Chapter 7 - Photogrammetric Surveys

This chapter does not supersede the NJDOT Aerial Mapping (Photogrammetry) Manual, but provides general overview. For more complete information on the subject, please consult the NJDOT Aerial Mapping (Photogrammetry) Manual.

7.1 General

Photogrammetry is a surveying and mapping method that has many applications in the Department of Transportation. Applications of photogrammetry in surveying practice include topographic mapping, site planning, earthwork volume estimation for proposed roads, compilation of digital elevation models (DEM), and image base mapping (orthophotography).

The term “photogrammetry” is composed of the words “photo” and “meter” meaning measurements from photographs. The classical definition of photogrammetry is:

The art, science and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images on photographs.

Photogrammetry is an art, because obtaining reliable measurements requires certain skills, techniques and judgments to be made by an individual. It is a science and a technology because it takes an image and transforms it, via technology, into meaningful results. Modern photogrammetry includes image sources and image forms other than photographs, such as radar images.

The photogrammetric process consists of project planning, image acquisition, image processing, control data for image orientation, data compilation and presentation of an end product. The end product of the photogrammetric process can be coordinate values of individual points, a graphic representation of the ground surface (topographic map), or a rectified image of the ground surface with map-like characteristics (orthophoto.)

Images used for photogrammetry can originate from a special (metric) camera, an ordinary camera or from digital sensors. The image can be recorded from a device mounted on a satellite, on an airplane (including helicopters), or on a tripod (terrestrial photogrammetry) which is set up on the ground. In this Manual, only applications that are based on aerial photographs recorded with a metric camera will be discussed.

7.1.1 Advantages and Disadvantages.

Some advantages of photogrammetry over conventional surveying and mapping methods are:

- It provides a permanent photographic record of conditions that existed at the time the aerial photographs were taken. Since this record has metric characteristics, it is not only a pictorial record but also an accurate measurable record.
- If information has to be re-surveyed or re-evaluated, it is not necessary to perform expensive field work. The same photographs can be measured again and new information can be compiled in a very timely fashion. Missing information, such as inadequate offsets for cross sections, can be remedied easily.
- It can provide a large mapped area so alternate line studies can be made with the same data source can be performed more efficiently and economically then other conventional methods.

- It provides a broad view of the project area, identifying both topographic and cultural features.
- It can be used in locations that are difficult, unsafe, or impossible to access. Photogrammetry is an ideal surveying method for toxic areas where field work may compromise the safety of the surveying crew.
- An extremely important advantage of photogrammetry is that road surveys can be done without closing lanes, disturbing traffic or endangering the field crew. Once a road is photographed, measurement of road features, including elevation data, is done in the office, not in the field.
- Intervisibility between points and unnecessary surveys to extend control to a remote area of a project are not required. The coordinates of every point in the mapping area can be determined with no extra effort or cost.
- The aerial photographs can be used to convey or describe information to the public, State and Federal agencies, and other divisions within the Department of Transportation.

Some disadvantages are:

- Weather conditions (winds, clouds, haze etc.) affect the aerial photography process and the quality of the images.
- Seasonal conditions affect the aerial photographs, i.e., snow cover will obliterate the targets and give a false ground impression. Therefore, there is only a short time normally November through March, that is ideal for general purpose aerial photography. A cleared construction site or a highway that is not obstructed by trees, is less subjected to this restriction. These types of projects can be flown and photographed during most of the year.
- Hidden grounds caused by man-made objects, such as an overpass and a roof, cannot be mapped with photogrammetry. Hidden ground problems can be caused by tree canopy, dense vegetation, or by rugged terrain with sharp slopes. The information hidden from the camera must be mapped with other surveying methods.
- The accuracy of the mapping contours and cross sections depends on flight height and the accuracy of the field survey.

7.2 Components of Photogrammetry

In general, photogrammetry has three major components. These components are image acquisition, image control and product compilation.

1. Image acquisition includes planning the over flight, selecting an appropriate camera system, photo taking film processing, film inspection and annotation, printing of paper prints and diapositives, and image scanning (if necessary.)
2. The control component includes selecting locations for ground control and targeting, field surveying control points and aerial triangulation. In the future, this component could be eliminated when advanced GPS methodology will be able to solve the photo orientation problem without needing ground control.
3. The product compilation component of photogrammetry varies and depends on the nature of the product. Topographic maps, orthophotos, or monoscopic updates are all photogrammetric products which are compiled in different ways as discussed

later. Each of these components requires the utilization of different equipment, different measurement techniques, and different data processing.

