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Lesson 4: Photogrammetry

INTRODUCTION

In this lesson you will learn about photogrammetry and the photogrammetric process. This lesson will cover fundamental concepts of photogrammetry which includes topics that are primarily related to aerial imagery. In addition, you will gain an understanding of the photogrammetric process which involves complex math functions, routines and expensive specialized photogrammetric software. This lesson will also describe concepts used to perform correction on aerial imagery.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Define photogrammetry.
2. Explain fundamentals of photogrammetry concepts.
3. Use photogrammetric concepts such as scaling resolution to interpret aerial photography.
4. Explain the concepts of calibration, rectification, and orthorectification.
5. Perform an image rectification.

LEARNING SEQUENCE

Required Reading	Read the following: <ul style="list-style-type: none">• Online Lesson Material
Resources	Review the following: <ul style="list-style-type: none">• None
Assignments	Complete the following: <ul style="list-style-type: none">• Quiz• Lab: Image Rectification

INSTRUCTION

Elements of Photogrammetry

Photogrammetry is the study of making highly accurate spatial measurements from aerial photos or images. Often the photogrammetrist is interested in making sure distances, areas, and heights of objects are accurate. The photogrammeterist is also capable of creating digital elevation models of surfaces, of landscapes or an urban environment. A photogrammeterist is



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one who creates digital orthophotos or image products from aerial photography or satellite imagery.

Prior to the use of computers and fast work stations photogrammetry was performed manually using devices called stereoplotters. Binocular scopes were used to make measurements and perform complex mathematical calculations. These were then translated on hard copy maps and products. In today's world photogrammetry is performed using fully digital means from the collection of the imagery to the photo corrections to the final products, typically orthorectified images.

Photogrammetry is a complicated and very technical field that involves experience and knowledge in complex calculus, trigonometry, and the understanding of how aerial images are taken on aircraft. In addition one must know how an image relates to the physical geography beneath it.

For those interested in the math and the technical details of photogrammetry, students are encouraged to review and study the material found at the end of this presentation. This photogrammetry unit will focus on some of the concepts and general processes photogrammetrists use to perform corrections and generate products for aerial imagery rather than discussing the mathematics behind the photogrammetric processes.

Common Issues with Aerial Imagery

To perform high quality photogrammetry, specialized photogrammetric software and a keen knowledge of math is needed along with the ability to understand the physical relationships of the image being collected on the sensor as it relates to the geography below the aircraft.

Photogrammetry is often conducted by highly trained staff that has additional education, training, and certifications. The American Society for Photogrammetry and Remote Sensing is the premiere organization for certifying photogrammetrists and remote sensing scientists. Students are encouraged to check [The Imaging & Geospatial Information Society](#) for more information regarding photogrammetry, remote sensing, and certification. Some of the common issues related to most aerial image collections include the following: differences in scale, feature distortion, sensor anomalies, and sensor position.

- **Differences in Scale:** Not all geographic areas are perfectly flat and so have varying scales throughout the image. This can be a problem when trying to measure accurate distances and areas.
- **Feature Distortion:** Due to changes in scale as well as vertical features not being imaged directly below the aircraft, these features can become distorted by leaning away from the center of the image. The leaning features or tilted buildings can obscure other important features in the image such as roads, sidewalks, natural areas, and other features.
- **Sensor Anomalies:** Anomalies in the lens on the camera and in the air craft can also introduce issues in the images.
- **Sensor Position:** The sensor position can also affect how features are imaged. Aircraft cannot fly perfectly level, straight or at a constant altitude. As a result features can appear tilted, elongated, shortened, or overlaying other features. The size and shapes of features can also be distorted. Photogrammetric methods and processes attempt to minimize and eliminate such issues in the images after they are collected.



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Accurately Measuring Distance and Area

Once images have been processed using photogrammetric methods, accurate distances and areas can be made, even in areas with a varying terrain.

