Photogrammetry

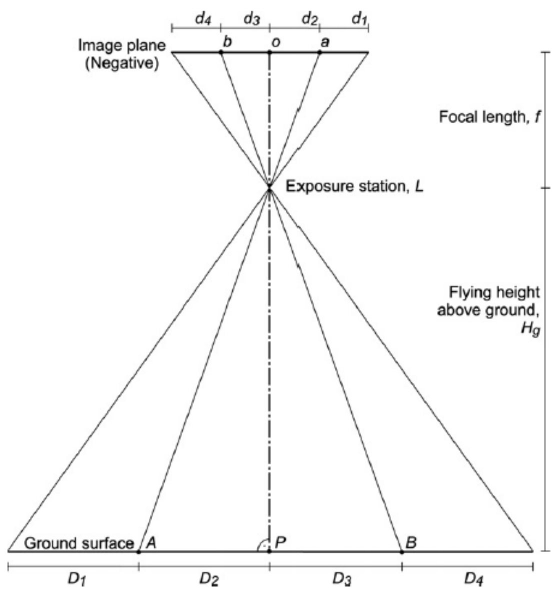
January 16, 2015

1 Introduction

Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena. The basic principle behind all photogrammetric measurements is the geometrical–mathematical reconstruction of the paths of rays from the object to the sensor at the moment of exposure.

2 Geometry of Single Photographs

2.1 Vertical Photographs Taken Over a Flat Terrain



Spatial Resolution

The triangles established by a ground distance$D$ and the flying height above ground H_g on the terrain side, and by the corresponding photo distance d and the focal length f on the camera side, are geometrically similar for any given D and d, so the scale S of the photograph is the same at any point. For digital images, the ground sample distance GSD determines the spatial resolution or smallest visible detail in the photograph, and can be computed as follows:

$S = \frac{d}{D} = \frac{f}{H_g}$

$GSD = \frac{PIXEL\ ELEMENT\ SIZE}{S}$

$DISPLAY\ SCALE = \frac{MONITOR\ DOT\ PITCH}{GSD}$

Example ($H_g = 100m$, $f = 35mm$, $PIXEL\,ELEMENT\,SIZE = 0.009mm$, $MONITOR\,DOT\,PITCH = 0.26mm$)

$S = \frac{0.35}{100} = 0.035$

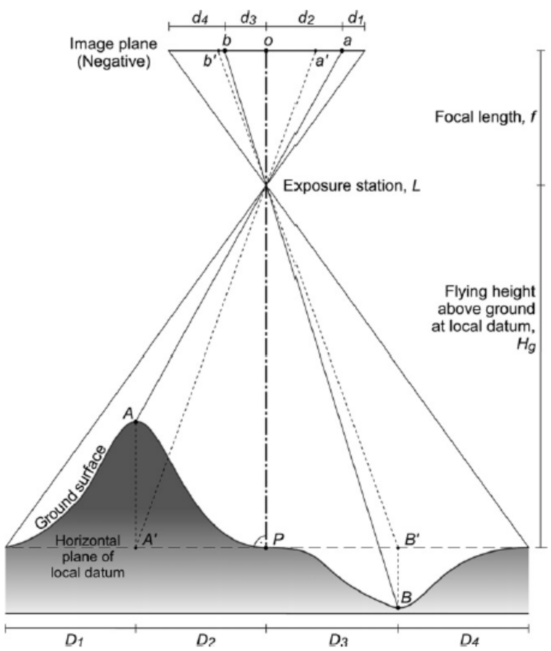
$GSD = \frac{0.000009}{0.035} = 0.026m$ (2,5cm per pixel)

$MONITOR\ DOT\ PITCH = \frac{0.00026}{0.26} = 0.01m$

Radiometric Resolution

The term radiometric resolution refers to the number of digital levels, also called precision, that the sensor uses for recording different intensities of radiationdusually 0–255 or 2^8 per image band for SFAP cameras.