A successful photogrammetric survey project depends on a thorough understanding of these components and on careful planning and execution of the project specifications.

7.2.1 Image Acquisition

7.2.1.1 Flight Mission Planning

A flight plan generally consists of two items:

1. A flight map which shows where the photos are to be taken. A flight map consists of flight lines, usually marked on a medium scale topographic map, showing the starting and ending points of each line. It is used by the pilot for navigation and by the photographer for taking the pictures. Usually, there are enough topographical features in the flight area to assist the pilot in flying the designated flight lines. Otherwise, a large arrow on the ground at the beginning and end of each flight strip is necessary to aid the pilot and photographer. The number of flight lines, their location, the spacing between them, and their orientation depends on the characteristics of the project to be mapped and on the specifications of the flight mission.
2. Specifications which outline how to take the photos, including camera and film requirements, scale, flying heights, end lap, side lap, tilt and crab tolerances, etc.

7.2.1.2 Aerial Cameras

Aerial mapping cameras are perhaps the most important photogrammetric instruments, since they record the image on which the photogrammetric principles will be applied. Aerial cameras must be able to produce very sharp images, almost distortion free, in rapid succession under the adverse conditions of a moving aircraft. Any error, distortion, or compromise in the clarity of the image will result in mapping and positioning errors.

7.2.1.3 Aerial Films

Aerial films are fine grained, high speed photographic emulsion on a stable polyester film base. The fine grain is necessary for identifying features as small as 1 micron on the negative. High speed film permits short exposure time which is necessary to prevent image smearing and displacement that may result from the movement of the aircraft. The image must be recorded on a stable film to prevent it from irregular shrinkage or expansion. Any change in the dimension of the film results in a measurement error and less accurate product. Aerial films come in a roll of about 200 exposures of 9x9 inches (23x23 cm) each.

To insure dimensional stability, the film should not be stretched or deformed in any way. It should not be subjected to extreme changes in humidity and temperature. The film should be sealed in its container and stored at a temperature recommended by the manufacturer at all times, except when in actual use during the flight mission or when being processed.

7.2.1.4 Image Scanning

Until recently, photogrammetric products were developed from diapositives or paper prints. With the emergence of digital photogrammetry, photographs are now scanned into a digital format that is compatible with digital image processing software.

Scanners for digital photogrammetry are precision devices that maintain the radiometric and geometric integrity of the scanned image

7.2.2 Control for Photogrammetry

7.2.2.1 General

The second element of the photogrammetric process is control, which is used to establish the position and orientation of the camera at the instant of exposure. The necessity, accuracy and the rigor of photogrammetric control depends on the particular product sought. Photo mosaics used for annotation, cultural studies, public meetings, and other varied purposes may not require any control. Rectified aerial photographs, used mainly for photo plan sheets, may require partial control in the form of measured distances. Field measured distances are scaled down to match corresponding distances on the photograph. However, most common photogrammetric products, such as mapping and orthophotography, require full control information. The minimum full control to establish a stereo model is two points with known horizontal positions (for scaling) and three points with known elevations (for orientation). Using this bare minimum is unacceptable; therefore, additional control is required for a processing a stereo model.

Photographs can be controlled using three different methods:

1. Ground control points that were surveyed on the ground using ordinary surveying techniques.
2. Bridging control through aerial triangulation. Bridging is accomplished by measuring on the photographs common points that appear in three consecutive photographs or in two adjacent strips and computing their 3 D coordinate values.
3. Aerial photography control through kinematic GPS technique in which the position and the attitude of the camera are computed without ground control.

In most photogrammetric projects, a combination of all or some of these methods are utilized.

7.2.2.2 Ground Control

Ground control can be classified as targeted and photo-identifiable (picked) control points, and can also be classified as horizontal control, vertical only control, or as 3-D control. Horizontal and vertical controls require different configurations to make them serve their intended purposes. The use of only ground control is now limited to small projects, such as bridge sites, borrow areas and where only one or two models are needed. Photo identifiable control points are rarely needed. The surveyor needs to know what type of control is called for when he or she attempts to pick or photo-identify the point. Accessibility for surveying should also be considered when selecting the locations for control points.

