Mapping Matters

Your Questions Answered

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

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

Question: What is a "bias" in mapping processing? Where does it come from? How is it calculated? How would one deal with it at different stages of the process?

Evgenia Brodyagina, Frederick, Maryland - USA

Dr. Abdullah: In statistics, the term "bias" has several meanings, depending on the branch of discipline for which is it being used. When used in reference to survey, geodetic and photogrammetric sciences, a bias is the systematic distortion in measurements caused by external influences that may affect the accuracy of the statistical estimation of the measurements.

To help you better understand this meaning, let's look at the example of a target shooter who, after examining the results of his shooting rounds on the target sheet, found that most of bullets clustered on the upper left side from the bullseye that he was originally targeting (Figure 1a). The target shooter continued this same pattern during every weekly target practice session, until he consulted an expert who determined that the problem was associated with poor alignment of the binocular on his rifle.

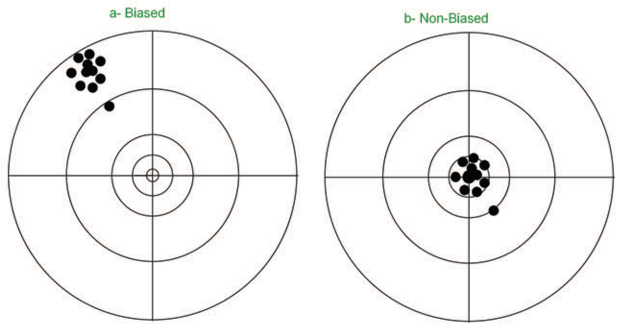

Figure 1. a) biased observations b) non-biased observations.

The muzzle was unintentionally directed away from the bullseye, causing all of his shots to deviate from the correct path and land in the upper left corner, despite the fact that he was aiming at the bullseye. Once the expert corrected the problem by adjusting the eye-piece of the rifle's binocular, the shooter's scores dramatically improved as most of his shots now clustered around the bullseye instead of in the upper left corner (Figure 1b). It is worth mentioning that the shooter's skill in hitting the target is noticeably strong, since all of his shots are clustered together with little variation. If the binocular had been functioning correctly, his shots would have been clustered around the bullseye from the start. Therefore, inaccurate shooting was not caused by lack of skill, but instead was caused by a problem with the rifle. This type of problem is what we call a systematic error or bias, because it was caused by an external influence (misalignment of the rifle's binocular) rather than a lack of ability.

> "Systematic errors are the most common cause of non-independence. They affect all measurements equally, causing the varying measurements to be highly correlated, so the average is no better than any single measurement."

Although in most cases the term "bias" is systematic in nature, biases cannot be completely eliminated from use in measurements. The following bullets provide basic guidelines for working with biases:

1. Keep the use of biases to a minimum;
2. Identify those biases that cannot be avoided;
3. Assess their potential impact on the final results; and
4. Factor in the potential impacts of biases when interpreting results.

To avoid biases, the measurements must be statistically independent or free from common repeated influences, like the problem with the rifle's binocular in the previous example. Systematic errors are the most common cause of non-independence. They affect all measurements equally, causing the varying measurements to be highly correlated, so the average is no better than any single measurement.

Several potential sources exist for biases and systematic errors within a mapping process. These may include:

1. **Biases introduced during ground survey work:** One of the most common biases results when incorrect GPS base station coordinates are used to determine the final adjusted coordinates of the ground control points. Survey teams also introduce biases by entering the wrong instrument height; entering the right figure for the instrument height but assuming the wrong linear unit (feet versus meters); or they fail to apply the correct offset values when surveying a power pole position because they measure a nearby point that is more accessible than the pole itself.
2. **Using the wrong sensor alignment values:** Incorrect lever arm values or misalignment angles for the sensor are often used in respect to the hover antenna center or inertia frame.
3. **Incorrect horizontal and vertical datum:** This bias is especially common in the US where many versions of the North American Datum of 1983 (NAD83) and the North American Vertical Datum of 1988 (NAVD88) exist. Some of these versions are not compatible with the GPS geocentric reference system (ITRS), which is represented by different realizations (versions) of the International Terrestrial Reference Frame (ITRF). Users are often confused about how these datums are related. Confusing NAD83(86) with NAD83(CORS96) or NAD83(HARN) could easily cause a systematic error of a foot or more when measuring mapping products.
4. **Incorrect camera calibration data:** Errors are often caused by entering the incorrect focal length, lens distortion, CCD or film deformation.
5. **GPS signal errors:** GPS signal errors usually result from incorrect data that is received in the project area or on-board the acquisition aircraft. These errors are often related to the strength of satellite

continued on page 761

inued from page 759

signals, signal reception quality and multi-path, signal attenuation due to ionosphere, or poor PDOP.

6. **Errors introduced by the Earth's curvature:** Negligence or poor modeling of the Earth's curvature in the mathematical model may cause unwanted biases. This is especially true for high altitude imaging where the earth's curvature is more apparent.
7. **Errors due to atmospheric refraction:** Negligence or poor modeling of the physical effect of air density on the signal when it passes through the different layers and conditions of the atmosphere may introduce a systematic error and loss of accuracy.
8. **Errors introduced by the sensor stability:** Non-metric systems lend themselves to excessive measurement distortions due to the lack of stability and repeatability of the imaging system.