2.2 Vertical Photographs Taken Over a Variable Terrain

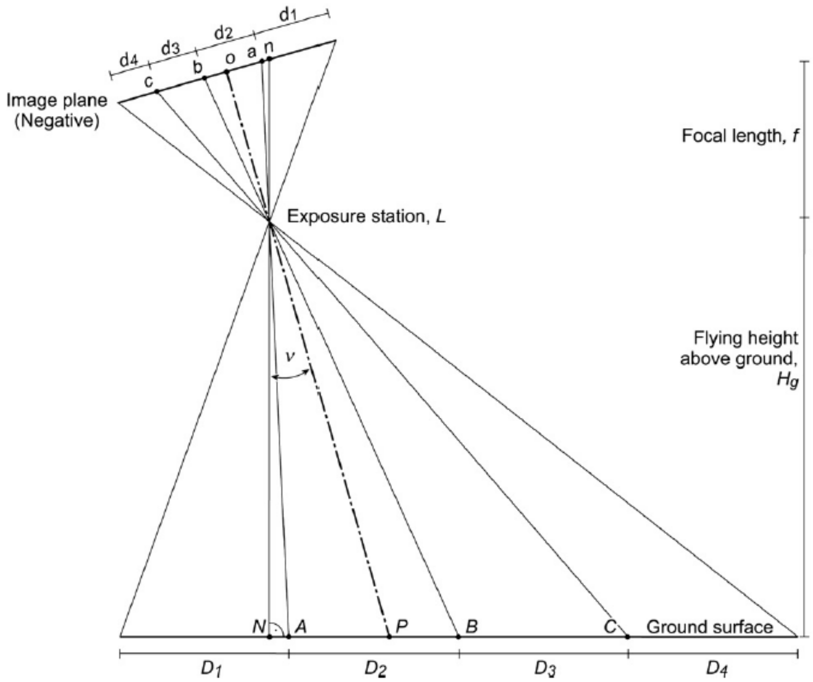


Relief Displacement

The elevation of the principal point P determines the horizontal plane of local datum. Points lying on this plane remain undistorted, whereas points above or below are shifted radially with respect to the image center. Note that the horizontal distances $D1$–$D4$ are the same in the object space but not in the image. This effect is called Relief Displacement.

The Relief Displacement or distorting effects of the central perspective are usually undesirable for the analysis of single photographs, but they also have their virtues. Because the magnitude of radial distortion is directly dependent on the terrain's elevation differences, the latter can be determined if the former can be measured.

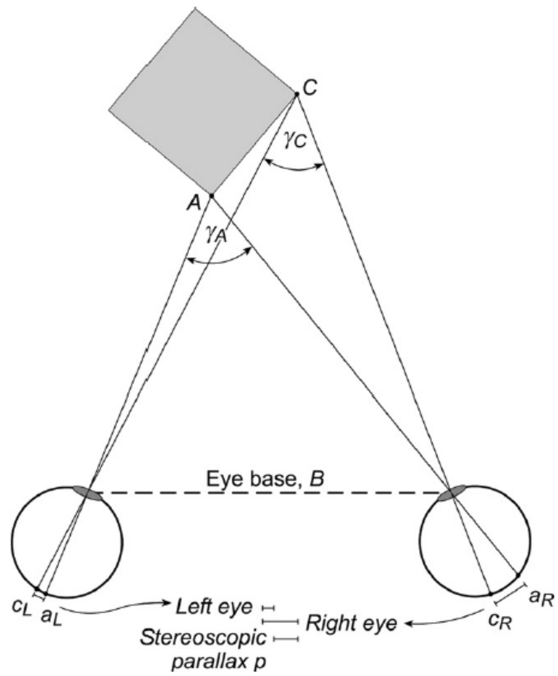
2.3 Tilted Photograph



Oblique images are useful for providing overviews of an area and they are easier to understand and interpret for most people. However, obliqueness undermines the validity of many principles and algorithms used in photogrammetry. For many practical applications, the errors resulting in simple measurements from slightly tilted images ($\nu < 3$) can be considered negligible.

