Vertical Photography

Chapter 9

Vertical photography is the process and the product of aerial photography taken with the axis of the camera held in a truly vertical position. If the vertical photography is taken over flat terrain, measured distances and directions may approach the accuracy of a line on a map. Procedures for determining measurements for vertical photography follow.

SCALE DETERMINATION

The linear scale is the relationship between distance on a map or photo and the actual ground distance. Scale is expressed as a representative fraction (RF). RF may be determined by one of three basic formulas:

$$RF = \frac{f}{H} \text{ or } \frac{f}{H-h} \qquad RF = \frac{PD}{GD} \qquad RF = \frac{P}{MD \times MSR}$$

Where--

RF= The representative fraction or the scale of the imagery
f = The focal length of the camera
H= Height of aircraft above sea level
h = average terrain height above sea level
PD = Photo distance on picture
GD = Actual ground distance
MD= Distance on map
MSR = Map scale reciprocal

Example: Find the RF of a photo where f equals 6 inches and H equals 5,000 feet.

$$RF = \frac{f}{H}$$

$$RF = \frac{6\ in}{5{,}000\ ft}$$

$$RF = 1:10{,}000$$

GROUND DISTANCE DETERMINATION

You must know the photo representative fraction (PRF) or the map representative fraction (MRF) to use the MSR or the PSR ground distance determination. To determine the actual distance or size of an object on an aerial photograph or map, use one of two formulas:

$$GD = PD \times PSR \text{ or } GD = MD \times MSR$$

Where--

GD = Ground distance
PD = Photo distance
MD= Map distance
PSR = Photo scale reciprocal
MSR = Map scale reciprocal

Example Find the GD covered by a photo where the PD = 0.026 feet and PRF = 1:8800.

$$GD = PD \times PSR$$
$$GD = 0.026 \text{ feet} \times 8800 \text{ feet}$$
$$GD = 228.8 \text{ feet}$$

PLOTTING TEMPLATE ADJUSTMENT

The plotting template is an adjustable instrument used for plotting vertical aerial photographs. The four sides of the template are graduated in inches and five hundredths of inches and may readjusted to any combination of lengths and widths from 0.05 inches by 0.05 inches to 5.0 inches by 5.0 inches. You can adjust the template during inspection or with the formula--

Where--

TS = Template setting in inches
PS = Photo side (in inches)
PSR = Photo scale reciprocal
MSR = Map scale reciprocals

Example Find the TS of a photo where PS equals 9 inches by 9 inches, PRF equals 1:5000, and MRF equals 1:25,000.

$$TS = \frac{PS\ (inches) \times PSR}{MSR}$$

$$TS = \frac{9\ inches \times 5{,}000}{25{,}000}$$

$$TS = 1.8\ inches \times 1.8\ inches$$

PROPORTIONAL DIVIDERS USE

The proportional divider is an adjustable, compass-like instrument designed especially for enlarging or proportionally reducing drawings and sketches. Use the formula---

$$scale\ ratio = \frac{MSR}{PSR} \text{ or } \frac{PSR}{MSR}$$

Where--

scale ratio = Proportional divider setting
MSR = Map scale reciprocal
PSR = Photo scale reciprocal

Example Find the scale ratio when MRF equals 1:25,000 and PRF equals 1:5,000.

$$scale\ ratio = \frac{MSR}{PSR}$$

$$scale\ ratio = \frac{25{,}000}{5{,}000}$$

$$scale\ ratio = 5{:}1$$

PHOTO COVERAGE

Photo coverage is the ground area captured on any photo. It may be expressed in square feet, square yards, or square miles. You can determine photo coverage by using the formula--

$$PSC = PSR \times PS$$

Where--

PSC = Photo side coverage on the ground
PSR = Photo scale reciprocal
PS = Photo side

Example Find the ground distance covered by each side of a photo with RF equals 1:10,000 and photo format equals 9 inches by 9 inches.

$$PSC = PSR \times PS$$
$$PSC = 10{,}000 \times 9\ inches$$
$$PSC = 10{,}000 \times 0.75\ feet$$
$$PSC = 7{,}500\ feet$$

The total ground area covered by this photo is 7,500 feet by 7,500 feet or 56,250,000 square feet.

