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: I noticed that according to both ASPRS and NSSDA standards, the vertical accuracy is more stringent than the horizontal accuracy. For example, if I produce orthophoto products from 15 cm (6 in.) digital imagery, the stated ASPRS standard for horizontal accuracy is 30 cm (1 ft), while the expected vertical accuracy is 20 cm (0.67 ft). We always believed that the vertical accuracy of any mapping product is less stringent than the horizontal accuracy. Why is that?

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Dr. Abdullah: PART II: In Part I of my answer (PE&RS, August 2010), I addressed the issues that resulted in the contradictory accuracy figures that came into question. I explained that many of the map accuracy standards used today, particularly here in the United States, were derived from the use of film sensors and paper maps. At the conclusion of Part I, I called on all concerned agencies and organizations in the United States to develop a new national standard that can be applied to modern geospatial data products. In Part II, I would like to introduce some high level thoughts and ideas to generate discussions on how to create such a standard, and I hope these ideas may even prove useful in the development of such a standard.

1. The new standard should be useful on a national level:

The standard should be accepted and endorsed by all those agencies and organizations that historically publish and maintain map standards in the United States, such as ASPRS, FGDC, USACE, FEMA, and others. In addition, the new standard should appeal to users from different sectors of the mapping and GIS community through its transparency and ease of use. When it comes to geospatial products, a single standard can be used if it is drafted carefully and in a way that satisfies varying user requirements. Different agencies or users should be able to apply different accuracy figures to the same standard and still achieve results that are specific to their unique suite of products. This is easily achievable by matching products to specific accuracies based on product resolution or map class. I will elaborate further on this concept later in this article. Currently, different agencies have already established, or are in the process of establishing their own individual standards. For instance, agencies such as FEMA, ASPRS, and the USGS have all published their own standards or guidelines for lidar data accuracy. Since lidar systems are based on the same fundamental laser technology, raw products from different lidar systems all possess more or less the same quality and accuracy. Quality and accuracy are essentially determined by the methods used to post-process and handle the data; therefore, users should have a single standard they can use to calculate accuracies that are specific to the methods being applied.

2. The new standard should be modular:

The old concept of "one sensor, multiple products" no longer applies to today's modern map-making practices. The diverse range of technologies currently used in map-making dictates the need for new standards that can be applied to new sensor technologies, such as lidar (topographic lidar and bathymetric lidar), interferometric synthetic aperture radar (IFSAR and InSAR), digital cameras, underwater survey by sonar, etc. Therefore, the standard should be modular, in the sense that it should encompass a set of sub-standards that can be individually applied to different technologies. For instance, one sub-standard may be used to define accuracies and specifications of products derived from imaging sensors. As a result, this group of products (e.g., orthophoto, compiled map, and elevation data) would share the same vertical and horizontal accuracy requirements.

Another sub-standard might address the specifications and accuracy of lidar and IFSAR data and would define products such as elevation data and ortho-like intensity images; and additional sub-standards could be defined for hydro survey or acoustic survey using sonar technologies to map sea, river, and lake floors.

By developing a single standard that simply and uniquely addresses each sensor-type, this modular approach eliminates the user's confusion when trying to interpret multiple unrelated standards from multiple unrelated agencies. Modularity also lends well to change and expansion over time. Rather than becoming outdated and inapplicable over time, this modular standard will change and adapt as new sensor technologies and products are added by the geospatial mapping community.

3. The new standard should apply one of the following two measures to classify the accuracies of final products:

a) Accuracy according to the resolution of the final delivered products

For example, an orthophoto produced with 15 cm GSD should have a horizontal accuracy of **RMSEX = $RMSE_Y$ = 1.25*GSD** (of the final delivered product) or **18.75 cm**, regardless of the sensor used or the flying altitude. The proposed accuracy figure is a little aggressive when compared with the current practice of assigning an ASPRS Class 1 accuracy of **$RMSE_X$ = $RMSE_Y$ = 30 cm** for such a product.

Vertical accuracy can be derived using a similar measure of **$RMSE_V$ = 1.25*GSD** (of the final delivered product) or **18.75 cm**, versus the current practice of labeling such products with an ASPRS Class 1 accuracy of **$RMSE_v$ = 20 cm** for 2 ft contour intervals.

The standard should not allow for the production of orthophotos with a GSD that is smaller than the raw imagery GSD (the GSD during acquisition). However, the standard should allow for re-sampling of the raw imagery for the production of coarser orthophoto GSDs, as long as the final accuracy figures are derived from the re-sampled GSD and not the native raw imagery GSD. Using the resolution or GSD of the imagery in referencing the final product accuracy introduces a more scientific and acceptable approach since a product's accuracy is no longer based on the paper scale of a map.

