Overview of the ASPRS Positional Accuracy Standards for Digital Geospatial Data

EDITION 2, VERSION 2 (2024)

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ASPRS Journey in Standards Development

The Global geospatial community relies on the American Society of Photogrammetry and Remote Sensing (ASPRS) when it comes to education and standardization. Since the early eighties, ASPRS championed the development of accuracy standards for geospatial data. Early versions of such standards, including the legacy standards of 1990, were designed for the mapping making practices of that era and characterized by paper-based maps. In 2014, ASPRS published the new Positional Accuracy Standards of Digital Geospatial Data that were developed for the new digital era of mapping practices. The new standards reflected the vast experience gained from decades of mapping practices and industry use of legacy ASPRS standards. However, challenges arose as past experiences were based on older practices and the medium of geospatial data production which may or may not apply to today's digital sensors, such as lidar and digital cameras. This paper will provide users of the new standards—specifically Edition 2, Version 2 (published on June 24, 2024)—the necessary details to better understand and apply new accuracy standards in their day-to-day activities.

Design Philosophy and the New Paradigm

The new standards are intended to be broadly based, technologically independent, and applicable to most common mapping applications and projects. The new standards were developed to embrace the new era of geospatial data acquisition technologies and processing methods. This new direction became apparent when we moved to digital sensors (e.g., lidar and digital cameras) and the resultant digital workflow required to process the acquired digital data. The introduction of digital sensors to our industry put an end to the old concepts of producing and representing map content. The previous era of geospatial data production dictated the use of paper as the only medium to present mapping data and the use of map scale and contour interval as measures to represent map accuracy. These legacy accuracy measures were based on the sensor's configuration and other acquisition parameters, such as flying altitude and base-to-height ratio (B/H ratio).

Such an approach worked for that era because film camera was the only sensor used to collect data for geospatial data production. Film cameras had one design based on film format of 220 mm x 220 mm (9 inches x 9 inches) and 150-mm (6-inch) lens focal length. The unique geometrical design made it easy to estimate product accuracy based on flight parameters. Today's digital cameras come with various designs that make it difficult to relate resulting accuracy to the flight parameters. Today's digital geospatial data workflow eliminates the use of these old accuracy measures. The new ASPRS standards were designed to be sensor-agnostic and data-driven. The new paradigm is founded on the fact that geospatial data users should not worry about data acquisition hardware as it is rapidly changing to follow the advancements occurring in sensor technologies. Moreover, users should only be concerned about the accuracy of the products they receive and be able to specify product accuracy to suit their project needs. This is what shaped the design philosophy of the new standards. It offers users unlimited accuracy levels without sensor or hardware limitations.

These standards are intended to be a living document to be updated in future editions to reflect changing technologies and user needs.

> **"Users should only be concerned about the accuracy of products they receive and be able to specify product accuracy to suit their project needs."**

Accuracy Explained

Historically, accuracy in our geospatial business takes two forms. Firstly, "absolute" accuracy quantifies how close the measured position is on a map or a dataset to the true physical

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position, as represented in a reference datum. The other type of accuracy quantifies the internal data quality to express how points within the data relate to each other. Older versions of the ASPRS standards called the latter "relative" accuracy. However, the latest version of these standards changed the term to "data internal precision," as there is wide belief that such measure of data quality does not fall under data accuracy. Accordingly, all references to "accuracy" in the new ASPRS standards and this paper refer to absolute accuracy.

Adopted Statistical Measures

The new standards embrace the use of the Root Mean Square Error (RMSE) as the only accuracy measure. This is a diversion from the earlier version of the standards, Edition 1, where both RMSE and 95% confidence level were used to express product accuracy. The main reason behind this change is to eliminate user confusion experienced since the release of Edition 1 of the standards. Experience showed that only users versed in the probability and statistical theories understood that accuracy expressed in both RMSE and 95% confidence level were the same, the only difference being the confidence levels assigned with each statistical term.