PHOTO COVERAGE FOR A SPECIFIC AREA

The photo coverage for a specific area refers to the number of photos required to cover a predetermined area at a desired scale and format size. You must know--

- The desired scale of the photography.
- The photo format.
- The size of the area to be covered.
- The percentage of forward overlap between photos.
- The percentage of side lap between flight lines.

Example Determine the number of photos required to cover an area 36,000 feet by 30,000 feet.

Where-- Photo format = 9 inches by 9 inches
Desired scale = 1:5,000
Forward overlap = 60 percent
Sidelap = 40 percent

Step 1. Determine the ground-area coverage of a single photo.

Area coverage = format x PSR
Area coverage = .75 feet x 5,000
Area coverage = 3,750 feet x 3,750 feet

Step 2. Determine the amount of ground gained forward (Ggf).

Ggf = Total area coverage minus forward overlap percentage
Ggf = 3,750 feet X 40%
Ggf = 1,500 feet

Step 3. Determine the amount of ground gained sideways (Ggs).

Ggs = Total area coverage minus sidelap percentage
Ggs = 3,750 feet x 60%
Ggs = 2,250 feet

Step 4. Determine the minimum number of photos per flight line.

$$\textit{Photo per flight line} = \frac{\textit{length of area}}{\textit{Ggf}}$$

$$\textit{Photo per flight line} = \frac{36{,}000ft}{1{,}500ft}$$

$$\textit{Photo per flight line} = 34$$

Step 5. Round off photos per flight line to the next higher number when an uneven number exists. Add two photos to each end of the flight line to ensure complete stereo coverage.

Step 6. Determine the number of flight lines.

$$\textit{Flight lines} = \frac{\textit{Area width}}{\textit{Ggs}}$$

$$\textit{Flight lines} = \frac{30{,}000}{2{,}250}$$

$$\textit{Flight lines} = 13 +$$

Step 7. Round off the number of flight lines to next higher number when an uneven number exists.

13+ = 14 flight lines

Step 8. Multiply the number of photos per flight line by the number of flight lines to get the total number of photos required to complete the mission.

14 x 38= 532 Photos required

HEIGHT DETERMINATION

Parallax Method

When you photograph a tall object from the air in two successive exposures, the position of the point between the two photos appears to change. This displace ment is called parallax, which you can measure to determine the height of an object or the elevation of a point, using two overlapping vertical photos and taking measurements in a prescribed manner. This is the most accurate method of measuring height.

Step 1. Attach the parallax bar to the cross member of the stereoscope legs with the gage to the right. Push the ends of the bar down to engage the spring clips. Slide the bar as close to you as the stereoscope legs will permit. This will place the dots directly below the stereoscope lens. (See Figure 9-l.)

Step 2. The stereometer is a stereoscope with special measuring attachments. Under each lens is a glass plate that rests on its respective photograph of a stereoscopic pair. On the bottom of each glass plate is a small dot. The dot under the left lens remains in a fixed position. You can move the dot under the right lens by an adjusting knob along the eye base of the stereometer. The movement of the

