Mapping Matters

By Qassim A. Abdullah, Ph.D., PLS, CP**

Your Questions Answered

The layman's perspective on technical theory and practical applications of mapping and GIS

Question: My questions are about accuracy degradation of horizontal and vertical data during the photogrammetric process for airplane based platforms. I know that there are many variables involved but is there a relative constant multiplier that determines the loss of accuracy between ground survey and AT results, as well as between AT results and final vector data and contours? Also, can I assume digital and film cameras will result in different multipliers? Finally, should the flying height be the sole determinant of the data accuracy?

Dr. Abdullah: My simple answer to the main question is "No," since no such multiplier exists. The process of aerial triangulation is much more complicated than it sounds and it is influenced by many variables as you mentioned in your question. In aerial triangulation, we treat all elements of the computational model as variable observations with certain random errors. These elements include, but are not limited to, interior orientation parameters, ground control points, airborne GPS-based camera centers, IMU-measured camera orientation (if any), and the measured/autocorrelated accuracy of tie, pass, and control points. Users can specify a different weight for each of these variable observations, which in turn contributes to the final error model.

"The accuracy of aerial triangulation, and ultimately the accuracy of the derived map or digital terrain model, is widely influenced by the geometry of flying. Characteristics that contribute to the geometry include altitude, image scale, block configuration, the ratio of the distance between two adjacent photographs and the flying altitude (B/H ratio), as well as other factors such as the quality of the airborne GPS, the ability of the computational model in modeling unforeseen errors, etc. As such, it is difficult to come up with a predictor to estimate the accuracy of aerial triangulation based on the accuracy of the input ground control alone."

In addition, the accuracy of aerial triangulation, and ultimately the accuracy of the derived map or digital terrain model, is widely influenced by the geometry of flying. Characteristics that contribute to the geometry include altitude, image scale, block configuration, the ratio of the distance between two adjacent photographs and the flying altitude (B/H ratio), as well as other factors such as the quality of the airborne GPS, the ability of the computational model in modeling unforeseen errors, etc. As such, it is difficult to come up with a predictor to estimate the accuracy of aerial triangulation based on the accuracy of the input ground control alone. By the same token, it is impractical to estimate the loss of accuracy during product generation as compared to the accuracy of the aerial triangulation; it depends on whether you are utilizing auto-correlation or manual measurements, the software precision in recording the operator measurements, the operator height indexing capability, etc. However, some indirect measure can be derived that you may find useful in estimating the final accuracy. Considering that you fulfill all the requirements needed for a successful aerial mapping mission — use of a metric aerial camera, a well planned and executed ground control network, a well planned and executed airborne GPS collection, and enough and accurate tie and pass points collection — the vertical accuracy of the derived mapping products can be estimated using the following equation:

$$\sigma_h = h \cdot \sigma_i / f.(b/H) \qquad (1)$$

where,

h is the flying height above datum,

σ_h is the required DEM accuracy,

f is the camera focal length,

b/h is the base to height ratio, and

σ_i is the image measurement (or matching) accuracy or standard deviation.

The formula in Equation 1 is very useful in estimating the vertical accuracy of products for different cameras and different flying parameters. With the ADS pushbroom sensor from Leica Geosystems, for example, a user can estimate the vertical accuracy of the product according to the formula of equation (1) as illustrated in following steps:

a) **B/H Ratio:** The ADS sensor multi-look angles capability results in three B/H ratios depending on which look angles are used in forming the stereo-pair. Such multi-look capability enables the user to construct the following different three stereo-pair combinations from each flight line for any point in the project:
   1) PANF02-PANF27 with 25 degree parallactic angle and B/H = TAN 25 = 0.46;
   2) PANF02-PANB14 with 16 degree parallactic angle and B/H = TAN 16 = 0.29;
   3) PANF27-PANB14 with 41 degree parallactic angle and B/H = TAN 41 = 0.87;

b) **Terrain Elevation Accuracy:** Utilizing the above three stereo combinations in the aerial triangulation (and subsequently in generating the digital elevation model), and using some type of averaging for the three different generated surfaces, we can simplify the problem by averaging the three B/H ratios to estimate the accuracy of the final product using Equation 1. Table 1 provides the expected vertical accuracy for different flying parameters using this approach, taking into consideration that the ADS sensor has a focal length of 62.77 mm and CCD size of 6.5 um and that the correlation was performed with a precision of 0.5 pixel size or 3.25 um.

The accuracy figures in Table 1 are consistent with the practical results

Table 1.

Flying Altitude (ft/m)	Resulting GSD (ft/m)	B/H	Vertical Accuracy σ_h (ft/m)
4,725/1440	0.50/0.15	0.54	0.46/0.14
9,450/2,880	1.0/0.30	0.54	0.92/0.28

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we are achieving using digital sensors for well planned and executed projects. I would like to mention here that the error budget added during the modern mapping process is very limited and at a minimum assumes that the process is performed with optimal care. In the past, when most mapping standards and practices were established, the final map acquired many layers of errors caused by the mapping technologies of the day. These techniques included the handling of diaspositives and/or film during the different stages of the mapping process; the manual and mechanical interior, relative, and absolute orientation of the optical-mechanical instruments; the scribing of the line maps on mylar paper; etc. Today's advances in mapping technologies result in minimal loss in accuracy as the mapping process is conducted in the same software and environment where the aerial triangulation is performed and right after the completion of the bundle block adjustment in a fully digital environment. The operator in a modern mapping operation gets the same precision of model orientation as it is computed by the computational mode used in the aerial triangulation; therefore eliminating the first layer of operational errors that would have resulted in the past from the mechanical orientation of the stereo model. Furthermore, having the map totally compiled in a digital environment eliminates the second major layer of error budget that formerly resulted from the scribing process that marked on paper the operator's terrain tracking within the stereo-plotter instrument. Better results are achieved when the digital elevation model is derived from an autocorrelation process, which eliminates any inaccuracy caused by operator actions. The autocorrelation process also utilizes the efficiency of modern computing power through image intelligence, recognition, and correlation algorithms.

