Chapter 10
Orthophotographs

10-1. Orthophotographs

Orthophotographs are photographic images constructed from vertical or near-vertical aerial photographs, such that the effects of central perspective, relief displacement, and tilt are (practically) removed. See Figure 10-1.

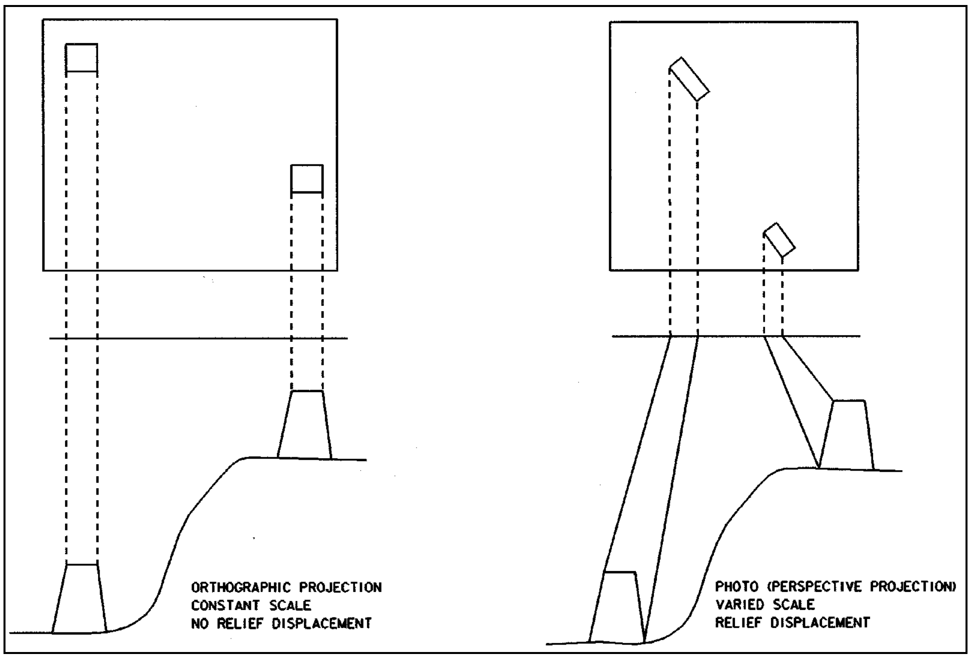

Figure 10-1. Orthographic and perspective images

A **digital orthphoto image** is rectified to thousands of geospatial (XYZ) points, and the image features are aligned orthogonally. The resulting orthophotograph is an orthographic product. **Orthophoto maps** are orthophotographs with overlaid line map data. The common line data overlays include grids, property lines, political boundaries, geographic names, planimetric features, and other selected cultural features as well as contour lines. See Figure 10-2.

10-2. Background

The concept of orthophotography dates back to the 1960s. Original procedures were labor intensive, therefore time-consuming. The first orthophotographs were cumbersome affairs. Elevation slices were taken from a contour map. Using masks, a series of photographic exposures were made from the negative onto a positive base. Each exposure segment covered only the area of a specific elevation range. Thus, the image was a composite of several exposures. They were used mostly by agencies of the Government for experimental projects. In the following 2 decades, analog stereoplotters were adapted to improve and simplify production procedures. The photo image was generated by running the instrument platen along a series of parallel continuous strips. While the film was being exposed, the operator moved the platen up and down, keeping the exposure slit in contact with the apparent ground level. During this period, the mapping industry expected that orthophotography was the answer to a lot of problems. Even though many orthogonal images were produced, acceptance of this product was not nearly as phenomenal as early anticipation.