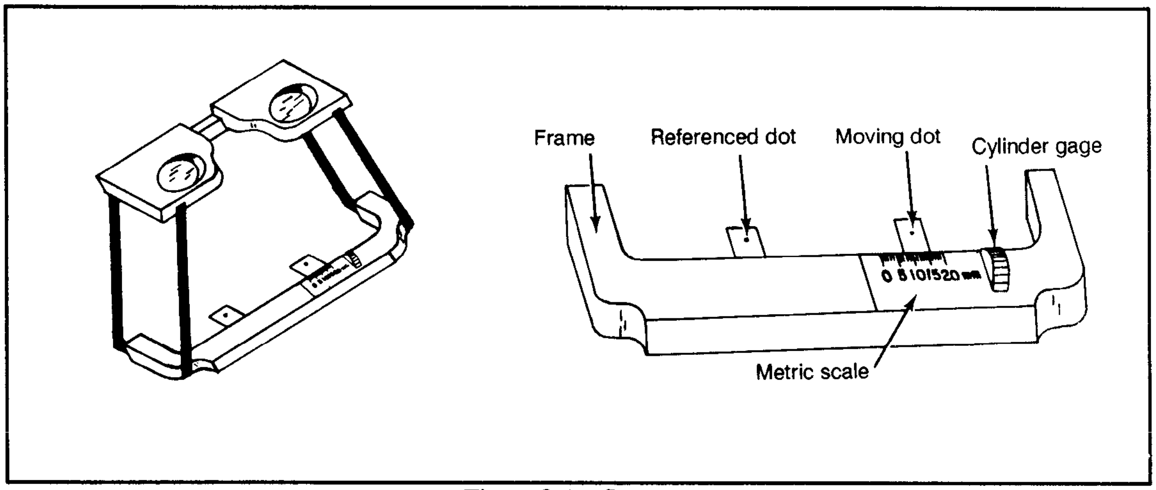

Figure 9-1 Stereoscope

right dot is measured by a micrometer dial. The range of distance between the dots is significant. For example, when you turn the adjusting knob on a stereometer so that the dots are at minimum separation, they may be 60 millimeters apart. When you turn the adjusting knob so that the dots are at a maximum separation, they may be 70 millimeters apart.

Corresponding points on two photographs must be between 60 and 70 millimeters apart when the photographs are properly oriented for stereoscopic vision. Relative to the graduation of the instrument the numbers may increase or decrease in magnitude when the dots converge. For example, if there is a range of 10 millimeters between minimum and maximum separation of the dots, the readings may be 0 at minimum and 10 at maximum or 0 at maximum and 10 at minimum, depending on the type of stereometer.

Step 3. Use fiducial marks to locate and mark principal points of both stereo paired photographs. Both photos have their own principal points but also contain the principal point of the adjacent photo in the aircraft flight line. To locate these points, transfer them from one adjacent photo to another with a stereoscope. Orient the photos for stereo viewing, locate the marked principal point, and mark the same point on the adjacent photograph. Repeat this procedure with the other photo. Each photo now has a principal point and a transferred principal point (see Figure 9-2).