To help readers understand this argument, I would like to describe the differences and similarities in these accuracy terms using the funnel approach. In Figure 1, the colored balls represent the errors resulting from an accuracy assessment session using independent checkpoints. The varying ball diameters represent the different values of errors found for each of the checkpoints. The spout diameter of the funnel represents the maximum error value that each of the statistical terms (50%, 90%, 95%, and 97.73%) allows. In Figure 1, the largest error allowed is by funnel D, which represents the 97.73% confidence level while funnel A which represents a confidence level of 50% will allow the smallest error value of 6.74-cm . If such numbers are presented to a geospatial data end user who is unfamiliar with these statistical terms, and you ask the user which accuracy term they prefer, most likely they would choose the smallest number of 6.74-cm that is represented by funnel A or the 50% confidence level. This choice makes sense for users who prefer the highest accuracy level they can get for their received products.

If we pose a similar question to those on the product producing side, they most likely will choose what is represented by funnel D with the thinking that the larger accuracy number of 30-cm will give them some leeway during production. However, both choices based on the accuracy number are wrong as both the 6.74-cm and 30-cm numbers represent the same accuracy level. When analyzing the 6.74-cm accuracy figure associated with the 50% confidence level, although it is a tight number, only 50% of these balls need to pass through the narrow spout of the funnel. In other words, only 50% of the checkpoints must show an error of 6.74-cm or smaller. Similarly, the 30-cm accuracy figure, although it may look like a looser accuracy figure, it requires that 97.73% of these balls need to pass through the wide spout of the funnel. In other words, 97.73% of the checkpoints must have an error of no larger than 30-cm. As you may notice, it gets very confusing for the layperson to notice and understand all these details. That is why we removed the 95% confidence level—it offers no additional benefits to the RMSE while causing considerable confusion.

The Trio Accuracy Approach

The new standards introduced yet another accuracy term for the new era of engineering and geospatial needs—three-dimensional accuracy. When considering the fast pace of development in the field of digital twin, smart cities, and other applications that require three-dimensional representation