3 Geometry of Stereo Photographs

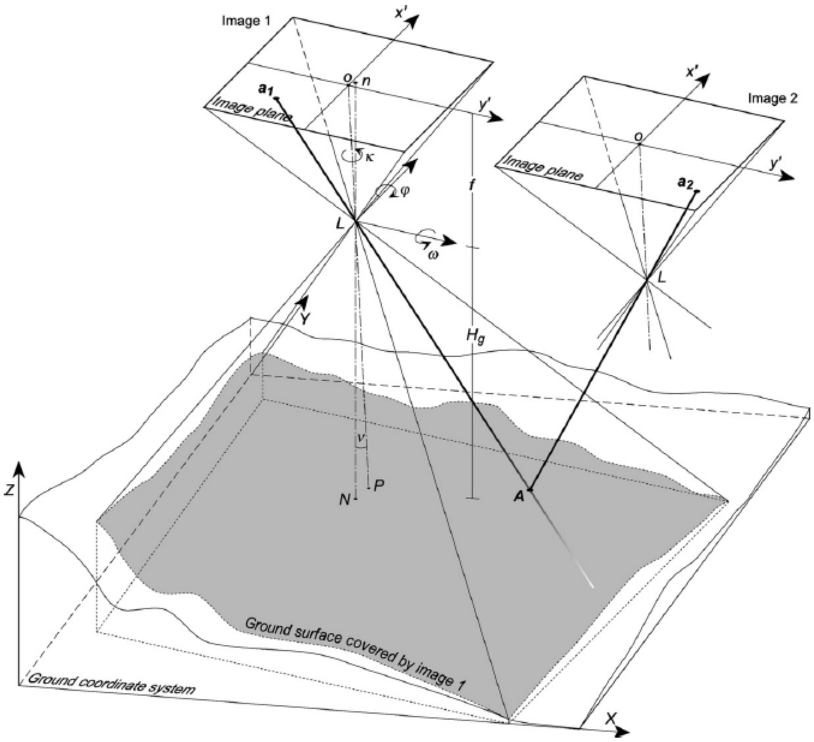
3.1 Principles of Stereoscopic Viewing



When the eyes focus on an object, their optical axes converge on that point at an angle (the parallactic angle γ). Objects at different distances appear under different parallactic angles. Because the eye's central perspective causes radial distortion for objects at different distances, the two images on the retinae are distorted. The amount of displacement parallel to our eye base, however, is not equal in the two images because of the different positions of the eyes relative to the object. This difference between the two displacement measures is the stereoscopic parallax p. The stereoscopic parallax and thus 3D perception increase with increasing parallactic angle γ, making it easier to judge differences in distances for closer objects.

Stereoscopic vision of objects, may be created by viewing not the objects themselves, but a couple of images of the objects, provided that they appear under different angles in the images. Such combination of images are called Stereomodels or Stereopairs.

3.2 3D Measurements from Stereomodels



In order to be able of measuring the position of a point A, with respect to the ground coordinate system, from a Stereomodel, it is needed to know beforehand the exterior parameters of the camera (position X, Y, Z and orientation κ, φ, ω with respect to the ground coordinate system) at the time of acquisition of both images. This can be achieved in two ways:

- with the usage of Ground Control Points in the ground
- with onboard accurate GPS and attitude sensors (this method is treated in other document)

Ground Control Points (GCPs)

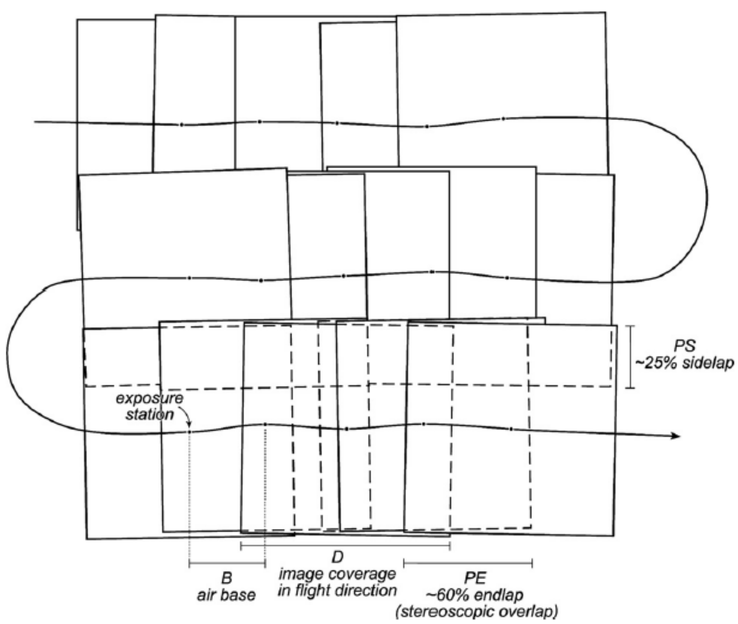
With the known 3D coordinates of three ground control points and their corresponding 2D image coordinates, the position X, Y, Z of the exposure center at the intersection of the three rays and the three rotations of the camera κ, φ, ω relative to the ground coordinate system can be calculated.