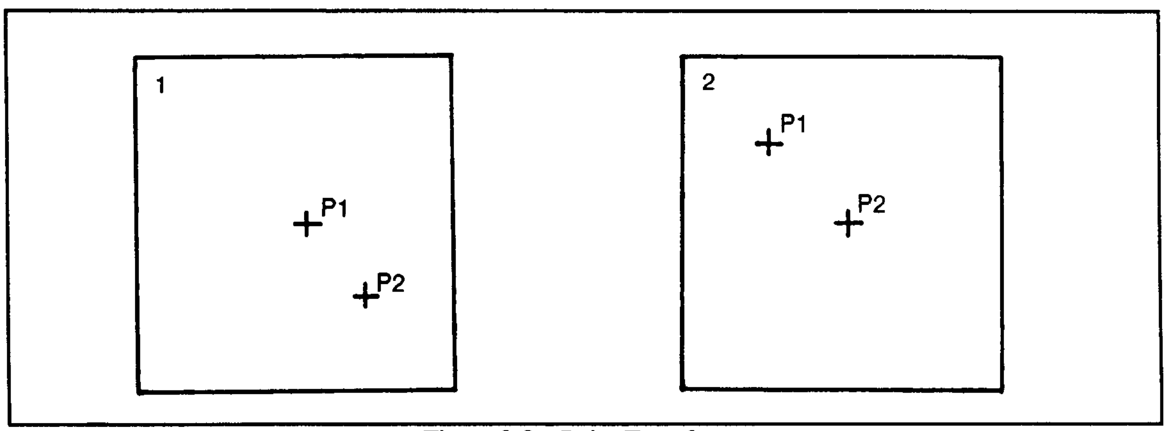

Figure 9-2 Point Transfer

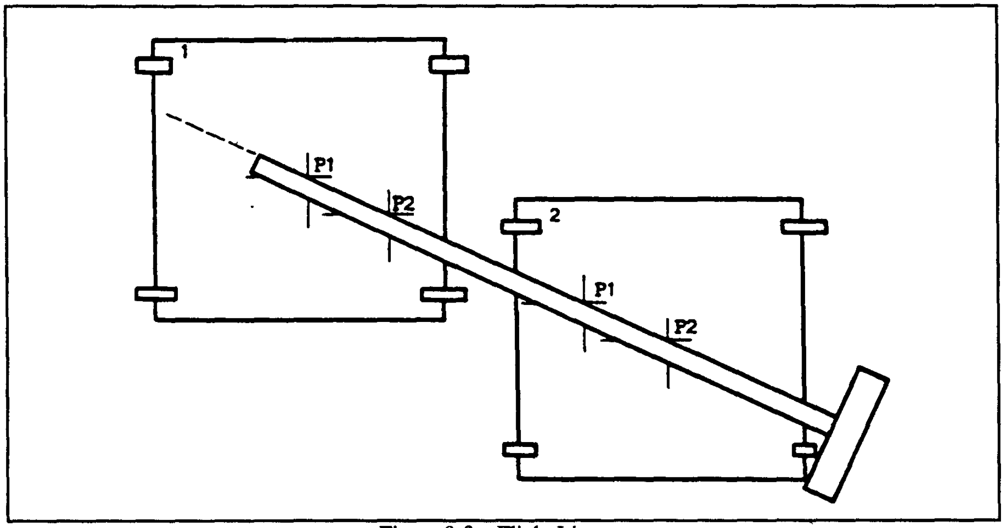

Figure 9-3 Flight Line

Now you can establish the flight line by drawing a line from the principal point to the transferred principal point on each photograph (see Figure 9-3). Measure the distance from the principal point to the transferred principal point (see Figure 9-4). Average these measurements using the formula--

$$b_m = \frac{b_1 + b_2}{2}$$

Where--

b_m = base means

b_1 = measurement from the principal point to the transferred principal point on photo #l

b_2 = measurement from the principal point to the transferred principal point on photo #2

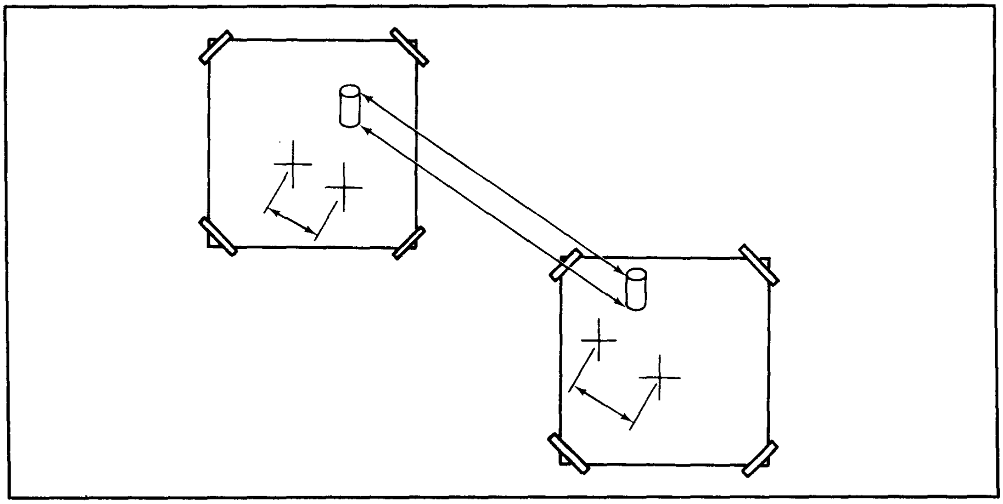

Figure 9-4 Point Measurement

Step 4. Locate the feature that you will measure using the stereoscope and stereometer. Measure the top of the feature frost to obtain the first parallax measurement p_1. Then measure the bottom of the feature to obtain the second parallax measurement, p_2. To obtain a parallax measurement, you must place the photos so you can see them in stereo. With the stereometer attached to the stereoscope, you can see a left and right dot through the eyepieces. Place the left dot on the point to be measured, then rotate the micrometer knob until the right dot fuses with the left dot. Record the micrometer reading as shown on the scale.

After you have taken both parallax measurements (p_1 and p_2), find the differential parallax (Δp) to help determine the height of the feature, using the equation below. You can use p, as a function of the elevation of the feature being measured, to calculate the height of any natural or manmade object.

$$\Delta p = p_1 - p_2$$

Step 5. Since all elevations are relative to each other, you must establish a reference elevation to measure height differences. This reference elevation is the average terrain elevation above mean sea level, the horizontal plane above which an aircraft photographs. You can reference the terrain elevation of certain objects shown on aerial photography from topographic maps of the same area. This data can be used to provide an estimation of the average terrain elevation (h). For parallax height determination, you must also know the altitude of the aircraft, which you can determine from the marginal information on the aerial photograph. The altitude shown on the photo is the aircraft height above mean sea level (H).