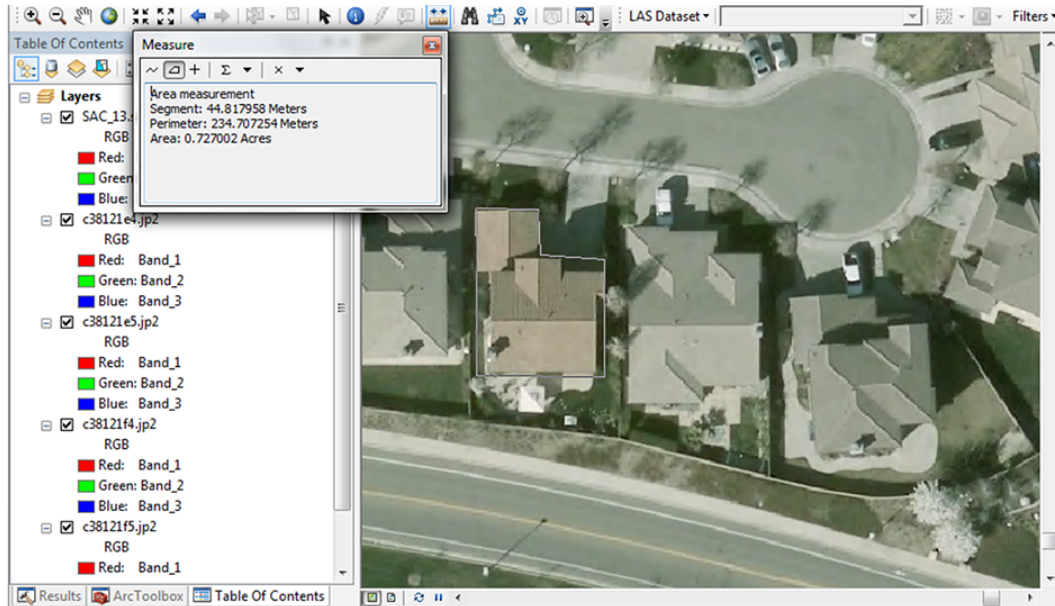


Figure 1 Screenshot: Accurately Measuring Distance and Area

LiDAR

LiDAR is often acquired in addition to aerial image collections since a high resolution digital elevation model is produced that can provide the elevation value for every pixel in the image. LiDAR may also provide additional elevation values so that vertical structures such as trees, buildings, bridges, levees, power lines, and towers can be accurately mapped. LiDAR often provides a more cost effective means of obtaining and mapping very small changes in the surface elevation; vertical structure versus traditional survey; and manual analytical photogrammetric methods. It is important to understand that photogrammetry may not produce as accurate of a product as do survey projects but the intent of photogrammetry for aerial imagery is to produce high quality air photo bases and products that satisfy "mapping grade" types of applications. These applications are usually accurate to a few inches to more than a meter or more and depend on the project and intended use of the products.



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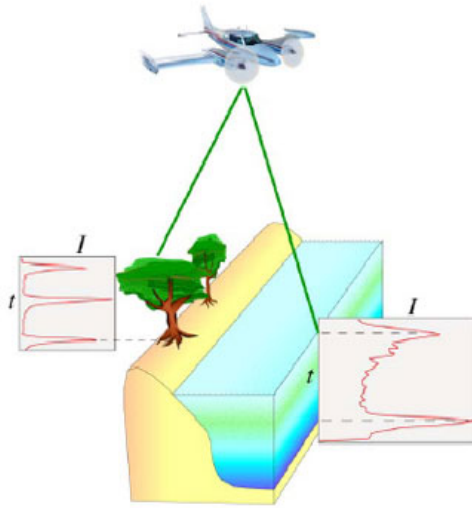


