



# Mapping Matters

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## Your Questions Answered

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

**Q1:** In Aerial Triangulation, once a least-squares adjustment has been run, the results have been found to be acceptable with no blunders or residuals out of tolerance, there is a decision to be made: Do you overwrite the given ground control values with the adjusted coordinates or do you keep the original coordinates provided by the land surveyor?

*Jon Martin, CP, Texas DOT*

**Dr. Abdullah:** I would like to quote part of Jon Martin's message that accompanied his question as he brings up a very interesting discussion on the topic that the reader needs to know about. In his message, Martin elaborated as follows:

"I've run this question by a number of colleagues. Among State DOTs, it appears that about half overwrite and half don't. Dr. Hintz has suggested that the proper procedure is to overwrite the given ground control with the adjusted values. I tend to agree with Dr. Hintz because mathematically, it doesn't seem to make much sense to not overwrite. Doing so means that you end up with a mix of best-fit tie points with non-adjusted survey control. In the big scheme of things, it shouldn't make a lot of difference. However, some software, like the software that displays imagery in stereo, runs a second least-squares adjustment on the data set coming out of the analytical triangulation process to form the stereo model. It seems that this second adjustment would be more accurate if all of the points used were part of a best-fit solution rather than a mix. My Land Surveyor colleagues feel that the ground control has to be held as a fixed value. I don't agree with this opinion. Unlike the survey world, we aren't going to "re-occupy" an aerial photo derived map. Our map product is a final product and no subsequent mapping (or surveying) is going to be done using our map as a coordinate basis. I believe that the most accurate mapping is done using least-squares, best-fit solution. Could you please weigh in on this issue?"

run least squares adjustments of geodetic control networks. Blunderous points need to be identified and removed by the survey adjustment process, and good control from a professional survey firm need to have been redundantly measured, adjusted and certified as to their accuracy at a given precision. The control survey should be magnitudes stronger than the air-trig, so the air-trig cannot supersede the values on any control point. That's not to say the erroneous control doesn't show up, and if held fixed would cause problems. So, the air-trig is not intended to "prove" the surveyor correct, but errors are errors. And if the control doesn't fit, that may indicate some other problem with the bundle as well."

**Colleague #2, Land Surveyor:** "This is an age old question without a known solution. In my view, the points must be adjusted with the rest on order to preserve the integrity of the adjustment. The surveyor's control is not gospel; they are prone to many types of errors, but would not be adjusted if held in place [Sic]. Thus, my solution is to preserve a copy of the original surveyor's points to document what was provided and used and then adjust the points with the solution provided that the solution does in fact meet the tolerance requirements. The bottom line is that the probability that the surveyor would measure his points one day and then measure the same points the next day with two different answers is great. Therefore, beyond good field techniques, redundancy in a least square adjustment is the key to a good solution. One man's view."

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"The combination of the added constraints due to the GPS-controlled principal point, the minimal ground control points (perhaps one control point for every 20 photos), and the high density of pass/tie points, has definitely weakened the effect of ground control points on the final computation or re-computation of the exterior orientation parameters."

The question and the comments given above represent very common arguments within the aerial triangulation community. I myself wanted to survey my colleagues in the field on their response to a question like this. Here are the different responses I got on the same question:

**Colleague #1, Land Surveyor:** "Absolutely, overwrite and hold fixed unless there is evidence of blunder. The way that I believe it works is: The bundle adjustment is run minimally constrained with only one control point fixed and all others free or to very low weights. As the control is evaluated, those with low (acceptable) residuals should then be held fixed, infinite weight, per the surveyor, not allowing for any adjustment to those data points. This has been how I have

He then added the next day, "I awoke thinking on this issue this morning and I have one additional point to add. When we are speaking of surveyor's points, what order of control are we speaking of? First order or CORS points or ground control as provided by the surveyor? I believe there may be a difference in how the two should be treated."

**Colleague #3, Aerial Triangulation Specialist:** "I say that you would overwrite with the adjusted control values for the main reason that individual measurements most likely would have inherent error even with their residuals being within tolerance. Using the adjusted coordinates would account for your network's normal distribution of error. Just a thought. I'm not a surveyor or a CP."