Figure 10-2. Orthophoto map (courtesy of BAE systems ADR)

10-3. Current Status

The 1990s realized a wide acceptance of orthophoto images. The demand for geographic information is shared by many disciplines (scientists, engineers, economists, geographers, etc.) and the demand is growing dramatically. The demand also drives the technology to create and process geographic data.

a. Geographical Information Systems (GIS) and Land Information Systems (LIS) projects demand pictorial mapping layers to enhance presentation of solutions.

b. Increased demand and use of remotely sensed multispectral imagery and high-resolution elevation data. Orbiting and air breathing sensor platforms are now capable of collecting high-resolution elevation data that can be used for orthophoto processing. Multispectral sensors are being economically brought down to air breathing platforms.

c. Ground control can be a significant time and cost factor in orthophoto development. Global Positioning System (GPS) technology has allowed for a decrease in the time and cost for the capture of ground control data required for orthophoto production. Airborne GPS technology can provide further decreases in time and cost of photo control required for orthophoto creation.

d. Computer processor development has increased the data storage, processing speed and capability of image workstations and software with continued decrease in unit cost. High-resolution metric scanners allow for accurate image creation. Image workstations capable of viewing and analyzing orthophoto data are now on many more desktops than ever before.

e. Digital Photogrammetry Systems (workstations, softcopy, digital stereoplotters) allow users to extract reliable planimetric and topographic data from orthophoto images to create precision thematic maps.

10-4. Map Substitute

Generally orthophotos may not be considered as a substitute for a precise line map since cultural features with a vertical elevation are not as accurate or discernable on an orthophotograph as a planimetric map produced in a stereoplotter. Orthophotographs can be used with caution as a substitute for a planimetric line map for certain smaller scale, nondesign applications. If terrain relief is slight, simple rectification of an aerial photograph might be sufficient. It is possible that ortho rectified images may not be specified when removal of relief distortion is not critical to the accuracy of the functional application. Nonorthorectified image products include photo enlargements and rectified photo enlargements. These products should not be misconstrued as being comparable to orthophotographs.

a. Photo enlargement. This is a photo image sheet enlarged from an aerial photograph to a factor governed by a distance between two points, most often measured from planimetric features on a small-scale map sheet.

b. Rectified photo enlargement. This is a photo image sheet enlarged from an aerial photograph to a best- fit solution to more than two coordinated (XY) points, often extracted from a small-scale map sheet. This procedure is also known as *rubber sheeting*.

In neither of these procedures is the normal image displacement, caused by terrain relief, eliminated. Therefore, image features are not in their true orthogonal location. These products usually involve faster delivery and are significantly less expensive than are orthophotographs; thus, it may be a temptation to use them as a substitute. Improper use of these products may lead to serious problems.

10-5. Image Quality

Throughout the orthophotographic process a wide range of factors can affect the integrity of a digital ortho. Some compound others.

a. Aerial photography. Such items as mechanical and optical integrity of the camera, weather conditions, and photographic lab processing initially influence the sharpness and radiometric density range of the transparency. See Chapter 5 for additional information regarding aerial photography.

b. Pixel scanner. Such items as optical integrity, radiometric sensitivity, dynamic range, and sampling rate influence radiometric quality. If the image collector is a remote sensing device or a digital camera, the capturing and scanning of digital data are a simultaneous operation. In these devices, the pixel resolution is fixed by the mechanical structure of the sensor. The scale of the final ortho image will be limited by the resolution of the system.

c. Magnification. Magnification factor is the relationship of photo scale to final orthophoto scale.

d. Scan resolution. Resolution is the length of one side of a pixel. Hence, a resolution of 20 microns means that the pixel measures 20 microns on each side. Once the final scale is determined, the photo scale and magnification can be calculated. Then the pixel resolution can be computed with the formula

$r = 105/\text{mf}$ (10-1)

where

r = resolution (microns)

mf = magnification factor

Assume a hypothetical situation requiring an ortho image scale of 1 in. = 200 ft (1:2400 metric) to the accuracy required by Class 1, ASPRS Accuracy Standards for Large-Scale Maps (Chapter 2). Assume that the project conditions indicate a four-time negative enlargement for maintaining Class 1 accuracy. This is the magnification factor. Hence, the scale of the aerial photos will be

(1"=200') X 4 = 1"=800' (1:9600)

and, using the above formula, the recommended pixel resolution is no larger than

105/4 = 26 microns

e. DPI. Resolution can also be described as the number of dots per inch (dpi) along a single scan path. The same parameters as described in the above item parameters are applicable. Since the magnification in this example has already been declared as 4,

dpi = mf x 240, or dpi = 4 x 240 = 960 (10-2)

f. Ground distance. Resolution can be thought of in terms of actual ground measurements. The size of identifiable ground features in pixels can be determined by either of two formulae, one metric and the other English. Inserting the final scale (fs) parameter in the above situation, the ground feature size would be