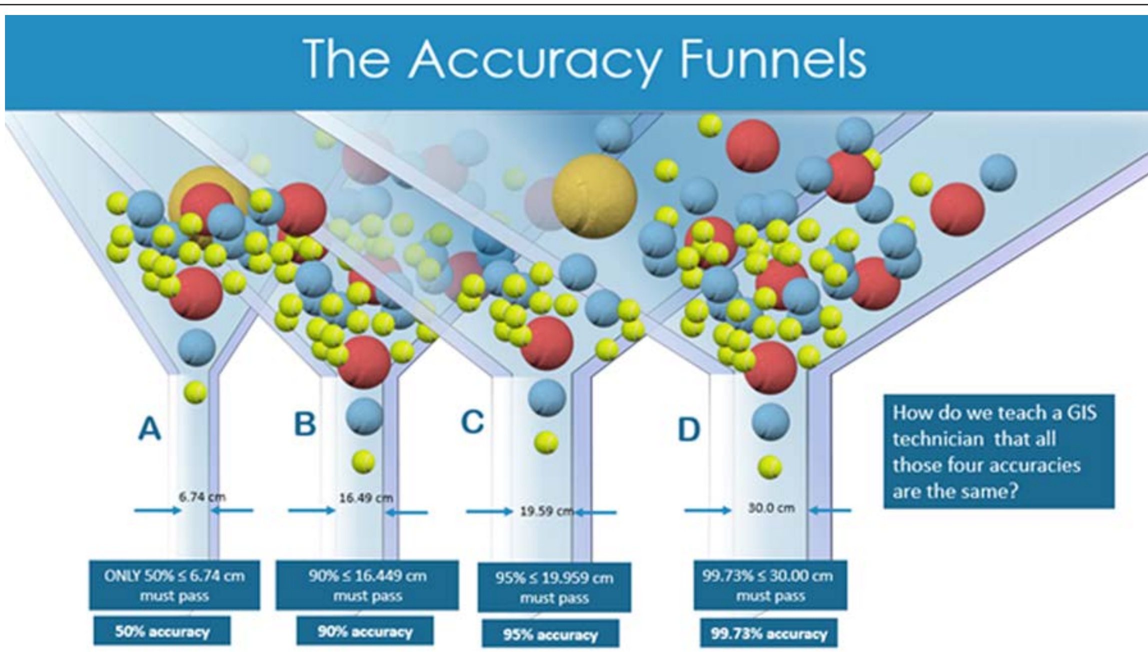

Figure 1. The Accuracy Funnel and Statistical Concepts

of features, we wanted to offer a way to measure feature accuracy within a three-dimensional model. Currently, we estimate horizontal and vertical accuracy separately, helpful in describing the accuracy of 3D models. However, it is not as efficient for representing accuracy in the native 3D environment.

Horizontal Positional Accuracy Standard for Geospatial Data

Horizontal accuracy is meant for products that live in a two-dimensional space like a planimetric map or an ortho map. In practice, geospatial data users pay less attention to feature vertical accuracy in products such as flat maps because there is no way to measure the height or model the vertical accuracy. The new standards offer a simple yet comprehensive approach for horizontal accuracy. They offer unlimited horizontal accuracy classes to suit any geospatial product and make it useful over time regardless of changes in future technologies or practices.

Table 1 presents the horizontal accuracy standards of the new standards. The accuracy class is determined by the user or by project needs. Once the users specify that their project requires, for example, an accuracy of 5-cm, that figure becomes the accuracy class according to the new ASPRS standard. Consequently, 5-cm will be interpreted as the absolute horizontal accuracy measured as RMSE. Additionally, the horizontal accuracy standards set an accuracy measure for the mosaic seamlines mismatch. Before the advanced digital image processing tools and efficient matching algorithms, users struggled to stitch images (or frames) together without visible shifts in features, like roads and buildings, extending over adjacent frames. Because it was impossible to eliminate a mismatch between frames, the industry (and therefore accuracy standards) accepted some mismatch, within a certain tolerance. This tolerance is provided in Table 1.

Today's image processing is more refined and rarely are users faced with these issues. Although it is rare, edge mismatch may still occur in some projects that were either poorly collected or processed, or if an inaccurate digital elevation model (DEM) was used during ortho-rectification.

Table 1. Horizontal Accuracy Classes for Geospatial Data.

Horizontal Accuracy Class	Absolute Accuracy RMSE$_H$ (cm)	Orthoimagery Mosaic Seamline Mismatch (cm)
#-cm	≤ #	≤ 2*#

To assess the horizontal accuracy for an ortho-rectified map, for example, a minimum of 30 independent checkpoints clearly visible in the map should be surveyed to an accuracy that suits the expected map accuracy.

Vertical Positional Accuracy Standard for Elevation Data

Like horizontal accuracy standards, vertical accuracy standards offer a simple but comprehensive approach for all geospatial products, see Table 2. Different from horizontal accuracy standards, vertical accuracy standards include two categories for vegetated and non-vegetated terrains. However, the non-vegetated vertical accuracy (NVA) is the one that will be considered when accepting or rejecting data based on the results of the vertical accuracy assessment. The vegetated vertical accuracy (VVA) has no threshold and should be assessed and reported as found, with no weight on accepting or rejecting the data unless there is a different agreement priorly reached between the data user and the data producer. If the user specifies a 10-cm vertical accuracy requirement for their product, this will go in the record as a 10-cm vertical accuracy class as NVA with RMSE$_V$ = 10-cm.

NVA should be assessed using a minimum of 30 independent checkpoints and up to 120 checkpoints for large projects. The VVA needs a minimum of 30 checkpoints regardless of the project size unless otherwise agreed upon between the data user and the data producer. The vertical accuracy standards also introduce measures for data internal precision such as within swath data smoothness and vertical shift in data from adjacent swaths. Here you notice that standards refrain from using the term "relative accuracy" and replace it with the new term "data internal precision" as data smoothness does not fall under accuracy. In lidar, for example, data smoothness is mainly related to the hardware performance and does not follow the theories of statistics and probability like absolute accuracy.