*continued on page 1313*

**Colleague #4, Aerial Triangulation Specialist:** "I would say not to overwrite because the adjusted values means they adjusted according to given actual control values and it shows you how the actual control network should be. As per Colleague #3, it is also correct that adjusted coordinates would account for your network's normal distribution of error since with the residuals being within tolerance, it will not make much difference if you overwrite".

I hope you agree with me that this issue has been a point of contention between professionals in the field of mapping and surveying since the beginning of analytical aerial triangulation. My view on this goes along with many of the opinions given above on the theoretical aspects of network controls and constraints. However, experience has taught me that what may sound theoretically correct may not necessary be the only acceptable solution. We currently collect an average of 100 to 200 auto-correlated pass/tie points per frame, most of which are of excellent quality. In addition, most if not all of triangulation today is performed with the help of the airborne GPS-measured camera position. The introduction of airborne GPS has changed the requirements for ground control and only a sparse control network is needed when an aerial triangulation project is planned. The combination of the added constraints due to the GPS-controlled principal point, the minimal ground control points (perhaps one control point for every 20 photos), and the high density of pass/tie points, has definitely weakened the effect of ground control points on the final computation or re-computation of the exterior orientation parameters. In my opinion, the question on whether to overwrite or not overwrite the original controls points used in the bundle block solution can be answered in two ways, as follows:

1. If the aerial triangulation software restricts you to the production of the exterior orientation parameters derived from the airborne GPS-controlled bundle block adjustment only, then you have no choice and the adjusted coordinates of the ground control will be used in the solution. This is the case when you adjust the block using airborne GPS, the ground control points, and possibly the IMU-derived orientations, and you then use the exterior orientation derived from this solution for stereo compilation or ortho rectification.
2. If the software routinely re-computes the exterior orientation parameters of each frame after the final bundle block adjustment has been performed and accepted and all the tie/pass points' coordinates are replaced with the final adjusted ground values, then the issue of overwriting will depend on the number of the pass/tie points used in each frame. Examples of different methods of re-computing the exterior orientation parameters vary with the software and user preferences. For example, Albany performs a space resection solution, while ISAT of Intergraph performs a so-called bulk orientation. Some users prefer to perform additional conventional adjustment using the adjusted pass/tie points following the original airborne GPS adjustment. With the introduction of softcopy aerial triangulation, the subject using the original surveyed coordinates or the adjusted coordinates for the ground control points has become irrelevant to a certain degree. To simplify the matter further, previously when we used only three principal pass points per photo, the entire frame during orientation (space resection) was controlled by an average of

nine pass, tie, and perhaps a few control points. In this case the control had a higher weight in the least squares adjustment and using adjusted coordinates versus original surveyed coordinates for ground control points could have a drastic impact on the photo orientation during mapping. This is not the case with the auto-correlated collection of tie/pass points. Most softcopy aerial triangulation packages perform either space resection or bulk orientation after all the pass/tie points are adjusted and densified into control points. Therefore, having one surveyed control point, if any, between hundreds of pass/tie-turned into control points has minimized the effect of the original ground control on the final exterior orientation computation for that individual frame. The individual control point or two present between hundreds of photo controls will have minimal weight and it will be outweighed by the presence of the dense network of densified pass/tie points in the final exterior orientation computation.

Based on the above, my recommendation is that if you are performing aerial triangulation today with hundreds of adjusted pass/tie points and you are re-computing the exterior orientation parameters again after the final bundle block adjustment was finalized and accepted, it does not really matter whether you overwrite or not. However, if the aerial triangulation was performed 20 years ago, then it will be a different story.

Finally, as for the question on whether one should on a routine basis overwrite the given ground control values with the adjusted coordinates or keep the original surveyed coordinates as provided by the land surveyor, I believe that the adjusted coordinates should be used for all subsequent computations or orientation. This is due to the fact that the mathematical and statistical models have found the best fit for that ground control within the different elements of the block. Introducing a different set of coordinates (in this case the one provided by the land surveyor) will offset that balance or fit assuming that all of the measurements and values used in the aerial triangulation were of high quality. To provide an example for this argument, assume that there is one control point that the mathematical model found to be erroneous by about 40 cm. The new adjusted value, which is off by 40 cm from the surveyed value, desirably fits the entire network of the block. Introducing the original value (erroneous according to the math model) in any subsequent computations of the network or part of it will cause misfit between that control point and the adjacent points.

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