Metric: fs/8,000 = (1:2,400)/8,000 = 0.3 m) (10-3)

English: fs/16.666 = (1 in. = 200 ft)/16.666 = 12 in.) (10-4)

10-6. Workstations

The accuracy of orthophotos is also directly related to the quality and accuracy of the hardware and software utilized in the data processing and manipulation steps that generate the orthophotos. Orthophoto workstations include several key hardware and software components. The systems must have the capability to generate and process accurate elevation models and high-resolution scanned images from transparent media (i.e., film or diapositives) or remote sensors. The system must be capable of incorporating vectorized line maps and raster images.

a. Hardware. A basic component of an orthophoto workstation is the central processor. The processor must be capable of interactively processing elevation models and gray-tone images. Primary requirements are high processing (RAM and ROM) speed, large memory and mass storage, high-speed graphics processor, and input and output devices. See Figure 10-3.

Other supplementary devices may be necessary for communication, data transfer, network links, film writing, screen digitizing, high-resolution metric scanners, and various printing devices. These devices must be compatible with the accuracy of the final orthophoto products. For example, the scanner must be capable of producing the required scanned image necessary for the final orthopohoto accuracy.

Figure 10-3. Orthophoto workstation (courtesy of Surdex Corporation)

b. Software. Several basic software packages are required:

(1) Operating system for the workstation.

(2) Application software required for the processing image matrices and the creation of elevation models.

(3) Orthophoto package used to rectify the image pixel matrix with the elevation model in the final step to create the orthogonal image.

10-7. Production Procedures

It is not the intent of this engineer manual to describe all of the processes by which an orthophoto image is created. Rather, a general procedure is offered. Imagery and ground control must first be properly planned and collected. The design of the image and ground control must be based on the required accuracy of the orthophotos. Orthophoto accuracy involves both the accuracy of distances and areas within the orthophoto and relative accuracy of features with respect to their true location on the earth. Distance and area accuracy is based on the pixel size. Relative feature accuracy is based on the accuracy of the DTM. The relative accuracy cannot be more accurate than the accuracy of the DTM. Image manipulation software and techniques used today negate the requirement for special aerial flight parameters for orthophotos in most cases. Additional overlap of photography to minimize image overlap is generally not required. See Chapter 2 for additional information and criteria.

a. Image rectification. There are two types of rectification that are employed in adjusting a pictorial image to the ground: simple rectification (also called rubber-sheeting) and differential rectification. Simple rectification is a single-step procedure, which rectifies an image to several points. This process is relatively inexpensive. Map users should employ this method with caution. The reason being is that the image is not sufficiently accurate throughout its bounds to provide reliable measurements. Depending on project accuracy requirement, simple rectification may be adequate for photographs containing no more relief in feet than the scale in feet to the inch multiplied by the factor 0.03. This assures that the displacement resulting from relief of any photographic image will not exceed the specification limit for planimetric features. For example, simple rectification may be used for a photograph with a scale of 200 ft to the inch in an orthophoto map project made from photographs taken with a 6-in. focal length camera lens if the relief in that photograph does not exceed 6 ft. Differential rectification is a phased procedure which uses several XYZ control points to georeference an aerial photograph to the ground, thereby creating a truly orthogonal image which can provide accurate measurements throughout its bounds. Production of orthophotographs requires the use of differential rectification procedures which are significantly more expensive than simple rectified images. If stringent accuracy specifications are required, orthophographs are recommended. Simple rectified images should not be confused with orthophotographs.

