

CHAPTER 10

Geographic Referencing

10.1 GEOGRAPHIC LOCATION SYSTEMS

To create a reliable map, it is necessary to relate the digital data to its true terrestrial situation.

10.1.1 Land Subdivision

The system of geographically parceling land in the United States has undergone changes since the American Revolution.

During the American colonial period, land subdivision was accomplished by metes-and-bounds surveys. Irregularly shaped parcels were segregated by surveying between visible features on the ground, such as boulders, piles of stone, trees, or fence corners. With the passage of time these objects had a way of disappearing, and retracing landlines has been difficult if not impossible.

Land in the United States, other than the 13 original colonies, is divided into units of the System of Rectangular Surveys.* Land is still parceled by the System of Rectangular Surveys on a variety of map sources in the United States. Anyone using county tax assessor's plat books, USGS quadrangle sheets, U.S. Soil Conservation soil type maps, U.S. Forest Service timber type maps, and other similar documents will come in contact with this land subdivision procedure.

Between 1803 and 1956 a number of initial reference points were established throughout the United States. In some localities a single reference point may serve more than one state. There are also situations where several initial reference points fall within a single state. For instance, Alaska contains five reference points. Using these points as initial surveying references, land is broken into townships, each 6 mi², which are further divided into 36 sections, each containing 1 mi² (640 acres). [Figure 10.1](#) indicates the standard pattern in which sections within a township are numbered.

* For a more detailed narration of land subdivision refer to Chapter 10 in *Aerial Mapping: Methods and Applications*, Lewis Publishers, Boca Raton, FL, 1995.

		Township Line					
Range Line		6	5	4	3	2	1
		7	8	9	10	11	12
		18	17	16	15	14	13
		19	20	21	22	23	24
		30	29	28	27	26	25
		31	32	33	34	35	36

Figure 10.1 Township and range identification on a USGS quadrangle sheet.

Figure 10.2 is a copy of a segment of a USGS quadrangle sheet showing the System of Rectangular Surveys. Note that the upper left corner R2E (along top margin) and T41N (along left margin) designate range and township coordinates, and the number group (36, 31, 1, 6) indicates the intersection of four individual sections.

When sections are subdivided into fractions for land parceling, the description begins at the smallest unit and works upward through the hierarchy. Contrarily, the creation of a unit works in reverse order. The 160-acre tract noted in Figure 10.3 would be identified as the NW/4 of Section 7, T6N, R11W.

10.1.2 Digital Mapping Data

A significant proportion of digital data generated by aerial surveys will eventually find their way into databases. Information derived from remote sensors is also incorporated into databases. Data from these and other sources can be mixed and matched in information system projects (Chapter 13). Hence, individual segments of the digital data must be keyed to the same geographic planes in order to be harmonious. Neither the metes-and-bounds nor the rectangular survey protocols are suitable for controlling contemporary digital mapping projects.

Digital information that represents a map resides in a database matrix composed of a multitude of individual points. Each point is spatial, having a coordinate triplet value for X (easting), Y (northing), and Z (elevation). Data are referenced horizontally to one of several grid coordinate projection systems. Elevation should be referenced to mean sea level.

10.1.3 Coordinate Systems

Coordinates can be referenced to any desired precise geographic grid system. The selected system is at the discretion of the user. This can be a standard reference