7.2.2.3 Targeting

Targeting operations are an essential part of photogrammetric mapping to be considered prior to establishing a control survey. Preflight targeting is performed to make ground locations of control points visible on the photographs. Easy identification and clear image of the control points on the photograph increases the accuracy and efficiency of the photogrammetric process. Highway design mapping often requires careful preflight planning for optimal target placement. To reduce the possibility of pre-marked points being moved or lost prior to the aerial mission, it is important to either paint them on a hard surface or schedule the field paneling operation as close as possible to the anticipated flight. Targets should be located where shadows will not adversely affect the visibility of the panel.

Photographic targets should be of symmetrical shape, adequate size, and appropriate photographic contrast and resolution. (See Figure 7.1).

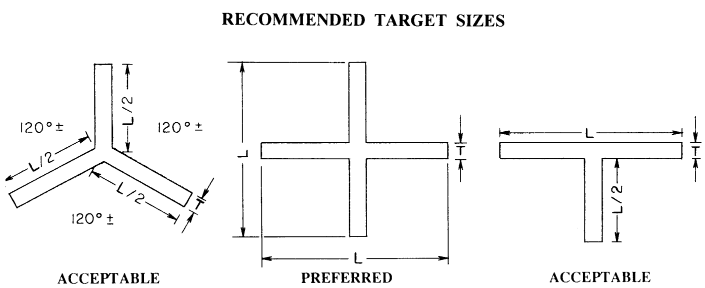

Figure7.1Photogrammetricground control targets

Photo. Scale	Thickness of Leg (T)	Length of Legs (L)
1:1800	6 Inches(150mm)	3 Feet(0.9m)
1:2400	6 Inches(150mm)	3 Feet(0.9m)
1:3000	6 Inches(150mm)	4 Feet(1.2m)
1:3600	6 Inches(150mm)	4 Feet(1.2m)
1:4200	6 Inches(150mm)	5 Feet(1.5m)
1:4800	8 Inches(200mm)	6 Feet(1.8m)
1:6000	8 Inches(200mm)	6 Feet(1.8m)
1:8400	12 Inches(300mm)	7 Feet(2.1m)
1:9600	15 Inches(375mm)	8 Feet(2.4m)
1:12000	18 Inches(400mm)	10 Feet(3.0m)
1:19200	24 Inches(600mm)	15 Feet(4.5m)
1:24000	30 Inches(750mm)	20 Feet(6.0m)

Table 7.1. Recommended target dimensions as a function of photo scale.

7.2.2.4 Field Survey of Photogrammetric Control

Field surveys for photogrammetric control should be treated as ordinary surveys. The methods and procedures that are described in this manual must be applied to photogrammetric control field work. The key issue here is to select suitable survey procedures that address the project requirements.

Photogrammetric control points are usually spaced widely around the project area. For large projects, this spacing could be extensive enough to require a significant surveying effort. Therefore, GPS is the better suited surveying method for most large photogrammetric projects.

Ground control that is to be used in successive photogrammetric projects or field surveys should be monumented accordingly.

7.2.2.5 Aerial Triangulation

Aerial triangulation, or aerotriangulation, is the process of determining X, Y, and Z ground coordinates of individual points based on measurements from photographs. Aerial triangulation is used extensively for many purposes. One of the principal applications is densifying ground control through strips or a block of photos to be used in subsequent photogrammetric operations. When used for this purpose it is often called bridging, because it allows the computation of necessary control points between those measured in the field. In a large project, with dozens of photographs, the effort and cost of providing the needed control using field surveys is prohibitive. Aerial triangulation is used to provide the necessary control for each stereo model with only a limited number of field surveyed control point. Other advantages of aerial triangulation are:

- The control densification is done in the office, thus minimizing delays and hardships due to adverse weather conditions.
- Field surveys in difficult or unsafe areas are minimized.
- Access to much of the (private or public) property within a project area is not required.
- The aerial triangulation process provides accuracy and consistency checks for the field surveyed control points.

7.2.2.6 GPS as Control for Photogrammetry

In recent years, GPS has been demonstrated to be able to replace, partially or entirely, the need for ground control. The basic concept of GPS controlled photogrammetry is to use GPS equipment to determine the position and orientation of the camera at the instant of exposure. Remember that the only reason for using ground control in photogrammetry is to recover the position and orient a photograph in space at the time that the photograph was taken. If the values of these parameters can be resolved at the time of photography with GPS and/or additional instruments, there is no need for ground control to compute them. Even if GPS controlled photography is not yet at a level of maturity to be able to completely replace the need for ground control, it does reduce the number of field surveyed control points in a given project.