Figure 2 LiDAR Detection Process

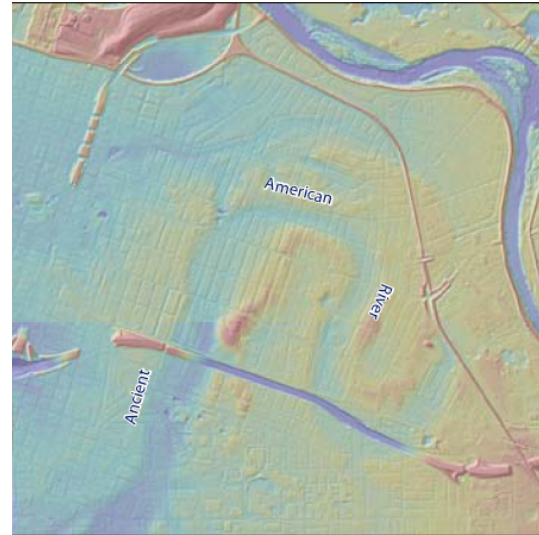


Figure 3 High Resolution Digital Model

Accurately Measure Heights and Adjust for Different Scales

LiDAR can assist by being able to accurately map heights and make the proper adjustments for differences in scale that are often found throughout a project area.

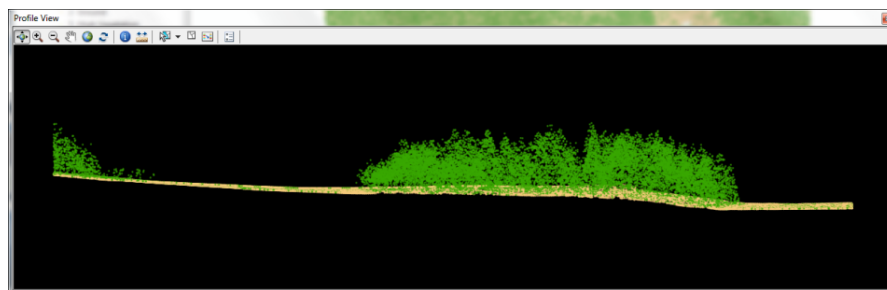
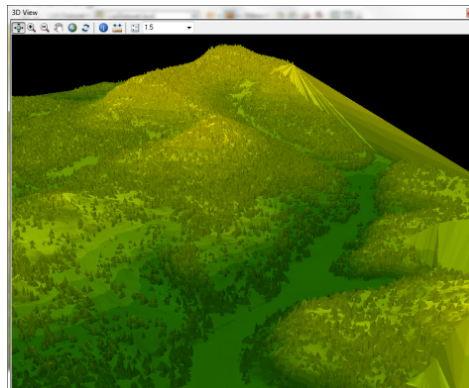


Figure 4 Screenshots: Examples of Differences in Scale



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Create Contours

Another product that is often produced from photogrammetric methods is the generation of high quality contours for a project area. The level of detail depends on the flying and image collection characteristics decided on in the project development phase.

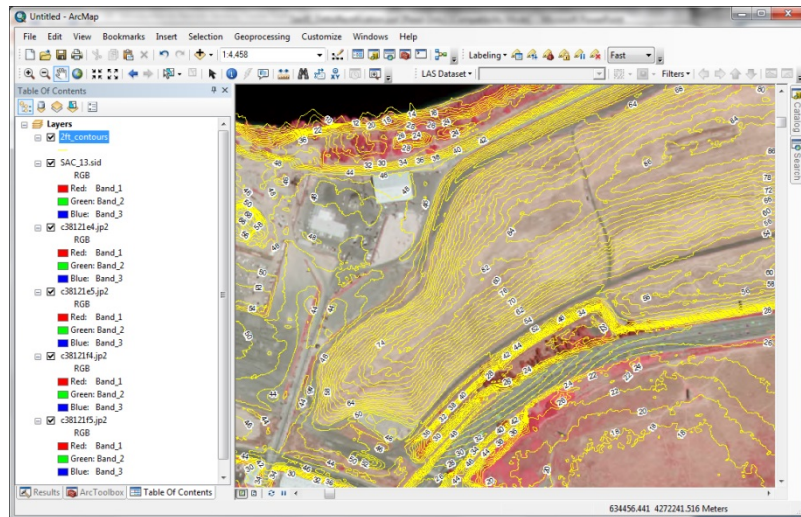


Figure 5 Screenshot: Using ArcMap to Create Contours

Creating an Ortho Image

One of the most commonly created products from photogrammetry is the orthophoto or ortho image. These images are often corrected and processed so that a high quality image base can be developed for many mapping purposes. Ortho images have a geographic reference and measurements made on features that are at the base elevation which are highly accurate. Vertical structures may or may not have a correction applied to them depending on how the project was developed for aerial collection and the project budget available.