AURORA, ILLINOIS

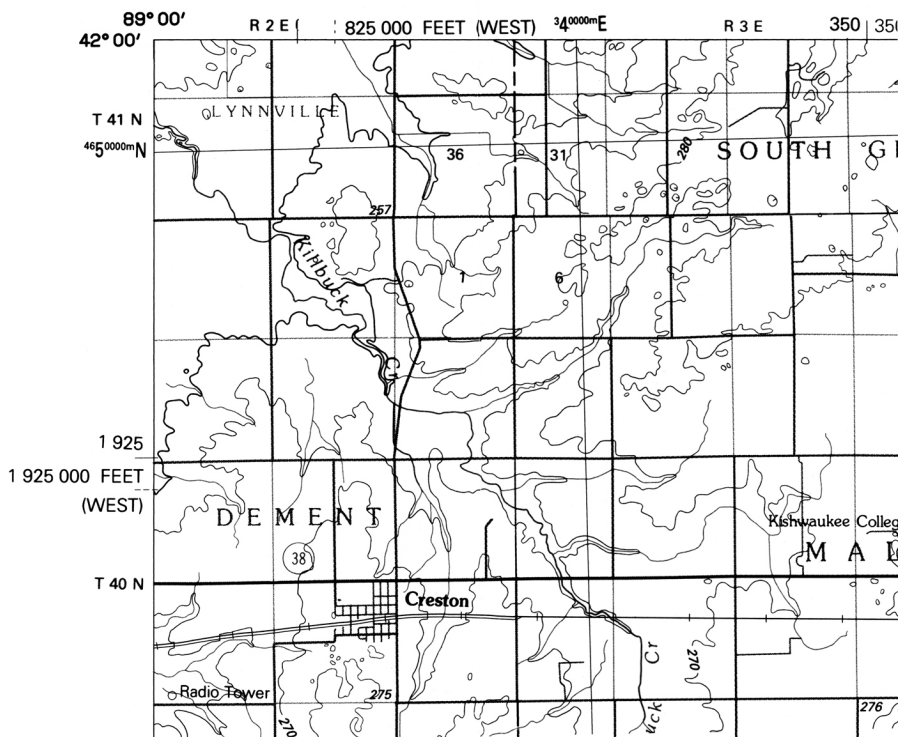


Figure 10.2 Section numbering system.

system to tie the mapping to the world or individual state, or it could be an assumed grid reference pertinent only to the specific site.

Data are increasingly incorporated into databases for information systems by diverse groups, and this trend will continue to grow in the future. If the data are to be inserted into a conglomerate of other packages of information, it must be translated to abide with the coordinate system of the whole.

It would be best to consider standard coordinate systems for collecting data to facilitate comprehensive use of the data. Three grid systems are popular for mapping within the United States, and all can be converted to match one another in a database. If one were to look at a quadrangle sheet, published by the USGS, he/she would note that all three of these coordinate systems are imprinted along its borders.

10.1.3.1 Universal Transverse Mercator

Universal Transverse Mercator (UTM), a metric (meters) grid structure, is a worldwide planar map projection which breaks the globe into 60 zones, each covering 6° of longitude. UTM is a cylindrical envelope intersecting the earth along two lines that are parallel to a central meridian. Data referenced to this grid system

ELSAH QUADRANGLE ILLINOIS-MISSOURI 7.5-MINUTE SERIES (TOPOGRAPHIC)