Three-Dimensional Positional Accuracy Standard for Geospatial Data

As mentioned earlier, our industry is heading towards a 3D GIS concept. This is evident in the use of colorized point clouds, 3D models, digital twins, etc. Such a 3D environment requires a new accuracy measure to suit such an environment. The introduction of a 3D positional accuracy standard as a new accuracy measure is introduced to meet such needs. Table 3 lists the 3D positional accuracy standard and presents unlimited accuracy classes to suit all application needs.

Table 2. Vertical Accuracy Classes for Digital Elevation Data.

Vertical Accuracy Class	Absolute Accuracy		Data Internal Precision (where applicable)		
	NVA RMSE$_V$ (cm)	VVA RMSE$_V$ (cm)	Within-Swath Smooth Surface Precision Max Diff (cm)	Swath-to-Swath Non-Vegetated RMSDZ (cm)	Swath-to-Swath Non-Vegetated Max Diff (cm)
#-cm	≤ #	As found	≤ 0.60*#	≤ 0.80*#	≤ 1.60*#

Table 3. Three-Dimensional Accuracy Classes for Geospatial Data

3D Accuracy Class	Absolute Accuracy RMSE$_{3D}$ (cm)
#-cm	≤ #

The one concern for future resolution by the software manufacturers is the lack of a commercial true 3D data visualization and manipulation viewer. The industry needs an application that is easily accessible to all geospatial data users with smooth viewing of the 3D model. Users need an application with a terrain-hugging floating mark or curser to measure feature position in a true 3D environment. Without such capability, users currently combine individually assessed vertical and horizontal accuracies to produce 3D accuracy for their products.

> **"There is no singular approach to determine such number and distribution schemes as it is based on practical experience coupled with user judgement."**

Ground Controls and Products Accuracy

Surveyed control points play a crucial role in assessing and improving products' absolute accuracy. Whether used to process lidar or digital imagery, the number and distribution of ground control points are determined by expected product accuracy. There is no singular approach to determine the number and distribution schemes as it is based on practical experience coupled with user judgement. However, it is a general rule that ground control points and checkpoints should be evenly distributed throughout the project area unless there are natural factors (such as water and heavy vegetation) that may prevent or skew such distribution. As for the quality of the surveyed control points, these standards require the survey meet specific accuracy criteria to produce the final mapping products from these points. Survey accuracy requirements differ per mapping product type, i.e., whether it's two-dimensional (ortho map) or three-dimensional (elevation data). The new standards set the following requirements for ground control points for imagery-based products:

- Ground control for aerial triangulation designed for digital planimetric data (orthoimagery and/or map) only:
  - $RMSE_{H(GCP)} \leq ½ * RMSE_{H(MAP)}$
  - $RMSE_{V(GCP)} \leq RMSE_{H(MAP)}$
- Ground control for aerial triangulation designed for projects that include elevation or 3D products, in addition to digital planimetric data (orthoimagery and/or map):
  - $RMSE_{H(GCP)} \leq ½ * RMSE_{V(MAP)}$
  - $RMSE_{V(GCP)} \leq ½ * RMSE_{V(DEM)}$
- Similarly, the accuracy of the ground control points used for lidar calibration and boresighting should be twice the target accuracy of the final products.
  - $RMSE_{V(GCP)} \leq ½ * RMSE_{V(DEM)}$

Currently, the industry is focusing only on the vertical accuracy of lidar datasets. If a horizontal accuracy measure is required for lidar data, users can adopt the one provided for imagery-based products or:

- $RMSE_{H(GCP)} \leq ½ * RMSE_{V(DEM)}$

Accuracy Assessment

For projects requiring accuracy testing per ASPRS standards, perform the testing according to the following understanding:

- **Horizontal accuracy:** Compare planimetric coordinates in the data set with those from a more accurate source.
- **Vertical accuracy:** Compare surface elevations in the data set with those from a more accurate source, using checkpoints and scientifically sound interpolation methods.
- **Three-dimensional accuracy:** Compare the combined X, Y, and Z coordinates in the data set with those from a more accurate source.