7.2.3 Product Compilation

7.2.3.1 Photogrammetric Plotters

The most commonly used photogrammetric instrument is the stereo plotter. A stereo plotter is used to reconstruct the actual orientation and geometric integrity of an image at the instant of exposure and to collect three dimensional (3 D) data. Data collection with a stereo plotter is a two stage process. The first stage is orientation, which consists of:

1. **Inner orientation** – Orient each photograph with respect to the geometry of the camera.

2. **Relative orientation** – Orient two photographs with respect to each other to form a stereo model.
3. **Absolute orientation** – Orient and scale the stereo model to the ground. In some instruments the relative and absolute orientation are performed simultaneously. The simultaneous solution of these orientations is called **exterior orientation**.

In the second stage, the operator views the image of the ground in 3 D. Data collection is performs by placing a floating mark on the images of the feature that is surveyed and record its X,Y,Z coordinates. Line features, such as roads or contours, can be digitized, point by point, or traced and recorded continuously.

There are different types of stereo plotters, analog, analytical, and digital (softcopy.) Each of these types of plotters are classified according to their accuracy characteristics as first, second, or third order stereo plotters. Another classification of stereo plotters is as precision, topographic, or simple plotters. Figure 7.2 summarizes the differences between the various types of photogrammetric stereo plotters.

Stereo Plotter

Characteristics	Analog	Analytic	Digital
Image	Film	Film	Pixels
Plotter	Analog	Analytical	Computer
Model Construc.	Mechanical	mechanic/computer	Computer
Stereo Viewing	Optical	Optical	Varies
Output	Mech./CAD	Mech./CAD	CAD
Aerotriangulation	Very limited	On/Off Line	Semi-automatic*
Orthophoto	Very limited	Unavailable	Automatic**
Limitations	Focal length Film format	Film Format	None
Accuracy	Average up to ±15 μm(microns)	Very high up to ±3 μm	Same as scanning accuracy
Cost	Very high	Very high	Reasonable to high

*Some operator assistance is needed. **If DEM is available

Figure 7.2. Characteristics of photogrammetric stereo plotters.

Two additional photogrammetric instruments that are used in aerial triangulation are the point transfer device and the comparator. The point transfer device is used to drill a hole into the diapositive to mark a pass or a tie point. The point transfer process is as follows. The operator views a pair of photographs stereoscopically. A pass or tie point is selected by placing the left and right floating marks on the same image on the corresponding photographs. A drilling device is then activated to pierce a tiny hole on the diapositives exactly at the location of the floating marks.

Comparators are precise digitizers, many of them with a one micrometer least count, with which image coordinates of pass, tie and ground control points are measured. Mono comparators measure one photograph at a time in monoscopic mode while stereo comparators measure the points in stereo mode. If a mono comparator is used, pass points must be marked on each photograph. However, if a stereo comparator is used, the pass points are marked only on one photograph. The marked photograph is the one on which the pass points appear along a vertical line at the center of the photograph.

7.2.3.2 Data Collection and Mapping

Photogrammetry can be used to collect a variety of data, presented in the following formats:

Planimetric maps – Planimetric maps are maps that represents only the horizontal features of the mapped area. Planimetric maps display features such as roads, sidewalks, buildings, river banks, shore lines, manholes, trees etc. No elevation information appears on planimetric maps.

Topographic maps – Topographic maps are maps on which both horizontal and vertical features of the mapped are represented. In addition to the above mentioned planimetric features, a topographic map depicts elevation information as contours and/or as spot elevations.

DEM’s – Digital Elevation Model (DEM) or Digital Terrain Model (DTM) are dense networks of spot elevations represented by X,Y,Z coordinates. The DEM points are collected in a regular grid with break points which depict the characteristics of the topography. DEM’s are used to draw contours and are an essential ingredient for the production of orthophotos.

In highway applications, DEMS can be used for producing cross sections, road profiles, and earth work computations. The advantage of using DEM’s for volume computations is that the computation and the generation of the associated plots are almost automatic if the design was made under the same coordinate system. This is another good reason to use state plane coordinates and a unique elevation datum in all NJDOT work. One should be aware that an appropriate photo scale must be used to obtain centimeter level elevations.