Both of the images provided have been "orthorectified", meaning that the features at the base elevation (i.e. those at ground level) have been corrected to a high accurate standard. Notice that the image on the left of the buildings is tilted whereas the image on the right includes a correction which has been applied to remove the tilt on the buildings so that the streets and sidewalks can be seen. Even though both images are considered orthorectified, the image on the right is considered to be a "true ortho image" because the building tilt has been removed.

One can see that for municipal use, the image on the right is more useful than the one on the left because all of the features appear in the image. In the image on the left some of the features are obstructed as a result of the building tilt.



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Figure 6 Orthophoto



Figure 7 "True" Orthophoto

Recommended References: For more technical and detailed explanations including examples, you are encouraged to refer to the following references:

Wolf and Dewitt, 2000. *Elements of Photogrammetry with Applications in GIS*, 3rd ed., McGraw Hill, ISBN: 0072924543 and ISBN-13: 978-0072924541

Lillesand, Kiefer, and Chipman, 2007. *Remote Sensing and Image Interpretation*, 6th ed., Wiley & Sons, ISBN: 0470052457 and ISBN-13: 978-0470052457

The Photogrammetric Process

A number of issues appear in aerial imagery that can be corrected through the photogrammetric process. These were described in the previous lesson and are summarized here again.

- **Differences in scale** can be due to differences in elevation throughout the image and can affect the accurate measurements of distances and areas such as lengths of roads or areas of land on the image.
- **Feature Distortion** is when vertical features, those features not lying directly on the ground, will appear distorted if they are not imaged directly below the camera. The distortions can come in the form of the features leaning off to one side and tall buildings appearing to be tilted.
- **Sensor Anomalies** are anomalies in the lens orientation and curvature which can introduce distortions on the image.
- **Sensor position** is the physical position and orientation of the camera on the aircraft during the time of image exposure it can impose distortions on the image. Even though great care is taken to build and mount a camera on an aircraft and even if the aircraft has inertial damping systems and a GPS to keep the plane oriented, there can still be distortions resulting from the camera's position and the attitude of the plane.



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Differences in Scale

The illustration provided demonstrates the aspects of a plane with an aerial camera flying at a specific height. A vertical object (shown in red) is shown at two different elevations. The yellow object off to each side shows what the object would look like on the image. Notice that the yellow object is leaning outward from the base of the object. In addition, since the red object on the right is closer to the camera, there will be even more pronounced lean than the object on the left. (NOTE, the image does not accurately represent this lean, but it is important to remember that the vertical features will appear distorted on the images.)