A non-biased accuracy assessment is the only way geospatial data users can be certain that the delivered products meet project or application requirements. For the assessment to be non-biased, the following conditions must be satisfied:

1. The surveyed checkpoints used in the assessment should be independent from the surveyed control points used in the data calibration process, i.e., assessment checkpoints are not used in the imagery aerial triangulation process or the boresighting of lidar data.
2. The accuracy of the checkpoints should be higher than the expected accuracy of the tested product. According to these standards, the accuracy of the checkpoints should be at least twice as much as the expected accuracy of the tested product.
3. Checkpoints should be evenly distributed around the project as much as feasible. Terrain and access may affect this distribution, requiring practical judgment to be applied.
4. A minimum of 30 checkpoints should be used for assessing horizontal accuracy and the NVA for project area of 1000 km^2. Such numbers increase with project size, see Table 4.

Table 4. Checkpoint Recommendations for Horizontal Accuracy and NVA Testing Based on Project Area

Project Area (Square Kilometers)	Total Number of Checkpoints for NVA
≤1000	30
1001–2000	40
2001–3000	50
3001–4000	60
4001–5000	70
5001–6000	80
6001–7000	90
7001–8000	100
8001–9000	110
9001–10000	120
>10000	120

If the project cannot meet the 30-checkpoint minimum due to small test areas (e.g., drones-based projects) or budget constraints, report accuracy verification with fewer checkpoints per Section 7.16 of these standards.

As for assessing VVA, the standards recommend a minimum of 30 checkpoints regardless of the project size. However, data users and data producers can agree on additional or fewer checkpoints as it suits the project requirements.

The previously recommended number and distribution of NVA and VVA checkpoints may vary according to the significance of different land cover categories and project requirements. The checkpoint numbers suggested in Table 4 are recommendations based on best practices. Data producers and data users may mutually agree to modify such requirements based on anticipated accuracy, project area and scope, terrain challenges, accessibility of the area, and budget constraints.

Accuracy Reporting

Horizontal, vertical, and 3D positional accuracies shall be assessed and formally reported according to one of the statements provided in section 7.16 of the standards. In addition to the accuracy class, the following related statistical quantities should be computed and reported:

- Residual errors at each checkpoint.
- Maximum error.
- Minimum error.
- Mean error.
- Median error.
- Standard deviation.
- RMSE.

The standards differentiate when the accuracy is performed by data users versus data producers.

Accuracy Reporting by Data Users or Their Consultants

The standards provided specific statements to report the three types of positional accuracies. Such statements were specific to whether the accuracy testing met the ASPRS standards requirement for 30-checkpoint minimum.

When Accuracy Testing is Meeting ASPRS Standards Requirements

Here the testing should be performed using a minimum of 30 checkpoints.

- Reporting Horizontal Positional Accuracy.
  "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) $RMSE_H$ Horizontal Positional Accuracy Class. The tested horizontal positional accuracy was found to be $RMSE_H$ = __(cm)."

- Reporting NVA.
  "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) $RMSE_V$ Vertical Accuracy Class. The Non-Vegetated Vertical Accuracy (NVA) was found to be $RMSE_V$ = __(cm)."