Special purpose maps – Special purpose maps are maps that are designed to meet special needs or depict a special theme. The rule is that if you can see it on the aerial photograph, you can map it with photogrammetry. For example, a right-of-way map can be produced if all property corners are either targeted or can be identified on the photographs. Another example is a wetland map showing the delineation of wetland areas.

7.2.3.3 Monoscoping Mapping and Updates

Aerial photographs can be used to produce photomaps mainly for indexing, referencing and general studies. Photomaps can be composed of a single photograph or of several photo parts mosaiced together. This is not an accurate metric product, but serves as a valuable means to present spatial information.

Monoscopic based photogrammetry is also used for minor updates of maps. The update that results from this process is of a lesser accuracy and is intended more for maintaining feature inventory at an approximate spatial location. Map updates are accomplished by locally rubbersheeting (superimposing) the photographic image and the map. A few common features are identified on the map and on the photograph. The photograph is then scaled and/or tilted to locally match the corresponding features. A special device called the "zoom transferscope" is commonly used for this purpose.

7.2.3.4 Orthophotos

Orthophotos are covered in section 7.5 of this manual

7.3 Accuracy and Errors

The attainable accuracy of a photogrammetric product depends on two main factors. The first is the scale of the photographs from which the product is derived and the second is related to errors in the photogrammetric process.

The scale of the photograph determines the ground resolution. If the smallest identifiable ground feature on the photograph is a 0.1 m^2 (1 ft^2)object, then the mapping accuracy from this photograph, assuming perfect data compilation, is limited to no better than 0.3 m (±1 ft). Selecting the appropriate photo scale for a particular product depends on product specifications. For example, the photo scale for topographic mapping is a function of the required map scale, the contour interval, and the quality of the photogrammetric plotter. A required accuracy can be met by either using smaller scale photographs and high quality equipment or larger scale photos with less accurate photogrammetric equipment. The photo scale is always smaller than the map scale but the ratio between these two scales should never be larger than eight.

The second factor controlling the accuracy of a photogrammetric product is the total amount of errors accumulated during its derivation. In photogrammetry, as in any other surveying and mapping procedures, there are systematic errors and random errors, assuming all blunders have been removed.

7.4 The Photogrammetric Procedure

The photogrammetric procedure will be outlined below:

7.4.1 Project Planning

Project planning is comprised of the following steps:

1. Convert project requirements to specifications in terms of area to be mapped, desired map scale and contour interval. The determination of these specifications depends on the required accuracy of the final map and on cost constraints. More accurate maps are more costly and take longer to compile.
2. Determine photogrammetric specifications in terms of flight height, the number of photographs needed, the number of strips needed, flight lines, approximate location for exposure stations, and equipment to be used. Specifications should also be developed for ground control, aerial triangulation, and compilation methodology.
3. Develop a schedule for aerial photography, field work, and map compilation. The schedule should be coordinated among the various groups involved in the project. A critical coordination is between the field crew placing the targets and the aerial photography crew. Targets should be placed as close as possible to the time of

photography. A project timetable with completion dates for different tasks and the approximate cost associated with them should be developed as well.

4. Define the expected deliverables, including details on what features are to be mapped and their graphic representation.

7.4.2 Aerial Photography

The aerial photography process consists of the following:

1. Verify that the weather conditions are suitable for flying. Flying under conditions of low visibility or potential strong turbulence should be avoided. Bad weather conditions could not only produce unacceptable photographic results, but also risk the flying crew.
2. Mount the aerial camera according to the established procedure. Test the camera to ensure that it functions properly.
3. Fly the designed routes and take the photographs according to plans.
4. Process the film according to specification to ensure radiometrically and geometrically quality images.
5. If necessary, print on the negatives the missing photo information (titles), such as serial number, date, project information, etc.
6. Prepare contact prints from the negatives. If necessary, prepare enlargements to be used later, according to the project requirements.
7. Inspect the photographs for image quality and for coverage completeness. Verify that all the photographs have enough end laps to assure stereoscopic coverage of the entire project area. A similar inspection should be made to verify complete side lap coverage. Incomplete end and side lap coverage or coverage gaps could void the entire aerial photography and require re-planning or re-flying.

   Another inspection that has to be made is identifying the preset targets. Target inspection includes checking whether they are visible, appear in a stereo coverage and whether there are enough of them to ensure reliable results. If some targets are missing, or the entire project was not targeted, points that can be identified and surveyed on the ground should be selected and marked on paper prints. A copy of the prints and a description of the points selected should then be submitted to the surveying crew for field measurements.
8. Select photographs that will be used for data compilation and develop diapositives for them.

