Chapter 3
Photogrammetric Processes

3-1. Photogrammetry

Photogrammetry is generally defined as the art and science of making accurate measurements from aerial photography. For the purposes of this manual, aerial photography will be limited to near vertical photography taken from a conventional fixed-wing or rotary-winged aircraft of satellite. Aerial photographs, as they are initially exposed, do not provide for accurate measurements. Distortions in the camera systems coupled with the curvature of the earth must be accounted for and eliminated in a series of techniques and processes in order to make measurements at a predicted accuracy across the area of coverage of an aerial photograph. These photogrammetric processes allow the user to view three dimensions from a two-dimensional surface (aerial photograph). Review Chapters 5 through 10 or a current surveying, photogrammetry, or remote sensing textbook for additional information regarding photogrammetric principles.

3-2. Photogrammetric Processes

a. Photogrammetric mapping is achieved through four general processes (Figure 3-1). The four processes are as follows:

(1) Imagery Acquisition.

(2) Ground Control Acquisition.

(3) Accurate Adjustment of the Imagery to the Earth.

(4) Feature Collection.

b. Generally, each photogrammetric project is unique. Each project is defined by spatial data collection for a unique piece of the earth with specific feature collection requirements. Feature collection requirements include accuracy and feature types. The general processes listed above may involve several significant sub-processes based on the feature collection requirements for a specific project.

3-3. Imagery Acquisition

Imagery for photogrammetric mapping (Table 3-1) may be broken into two general areas. Imagery for feature vertical and horizontal location and shape detail may be captured with the use of panchromatic (black and white) or natural color near vertical aerial photography or from digital satellite imagery. Other types of imagery such as color infrared aerial photography, thermal scanner imagery, and microwave imagery, multispectral and hyperspectral satillite imagery are generally used to detect unique feature data other than location and shape detail. These type images may be incorporated into a GIS and registered to other georeferenced data sets.

3.3.1 Vertical aerial photography

Near vertical aerial photography to be used for planimetric and topographic mapping is generally collected as stereo pairs. The photography is collected with forward overlap between each photograph as they are captured down a flight line. Mapping areas may require multiple flight lines in order to include all necessary mapping area within the imagery. In these cases, the imagery flight lines are flown so that they overlap (sidelap). Generally near vertical aerial photography is flown with a forward lap of 60 percent and side lap of