- Reporting VVA.
  "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) $RMSE_V$ Vertical Accuracy Class. The Vegetated Vertical Accuracy (VVA) was found to be $RMSE_V$ = __(cm)."
- Reporting 3D Positional Accuracy.
  "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a ___ (cm) RMSE3D Three-Dimensional Positional Accuracy Class. The tested three-dimensional accuracy was found to be $RMSE_{3D}$ = ___(cm) within the NVA tested area and $RMSE_{3D}$ = ___(cm) within the VVA tested area." [1]

When Accuracy Testing Does Not Meet ASPRS Standards Requirements

The following reporting statement is designed for when testing is performed using fewer than 30 checkpoints. This could be due to the small size of the project or low budget. Many drone projects fall under this category. Although the standards do not endorse the assessed accuracy performed with fewer than 30 checkpoints, it provides a vehicle to report findings regardless and at the same time encourage truth-in-reporting:

- Reporting Horizontal Positional Accuracy.
  "This data set was tested as required by ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024). Although the Standards call for a minimum of thirty (30) checkpoints, this test was performed using ONLY __ checkpoints. This data set was produced to meet a ___(cm) $RMSE_H$ Horizontal Positional Accuracy Class. The tested horizontal positional accuracy was found to be $RMSE_H$ = ___(cm) using the reduced number of checkpoints."

- Reporting NVA.
  "This data set was tested as required by ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024). Although the Standards call for a minimum of thirty (30) checkpoints, this test was performed using ONLY __ checkpoints. This data set was produced to meet a ___(cm) $RMSE_V$ Vertical Positional Accuracy Class. The tested vertical positional accuracy was found to be $RMSE_V$ = ___(cm) using the reduced number of checkpoints in the NVA tested area."

1. The 3D positional accuracy in vegetated areas can be omitted from this report based on a mutual agreement between the data user and the data producer.

- Reporting VVA.
  "This data set was tested as required by ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024). Although the Standards call for a minimum of thirty (30) checkpoints, this test was performed using ONLY __ checkpoints. This data set was produced to meet a ___(cm) $RMSE_V$ Vertical Positional Accuracy Class. The tested vertical positional accuracy was found to be $RMSE_V$ = ___(cm) using the reduced number of checkpoints in the VVA tested area."

- Reporting 3D Positional Accuracy.
  "This data set was tested as required by ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024). Although the Standards call for a minimum of thirty (30) checkpoints, this test was performed using ONLY __ checkpoints. This data set was produced to meet a ___(cm) RMSE3D Three-Dimensional Positional Accuracy Class. The tested three-dimensional positional accuracy was found to be $RMSE_{3D}$ = ___(cm) using the reduced number of checkpoints in the NVA tested area and $RMSE_{3D}$ = ___(cm) using the reduced number of checkpoints in the VVA tested area."

Accuracy Reporting by Data Producers

Data producers usually do not have access to independent checkpoints and, most of the time, they use the ground controls used in aerial triangulation or the lidar boresighting to assess product accuracy. Of course, this practice is a biased test (and therefore unacceptable) because the checkpoints were used in product calibration. However, reporting statements by data producers are much simpler as they do not report the accuracy results. It is merely a declaration of what they promised to produce according to the contract requirements. Data producers rely on their vast experience producing similar products in the past, assuming they employ mature technologies, and follow the best practices and guidelines through established and documented procedures during project design, data processing, and quality control, as set forth in the addenda to these standards.

- Reporting Horizontal Positional Accuracy.
  "This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) $RMSE_H$ Horizontal Positional Accuracy Class."

- Reporting NVA.
  "This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) $RMSE_V$ Non-Vegetated Vertical Accuracy (NVA) Class."

- Reporting VVA.
  "This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) $RMSE_V$ Vegetated Vertical Accuracy (VVA) Class."

- Reporting 3D Positional Accuracy.
  "This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a ___ (cm) $RMSE_{3D}$ Three-Dimensional Positional Accuracy Class within the NVA tested area and $RMSE_{3D}$ = ___(cm) within the VVA tested area."

Horizontal Accuracy of Elevation Data

The topic of horizontal accuracy of elevation data was rarely dealt with before issuing Edition 1 of the ASPRS standards. Among the main reasons for this lack of focus:

Horizontal accuracy is difficult to verify in the field: Whether it is from lidar or imagery, a point cloud is a discrete data set with sparse points which make it difficult to model a ground feature to accurately recognize it in the field and pinpoint its horizontal accuracy within a few centimeters. One example is a lidar data set produced to meet the USGS QL1. The nominal post spacing for QL1 is 35 cm, which does not support measuring horizontal features much smaller than 35 cm. However, as point cloud density increases with the advancement of lidar technology, this task is becoming more achievable. Fortunately, that is not the case for a point cloud produced from imagery because there is more control over producing a very high point cloud density.