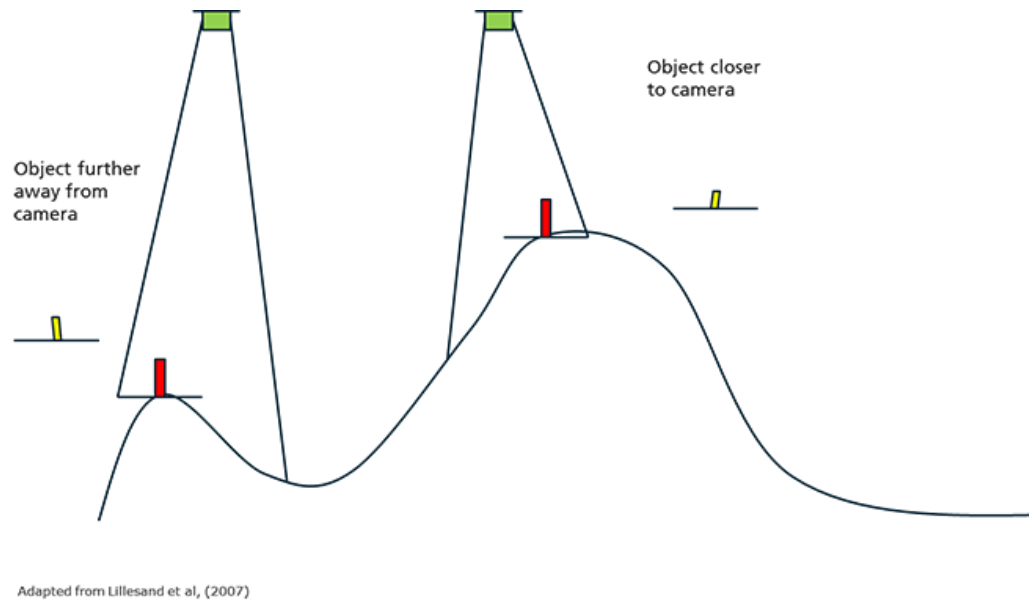


Figure 8 Differences in Scale

Building Tilt

The images below show the effect of building tilt. Both images show the same features although the image on the right shows the two buildings with pronounced tilt. The sides of both buildings are seen in the image and the buildings appear to lean up to the right. This results from the building images being captured directly below the aircraft.

The image on the left shows only the roof tops of the buildings and they are not tilted. This results from the building images being directly below the aircraft at the time of exposure.



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Figure 9 Building Tilted



Figure 10 Building not Tilted

Heights of Objects and Elevation

The heights of objects and elevations can be measured and derived from the use of parallax. Parallax is the relative position of an object from two different perspectives. In the case of aerial photography parallax can be measured and quantified from measuring the same feature in two overlapping images or "stereopairs." A mathematical relationship exists between the same object on two overlapping photos and it can be used to derive the heights of objects as well as the elevation for every pixel in the image.

Requirements

Several pieces of information are needed to perform the mathematical computations needed to correct issues found in aerial imagery.

Fiducial Marks

Aerial images must contain fiducial marks (which are often shown as crosshairs in each corner and on the sides of a photograph). For fully digital imagery, digital image calibration techniques are used.

Images within a given flight line and for subsequent flight lines need to have significant overlap on the ends and sides. It is common to have greater than 60% end lap and 40% side lap in aerial imaging missions.

Camera Calibration Report

A Camera Calibration Report is required for aerial imaging projects. This report provides detailed measurements and specifications that are required to perform some of the photogrammetric processes. Some of the important information on the camera calibration report includes:

- The focal length of the lens stated in millimeters.
- The principle point which is the point on the image that represents a line from the back of the camera and intersects the focal plane. This line is perpendicular to the focal plane. The focal plane is the planar surface where the image is



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exposed or recorded. The principle point of a camera is expressed as an x and a y value and is provided in millimeters. The approximate principle point can be derived by intersecting opposing fiducial marks on the image.

- The image resolution is also required. For scanned film this will be the scanning resolution stated in millimeters or dots per inch. For digital images this will be the pixel size.

Digital Elevation Model

A digital elevation model may be available that can be used in aerial image collection projects. If a digital elevation model does not exist and there is enough overlap in the imagery then a digital elevation model can be derived. This will be dependent on how the aerial image collection is specified and defined.

Surveyed Ground Control

Surveyed ground control points of static known locations are also required. This will help relate the imagery collected on the camera to the ground and can also help with the derivation of the digital elevation model. Surveyed ground control points can provide a quantitative accuracy assessment on the image collection, derived image, and elevation products.

Special Photogrammetric Software

As mentioned earlier, specialized photogrammetric software will be required to perform all of the photogrammetric adjustments, computations, and to derive the digital image products such as ortho images and digital elevation models.

Common Photogrammetric Steps

The general photogrammetric process follows these steps.

Step 1: Georeference

Assign a georeference so that the analyst knows which spatial coordinate system will be assigned to the imagery.

Step 2: Interior Orientation

Perform the interior orientation. This step sets up the orientation of the camera and photographic plane at the time of image collection.