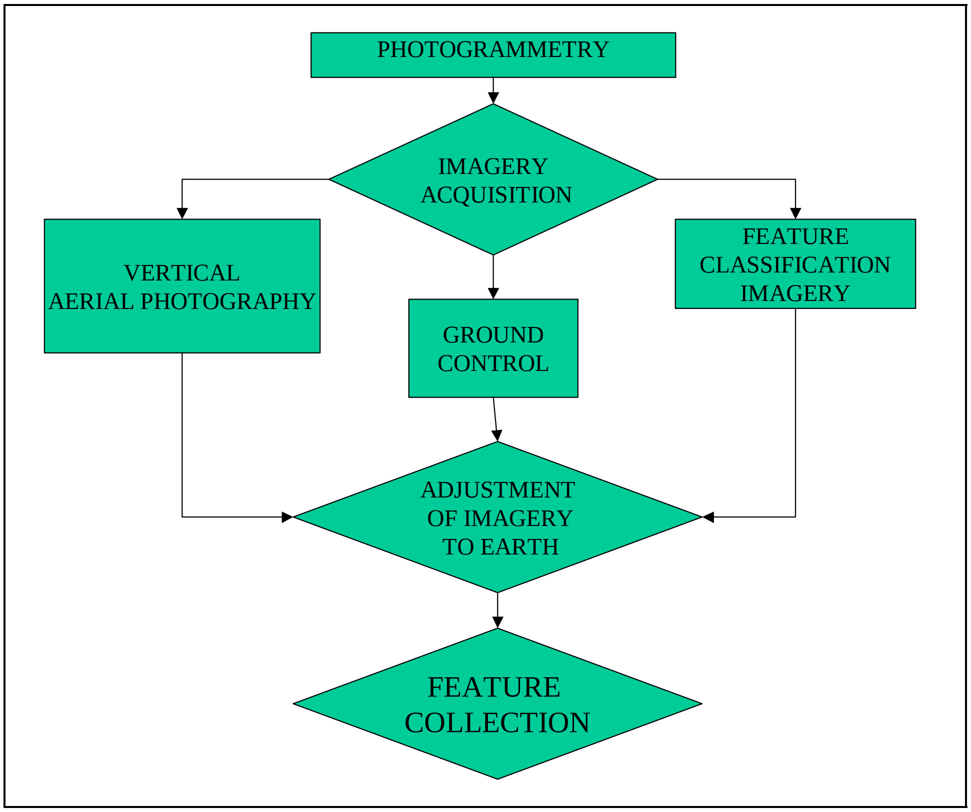

Figure 3-1. Photogrammatic mapping processes

Table 3-1
Imagery Types and Uses

Imagery Type	General Purposes
Black and White Aerial Photography	Topographic and Planimetric Mapping
Natural Color Aerial Photography	Topographic and Planimetric Mapping
Infrared Aerial Photography	Vegetation Analysis, Landuse/Land Classification
Satellite Imagery	Small-Scale Mapping, Vegetation Analysis, Land use/Land Classification
Microwave	Groundwater
Thermal	Heat Loss

30 percent. These parameters allow the pilot and photographer some latitude in the imagery collection and should provide enough overlap for the compiler to see stereo and map the required features. Generally, planimetric (buildings, roads, above ground utilities, etc.) and topographic features (mass points, breaklines, and contours) are collected from either black and white or natural color near vertical aerial photography. Planimetric and topographic mapping are generally the base mapping data set in a GIS or engineering data set. The accuracy of computations and queries made from these base mapping data sets is based on their thoroughness and accuracy. Black and white and natural color aerial photography generally provide the clarity and spatial resolution required to achieve most large- and small-scale mapping accuracies (Figure 3-2).

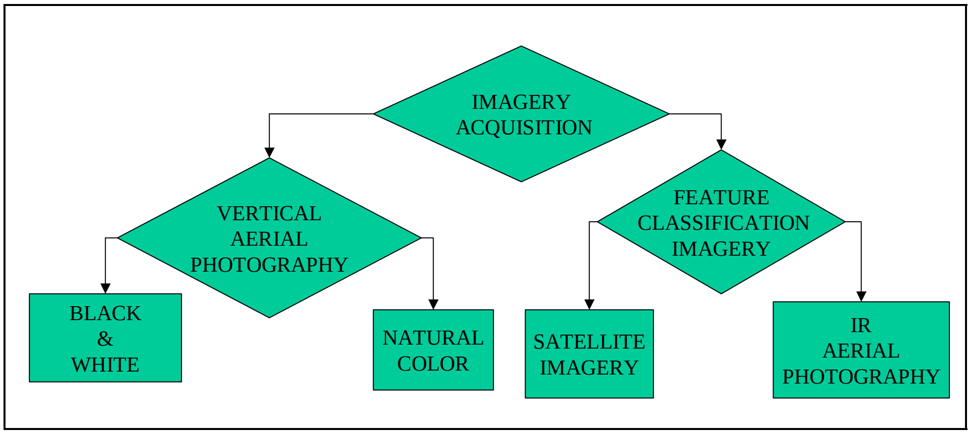

Figure 3-2. Imagery acquisition processes

3.3.2 Feature Classification Imagery

Feature classification imagery includes infrared (IR) aerial photography, satellite imagery (multispectral and hyperspectral) and digital scanners (thermal, microwave, etc). These types of imagery can be rectified to other base imagery or datums and used in various GIS analyses.

Primary uses of infrared imagery include the analysis of vegetation health and camoflaugh detection. Infrared imagery cannot detect thermal changes. Infrared imagery can be black and white or color. Black and white infrared has a relatively coarse imagery resolution compared to color infrared (CIR) and therefore is not used as frequently.

Satellite platforms operated by the United States, other countries, and private industry provide various sensors that can capture digital images of the earth. These sensors can provide panchromatic, color, and IR digital data at various spatial resolutions. Recently, private industry has launched satellites to provide high resolution digital imagery. These types of data may provide cost effective imagery over large portions of the earth. These types of spatial data are generally at a resolution far larger than that provided by aircraft platforms and may not be suitable for many large-scale mapping and GIS projects. However, high resolution satellite imagery may be an economical solution for some medium- to small-scale projects. The Corps of Engineers Topographic Engineering Center (TEC), Alexandria, VA, has staff trained to search out available data sets and contract vehicles to purchase the data for other USACE offices.