Horizontal accuracy was not needed: The previous era of mapping was not focusing on the 3D model representation and most applications focused on producing land contours. In today's world and with the introduction of new concepts like digital twin, smart city, autonomous driving, indoor scanning and BIM, etc., knowing how accurate the data is horizontally is crucial for public safety and data performance reasons. The introduction of new 3D accuracy in the ASPRS standards is a testimony to these new applications and requirements.

The new standards offer the following approaches for deriving or estimating horizontal accuracy of elevation data:

- **For photogrammetrically derived elevation data**, adopt the same horizontal accuracy class assigned for planimetric data or digital orthoimagery produced from the same source, based on the same photogrammetric adjustment.
- For lidar elevation data, the standards provided the following formula for estimating the horizontal accuracy (see Equation 1).

Where:

- Flying height above mean terrain is in meters.

$$RMSE_H = \sqrt{(GNSS\,positional\ error)^2 + \left(\frac{\tan(IMU\ roll\ or\ pitch\ error) + \tan(IMU\ heading\ error)}{1.478} * flying\ height\right)^2} \quad (1)$$

- GNSS positional errors are radial, in meters, and can be derived from published manufacturer specifications.
- IMU errors are in angular units and can be derived from published manufacturer specifications.

The formula was crossed checked with horizontal accuracy computation by two of the main manufacturers of aerial lidar for their lidar systems and resulted in high agreement.

The above formula simplifies the error budget in lidar and reflects the main contributors to that error budget. Horizontal error in lidar-derived elevation data is largely a function of the following parameters:

- Sensor positioning error as derived from the Global Navigation Satellite System (GNSS).
- Attitude (angular orientation) error as derived from the IMU.
- Flying height above the mean terrain.

There are other error sources in the lidar system, such as laser ranging and clock timing ignored by the equation as it minimally contributes to the error budget and considered negligible when estimating horizontal error. The error caused by laser beam divergence was also ignored for reasons details in section 7.6 of the standards.

The Role of Control Survey Accuracy on Product Accuracy

Edition 2 of the standards introduced a requirement for considering ground control and checkpoints survey accuracy when computing product final accuracy. Today's advances in lidar, digital sensors, and digital analytical modeling enabled us to produce highly accurate geospatial products that in some cases exceed the accuracy of the field surveying techniques like GNSS-based RTK. Incorporating the field surveying accuracy is now crucial in determining the real product accuracy but was not needed decades ago when sensors and procedures yielded far less accurate products as witnessed today. Therefore, when we're dealing with products like the DOQQ with an accuracy of 10 m, a few centimeters of error in the checkpoints does not impact the final product accuracy.

The new approach introduced by the ASPRS standards divided the product accuracy into two parts or components. The first component includes $RMSE_{H_1}$ and $RMSE_{V_1}$ error is derived from the product fit to the checkpoints. The second component include $RMSE_{H_2}$ and $RMSE_{V_2}$, is error associated with the accuracy of the checkpoint's surveys. Both components are needed to compute the product's final accuracy:

- *Horizontal Product Accuracy* ($RMSE_H$)= $\sqrt{RMSE_{H_1}^2 + RMSE_{H_2}^2}$
- *Vertical Product Accuracy* ($RMSE_V$)= $\sqrt{RMSE_{V_1}^2 + RMSE_{V_2}^2}$
- $RMSE_{3D}$= $\sqrt{RMSE_H^2 + RMSE_V^2}$

Such requirements made it obligatory for data users and data producers to be acquainted with the field surveying process through their surveyors. In other words, they ultimately will need to know the accuracy of the survey so they can use it in the previous formulas. Experience reveals that many of the field surveying manufacturers do not provide the absolute accuracy figures needed for the previous formulas. In some cases, several instead produce quality figures that represent data internal precision that should not be used in these formulas. Acknowledging such a problem, the standards provided in Table II.A.3 (see Table 5) a list of the predicted accuracy for most of the surveying techniques used by the industry today. We hope that the manufacturers of surveying equipment recognize the needs of their clients who want to embrace the new ASPRS standards by coming up with a way to compute the absolute accuracy of the survey.