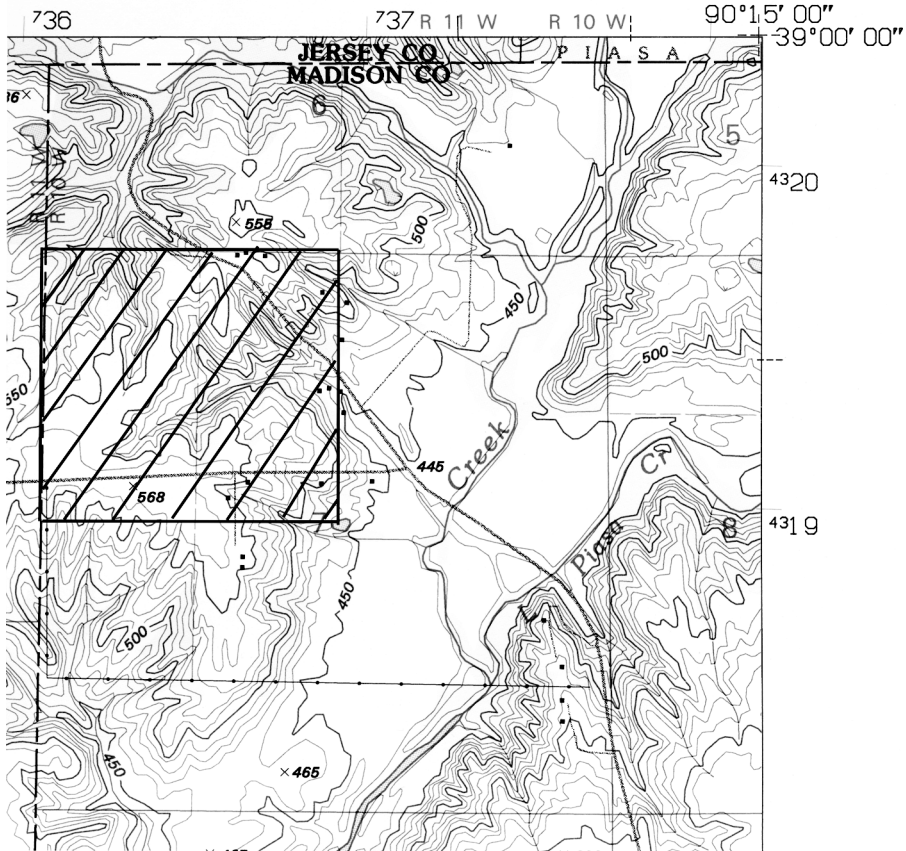


Figure 10.3 Land subdivision system tract identification.

can be correlated to worldwide mapping. Many GIS projects utilize this grid system to incorporate analogous data from diverse sources.

10.1.3.2 State Plane

The State Plane Coordinate System (SPCS), expressed in feet, segregates 120 zones throughout the United States. Conformal conic projection can be used in states that are wide in the east–west direction. Transverse mercator projection can be used in states that are narrow in the east–west direction. Much of the engineering mapping within state boundaries is controlled by this grid system.

10.1.3.3 Latitude/Longitude

Latitude/longitude coordinates are not normally used on large-scale mapping, but they are common to small-scale cartography and marine charting. If captured data are to be used in a national or international database, then this projection may be appropriate.

10.2 GROUND CONTROL SURVEYS

There are survey systems for referencing any tract of land to its true geographic placement on the earth.

10.2.1 Basic Surveying

Surveying is an ancient technology.* Mapping by either conventional or electronic methods requires the determination of spatial coordinates of specific strategically placed features on the ground. To arrive at these coordinates with conventional surveying techniques, three functions must be performed. Horizontal coordinates (X and Y) are derived by turning angles, and measuring distances and hypsometric measurements determine elevations (Z).

10.2.1.1 Angles

Horizontal angles must be sighted between successively selected points on the ground. For this procedure, magnetic compasses progressed into the transit — an instrument combining magnetic compass, horizontal azimuth card, and vertical angle vernier — then progress into the theodolite, a precision instrument for measuring horizontal and vertical angles.

10.2.1.2 Distances

In conjunction with turning angles, distances must be measured. The Gunther chain, which was probably preceded in some point in history by pacing or knotted string, developed into steel tapes for measuring distances. The age of electronics ushered in the electronic distance-measuring device. This apparatus emits light beams, at first visible and then laser, and measures the time it takes the beam to bounce off a reflector set over a distance point. A laser is a phased monochromatic beam of light that has been electronically stimulated.

10.2.1.3 Levels

Over the years elevations have been derived through the use of hand levels, dumpy levels, aneroid barometers, trigonometric levels, and differential spirit levels.

* A brief history of the technology of surveying is discussed in Chapter 11 in *Aerial Mapping: Methods and Applications*, Lewis Publishers, Boca Raton, FL, 1995.

10.2.2 Electronic Surveying

Electronic tacheometers (ETI), also termed total stations, incorporate both theodolite and electronic distance-measuring capabilities within a single instrument. Total stations are capable of calculating and outputting:

- Horizontal angle
- Vertical angle
- Horizontal distance
- Slope distance
- Vertical distance

When cabled to an electronic field book, total stations collect survey information directly in digital form. These data can be downloaded into a computer to perform coordinate geometry functions and topographic mapping.

10.3 GROUND SURVEY TOOLBOX

Locating features on the earth that can be seen and measured in the imagery is required in the photogrammetric mapping process. The required accuracy of the established feature locations is dependent upon the required map accuracy. Generally, the accuracy of the required feature locations must be more accurate than the mapping requirements for similar features that will be compiled in the spatial data collection. Therefore, the required map scale is an important consideration when deciding methods to be employed for ground control.