7.4.3 Ground Control

1. Research project region for existing control. Existing control that can be targeted can save time and money by avoiding unnecessary field surveys. Sometimes it is more cost efficient to expand the aerial photography slightly beyond the project area to include existing control than to establish new control.
2. Place targets according to the discussion in section 7.2.2.3 of this manual.
3. Perform field surveys as discussed in Sections 7.2.2.2, and 7.2.2.4 of this manual. Field surveys of picked points could be necessary after the aerial photography is completed.

4. Compute and adjust the field data and establish coordinate values for the control points.
5. Prepare a report on the surveys and on the results. An accuracy analysis of the results should be included in the report. The analysis should indicate the methodology used to determine that the results are in agreement with the project specifications.

7.4.4 Aerial Triangulation

1. Order the photographs as a continuous strip, or a block if the project encompasses more than one strip.
2. Select and mark pass and tie points. Pass and tie points should be clearly marked and numbered on the paper prints. Establish a point numbering system that will make it easy to associate these points with the project and with individual photos. The selection criteria are described in Section 7.2.2.5 of this manual.
3. Mark artificial pass and tie points on the diapositives with a point transfer device. Points that are marked in stereo (tie points) should be executed with utmost care. A marking error in the latter causes a measurement error that is equivalent to observing an incorrect point.
4. Measure and record pass and tie points with a photogrammetric plotter (including digital workstations) or a comparator. At least an inner orientation must be performed prior to measuring pass and tie points so that image coordinates of these points can be obtained. If the operator encounters difficulties in measuring some points, these difficulties should be documented. The operator may want to record supplemental points in areas where there are no well defined features or suitable image texture to be used for pass or tie point selection.
5. Measure and record ground control points. Ground control points are measured with the same stereo model setup or photograph measurements as for the pass and tie points.
6. Compute and adjust the aerial triangulation measurements. Check the results for possible measurement, marking, identification and control errors. If necessary, repeat some measurements and computations until the adjustments consist of only small random errors.
7. Prepare a report on the aerial triangulation results. The report should include the photogrammetric block layout and a diagram showing the location and names of all the points that participated in the adjustment. Erroneous points that were removed from the computation or had to be measured again should be listed. The results of the computations and an accuracy analysis of final adjustment with respect to the project specifications are to be documented as well.

7.4.5 Stereo Compilation

The use of mostly CAD based digital mapping software have simplified the manuscript preparation, editing and error checking of the stereo compilation process. The stereo compilation process is as follows:

1. Select models to be used for mapping. The selection should include a layout of what areas are to be mapped from which stereo model. Mapping from the fringes of the stereo model is usually less accurate than at the center. Therefore, the operator should be instructed on the limits of stereo model that should be used for mapping.

2. Set up the stereo models by performing interior and exterior orientations.
3. Compile the planimetric features according to the project specifications. The specifications should be clear in terms of what features are to be mapped and their graphic representation in terms of color, shape, symbol, and other attributes.
4. Compile elevation features as contours or spot elevation. Contours should be compiled according to the specified contour interval. Nowadays, contouring is performed by interpolating a DEM, instead of plotting them directly from a stereo model. DEM must be comprised of spot elevations (regularly or irregularly spaced) and breaklines. A DEM that does not include breaklines will probably produce unacceptable contouring accuracy.
5. Inspect the map for completeness, consistency and accuracy. The purpose of inspecting the map for completeness is to verify that all the required features have been mapped. Modern photogrammetric plotters have a capability of superimposing the map on the photographic image so that both of them can be viewed simultaneously with correct spatial registration. This superimposition makes it very easy to perform the completeness inspection. The stereo model is visually checked for required features and the features can be immediately verified.

   Consistency and accuracy inspection is performed to verify that the features are mapped in the correct location with the correct attribute. For example, a line representing a sidewalk should correspond to an actual sidewalk and it should spatially coincide with the image of the sidewalk in the stereo model. This inspection is important, especially for features that are mapped from more than one stereo model since, for example, a road can span over several stereo models. One has to make sure that features are mapped continuously and accurately.
6. Edit the map and make the necessary corrections.

7.4.6 Field Completion

Photogrammetry can be used for mapping only what is visible on the photographs. Thus, if important features are obscured by trees, man-made structures or steep topography, they cannot be mapped. Therefore, a field completion activity has to take place to map the missing features. The field completion phase of the project should be used for accuracy testing of the map.