Measuring Position of Point A

The position of an object point A in the landscape can be reconstructed by tracing the rays from the homologous image points $a1$ and $a2$ back through the lens. With a single image (the left photo in the figure), no unique solution can be found for the position of A along the reconstructed ray. By adding a second (stereo) image on which A also appears, a second ray intersecting the first can be reconstructed and the position of A can be determined. This method is called a *Space-Forward Intersection*; it is based on the formulation of collinearity equations describing the straight-line relationship between object point, corresponding image point and exposure station.

3.3 Creating Stereomodels with Aerial Triangulation

Acquisition of Images



Stereomodels from professional aerial surveys are acquired in blocks of multiple flightlines in such a way that full stereoscopic coverage of the area is ensured with multiple stereopairs. Each photograph overlaps the next photograph in a line by approximately 60% (forward overlap or endlap), while adjacent lines overlap by $20-30\%$ (sidelap).

The required air base or distance between exposure stations B is dependent on the dimensions of the image footprint and the desired endlap. If D is the image coverage in direction of the flightline and PE the percent endlap, B calculates as:

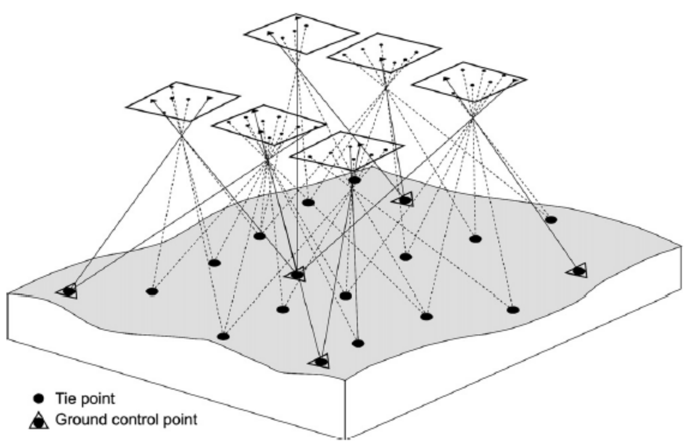
$B = D\left(1 - \frac{PE}{100}\right)$

$\Delta t = \frac{V_g}{B}$

The same equation can be used for calculating the required distance between adjacent flightlines for a desired sidelap PS; keep in mind, however, that SFAP cameras most probably feature a rectangular image format (d_L , d_W) and a decision has to be made as to its longitudinal or transversal orientation along the flightline (substituting D in the equation by D_L or D_W, respectively).

Difficulties with stereoscopic viewing and image matching may arise if the image scales differ more than 10% or so.

Bundle Block Adjustment



In praxis, photogrammetric analysis is mostly done using not one, but several or even many stereopairs for covering larger areas. In order to avoid the individual orientation of each stereomodel with accordingly large numbers of ground control points, multiple overlapping images forming a so-called block can be oriented simultaneously with fewer ground control points using aerial triangulation techniques. One of the most commonly used and most rigorous aerial triangulation methods is the bundle adjustment or bundle-block adjustment.

In theory, bundle-block adjustment allows the absolute orientation of an entire block of an unlimited number of photographs using only three GCPs. This requires that the relative orientation of the individual images within the block first be established by additional tie points (image points with unknown ground coordinates which appear on two or more images and serve as connections between them). These tie points can be identified either manually or with automatic *image-matching techniques* (SURF or SIFT procedures).

3.4 Automatic DEM Extraction from Stereomodels

A digital elevation model (DEM) is a digital representation of terrain heights. The most common forms are a regular grid (usually saved in raster format) or a triangular irregular network (TIN) of triangle facets (vector format).

With the advent of digital photogrammetry, it has become possible to extract elevation information automatically from stereomodels using stereo-correlation or *image-matching techniques* (SURF or SIFT procedures).

Once a set of corresponding points in the overlapping images has been identified, their 3D coordinates are computed by space-forward intersection using the block triangulation results.