A good source for current ground survey accuracies and recommended standards and tolerances for various types of spatial data collection is the FGDC Geospatial Positioning Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management, July 1998. Other considerations may include the following:

- Terrain within the mapping area
- Accessibility within and around the mapping area
- Vegetation and tree canopy within and around the mapping area
- Building heights and density within and around the mapping area
- Time and funding available to collect the ground control information

Therefore, the method employed to collect the data should not be based solely on “what is the newest technology.” Surveyors have many types of equipment and methods available. Conventional traversing and level loops, as well as GPS methods, may be used. The decision should be based upon what survey methods within the surveyors toolbox fit the project. This chapter will not address detailed survey procedures and practices, but will discuss general requirements and information needed to make necessary decisions regarding types and methods to employ for a specific mapping project. A good source of current detailed information regarding conventional ground survey and GPS survey practices is the U.S. Army Corps of

Engineers, Engineering Manuals EM 1110-1-1002, Survey Markers and Monumentation and EM 1110-1-1003, NAVSTAR GPS Surveying.

10.3.1 Conventional Ground Survey

Many relatively small photomapping projects still rely upon conventional ground survey methods which include the use of survey transits, levels, and tapes to establish distances, horizontal locations, and elevations. These methods can produce location data to the accuracy required for most photogrammetry projects. The size, location, and terrain within the project and the time allotted for ground survey collection affect the staffing requirements when employing these methods.

10.4 GLOBAL POSITIONING

GPS methodology is often employed for establishing survey data. A GPS brings into play a surveying system that can isolate the position of a point on the earth's surface by making simultaneous observations on several orbiting NAVSTAR navigational satellites. Essentially, an electronic receiver measures the distances between the ground point and a minimum of four satellites, and the intersection of the divergent rays establishes the spatial coordinates of the observing station.

The courses of the two dozen operating satellites are predicted and tracked by the National Geodetic Survey. The anticipated ephemerides (positional) information is broadcast by the satellite. Several continuous tracking stations are scattered throughout the world, meticulously charting the paths of the satellites. Both the tracking data and broadcast information are available to the user, with the former providing more accurate data for processing receiver information.

10.4.1 Determining Spatial Coordinates

Determination of the coordinates of a ground station by GPS procedures relies upon intersection geometry. The GPS receiver, a pseudo-range measuring device, accepts carrier signals (microwaves with a set velocity) from multiple satellites, measures transmission time lapse, and determines distance from each satellite to the receiver. By measuring the carrier waves from a ground station to several satellite positions simultaneously, the XYZ coordinate can be determined. For ascertaining three-dimensional coordinates, the receiver must maintain a continuous lock on a minimum of four orbiting platforms simultaneously. [Figure 10.4](#) depicts a point position at the intersection of four satellite ranges. R1 through R4 are measured pseudo-ranges between the receiver and satellites.

10.4.2 Global Positioning System Procedures

The accuracy requirement (horizontal and vertical) for the final mapping data sets establishes the ground survey accuracy requirements and thus the GPS methods

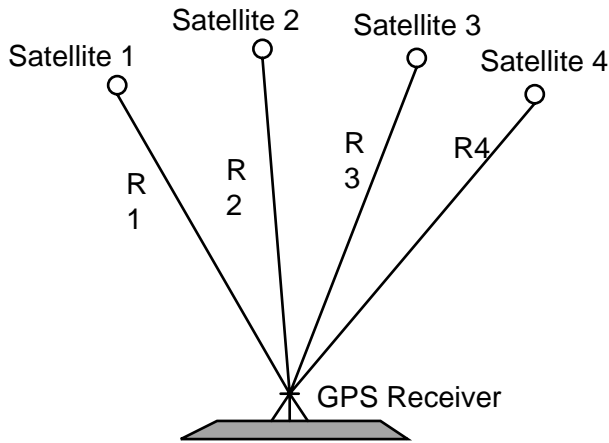


Figure 10.4 Intersecting satellite ranges.

that may be employed. Generally, for photogrammetric mapping, kinematic GPS methods will produce the feature location accuracy required. Some projects may require the establishment of selected features to an accuracy level only obtainable by static GPS methods.

When GPS is to be employed, the location of ground features for photo control must be carefully planned. A good reference for GPS planning is the U.S. Army Corps of Engineers, Engineering Manual EM1100-1-1003, NAVSTAR Global Positioning System Surveying.