Step 6. Once you have taken all measurements from the stereo-paired photographs, you can use the parallax equation to solve height determination, as follows:

Example:

a. Determine the base means.

$$b_m = \frac{b_1 + b_2}{2}$$

$$b_m = \frac{.305' + .313'}{2}$$

$$b_m = \frac{.618'}{2}$$

$$b_m = .309'$$

b. Determine the differential parallax.

$$\Delta p = p_1 - p_2$$

$$\Delta p = .0435\,\textit{feet} - .0410\text{ feet} = .0025\,\textit{feet}$$

c. Determine height.

$$Height = \frac{(H - h) \times \Delta p}{b_m + \Delta p}$$

$$Height = \frac{(5{,}990\,ft - 640\,ft) \times .0025\,ft}{.309\,ft + .0025\,ft}$$

$$Height = \frac{(5{,}350\,ft) \times .0025\,ft}{.3115\,ft}$$

$$Height = \frac{13.38\,ft^2}{.3115\,ft}$$

$$Height = 43\,feet$$

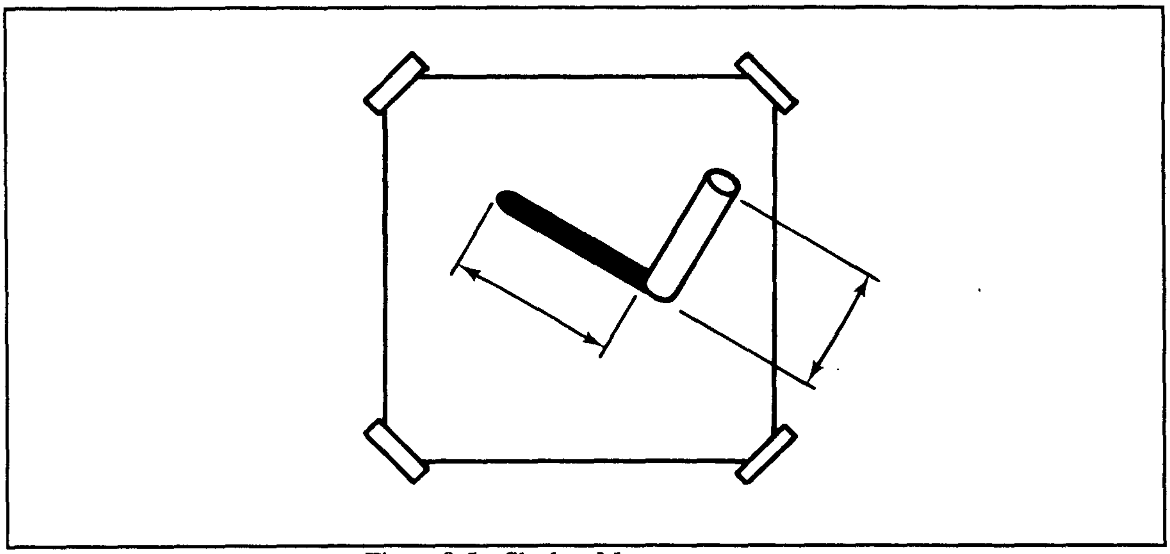

Figure 9-5 Shadow Measurement

Shadow Method

The shadow method is the least accurate of the three methods. You must have an object with a known height, and the unknown object must cast a shadow onto flat ground (see Figure 9-5). If the ground is uneven, the answer will be inaccurate. For any relatively small area of level ground, shadow length is directly proportional to object height. For example, a 40-foot tower casts a shadow twice as long as a 20-foot tower. If the shadow lengths are in a certain ratio, their photo images will be in the same ratio. To determine the height of an unknown object, measure its shadow length and multiply it by the ratio of height to shadow length established from the known object. Using the microcomparator or the photo interpreter's scale, measure the height of the unknown object and its shadow length. Place those measurements into the equation and determine the height using the following formula

Example:

h_k = 123 feet
s_k = .027 feet
s_u = .012 feet

$$h_u = \frac{h_k \times s_u}{s_k}$$

$$h_u = \frac{123 \times .012'}{.027'}$$

$$h_u = 55 \text{ feet}$$

Where--

h_u = height of unknown object
k = height of known object
Su = shadow length of unknown object
S_k = shadow length of known object