Step 3: Exterior Orientation

Perform the exterior orientation. This step is performed multiple times for each image in the image collection area and determines the orientation of the image when it was collected on the camera. This establishes a relationship between the images coordinates and the real-world coordinates on the ground. This step is often very involved and can take a significant amount of time. The corrections can be applied to a single image, a strip of images in a flight line, or as a block of images across a project area.

Step 4: DEM Extraction

Step four involves the creation of a digital elevation model (DEM). If one is already provided or available then this step may not be required. In addition, digital contour data sets can be created from the digital elevation model.

Step 5: Ortho Image Production



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Ortho image production is one of the primary final steps in the photogrammetric process. Photogrammetry is use quite a bit to generate ortho images. Ortho images are those that have all of the mentioned anomalies removed so that accurate measurements and locations can be made. Ortho image products results in a high quality image based that can be used in other GIS and analytical processes.

In addition to the ortho image production, images in a flight strip or block are often mosaicked into a single image data set where the individual images have been color balanced so that the resulting image has a similar tone and color across the entire collection area.

Georeference

When assigning a georeference to an image for ortho image production, the real-world coordinate system must have values in the horizontal (latitude, Y/longitude, X) and vertical planes (elevation, Z). Images must be **georeferenced** to a real world coordinate system and must **have X, Y, Z values (lat (Y),long (X), elevation (Z))**.

Exterior Orientation

The illustration provided shows a simplified version of the exterior orientation process. Essentially, a mathematical relationship exists between the orientation of the photo on the aircraft at time of collection and the physical ground. Basically, there are a number of parameters that are determined mathematically through the exterior orientation process. These parameters are required for each image in an air photo collection (which can often involve thousands of photos). The exterior orientation parameters and computations are used to perform a variety of corrections on the image to generate the ortho image or the collection of ortho images in an aerial project. Exterior orientation involves re-creating the position and angular orientation of photos at time of exposure of the image.

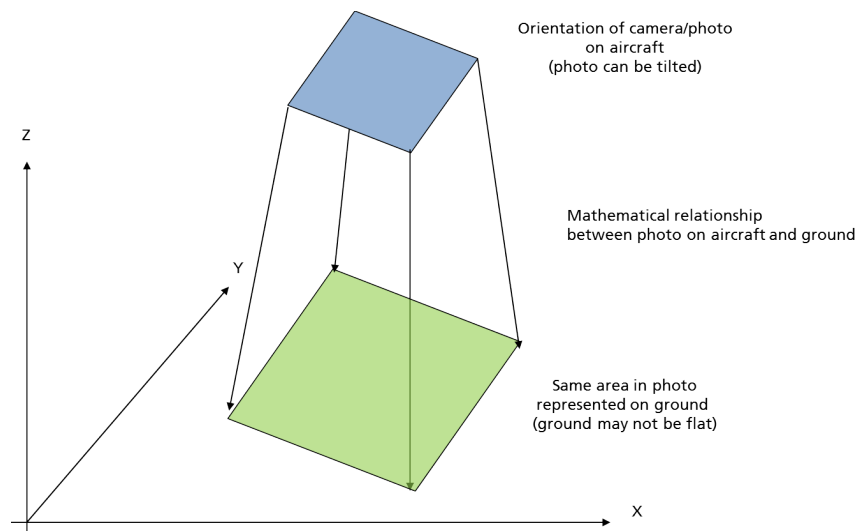


Figure 11 Exterior Orientation Process



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Recommended References: For a more technical and detailed explanation including examples, you are encouraged to refer to the following text.

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Ground Control and Tie Points

As it relates to the relationship between the image and the ground, it is common to have a large number of ground controls and/or tie points. The ground control points are often collected through survey methods and may already exist or need to be collected as part of an aerial image collection. Tie points are often commonly identified objects or pixels in the overlap area of neighboring images. Tie points can number in the dozens, hundreds, or thousands depending on the aerial extent of the image collection and the number of images collected. Current photogrammetric methods have automated ways of collecting and evaluating the quality of tie points.