10.4.2.1 Static Global Positioning System

In static traverses, at least two receivers must be used; both must be locked on to the same group of satellites. One receiver resides over a location with known coordinates, which could be a previous point in the circuit. The other receiver is set over a point with unknown coordinates. Observation time spent at each baseline point pair may span a significant period of time. After the observation is complete at the baseline pair, both receivers can be moved to new positions so long as one occupies a point with known coordinates. In this fashion, observations are made at all of the stations on the traverse in turn.

10.4.2.2 Kinematic Global Positioning System

As in static mode, kinematic traverses demand the inclusion of at least two receivers. One receiver must remain fixed over the same point, with known coordinates, during the entire survey period. The other receiver roves to each point of unknown coordinates in turn. Time spent by the roving receiver at each circuit point is much less than that used in static mode, perhaps as little as a few minutes.

10.4.3 Airborne Global Positioning (ABGPS)

Today many photogrammetric mapping projects employ ABGPS technology to minimize ground control collection for the mapping project. By locking on to several navigation satellites this device maintains a constant spatial positioning record of the sensing systems. Relating the film coordinates to a map allows the pilot to pinpoint the location of the aircraft on a specific exposure frame. This coupling of remote sensing and spatial positioning offers unique mapping capabilities.

ABGPS technology has been developed to a point where standard procedures and repeatable results make it almost standard practice for all medium to large project areas. GPS hardware and software vendors have teamed up with mapping hardware and software vendors to develop planning and processing tools that minimize errors and drastically reduce the time from aerial photography to a map file in hand.

10.4.3.1 Aircraft

Many private and public organizations currently mount GPS receivers in the airplane during a photo flight mission. This system allows the spatial fixing of the camera at the instant of exposure. Relating this position to the mapping site, it is possible to produce planimetric and/or topographic maps without the necessity of putting surveyors onto the site.

10.4.3.2 Reference to Ground Station

This system allows the ABGPS receiver to be interfaced with a camera system. In this procedure, the GPS in the aircraft is correlated with a static GPS ground station so as to relate the onboard receiver with the known ground station.

10.4.3.3 Aircrew Duties

The traditional concept of the duties of the aircrew members is changing. An aerial mission now can be considerably automated. Herein is described the general working of one such system. In an electronic guidance situation, both the pilot and the photographer must be conversant with computers and GPS.

Flight Map

The exterior boundary of the mapping site is digitized relative to an appropriate ground coordinate system. Flight parameters (photo scale, endlap, and sidelap) are input into the computer along with the digitized site boundary. Upon command, the computer will produce a hardcopy map delineating the location of each flight line upon the site map.

Preflight

Before takeoff, the flight map information is entered into an airborne personal computer which is linked with the onboard geographic positioning and camera systems. The flight map is displayed on the graphic screen in full view of the pilot.

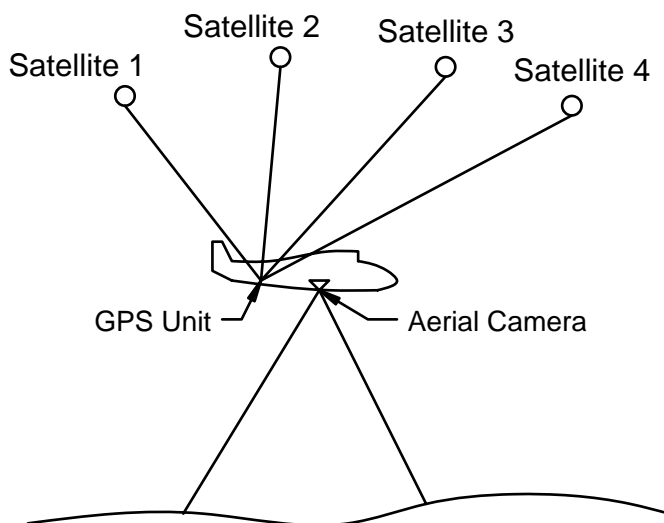


Figure 10.5 Airborne GPS system in flight.