4 Mapping

Mapping involves the following phases:

- Aerial Survey with Overlapping
- Geometrial Correction and Georeferencing
  - Polynomial Rectification (requires ground control points)
  - Orthorectification (requires a digital elevation model)
- Additional Corrections
  - Atmospheric
  - Vignetting
  - Bidirectional reflectance effects
  - Intra-date and date-to-date calibration
- Mosaicing

4.1 Aerial Survey with Overlapping

Most aerial photographs deviate from the situation showed in Vertical Photos Taken Over a Flat Terrain for three reasons:

- *Relief Displacement:* the ground is not completely flat.
- *Image Obliqueness:* the photograph is not completely vertical.
- *Lens Distortions:* the paths of rays are bent when passing through the lens.

All three situations spoil the similarity of the triangles and result in scale variations and hence *Geometric Distortions* of the objects within the image. The first problem, geometric distortions caused by varied terrain, does not depend on camera specifications and occurs with any remote sensing images. The last two problems can be minimized with modern survey and manufacturing techniques for professional high-tech survey cameras and mounts, but may be quite severe for the platforms and cameras often used in small-format aerial photography.

4.2 Geometrical Correction and Georeferencing

The photographs, in order to be suitable as a base for mapping, have to be geometrically corrected and georeferenced. This can be done by one of the following methods.

Polynomial Rectification

Polynomial equations formed by ground control point coordinates and their corresponding image-point coordinates are used in order to scale, offset, rotate and warp images and fit them into the ground coordinate system. This approach has several inconvenient:

- Because the polynomials are computed from the GCP points only and then applied to the entire image, they only produce good results if the GCP locations and distribution adequately represent the geometric distortions of an image.
- The rectification of the image areas between the GCPs is interpolated by the polynomial equation and not a direct function of radial Relief Displacement. Vertical or oblique images of flat terrain can be quite successfully rectified with 1st or 2nd order polynomials, but the relief distortions present in images of variable terrain are much more difficult to correct.

While polynomial rectification by GCPs may well be sufficient for low-distortion images or applications with limited demand for accuracy, seriously distorted images and more precise applications require full modelling of the distortion parameters (relief displacement, image obliqueness, lens distortion).

Orthorectification

Orthorectification procedures make use of digital elevation models (DEMs) in relation to which the photographs are oriented in space so that the relief displacement (with the added effect of image obliqueness and lens distortion) of each single pixel can be determined. In the new, orthorectified image file, each pixel is then placed in its correct planimetric position. For orthorectifying SFAP images, a DEM with appropriately high resolution is normally not available from external sourcesdthus, the best solution would be to generate a DEM from the SFAP images themselves first and subsequently use this for orthophoto correction.

4.3 Additional Corrections

Atmospheric Correction

Given the low-height operation for most SFAP (below 300 m or even <100 m), acquired images suffered minimal degradation from atmospheric scattering or absorption. This is an important consideration in terms of spectral signatures of objects depicted in SFAP images.

Vignetting Correction

Vignetting is the image darkening in circular gradient from the image centre to its borders, due to light obstruction and differences in light path in some parts of the optics combination (lens + filters + neutral glasses). It is typical a decrease of about 5% in the visible bands and 35% in the infrared one.

A three-step method usually adopted in astronomy can be used for vignetting correction (see Lelong et all 2008):

- vignetting characterization of each sensor with an illumination radial profile
- antivignetting filter production
- application of the filter to the images

Bidirectional Reflectance Effects Correction

Surface reflectance varies with the incidence and view angles, following the Bidirectional Reflectance Distribution Function (BRDF). A given object will thus reflect different intensities of light in different directions.

A five-step method that regularizes the received light quantity on any part of the image can be applied (see Lelong et all 2008):

- sub-sampling of the original image
- gaussian filtering on a 3x3 pixels window
- over-sampling to the original size by bicubic interpolation
- inversion of the resulting image by subtracting it to 255, then scaling it to null origin
- application of the filter to the images

Intra-date and date-to-date calibration

BRDF causes radiometric variations inside a single image and thus generates differences between a given object radiometry on two consecutive images: the observation configurations are not equivalent for the two acquisitions. This effect was corrected based on common features comparison (see Lelong et all).

4.4 Mosaicing

If a single rectified photograph or orthophoto does not fully cover the study area, an Aerial Mosaic or Orthomosaic may be constructed by stitching the georeferenced images together.