3-4. Ground Control

a. Ground control for photogrammetry is necessary to rectify the images to the earth prior to feature collection. Ground control accuracies must generally be greater than the accuracy required of the photogrammetric mapping. See Chapter 2, Table 2-1, for ground control accuracy requirements. Conventional traversing and level loops or GPS techniques, may be employed to obtain the necessary horizontal and vertical information (Figure 3-3).

b. Ground control must be planned based upon the method of image rectification to be used for the project. A team of a photogrammetrist familiar with the mapping requirements and a survey engineer should accomplish the planning of ground control or technician with unique experience in planning and establishing ground control for photogrammetry. Generally, the ground control must be around the perimeter of the mapping area. Some ground control points may be established on a portion of an existing ground feature that will be seen in the photography. Others will need to be established in a location with no existing suitable ground

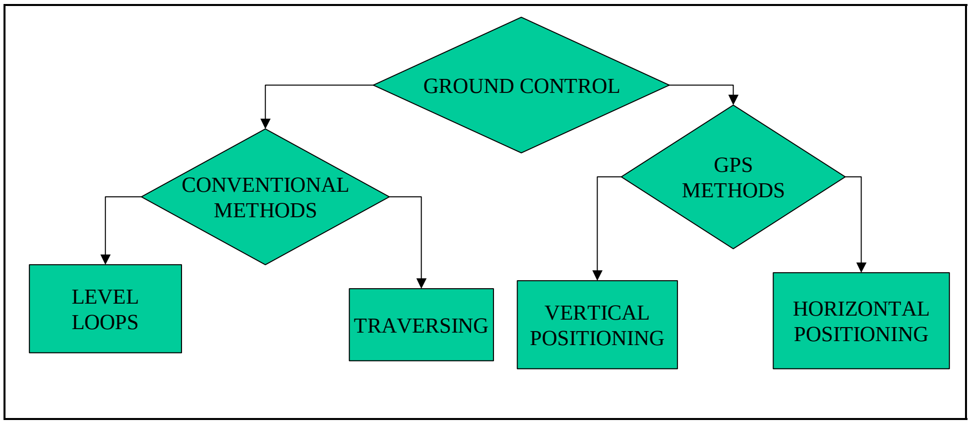

Figure 3-3. Ground control methods

feature. In these cases, a panel is placed on the ground that will be identifiable in the photography. The ground survey team can then establish the location of the panel.

c. Recent advancements in the GPS technology have provided for the collection of the horizontal and vertical location of the center of each photograph captured during a photography mission. This technology is referred to as airborne GPS (ABGPS). This technology can capture a large amount of ground control very efficiently and can supplement and in some cases reduce the amount of conventional ground control point collection. Again, planning for an ABGPS ground control project should be accomplished by an experienced team including photogrammetrists and survey engineers and/or technicians. See Chapter 7 for additional information regarding ABGPS technology.

d. The amount and location of ground control points is based upon the imagery rectification methods to be employed. Very small project areas (a few stereo models) may be economically rectified by convention methods. Conventional methods require a minimum of three horizontal points and four vertical points per stereo pair. Aerotriangulation is a mathematical process that allows for fewer ground points to be established. Aerotriangulation extends the horizontal and vertical control from a relatively few ground unknown points throughout a block of imagery. See Chapter 6, for additional information regarding ground control and aerotriangulation.

3-5. Adjustment of Imagery to the Earth

The process of adjusting the aerial photography to the earth is critical to the accuracy of final mapping products. Today most projects are adjusted using aerotriangulation methods. These methods require fewer ground control points than conventional adjustment methods. Aerotriangulation methods are accomplished with computer software. The software is very efficient and allows for quality control checks throughout the process. Aerotriangulation requires that the imagery be collected in blocks. Therefore, it is most efficient for large project areas. Unusually aerotriangulation of small areas or areas that have very irregular shapes looses efficiency and cost savings. However, the speed and quality control may still make this process acceptable for many small or irregularly shaped projects. Aerotriangulation accuracies should generally be greater than these required for the final mapping data sets. See Chapter 2, Table 2-8, for additional information regarding aerotriangulation accuracy criteria.