7.4.7 Drafting

Drafting of photogrammetrically derived maps is performed with CAD software. It consists of the following:

- Sheet Layout
- Sheet Format
- Scale Change
- Edit and Final Corrections

All of these parameters should be part of the project specifications and should be performed accordingly.

7.4.8 Quality Control

A final report on the quality and accuracy of the maps should accompany the submission of the final product. The report should review the accuracy of the control, as described in sections 7.4.3 and 7.4.4. The procedure used to determine the map's spatial and content accuracy should be documented as well. A statement, such as "this map meets the National Map Accuracy Standards" or "this map meets the project requirements", is unacceptable. Any claim of accuracy or standard must be substantiated by an actual test and analysis. The testing methodology used and the findings of its implementation should be documented in a final report.

7.5 Orthophotos

7.5.1 General

An orthophoto is an aerial image that has been rectified so that it possesses characteristics of a line map. The rectification process is performed by combining photogrammetric principles with digital elevation model (DEM) data. Orthophotos have been used for many years by a diverse group of users. Recently, orthophotos have been re-discovered by GIS/LIS users and are rapidly becoming a leading form of base maps.

7.5.2 Aerial Photograph vs. Orthophoto

An aerial photograph does not have a constant scale throughout the entire image; therefore, it cannot be used as a map. The scale of an aerial photograph is defined as the ratio between the focal length of the camera and the height of the camera above the surface (topography). This scale is correct only for one point in the entire image (usually somewhere around the center of the photograph). All other points (or features) have different scales caused by the perspective nature of the image, by the tilt of the camera at the instance of exposure and by changes in elevation. A feature, such as a tall building, will also have shape distortion because the top of the feature will have a larger scale than the bottom of it. In addition, the sides of the building, which are not supposed to be mapped, will show on a photograph.

An orthophoto is a picture of the ground prepared in such a manner that all of these scale and shape distortions have been removed. In the past, orthophotos were produced with a specially outfitted photogrammetric stereo plotter. With the advent of digital photogrammetric methods, an orthophoto can now be produced, even on a desktop PC, provided that appropriate software and data are available. An orthophoto is produced by computing the scale and position distortions of each pixel of the aerial photograph, re-scaling and re-positioning the pixels in a new computer generated image. This process is called *differential rectification*. Orthophotos that are produced from, and saved as, digital images are sometimes called *digital orthophotos*.

7.5.3 Advantages of Orthophotos

Orthophotos have several advantages over a typical planimetric map:

1. An orthophoto has map-like characteristics, while preserving the pictorial image. A major drawback of a map is that it shows only what the mapper decided to include. For example, if the client was not interested in trees they will not be shown on the map, except for those that the surveyors or the photogrammetrist decided to include. If a hut was left out during data collection, it will not appear on the map. However, if the map is a picture, this problem does not exist. Whatever exists on the ground and is large enough to be recorded on the image, will automatically be mapped. One does not have to decide in advance (usually a budget constrained decision) what features should be mapped. Everything is mapped by default for the same price.

2. Speed of production, which becomes more evident when maps have to be revised or updated.
3. Cost. They are less expensive, especially when a DEM for the project area is available.
4. Hard and soft copy products.
5. GIS compatible. Almost all GIS software can integrate digital orthophotos into a project.
6. Cartographic overlay can be added to enhance interpretability.
7. Ability to perform change analysis by comparing images from before and after.
8. Use of wider sensing spectrum, such as infrared for special studies.
9. Mapping inaccessible areas, such as contaminated areas.

7.5.4 Disadvantages of Orthophoto

Orthophotos have several disadvantages as well:

1. In order to produce a very accurate orthophoto one needs to know not only the elevation of the surface (topography) but also the height of every feature (buildings, trees etc.) above that surface. Otherwise, these features will be positioned incorrectly on the orthophoto.
2. Missing images of obstructed features. Let us assume that the elevation of every pixel on a building is known and that the building was rectified correctly (the pixels were relocated to their proper locations). The problem is how to map the area that was obscured by the building (i.e. the street segment behind the building), which has now no available images. One needs to search for additional information and somehow blend it into the orthophoto.
3. While the pictorial images present all the existing features on the ground, their interpretation and classification could be difficult at times. A map with a clear legend is more easily understood and interpreted than a picture. Thus, an added cost of a cartographic enhancement becomes imperative.