One may argue that some users (e.g., a soldier on a battlefield) may need hard copy maps for field investigations. This is a valid concern. The new standard should allow users the option to produce paper maps using any scale they choose, as long as the map accuracy is stated on the paper map and the scale is represented by a scale bar that automatically adjusts to the map scale.

b) Accuracy according to national map classes

In this case, the standard can specify multiple map categories for all users, and the standard will provide specifications and accuracy

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figures to support each of these classes. The following proposed categories represent reasonable classes that should fit the needs of most, if not all users:

1. **Engineering class-I grade maps** that require a horizontal accuracy of $RMSE_X = RMSE_Y = 10$ cm or better and vertical accuracy of $RMSE_v = 10$ cm
2. **Engineering class-II grade maps** that require a horizontal accuracy of $RMSE_X = RMSE_Y = 20$ cm or better and vertical accuracy of $RMSE_v = 20$ cm
3. **Planning class-I grade maps** that require a horizontal accuracy of $RMSE_X = RMSE_Y = 30$ cm or better and vertical accuracy of $RMSE_v = 30$ cm
4. **Planning class-II grade maps** that require a horizontal accuracy of $RMSE_X = RMSE_Y = 50$ cm or better and vertical accuracy of $RMSE_v = 50$ cm
5. **General purpose grade maps** that require a horizontal accuracy of $RMSE_X = RMSE_Y = 75$ cm or better and vertical accuracy of $RMSE_v = 75$ cm
6. **User defined grade maps** that do not fit into any of the previous five categories.

This concept provides more flexibility for data providers in designing and executing the project. However, it may be problematic for users who are not well educated in relating map classes to product spatial resolution (GSD). Keep in mind that due to the fact that digital sensors are manufactured with different lenses and CCD array sizes, different scenarios for image resolution and post spacing may result in the same final product accuracies and therefore, it is important that users clearly define their required GSD or work with the vendor to determine the optimal GSD for their needs.

4. The new standard should address aerial triangulation, sensor position, and orientation accuracies:

Currently, there is no national standard that addresses the accuracy of sensor position and orientation. As a result, the subject has been left open to interpretation by users and data providers. The accuracy of direct or indirect sensor positioning and orientation (whether derived from aerial triangulation, IMU, or even lidar bore-sighting parameters) is a good measure to consider in determining the final accuracy of the derived products. Furthermore, issues can be detected and mitigated prior to product delivery if the standard defines and helps govern sensor performance. In the past, we adopted the rule that says aerial triangulation accuracy must be equal to RMSE = 1/10,000 of the flying altitude for Easting and Northing and 1/9,000 of the flying altitude for height. Obviously, the preceding criteria were based on the then-popular large format film cameras that were equipped with 150 mm focal length lenses. Today's digital sensors come with different lenses and are flown from different altitudes to achieve the same ground sampling distance (GSD), so relying only on the flying altitude to determine accuracy is no longer scientific or practical and new criteria needs to be developed.

When examining the 1/9,000 and 1/10,000 criteria, the following accuracy figures apply for 1:7,200 scale imagery that is flown using a large format film metric camera. such as Leica RC-30 or Zeiss RMK, to produce a 1:1,200 scale map:

$$\mathbf{RMSE_X = RMSE_Y = 1/10{,}000*H = 1/10{,}000*1{,}100 = 0.11\ m}$$

$$\mathbf{RMSE_Z = 1/9{,}000*H = 1/9{,}000*1{,}100 = 0.12\ m}$$

When using the current ASPRS class 1 standard, the following accuracy figures would be expected for a map derived from the same imagery:

$\mathbf{RMSE_X = RMSE_Y = 0.30\ m}$

$\mathbf{RMSE_Z = 0.20\ m}$ (assuming 0.60 m [2 ft] contours were generated from the imagery)

The previous accuracy figures call for aerial triangulation results that are 270% more accurate than the final map accuracy. Old photogrammetric processes and technologies required stringent accuracy requirements for aerial triangulation in order to guarantee the final map accuracy, and past map production methods have transitioned through many different manual operations that ultimately resulted in the loss of accuracy.

Today's map-making techniques have been replaced with all-digital processes that minimize the loss of accuracy throughout the entire map production cycle. In my opinion, the new standard should support accuracy measurements for aerial triangulation based on the resulting GSD. Considering all of the advances we are witnessing in today's map making processes, aerial triangulation horizontal and vertical accuracy of 200% of the final map accuracy should be sufficient to meet the proposed map accuracy. Accordingly, the aerial triangulation accuracy required to produce a map product with a final GSD of 0.15 m, regardless of the flying height, is shown below:

$$\mathbf{RMSE_X = RMSE_Y = RMSE_Z = 0.625*GSD = 0.625*0.15 = 0.09\ m}$$

(if the final map accuracy is based on $RMSE_X = RMSE_Y = RMSE_Z = 1.25*GSD = 0.1875$ m)

Similar calculations can determine the required accuracy for direct orientation (no aerial triangulation required) using systems such as IMUs. To derive the required accuracy for raw, pitch, heading, and position, the previous aerial triangulation error budget of 0.09 m can be used to mathematically derive the acceptable errors in the IMU-derived sensor position and orientation.

Lastly, I feel that a new approach should be developed to calculate lidar orientation and bore sighting accuracies. Since the sensor's geopositioning and not the laser ranging is the main contributor to the geometrical accuracy of lidar data, this calculation should link lidar final accuracy to sensor orientation and positioning accuracies.

In the forthcoming issue of *PE&RS,* I will introduce the final part (Part III) of my answer which focuses on the importance for the new standard to deal with data derived from non-conventional modern mapping sensors such as lidar, IFSAR, and under water topographic survey using acoustic devices such as active SONAR (**SO**und **N**avigation **A**nd **R**anging). In addition, Part III will provide recommendations on the statistical methodology and confidence level to be used in the standard.

to be continued...

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