Photo Mission

After takeoff, the pilot flies to the starting point of the initial flight line. [Figure 10.5](#) is a schematic diagram of an ABGPS. As the aircraft proceeds along the intended flight path, its position is graphically superimposed on the screen. By observing the true position of the aircraft and the intended course, the pilot can adjust the heading of the aircraft to adhere to the designated flight path. At periodic intervals the camera automatically makes an exposure, and the location of the perspective center is displayed on the graphics monitor.

By relating the precise instant of mid-exposure recorded by the camera, the geodetic XYZ position of the camera perspective center can be determined from the data captured through interfacing with the GPS receiver.

The ABGPS, like other photogrammetric surveying and mapping tools, has unique limitations and requirements. The cost and experience of a photogrammetric mapping team are always considerations. The experience of the team and additional equipment does affect overall cost, quality, and time to complete a project.

Considerations

Some unique factors which influence the cost of photo missions should be considered when pondering the utilization of ABGPS:

- In the past, the aerial photo mission has been typically the least costly phase of a mapping project. With the application of ABGPS the cost of the aerial photographic phase will increase, perhaps significantly.
- Crew members must be proficient in computer manipulation and GPS procedures. This could require higher salaries.
- Airborne computers and GPS receivers present additional equipment costs.

10.5 BASIC CONTROL NETWORKS*

Prior to collecting ground survey data at photo control points, it may be necessary to accomplish basic survey circuits in order to reference them to existing networks.

10.5.1 Conventional Surveys

Initially, project control is referenced to an existing station for which appropriate coordinates and/or elevations have been established by the USGS or the NGS (National Geodetic Surveys). This may require the surveyor to run horizontal traverses or vertical circuits from points outside the mapping area. Field surveys for establishing horizontal control point information require that vector traverses be run through a series of basic control points. Field surveys for establishing basic vertical control point information require that a differential level circuit be run between successive stations.

Field surveys are links between aerial photography and map compilation; all are of equal relevance to project quality assurance. Any weak link in this “chain” can negate the judicious effort of the other links. The practice of establishing an unproven coordinate position or elevation of control points is detrimental to the scheme of quality control.

Once the basic control has been established, the surveyor then runs spur traverses or circuits from the temporary turning points or benchmarks to individual photo control wing points.

10.5.2 Control Reference

For aerial mapping to be functional for the map/data user, the surveyor must reference the control data to legitimate established geographic data.

10.5.2.1 Horizontal

Coordinates are derived from the azimuth and distance of each tangent as measured in the field for whatever grid system to which the mapping is to be referenced. Computed coordinates can refer to whatever grid system the user specifies, but there are two standard systems which are probably most commonly employed, State Plane Coordinate System (SPCS) and Universal Transverse Mercator (UTM).

State Plane Coordinate System

Each state has at least one grid zero reference point, and state plane coordinates are read as northings and eastings, in United States feet, from the relevant reference.

Universal Transverse Mercator

The UTM locates northing and easting, in metric units, coordinates within various designated global zones.

* An expanded view of basic control networks can be found in Chapter 11 in *Aerial Mapping: Methods and Applications*, Lewis Publishers, Boca Raton, FL, 1995.

10.5.2.2 Vertical Control

Most mapping projects require that elevations be referenced to a known vertical datum by commencing and closing on established benchmarks, which may be a considerable distance from the mapping site.

10.5.3 Traverse/Circuit Accuracy

The Federal Geodetic and Control Committee (FGCC) has established accuracy limitations for first-, second-, and third-order horizontal and vertical surveys. These standards are used in surveys requiring sophisticated geodetic control.

10.5.3.1 Horizontal

For the largest scales, third-order, class I accuracy should suffice for horizontal control efforts on most mapping projects; for smaller scales, third-order, class II accuracy should be sufficient. FGCC horizontal accuracy standards stipulate accuracies noted in [Table 10.1](#). Equation 10.1 defines distance accuracy in terms of a ratio in the form of 1:a.

$$a = d/e_{xy} \quad (10.1)$$

where:

- a = distance accuracy
- d = horizontal distance between survey points
- e_{xy} = standard error of horizontal point pair

Table 10.1 FGCC Horizontal Accuracy Standards

Survey Class	Minimum Distance Accuracy
First order	1:100,000
Second order, class I	1:50,000
Third order, class I	1:10,000
Third order, class II	1:5,000