7.5.5 Digital Orthophoto Production

The production of digital orthophotos has many steps in common with photogrammetric mapping. These steps are:

1. Project and flight mission planning.
2. Image acquisition with precise aerial cameras.
3. Film processing, annotation etc.
4. Image scanning.
5. Control points and aerial triangulation.

Details on these operations have been discussed earlier in this chapter. Procedures that are specific for orthophotos are:

1. Image rectification

   In order to correct scale distortions resulting from the perspective projection of an image, the elevation of each pixel must be known. The pixel elevation is interpolated from a Digital Elevation Model (DEM). There are several sources for DEM data. They vary mainly by cost and accuracy of data compilation. The most accurate source for elevation is from field surveys. But the cost associated with developing a DEM (even for a small project) from field surveys is prohibitive to most users. A more common source for DEM is photogrammetry. One should note that the same photographs that are used for the aerial triangulation could also be used for developing the DEM. Other methods for deriving DEM's are kinematic GPS or digitizing contours from topographic maps. DEM data for small scale applications is also available from USGS. The decision on which DEM to use depends on the scale of the orthophoto. Small scale orthophotos can use less accurate DEM (i.e. USGS data), while large scale orthophotos require a more accurate DEM (i.e. photogrammetry). One should note that DEM data has a much longer "shelf life" than planimetric data. Thus, a good DEM could be reused for several cycles of orthophoto production.

When all the data (image, orientation and DEM) is available, each (digital) photograph, or part of it, is rectified individually using a special software. A single rectified photograph usually covers only a small portion of the entire orthophoto project. Thus, a mosaicing process becomes necessary. Mosaicing is the process of piecing together multiple image patches into a seamless and continuous orthophoto. Some of the technical difficulties of this matching process are:

2. Mosaicing and Image Enhancement

   Spatial continuity or edge matching – Features that appear on more than a single image patch must be continuous. For example, a road must form a continuous line and show no jumps at the original photo edges where the images are connected.

   Radiometric consistency – Different photographs may have different contrast and brightness resulting from lack of uniform conditions during the photographic processing, image scanning or from changes in illumination conditions. For example, a lake could appear as white in one image, because of the reflection of the sun, and black on another image, where there is no reflection. This must be corrected during the mosaicing process.

3. Quality Control

   The quality control involves inspecting the orthophoto for incorrect rectification, image matching problems, and missing images due to hidden ground problems.

4. Output Design and Cartographic Enhancement.

   Output design and cartographic enhancement consists of formatting the image and enhancing it by adding:

   - line information that either appears fuzzy or does not exist on the image (for example, parcel boundaries)
   - area (polygon) information (for example shading a park area)
   - a contour layer to show hypsography (relief features)
   - coordinate graticules and North arrow
   - annotation (text and symbols)
   - legend, product information etc.

7.5.6 Accuracy and Quality Issues

The elements that contribute errors to an orthophoto product are:

1. Camera (characteristics and calibration)
2. Scanner (characteristics calibration and resolution or image scale)
3. Ground control (accuracy, distribution, and abundance)
4. Aerial triangulation (design, measurement, and computation)
5. Digital Elevation Modeling(DEM)-(method of compilation; quality of the source material; characteristics of the terrain; sampling spacing, with or without breaklines; type of breaklines used; method of interpolation into pixel grid and availability of height information on or above surface features, such as buildings.)
6. Rectification process (method and software). When all of these errors are propagated and summed up following a valid error theory methodology, one can assess the spatial accuracy of the final product.

Image quality issues of orthophotos are:

1. Pictorial defects caused by orthophoto production:
   - Contrast and brightness differences resulting mainly from the mosaicing process.
   - Dirt and scratching marks that appear on the image resulting from inappropriate handling of the film during the lab processing or during the scanning process.
2. Image defects caused by inaccurate DEM:
   - Missing images
   - Image blurring
   - Double image
   - Discontinuities of features

The ground resolution of each pixel and the added impact of the above errors define the spatial accuracy of the orthophoto. To assess that accuracy, one should test it with the same procedure used for line maps.

Additional reading and information on orthophoto on the Web:

http://www.esri.com/base/common/userconf/proc95/to150/p124.html

http://wwwsgi.ursus.maine.edu/gisweb/spatdb/gis-lis/gi94093.html

http://www-nmd.usgs.gov/metadata/doq.html