Relief Displacement Method

The determination of height from relief displacement employs a single, vertical aerial photograph where both the base and the top of a vertical object are measurable. This method is particularly effective on large-scale imagery. For it to work, the displacement of the image must be visible. The formula for determining the height of an object based on its relief displacement is--

$$Hgt = \frac{\text{displacement x flying height}}{\text{radial distance}}$$

$$Hgt = \frac{d\,x\,(H-h)}{r}$$

Hgt = Height of the object above the average terrain elevation
H = Altitude of the aircraft above mean sea level
h = Average terrain height above mean sea level
H-h = Altitude above ground level
d = Image distance representing vertical side of the object
r = Distance between principal point and top of the object scaled from the photograph

You will first need to use a straightedge and mark the center of the photograph with fiducial marks. Always measure *r* from the top of the object to the center of the photograph, which you must determine by the intersection of the lines connecting the opposite fiducial marks. Measure *d* between the same point on the top and on the bottom of the object. The top of the object is always farther away from the center of the photograph than the bottom (see Figure 9-6). Using the photo-interpreter's scale, measure the distances and place the numbers into the equation, using procedures discussed earlier.

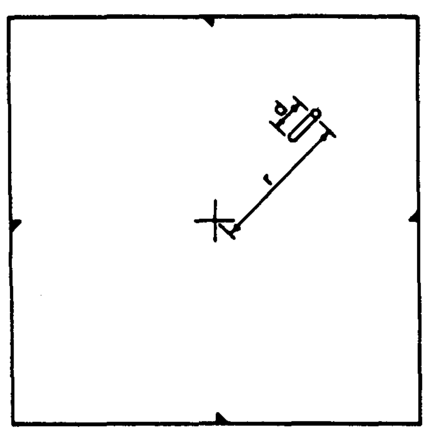

Figure 9-6 Displacement Measurement

Example

$$Hgt = \frac{d\,x\,(H-h)}{r}$$

$$Hgt = \frac{.017\,ft\ x\ 4{,}750\,ft}{.261\,ft} = 309\text{ ft}$$

AREA MEASUREMENT

You can use the dot grid template to measure area. Randomly place it on the lake or area to be measured. Count the dots that fall within the lake and those that fall on the line. Record the number, repeat the procedure at least three times, and determine the mean number of dots by adding the numbers together and dividing by the number of counts.

Example

First count	= 13
Second count	= 12
Third count	= 12
13+12+12	= 37
37/3	= 12.3
Mean number of dots	= 12.3

Step 1. Calculate the area in cm using the formula:

$$cm^2 = \frac{MEAN\ NUMBER\ OF\ DOTS}{25}$$

Example:

$$cm^2 = \frac{12.3}{25}$$

$cm^2 = .49\ cm^2$

Note: Dots per cm^2 in this example are 25. Other dot grids are available, so check in each case to determine the dots per cm^2.

Step 2. Calculate the ground area using the formula--

Area = object area in cm^2 x DRF^2

Example:

$DRF = 24{,}000$
$DRF^2 = 5.76x10^8$
$Area = (.49cm^{2)}\ x\ (5.76\ x\ 10^8)$
$Area = 2.8224\ x\ 10^8\ cm^2$

Where-- DRF = the denominator of the map or photo RF

Step 3. Convert the answer you obtained in Step 2 to square meters, using the formula--

$m^2 = cm^2\ x\ .0001$
$m^2 = (2.8224\ x\ 10^8\ cm^2)\ x\ (.0001)$
$m^2 = 28{,}224$

Examples:

a. Calculate the volume of a lake which is 3 meters deep and has a surface of $28{,}800m^2$.

$$\text{Volume} = 28{,}800m^2 \times 3m$$

$$\text{Volume} = 86{,}400m^3$$

b. Calculate the lake volume in gallons.

$$1\ m^3 = 264.7 \text{ gallons of water}$$

$$\text{Number of gallons} = (264.7 \text{ gallons} / m^2) \times (86{,}400m^3)$$

$$\text{Number of gallons} = 22{,}870{,}080$$

QPS AREA MEASUREMENT

The QPS computes measurements automatically, greatly helping analysts find surface areas and volumes (see Figure 9-7).