Table 10.2 FGCC Vertical Accuracy Standards

Survey Class	Maximum Elevation Difference (mm/ $\sqrt{\text{km}}$)
First order, class I	0.5
First order, class II	0.7
Second order, class I	1.0
Second order, class II	1.3
Third order	2.0

10.5.3.2 Vertical

Third-order, for larger contour intervals, or second-order (class II), for smaller contour intervals, accuracy should suffice for vertical control efforts on most mapping projects. FGCC vertical accuracy standards stipulate accuracies noted in [Table 10.2](#). Equation 10.2 defines elevation difference accuracy.

$$b = e_z / \sqrt{d} \quad (10.2)$$

where:

- b = elevation difference accuracy ratio
- d = distance between survey points (kilometers)
- e_z = standard error of difference between vertical points (millimeters)

10.6 PHOTO CONTROL POINTS

Prior to commencing mapping from aerial photos, ground survey information is required on specific terrain features in order to relate the photogrammetric spatial model to its true geographical location. These terrain features may be portrayed in two ways: by identifiable photo image features or ground targets (panels). Some project conditions may dictate that a combination of image points and targets can be most realistically employed.

Acquisition of ground control data on photo image points is a necessary requirement for photogrammetric mapping for two primary reasons:

- To georeference the base imagery prior to spatial data collection
- To check the accuracy of the spatial data collected

Technology is constantly changing and adding to the tools that can be used to collect ground control. Recent advances in GPS are the underlying reason for many of the advances in ground survey methods, as well as photogrammetry in general.

10.6.1 Photo Image Points

Photo image points must be readily identifiable pictorial image features that are selected after the aerial flight is completed or pretargeted prior to the photo mission.

10.6.2 Ground Targets

A target is some kind of a panel point that is placed on unobstructed ground prior to photography. [Figure 10.6](#) illustrates the effective presentation of a ground target (X) on an aerial photo. Ground targets create a discrete image point and can perhaps lead to better map accuracy. Targets stand less chance of being misidentified than an image feature, either by the surveyor or stereocompiler.



Figure 10.6 Ground target on an aerial photograph. (Courtesy of U.S. Army Corps of Engineers, St. Louis District.)

10.6.3 Size

A target must be of sufficient size to be recognized on the image. Dimensions of a target in the shape of a cross are easily computed.

Equation 10.3 defines the width of the legs of a typical ground target, as diagrammed in [Figure 10.7](#), for any photo scale.

$$w = s_p * 0.002 \quad (10.3)$$

where:

w = width of target legs (feet)

s_p = scale denominator (feet)

Equation 10.4 defines the length of the target legs of a typical ground target, as diagrammed in [Figure 10.5](#), for any photo scale.

$$l = 10 * w \quad (10.4)$$

where:

l = length of each cross arm (feet)

w = width of target legs (feet)

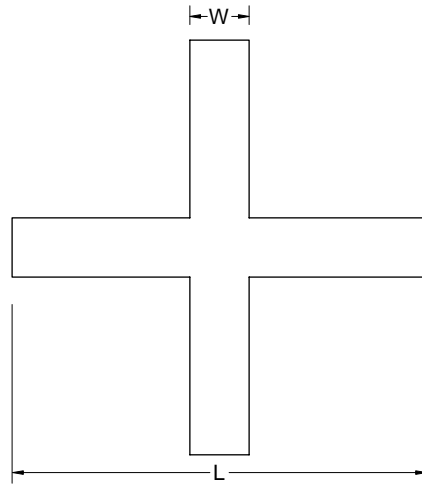


Figure 10.7 Typical ground target.

As an example, assume that a project requires a photo scale of 1 in. = 500 ft, the target size would be:

$$w = s_p * 0.002 = 500 \text{ ft} * 0.002 = 1 \text{ ft wide}$$

$$l = 10 * w = 10 * 1 \text{ ft} = 10 \text{ ft long, each cross arm}$$

10.6.4 Control Point Selection

To produce mapping from stereomodels, the aerial photo image must be scaled and leveled so as to cause the model to be georeferenced to a true geographic ground location. To do this, it is necessary to accurately relate the photos to the ground, both horizontally and vertically. This is done by establishing coordinates on specific horizontal “scale” points and elevations on vertical “level” points at the mapping site. In current mapping procedures, most points contain both horizontal and vertical information and are used for both scaling and leveling. The density of photo control points must be no less than four on each stereomodel, and the pattern should be one point in each of the corners, similar to the pattern illustrated in [Figure 10.8](#).

