The Accuracy Triangle – The Photogrammetric Triad

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We get a lot of questions regarding accuracy in drone mapping projects. These questions range from ground control layout suggestions to the necessity of calibration cameras. Sometimes it is useful to step back a bit and take a wholistic view of the elements that impact photogrammetric accuracy.

The information in this article is meant to be a thought exercise, not a mathematically precise discussion, of the elements that affect photogrammetric accuracy. I find it quite useful for making "rule of thumb" decisions regarding accuracy planning.

If we consider the triangle of Figure 1, we recall that given any two sides, we can solve for the third. Similarly, given any two angles, the third is defined.

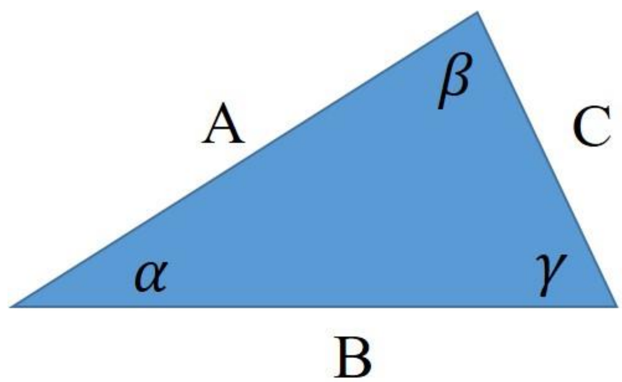

Figure 1: Triangle Solution

We can think of the photogrammetric solution in this same way (see Figure 2). The elements that form the triad of the structure are:

- Exterior Orientation (EO) – The location (X, Y, Z) and orientation (Pitch, Roll, Yaw) of the camera for each image
- Interior Orientation (IO) – The intrinsic parameters of the camera(s) being used in the imaging operation such as the focal length and lens distortion; the *camera calibration* parameters
- Object Space (OS) – Known positions in the *object space*. The object space is what we are imaging (e.g. the mine surface)

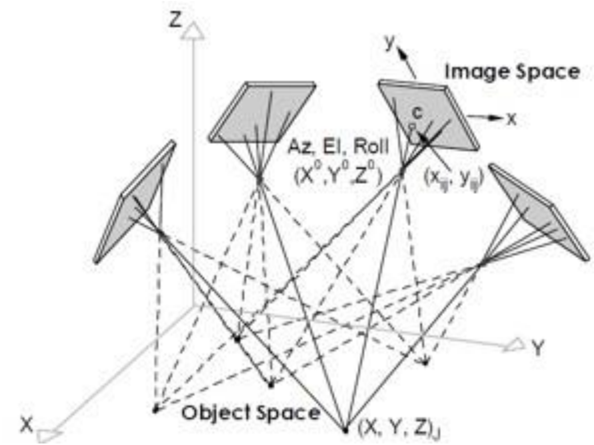

Figure 2: The photogrammetric "Triad"

In general, the more accurate I know two of these three sets of contributors, the less I need to know about the third and still achieve the desired project accuracy. The situation is, of course, much more complex than this but it does give you a good framework to discuss maintaining or improving accuracy.

Elements of these factors are:

- Exterior Orientation (EO) – We can get a first cut at the position (X, Y, Z) portion of the EO from the navigation grade Global Navigation Satellite System (GNSS) that forms part of the drone's autopilot. A navigation grade GNSS will provide around 8 feet (2.5 m) of horizontal accuracy and perhaps 15 feet (5 m) vertical. An approximation of the orientation of the camera can be obtained from the autopilot orientation sensor and/or camera gimbal sensor although these are not really necessary in the Structure from Motion (SfM) algorithms used for creating 3D point clouds from overlapping images. We can dramatically improve our estimate of the EO position by adding a "survey grade" dual frequency, differential phase detection GNSS to the drone. This is a fancy way of saying a GNSS survey "rover" similar to those used in land surveying. This kit will improve our *a priori* estimates of camera position to an accuracy of about an inch (several centimeters) – this is the function of AirGon's Loki system.

- Interior Orientation (IO) – The IO is the model of the geometry of the sensor (in our case, the camera). We can model the sensor by a laboratory calibration procedure (preferred) or by deriving these elements using a technique called *self-calibration* or *in situ* calibration. AirGon provides laboratory calibration of drone cameras as a service.

- Object Space (OS) – We usually add Object Space information to our solution by using image or point cloud identifiable markers whose locations are known to a high level of accuracy/precision. We usually call these Ground Control Points or Ground Check Points (GCP). At AirGon, we typically use a white ceramic bathroom floor tile (obtainable from Lowe's for about one dollar) with a cross or diamonds added using black duct tape. The location of these targets is measured using a standard GNSS base-rover survey kit. An example of a GCP target being placed is shown in Figure 3.

Figure 3: Setting a "homemade" ceramic tile GCP

Using our idea of the photogrammetric accuracy triangle, we see how to control project accuracy in a fairly straightforward (albeit heuristic) way.

The (photogrammetric accuracy) triad makes it easy to think about drone mapping accuracy in a generalized way. The highest possible accuracy will be achieved if you know all three elements of the triad (Exterior Orientation, Interior Orientation, Object Space reference points) to a high degree of accuracy. For example, if you are doing cut and fill computations where every inch matters, you should use direct geopositioning on the drone (high exterior orientation knowledge, at least of the position elements), a laboratory calibrated camera (well-known interior orientation) and dense ground control points (high 3D object space reference point knowledge).

On the low side of the accuracy scale, you might be simply collecting data to form an orthophoto mosaic that will be used only for synoptic viewing. Here you might choose to use navigation grade EO, self-calibration for the camera Interior Orientation (e.g. no *a priori* IO at all) and no ground control (no knowledge of OS locations). Your mosaic will look fine but its absolute position[1] will be wrong (meaning it will not correctly register with other data such as a map on Google Earth) and it could have incorrect scale (poor local accuracy).

We are often faced with situations where a certain level of network accuracy is required but we have limited access to the site for placing ground control points. For example, if the product to be produced from the collected data are 1 foot contours, a network vertical accuracy of 4" (10.2 cm) is required of the source data[2]. Reducing GCPs means we have a lower confidence in the Object Space (OS) part of the accuracy triad. This means we will have to increase our knowledge of the other two "sides" of the

[1] Technically, this is Network accuracy
[2] When we generically state a specific value for accuracy, we are referring to the root mean squared error (RMSE).

triangle; Exterior Orientation (EO) and Interior Orientation (IO). We can increase the accuracy of IO by calibrating the camera. We can increase the accuracy of the camera exposure estimates (EO) by using a survey grade direct geopositioning system (e.g. Loki) on the drone.

You can use these ideas in a general way for planning drone mapping missions. For example, if you are daring enough to try a project with no ground control at all (zero Object Space knowledge), you'll want a very good, recent laboratory camera calibration and a survey grade direct geopositioning system on the drone.

Again, I caution that the photogrammetric triad is not a precise mathematical relationship. It is simply a useful heuristic tool for assessing the project structure necessary to achieve a specific project accuracy.