The above error sources must be considered during the early stages of project planning and execution in order to minimize their impacts on the final photogrammetric or computational model. The simplest way to achieve this is to recognize them early on and take the necessary steps to avoid them. Most biases can be detected and removed, or minimized if careful considerations are taken during the production processes. Mitigation starts with quality protocol that is followed during post processing of the GPS and inertial data. The quality of the final bundle block adjustment is represented by a comprehensive mathematical model that provides users with full capabilities to detect and model most of the errors. Biases are one of the easiest types of errors to spot and mitigate through efficient modeling and careful handling of data.

As for how we calculate biases, I recommend looking at the statistical summary of the computational model. From first glance, biases can be represented by high average (mean) values of the residuals or errors during observations; however, high average or high mean values may not always indicate biases as they are subject to another criteria or measure called "standard errors", which is the magnitude of fluctuation of error in the measurements around the mean value. For a bias to be removed effectively from a set of measurements, the standard errors must be small, and they must be smaller than the average or the mean. A real-life example is shown in Table 1, which represents the residuals or errors estimated from the measurements of 20 check points on ortho-rectified images where all 20 measurements were performed by the same technician using the same equipment. You may notice that the average value of the residuals for the easting coordinates (ΔE) is relatively high when compared to its equivalent from the northing coordinates (-0.47 ft versus –0.02 ft). Also, the standard deviation of the residuals for the easting coordinates is much smaller than the average value (0.22 ft versus –0.47 ft). This common case demonstrates that when the high average value of the easting coordinates is inflated by a bias (that is, if removed), the final errors figure for the easting coordinates will improve substantially.

"Most biases can be detected and removed, or minimized if careful considerations are taken during the production processes. Mitigation starts with quality protocol that is followed during post processing of the GPS and inertial data."

Now, let's remove as many biases as we can from the resulting residuals (from Table 1) by subtracting/adding the average values of 0.22 ft from all of the individual easting coordinate residuals (this is equivalent to subtracting/adding the average value from the individual ortho-measurements). We will do the same for the northing coordinate residuals, despite the fact that the northing residuals do not show signs of bias (very small average value with relatively high standard deviation).

Table 1. Statistical Calculations for a Biased Set of Observations

Point ID	ΔE (Easting) (US Survey Feet)	ΔN (Northing) (US Survey Feet)
H01	-1.03	0.57
QC-H02	-0.30	0.10
QC-H03	-0.38	0.24
QC-L01	-0.34	-0.52
QC-L03	-0.37	-0.11
H03	-0.70	0.34
H04	-0.45	0.20
H05	-0.27	-0.13
H06	-0.31	0.09
H07	-0.30	0.08
H09	-0.58	-0.41
H10	-0.34	-0.13
H11	-0.19	0.02
L01	-0.58	-0.18
L02	-0.76	0.03
L05	-0.76	-0.30
L06	-0.66	0.02
L08	-0.34	-0.18
L09	-0.41	-0.04
L07	-0.40	0.17
Mean (Bias)	-0.47	-0.01
StDEV	0.22	0.26
RMSE	0.52	0.25

Table 2 demonstrates the improved accuracy for the same data set by simply shifting the coordinates of all products by the amount of bias. At this late stage of production (and if such a problem was not detected and addressed during aerial triangulation), the best remedy is to adjust the easting coordinate in the headers of the geotiff or the tiff world files by 0.22 ft. Such correction doubles the accuracy of the final maps (from an RMSE of 0.52 ft in easting, to 0.21 ft) without added cost. On the other hand, if the problem is detected and corrected during the aerial triangulation stage and prior to ortho-rectification, then no correction is needed for the ortho products. In my opinion, the above ortho problem could very well be caused during the final stage of ortho–production. Often orthos are re-projected from the datum internally used for production, such as WGS84 or ITRF to the final client-specified datum such as NAD83(86) or NAD83(CORS96) during which, technicians may unintentionally choose the wrong datum. This represents one of many examples where a full understanding of biases and how to deal with them as they are introduced in products during different stages of production may save the entire delivery from being rejected by the client.

continued on page 762

continued from page 761

Table 2. Statistical Calculations After Bias is Removed from a Biased Set of Observations

Point ID	ΔE (Easting) (US Survey Feet)	ΔN (Northing) (US Survey Feet)
H01	-0.56	0.58
QC-H02	0.17	0.11
QC-H03	0.09	0.25
QC-L01	0.14	-0.51
QC-L03	0.11	-0.10
H03	-0.23	0.35
H04	0.03	0.21
H05	0.21	-0.13
H06	0.17	0.10
H07	0.18	0.09
H09	-0.10	-0.41
H10	0.13	-0.13
H11	0.28	0.02
L01	-0.11	-0.17
L02	-0.29	0.04
L05	-0.29	-0.29
L06	-0.19	0.03
L08	0.13	-0.17
L09	0.07	-0.03
L07	0.08	0.17
Mean (Bias)	0.00	0.00
StDEV	0.22	0.26
RMSE	0.21	0.25

Please send your question to Mapping_Matters@asprs.org and indicate whether you want your name to be blocked from publishing.

Answers for all questions that are not published in *PE&RS* can be found on line at www.asprs.org/Mapping Matters.

***Dr. Abdullah is the Chief Scientist at Fugro EarthData, Inc, Frederick, MD. He is the 2010 recipient of the ASPRS Photogrammetric (Fairchild) Award*