b. Image scan. If a remotely sensed image, generated by a data sensor or a digital camera, is available, the data are already in digital form and need not be subjected to this process. The processes discussed herein are similar for color and gray-scale, except that if a color image is involved it may necessarily be scanned three times, once each for the primary colors of red, green, and blue. This is dependent upon whether the scanner is constructed as a single-pass or multipass instrument. Therefore, the database is three times as large and each of the phases requires at least three times as much processing time. Currently, data gathered by an analog camera are much more precise than a digital camera, because of the construction and limited data gathering capacity of the digital camera. In the case of a photograph exposed in an analog camera, the image must be translated into digital form. It may be best to scan an autododged second-generation transparency (diapositive), rather than the negative, because this procedure may yield better radiometric values. The diapositive is placed in a densitometric scanner, which produces a gray-tone matrix of pixels of a specific size. Each pixel consists of a radiometric value plus an X,Y coordinate set. Digital aerial cameras are also available to produce aerial photography in digital data format. Radiometric grayscale of a single picture element may fall between reflectance values 0-255. Zero is no reflectance (black) and 255 is full reflectance (white). Both quality and economy must be factored into the selection of the pixel size. Pixel and scanned image file size are easily calculated. See Table 10-1. The proper flight altitude and scan rate must be designed for the orthophoto design horizontal scale. Reducing pixel size greatly increases database magnitude, which affects storage capacity and processing time. A single aerial photograph may require as much as 100Mb of memory, depending on the pixel resolution. Contrarily, smaller pixels may assure greater accuracy. Once the data are scanned, histograms can be developed. These are used to adjust radiometric contrast in the formation of a more pleasing overall image tone.

Table 10-1
Digital Orthophoto File Size Based on Neat Double (7.2" H 6.3") Model for Black and White Uncompressed Images

Scan Sample Rate (in micron and dpi)	7.5 microns	15 microns	22.5 microns	30 microns
	3,386 dpi	1,693 dpi	1,128 dpi	846 dpi
File Size (in megabytes)	496 meg	124 meg	55 meg	31 meg

c. Transport image data. If linked to a network, the radiometric matrix may be imported directly to the workstation. Otherwise, a data conversion may be required before it is transferred. At this point the image is not georeferenced to the ground.

d. Orientation. The radiometrically corrected database may be transformed into a digital image by a digital workstation. A two-step orientation procedure is required to georeference the image to the ground.

(1) *Interior orientation* (also known as "inner"). Precision aerial cameras are periodically subjected to an inspection by the United States Geological Survey, Reston, VA, and a Camera Calibration Report is prepared. Such data as the fiducial marks positions, principal location, and radial distortion factors are input into the transformation equation. Using a reference marker, the fiducial marks are identified on the screen of a

workstation. Then the software causes the radiometric matrix to be resampled in a new database related to the fiducial marks.

(2) *Exterior orientation* (also known as "absolute"). Spatial coordinates of photo control points determined by an aerotriangulation procedure (see Chapter 7) are imported into the workstation or stereoplotter. The operator of the instrument identifies each control point with a reference marker. Then the computer searches out its geometric position data. Through a mathematic spatial adjustment the radiometric pixels are transformed into a matrix which is georeferenced (XY coordinates) to the ground.

e. Produce elevation model. An elevation model must be created in a stereoplotter or softcopy workstation. The elevation model may be created in several ways.

(1) Cost and time savings can be obtained in this process if the elevation model is only to be used for the rectification of the orthophoto image. An elevation model utilizing mass points and breaklines to denote the major changes in topography (DTM) can be generated in the stereoplotting device. The DTM can then be used to produce a Triangulated Irregular Network (TIN) of the topographic surface. Software can then generate an accurate grid of points over the TIN. The grid is at a specified interval posting. The closer the spacing the more accurate the ground character.

(2) A grid of points along with mass points and breaklines denoting abrupt changes in topography can be read and captured from direct readings on stereo images in a stereoplotter or softcopy workstation. This method would theoretically provide the most accurate elevation model. However, the time and subsequent cost difference over other less costly method would increase. Each point must be read by the stereooperator. In most cases this method of elevation data collection is not warranted.

(3) A software process known as autocorrelation may be employed to establish a grid of mass points at a specified interval. This method uses software that allows the computer to automatically collect points at a specified grid over a stereo image. This method is very quick. However, editing must be accomplished to ensure that the vertical location of all points is on the earth surface at the specified location. The initial vertical location can sometimes be the top of a tree or building. Software and stereooperator editing must then be accomplished to edit these type of points and establish their vertical location on the earth surface. The mass points and breaklines are then captured in a manner similar to that described above. This method may save time and cost in certain areas (i.e., areas with minimal vegetation and planimetric features).