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The mapping community has long utilized a measure to estimate acceptable aerial triangulation results. This measure takes into account the flying altitude regardless of the camera being used and calls for the horizontal and vertical accuracy of the aerial triangulation to be equal to or better than 1/9,000 to 1/10,000 of the flying height. Recent digital cameras come with different camera designs and subsequently are flown from different altitudes to obtain the same imagery resolution. It is therefore impractical to apply the old accuracy measure that was based on 9"x9" film camera format and 6" focal length.

Another former concept used to estimate vertical mapping accuracy assigns a certain flying height to a certain contour interval, and is thus called the "C-factor". The C-factor was utilized for the last several decades in designing the favorable flight altitude to meet certain mapping product specifications. Again, the C-factor was based on the physical limitations of the mapping technologies, computational models, and procedures utilized during the first part of the 20th century. Now outdated, the C-factor is no longer useful in describing the capabilities of modern imaging sensors. Similarly, the enlargement ratio, which limits the degree of magnification for a film-based photo given a particular map scale, is also outdated. An enlargement ratio of six was the industry standard until the digital camera came online and changed the equation forever. Using the ADS sensor for example, the enlargement ratio is about 19 while the final orthophoto is produced with the finest quality. The negative or film scale is no longer meaningful when it comes to the digital camera imagery produced by smaller and finer CCD arrays. The ground sampling distance (GSD) measure represents the new standard in expressing imagery scale within a digital environment.

As for the horizontal accuracy, results are very close to the quality of the vertical accuracy expressed in equation (1). A root mean squares error (RMSE) of one to 1.5 pixels (or GSD) is achievable during the orthorectification process, assuming that an accurate digital terrain model is used. The quality of the digital terrain model may influence, and therefore limit, the achieved accuracy. The ASPRS horizontal accuracy standard of 2 ortho pixels (or 2xGSD) is met on a regular basis using any of the main brands of the digital aerial cameras.

Theoretically, the products derived from film cameras are no less accurate than digital cameras if all processing is performed in a fully digital workflow (after scanning) using modern software. However, we are finding that high accuracies from digital sensors is not only easily achievable, but perhaps provides even higher accuracies than what we used to achieve from metric film cameras. This should be expected as the digital sensor provides 12 bits radiometric resolution, which results in better autocorrelation of tie and pass points and quality of the autocorrelated digital elevation model. As a final remark, the accepted accuracy standard for map products, at least here in the United States, is the one published by the American Society of Photogrammetry and Remote Sensing (ASPRS). The ASPRS standard calls for the following accuracy figures for class 1 map, Table 2, (the highest accuracy between the three classes specified in the standard):

It is worth mentioning that the ASPRS standard was developed prior to the introduction of the digital aerial sensors. As such, a revision soon will be required if the standard is to represent the numerous recent advancements in mapping, including not only digital aerial sensors, but also lidar and IFSAR mapping, as well. The lidar standard accuracy for elevation modeling is widely accepted to be in the range of 9 cm to 15 cm RMSE, which puts it in an odd situation with the performance of digital maps produced from digital aerial sensors as specified by the ASPRS standard shown in Table 2. In order for the vertical accuracy of a map produced from digital imagery to be compatible with the vertical accuracy of the lidar elevation model, the aerial imagery has to be collected at 3" (or 7.5 cm), GSD

Table 2.

Native Image and Final Map GSD (ft/m)	Supported Map Scale	Supported Contour Interval (ft/m)	Horizontal Accuracy as RMSE (ft/m)	Vertical Accuracy as RMSE (ft/m)
0.25/0.075	1"=50' or 1:600	1.0/0.30	0.5/0.15	0.33/0.10
0.50/0.15	1"=100' or 1:1,200	2.0/0.60	1.0/0.30	0.67/0.20
1.0/0.30	1"=200' or 1:2,400	5.0/1.50	2.0/0.60	1.67/0.50

Table 3.

Native Image and Final Map GSD (ft/m)	Supported Map Scale	Supported Contour Interval (ft/m)	Horizontal Accuracy as RMSE (ft/m)	Vertical Accuracy as RMSE (ft/m)
0.25/0.075	1"=25' or 1:300	0.50/0.15	0.25/0.075	0.17/0.050
0.50/0.15	1"=50' or 1:600	1.0/0.30	0.5/0.15	0.33/0.10
1.0/0.30	1"=100' or 1:1,200	2.0/0.60	1.0/0.30	0.67/0.20
2.0/0.60	1"=200' or 1:2,400	5.0/1.50	2.0/0.60	1.67/0.50

which is impractical from an economic point of view. Digital imagery with 6" (or 15 cm) GSD is currently becoming the standard scale and will likely remain so in the near future. This fact, combined with the latest vertical accuracies achievable from lidar, will exert tremendous pressure on the technical and administrative management of the mapping industry to refine the ASPRS standard and its applicability to the modern digital imagery. Considering the improved accuracy we witnessed with the introduction of the end-to-end digital workflow and the pressure that lidar accuracy is generating, I expect that in the very near future intense efforts from the mapping scientists and sensor technologies providers are required to slightly enhance the performance of the digital sensor and the mapping process so we can move the map scale support of the digital imagery one class higher. Once this is achieved, the latter table will be republished to reflect Table 3.

In its simplest and most ambitious terms, the new ASPRS standard is expected to call for a horizontal accuracy of 1 pixel equivalent on the ground (1 GSD), and perhaps a vertical accuracy of about 2/3 of a pixel.

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