3-6. Feature Collection

a. Photogrammetric mapping feature collection can generally be divided into four categories (Figure 3-4).

(1) Topographic Features.

(2) Planimetric Features.

(3) Orthophotography.

(4) Landuse.

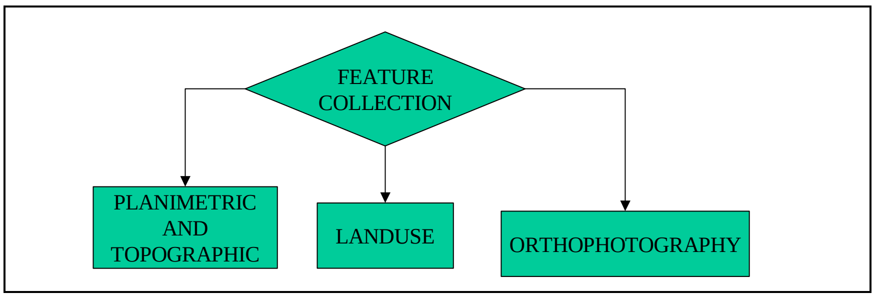

Figure 3-4. Feature collection processes

b. These feature types can be collected accurately using stereo imagery and stereo viewing equipment. Spatial data collection is expensive and it is important that the end user understand what his needs are regarding accuracy and format. Terminology between a photogrammetrist and the end user can often be confusing. Therefore, it is also important that a common understanding regarding data type, accuracy, and format be established prior to contract development.

3.6.1 Topographic features

a. Topographic features can generally be divided into two categories.

(1) Mass points

(2) Breaklines

b. Mass points define the horizontal and vertical location of specific points on the earth. These points generally define areas of change in elevation. Breaklines are lines that define an abrupt change in elevation such as a drainage feature, edge of roadway, etc. These two products are used to produce several elevation model types that are commonly requested by an end user.

(1) Together, mass points and breaklines are considered as a digital terrain model (DTM).

(2) An end user may require only mass points collected on an evenly spaced grid (every 10 m). This type of elevation model is considered a digital elevation model (DEM).

(3) A DTM is often imported into software that will generate a Triangulated Irregular Network (TIN) model. A TIN is often referred to as a surface model.

(4) A TIN model can be processed through software to generate contour lines (lines of equal elevation). TIN models can also be used to lay out and produce cross-section data across an area of interest (i.e., stream crossings for hydraulic analysis).

3.6.2 Planimetric features

a. Planimetric features include buildings, roads, railroads, utilities, etc. These features are generally collected as polygons denoting the perimeter of the feature. The features collected must be seen in the aerial imagery. Underground features cannot be photogrammetrically collected. However, utility data from another data source are often added to a photogrammetric mapping data set. The level of planimetric detail to be collected is generally determined by the scale of the photography. For example:

(1) 1:600-scale mapping would generally provide side walks, utility poles, fences, roads and curbs, manholes, catch basins, and shapes of individual structures.

(2) 1:16,800-scale mapping would not show sidewalks, most utility poles, fences, manholes, and catch basins. Structures would be symbolized and not drawn as unique feature shapes.

b. Large-scale photogrammetric mapping requires compatible large-scale aerial photography. See Chapter 2, Tables 2-6 and 2-7. The larger the photogrammetric mapping scale the more planimetric feature detail that can be seen and plotted. However, some features that may be seen in very large-scale mapping (1:600 and greater) may not normally be collected (i.e., parking lot strips, roof detail, mail boxes, moveable features). If these features are required, they should be specified in the SOW and will require extra time and cost.