10.6.4.1 Conventional Control

Conventional photo control point patterns require that spatial (XYZ) coordinates for every photo control point must be gathered on the ground. In conventional control point surveys, the photographs are exposed first, and then each required field control point is selected as an identifiable photo image point. The surveyor locates these points on the ground and gathers the appropriate field information.

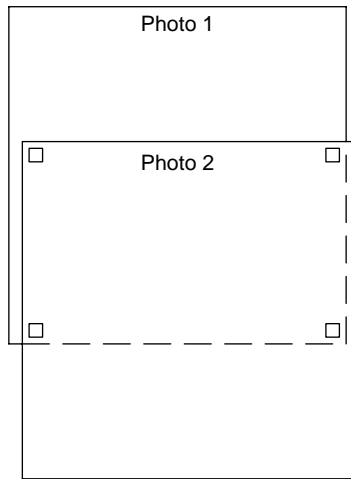


Figure 10.8 Photo control point requirements per stereomodel.

10.6.4.2 *Skeletal Control*

Skeletal surveys are run when the intent is to use aerotriangulation procedures to generate mapping photo control. In this situation, a lesser number of field control points are required than that needed in a conventional control pattern. [Figure 10.9](#) illustrates a mapping project involving three successive stereomodels. [Figure 10.10](#) notes the amount of conventional control that would be required to map the site.

By comparison, [Figure 10.11](#) suggests the amount of skeletal field control needed to resolve the supplementary photo control bridging. The process to accomplish this will be outlined in Chapter 11 (“Aerotriangulation”).

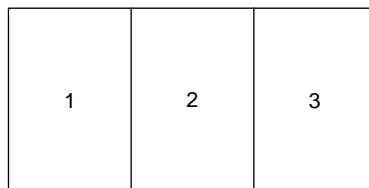


Figure 10.9 Three-model mapping site.

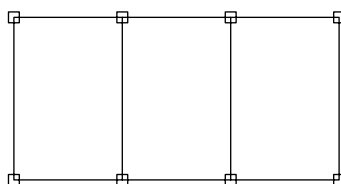


Figure 10.10 Conventional control point pattern on a triple model strip.

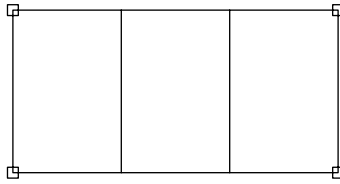


Figure 10.11 Skeletal control point pattern necessary to employ aerotriangulation on a three-model strip.

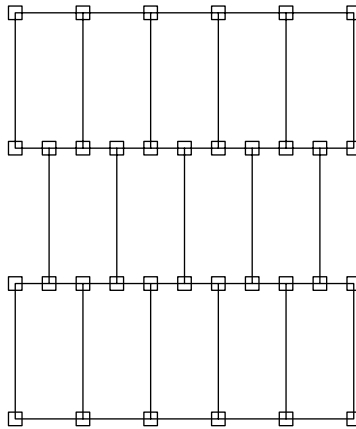


Figure 10.12 Conventional photo control point pattern on a multiple strip project.

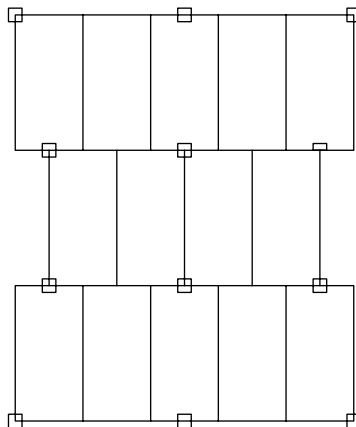


Figure 10.13 Skeletal photo control point pattern on a multiple strip project.

Broadening the scope of the mapping project to include several stereomodels on three adjacent flight lines, [Figure 10.12](#) represents the amount of obligatory conventional control, while [Figure 10.13](#) depicts the skeletal pattern which would satisfy the same qualifying factors.