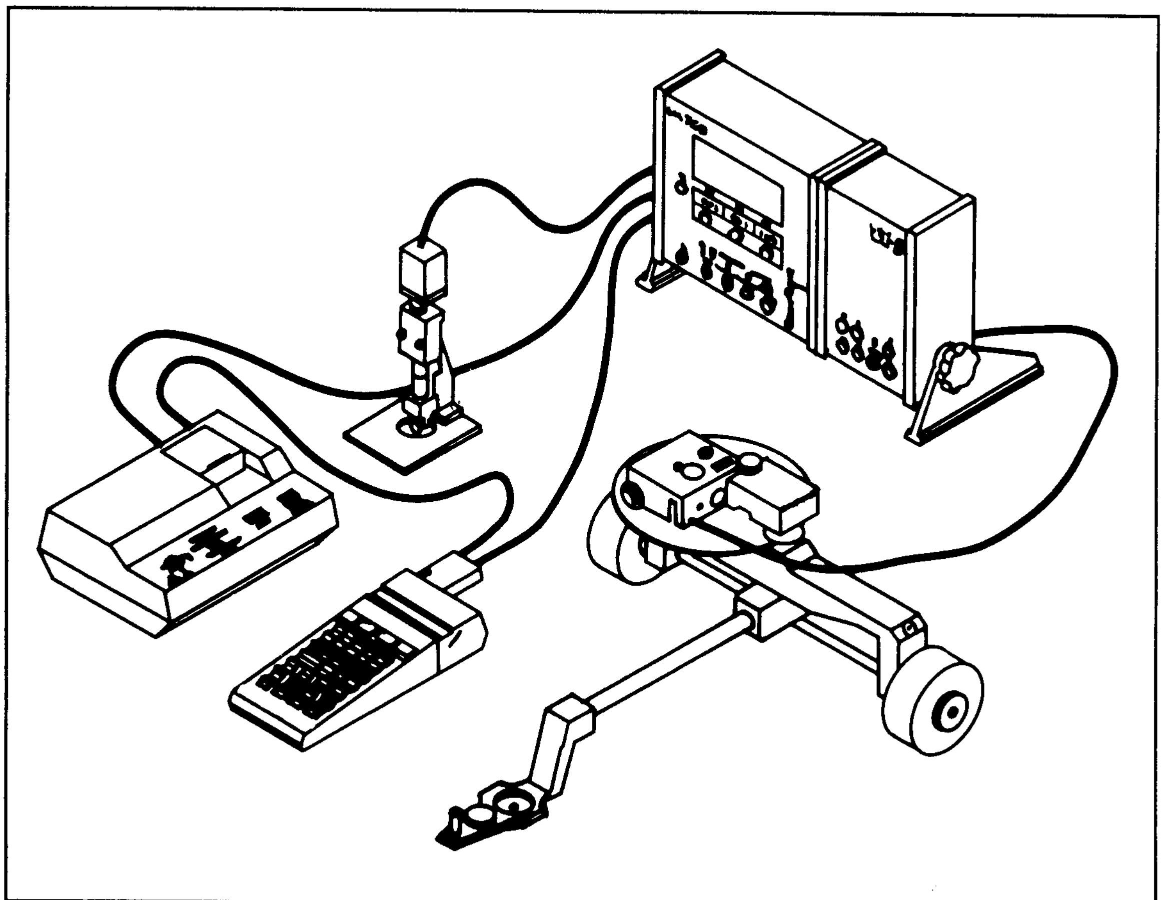

Figure 9-7 QPS

When the operator moves the QPS, it measures length, area, or volume. All measurements are displayed in the proper scale and units, and analysts can print a hard copy of the measurement results on command or automatically. The QPS is not affected by any detrimental physical condition of a map or photograph that is to be measured, such as tears, wrinkles, or folds. QPS components include--

- A calculator, which is capable of data storage and manipulation.
- A point counter, which enables automatic determination of the count total for specific features or items located on drawings, maps, and so forth.
- A planimeter, which estimates surface areas and volumes.
- A linear measuring probe, which measures lines and distances.

See TM 5-6675-324-14, TM 5-6675-325-14, and TM 5-6675-326-14 for more information on the QPS system. See Appendix C for sources of aerial and ground imagery.