An elevation model is important because the geometric integrity of spatial pixels in an orthophoto is dependent on a reliable vertical aspect. Therefore, in order to maintain accuracy of the ortho image, it is imperative that the accuracy range of the elevation model points be compatible with the scale of the orthophoto. The elevation model, as well as the image source, ground surveys, and image scan resolution must be designed for the orthophoto design horizontal scale. For instance, production of an orthophoto to scale 1 in. = 2,000 ft (1:24,000) may utilize a DEM suitable for the production of 20-ft contours, available from the U.S. Geological Survey for a modest price. Be advised, this level of DEM would not be suitable to produce a 1-in. = 50-ft (1:600) ortho image. A DEM suitable for 1-in. = 50-ft orthophoto images would cost significantly more time, effort, and funding.

f. Geometric transformation. However the DEM is collected, its data can be used to create an elevation (Z coordinate) for each radiometric pixel, thus forming a matrix of spatial points. Each picture element is assigned a gray-tone value and a spatial (XYZ) coordinate. In small-scale image construction, the simpler nearest-neighbor or bilinear interpolation algorithms may provide an acceptable product. For large-scale precision mapping projects which require discrete measurement confidence, the image rectification should employ an algorithm that can maintain an accuracy equal to or greater than that which is assured by resampling with a cubic convolution transformation.

g. Mosaicking. Orthophotos are made from single model images, but many projects are not limited to the area of a single orthophoto. In these situations multiple images must be mosaicked into block coverage. Radiometric matching must be accomplished in boundary areas between individual images. Orthophoto projects multiple images must be designed to accommodate the hardware and software limitations of the end user. The size of blocks of ortho images can become very large very quickly and can exceed the limitations of hardware and software. Block size should be addressed in the SOW. Compression routines used to minimize file size should be selected carefully to insure that critical data is not lost during compression. Compression efforts should also be addressed in the SOW.

h. Film writing. Once the scanned and rectified data file is collected, high-quality hardcopy reproductions can be generated by an instrument known as a film writer. This equipment allows the radiometric pulses from the database pixels energize three electro-optical light valves at a high rate of passage, converting the pixels into a fine-resolution dot matrix image on a sheet of film. Instrumentation supports raster files of text and/or graphics and produces continuous tone color or black-and-white positives or negatives.

10-8. Enlargement Factor

The enlargement from the aerial photo scale to the final orthophoto map is critical in the orthophoto process. The enlargement factor is dependent upon several items and conditions that may be unique to the contractors equipment and or the project area. Unique considerations may be the contractors camera type, type of terrain and vegetation the images are to cover, final scale of the orthophotos, and the elevation model accuracy to be used in the orthophoto process. The enlargement factor may vary between 4 to 10 times the photo negative scale as shown in Table 10-2.

Table 10-2
Digital Orthophoto Enlargement Factor from Negative Scale

Class 1	4X TO 6X
Class 2	7X TO 8X
Class 3	9X TO 10X

10-9. Limitation of Orthophotography

The original aerial negative from which the orthophotograph is made is a central projection and, as such, displays relief displacement and obscuration of features. For example, a building will obscure the terrain that lies behind it. This obscuration results in gaps of information that can be gotten only from other sources of information, such as field survey or separate photograph. In order to meet position accuracy requirements, special considerations may be necessary at locations where the ground elevation changes abruptly, as at vertical cliffs, retaining walls, overpasses, and bridges. If the equipment used cannot accommodate such a sudden vertical change, it may be necessary to prepare two orthophotographs of such areas: one that depicts faithfully the upper level of the feature and another that depicts faithfully the lower level of the terrain. The two shall then be combined by special image editing techniques or by removing a portion from one orthophotograph and inserting it into the other. The resulting montage shall meet all dimensional and aesthetic specifications. No attempt shall be made to place the tops of buildings, tanks, towers, trees, etc. in map position; rectification shall be at a ground level.