Ground control and tie points are also used to generate the digital elevation model. The quality of an ortho image is only as good as the quality of data provided to the input parameters.

Quality data would entail:

- Identifiable ground control points.
- High scanning rate or high image resolution
- Well distributed high density of ground control and tie points.

Correcting Strips and Blocks of Images

The photogrammetric process can be used for single images, strips of images along flight lights, and blocks of images. These can be comprised of multiple flight lights over a given aerial image project area.

Ortho Image Production

The typical method used to generate an ortho image involves determining the elevation value for each pixel in the oriented and corrected image. Next write each pixel to an output image. The resulting ortho image will no longer include distortions.

In an ortho image product all of the distortions have been removed such as the differences in scale, the image tilt, and relief displacement (or the displacement of objects on the image resulting from them not being imaged directly below the camera).

It is important for the image analyst (or photogrammetrist) to pay close attention to the parameters used and assigned in the photogrammetric process. This is because small inaccuracies in the orientation parameters and digital elevation values can have dramatic effects on the quality of output to generate the ortho image products.



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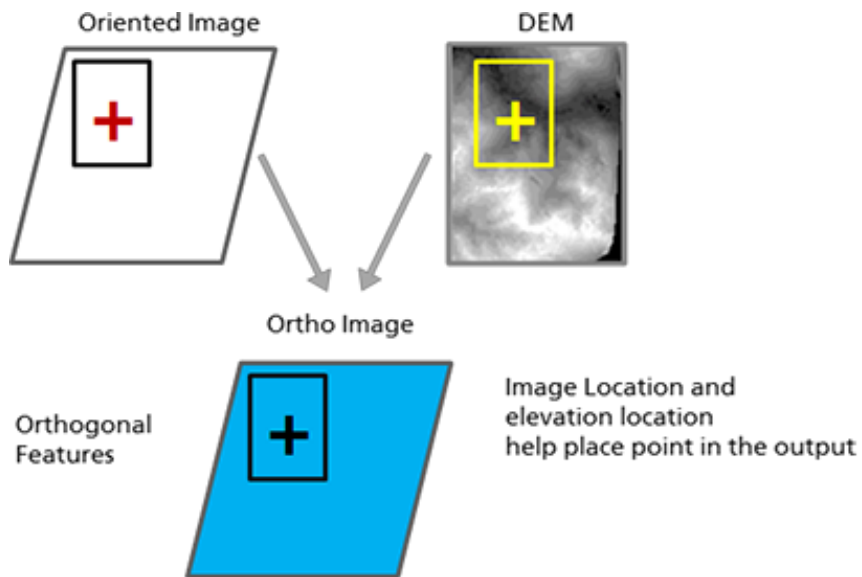


Figure 12 Illustration: Ortho Image Production

Example: Ortho Images

The images below are the same images that were seen earlier in the presentation. Both of these images are ortho images, however, only the image on the right is considered a “true ortho image” because the building tilt distortion has been removed. In some cases, an ortho image aerial collection project may want to include areas that will be “true ortho corrected.”

Areas such as metropolitan areas with tall buildings, road infrastructure with bridges, and multi-level overpasses and interchanges may be areas where the “true ortho” image correction are performed. Other areas that do not have tall buildings or metropolitan areas where surface infrastructure (such as road striping, manholes, sidewalks, trees, and other features) need to be seen, do not have to have the “true ortho” correction process applied. “True ortho” areas will require additional images to be collected and can add to the overall aerial image project cost.



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Figure 13 “True” Ortho Image: Building tilt has been removed

Figure 14 Building not Tilted

SUMMARY

In this lesson you learned about photogrammetry and the photogrammetric process. The first part of the lesson covered fundamental concepts of photogrammetry which included topics that are primarily related to aerial imagery. In addition, you gained an understanding of the photogrammetric process which involves complex math functions, routines and expensive specialized photogrammetric software. This lesson described concepts used to perform correction on aerial imagery.

ASSIGNMENTS

1. Quiz
2. Lab: Image Rectification



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