3.6.3 Orthophotography

a. Obviously, planimetric feature collection can be time- and cost-consuming. Orthophotography can be an economical compromise for many projects. Orthophotography is not a simple scan and rubber sheeting process. A simple aerial photograph has distortions because of various mechanical and optical features in the camera system. The errors are not linear and therefore not uniform across a photograph. Horizontal measurements taken from a simple rubber-sheeted digital photograph are not accurate or consistent. Orthophotography involves a process (Figure 3-5) that eliminates the distortions in original aerial photography because of the camera system and distortion because of the elevation change.

b. It is very important to plan an orthophoto project properly. The aerial photography scale must be compatible with the final expected orthophoto horizontal scale and accuracy and the final ground pixel resolution. Generally, a four-times enlargement from the aerial photography will produce a suitable “ASPRS Class 1” orthophoto. See Chapter 2, Table 2-9.

c. The photography must be scanned at a resolution that is compatible with the final map scale and expected ground pixel resolution. See Chapter 2, paragraph 2-6, and Table 2-10. The scan should be accomplished with a high resolution (capable of scanning to resolutions as small as 7 microns) transmissive metric scanner. The end user should be aware of the final file sizes when requesting Orthophotography. It is often tempting to get as high a resolution orthophoto as possible. However, the file sizes can be prohibitive in some view software. Color orthophotos create file sizes that are three times as large as black and white orthophotos. If very high-resolution orthophotos are required, the end user may have to request that the Contractor also provide the data in a compression format with a viewer that allows for speedy viewing of large digital orthophoto files.

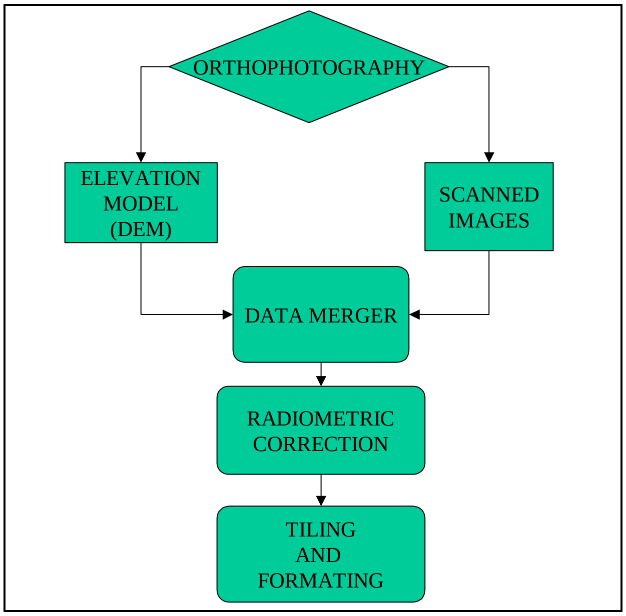

Figure 3-5. Orthophoto processes

d. The course digital elevation model (DEM) must be obtained from the aerial photography to be scanned. The DEM for orthorectification does not require as many points as a DEM to be used for the generation of a surface model or contour file. In some instances, a DEM that was developed from another imagery source of the project area may be used. However, review of the DEM must be accomplished prior to utilization in the orthophoto process to ensure that it was captured with compatible aerial photography (time period, photo scale, datum, and accuracy). Often USGS DEM data can be obtained, checked, and used to rectify an orthophoto.

e. Once a suitable scan and DEM are collected, orthophoto software can be used to merge the DEM with the scanned image and create the orthophoto image files. The image files are then reviewed and checked for scratches, dust, blemishes, and radiometric anomalies that can be corrected. A quality final orthophoto may not appear seamless throughout the total area. However, if the source photography was captured under the same general weather conditions and during the same general time period, the files' radiometric correction work should correct most anomalies and provide a near seamless image file. Additional work may also be required at bridges and overpasses to provide additional corrections necessary because of the elevation change between the bridge and the earth. The SOW should be clear regarding this correction work when necessary. Correction of tall building tilt is generally not required in an orthophoto mapping project unless specifically requested. This work can be time-consuming and the value may be questionable.

f. The overall file may then need to be tiled and formatted as per the SOW. Tile size may be a function of the equipment that will be used to view and work with the orthophotos. Resampled and/or compressed file formats may be necessary for the end user. The end user should discuss these requirements with the Contractor prior to negotiations and address the issue in the SOW.

3-7. Quality Control / Quality Assurance

The USACE generally obtains photogrammetric mapping products through Architect – Engineer type contracts. The selection criteria for photogrammetric mapping contractors are qualifications-based contracting. Therefore, demonstrated quality procedures must be in place to ensure that contractors are producing photogrammetric mapping products that meet the specifications requested. QC is procedures and processes that a contractor performs during the generation of photogrammetric mapping products to ensure that the products meet the intent of the contract. QA is procedures and processes that the Government performs during photogrammetric map production and or after delivery of final photogrammetric mapping products to ensure that the products meet the intent of the contract.

