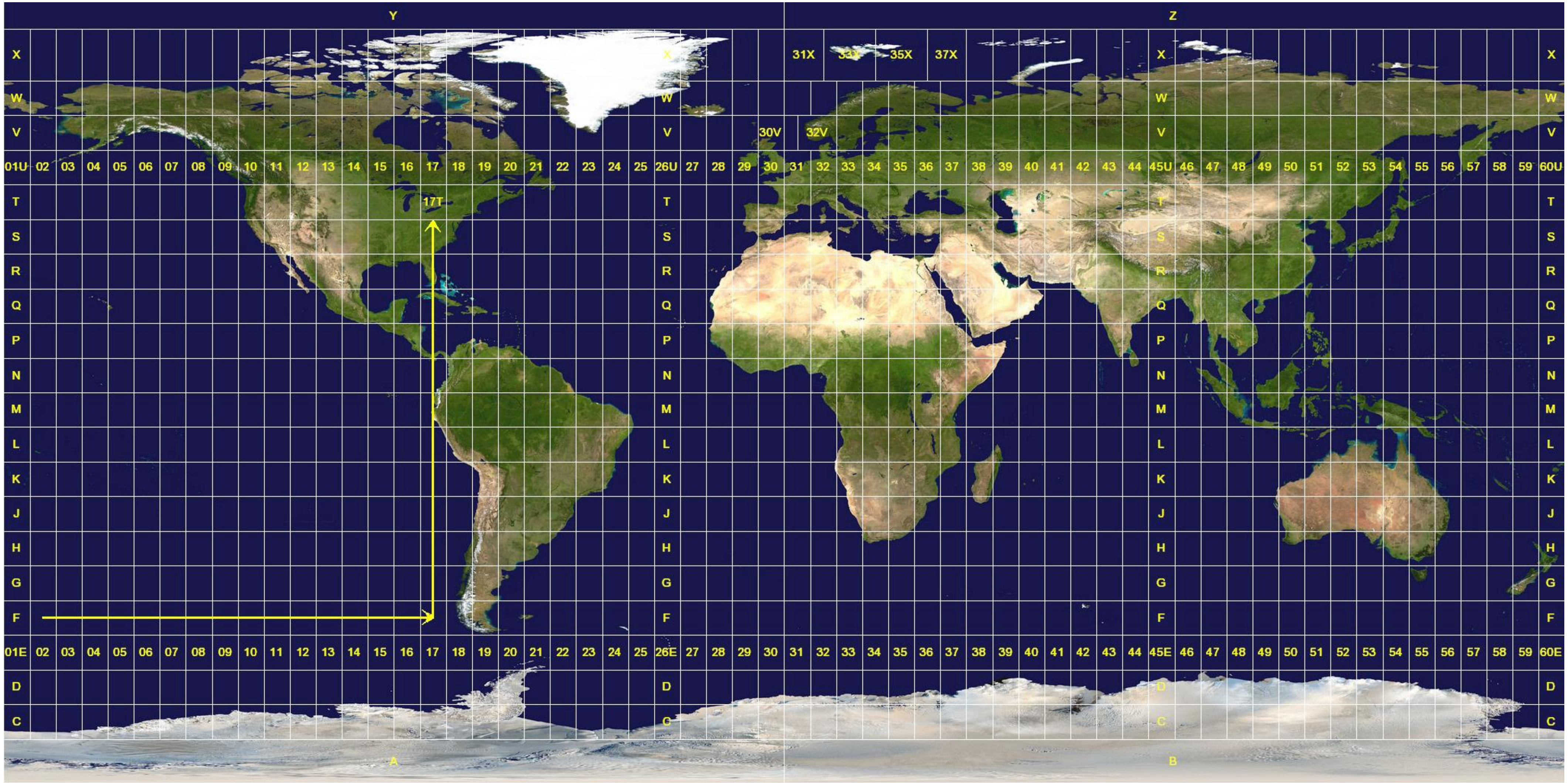


Figure. UTM coordinate system: 60 cells in west-east; c~x divisions in south-north

14. Measurement of Feature Positions and Edges

- Under magnification or image zoom, the edges of an object will appear to be somewhat indistinct although the center can still be identified to a high precision.

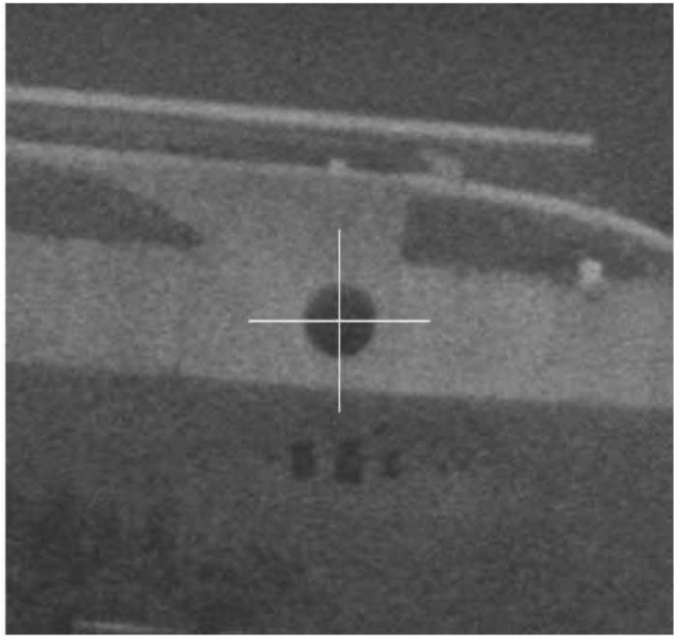


FIGURE 4-7 Zoomed-in view of a manhole with cross-hair at center.

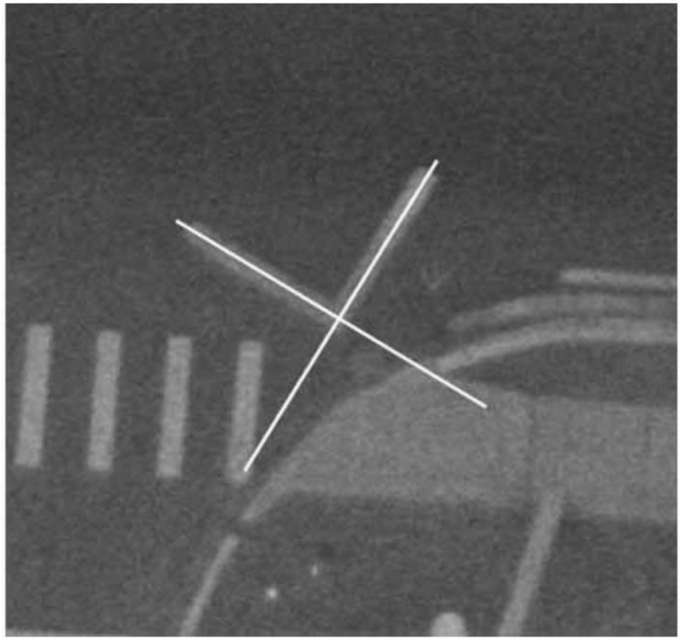


FIGURE 4-8 Zoomed-in view of a chevron target with cross-hair at the intersection of centerlines of stripes.