3.7.1 Quality control

General QC procedures (performed by the Contractor) for a photogrammetric mapping project should be part of the contractor selection process. Quality control should include project management as well as checking all interim and final products to insure compliance with the SOW. Quality control should be performed and documented on all required processes. A typical photogrammetric mapping project may include aerial photography acquisition, ground survey data collection, planimetric and topographic feature collection, and orthophoto production. Proper design and planning of a photogrammetric mapping project is critical in obtaining quality final products. A clear and concise SOW is vital to proper planning, design, and quality. Listed below are some of the QC steps that should be taken by a Contractor in a typical photogrammetric mapping project.

a. Aerial photography acquisition.

(1) The film type, flight height, and overlap should be designed to meet the requirements of a project and should be stated in the SOW.

(2) The current camera calibration report for the camera actually used for a project should be submitted with the processed film.

(3) Processed film negatives should be checked for aerial coverage and overlaps, scratches, and blemishes.

(4) Aerotriangulation. An aerotriangulation report should be generated and independently reviewed by qualified staff within the firm to ensure that procedures were followed that will ensure the final mapping accuracy stated in the SOW. The report should include an explanation of the procedures used, what ground points were not used in the solution (with an explanation), and a listing and discussion of the final results. The report should be signed and dated by the responsible aerotriangulation technician.

b. Feature compilation. Feature compilation should be checked for accuracy and completeness. This review process may involve resetting selected stereo models for accuracy checks against data withheld from the original compilation staff. Review may also include checking models in the stereo plotting system for thoroughness of planimetric and topographic feature compilation.

c. Final digital and hardcopy formatting. Final data sets (hardcopy and digital) should be review to insure compliance with the SOW. Marginalia, titles, symbology, line weights, etc should be reviewed on all hardcopy maps submitted. Digital files should also be reviewed for marginalia, titles, symbology, line weights, etc. Review of GIS maps should include a review of topology and annotation as requested in the SOW. When multiple copies of digital data are requested, the Contractor should insure that the copies have been accomplished accurately and completely on all digital storage media.

3.7.2 Quality assurance

a. Quality assurance is review of photogrammetric mapping products to ensure compliance with the SOW. Generally, a photogrammetric mapping project SOW should be end product oriented. Example: Fly and photograph the project area using a black and white aerial film at 1:3,600 negative scale with a 6-in. focal length camera. Produce planimetric and topographic mapping that meets or exceeds ASPRS Class 1 Standards for 1:600-scale mapping. The final products shall fully comply with the Tri-Service Spatial Data Standards (TSSDS) for Engineering and GIS mapping.

b. Quality assurance should involve checking deliverables for completeness and accuracy.

(1) Accuracy is generally accomplished by comparing data points to other known ground survey data in the same general area. This method of quality assurance can be costly. Every attempt should be made to minimize these types of checks. Existing ground survey data should be located and used to compare to final mapping products. Photogrammetric mapping projects generally require some ground survey data to be collected as part of the overall process. Minimal ground survey check data (individual points or short profiles) may be economically collected by the contractor staff at this time and submitted only to the Government to be used as a check of the final mapping.

(2) Quality assurance for completeness and thoroughness can be accomplished by comparing the final mapping with the aerial photographs or existing mapping. Field checks should be kept to a minimum when cost is a factor. Digital data files should be opened and reviewed for completeness and thoroughness also.

c. Contractors are obligated to provide products as specified in a SOW. Quality assurance should be accomplished immediately after receipt of the products. Errors or omissions are noted and agreed upon with a Contractor. Corrections should be made and revised data submitted in a timely manor. Contractors do not want to submit bad data. They do want to ensure a good reputation. Many errors and omissions are a result of a poorly written SOW. The SOW should be thoroughly understood, reviewed, and agreed upon by both the Government and the Contractor. Negotiation sessions should insure understanding of the intent of the SOW and correct any misunderstandings. When possible sample files or maps should be provided to the Contractor prior to negotiations and SOW review. Technically knowledgeable staff should be an integral part of the project planning, SOW development, cost estimating, and negotiations as well as QA checking of the final products.