Vegetated Versus Non-Vegetated Accuracy

The new standards introduced a major and important change to the assessment of accuracy in vegetation. Some vegetated environments are challenging for many aerial data acquisition sensors, such as lidar and imagery. The new standards removed the pass/field criteria for the VVA and now it only needs to be tested and reported according to the requirements outlined in these standards. The logic behind this change is based on the following facts:

The lidar (and imagery) cannot penetrate dense vegetation perfectly: This problem results in a less dense lidar point cloud under trees. A sparse point cloud results in

Table 5. Predicted Accuracies of Field Surveying Techniques

Survey Methodology	Predicted Accuracy Values		
	Horizontal	Vertical	3D
Adjusted Closed Loop–Digital Leveling		5 mm	
Real-Time Network Following Section C–Recommended Procedures	10 mm	16 mm	19 mm
Real-Time PPP After Convergence Following Section D–Recommended Procedures	15 mm	24 mm	28 mm
Real-Time Kinematic (RTK) Base and Rover Following Section B–Recommended Procedures	20 mm	32 mm	38 mm
Closed Conventional Traverse Following Section E–Recommended Procedures	25 mm	40 mm	47 mm
Real-Time PPP After Convergence, Single Measurement	20 mm	50 mm	54 mm

less favorable modeling of the terrain under trees. Due to that bad modeling of the terrain, the VVA assessment results in a bad fit of the checkpoints to the lidar point cloud. Figure 2 illustrates the problem in modeling a terrain using a sparse point cloud and a dense point cloud. When a terrain is modeled with less dense point cloud, there is a risk of estimating the wrong elevation for the desired location like point A of the top profile of Figure 2. Depending on the software one uses, most likely it creates an Irregular Triangulated Grid (TIN) when connections between points of the point cloud form triangles. Software reports terrain elevation at a certain location based on interpolating the elevations surrounding the triangle that the location falls within.

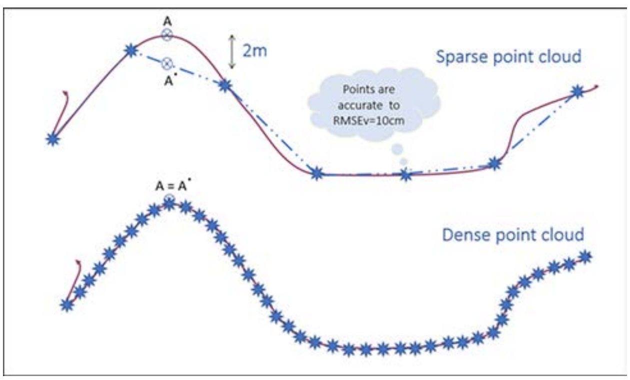

Figure 2. Terrain Modeling Quality as a Function of Point Density and Vertical Accuracy

As depicted in Figure 2, due to the sparse point cloud around point A, its elevation could be estimated with an error of 2 m. Point A could be one of those checkpoints surveyed under trees to assess VVA. When this happens, the derived VVA cannot be trusted. The only way to prevent such error introduction is by having a smooth continuous model to represent the terrain, which can only be guaranteed by having a dense point cloud to accurately model the terrain, as illustrated in the lower surface of Figure 2. More details on this topic can be found in section D of addendum I of the standards.

Surveying under trees is not reliable: GPS signals and PDOP get disturbed under dense canopies, resulting in inaccurate surveys.

Field survey measures the actual ground: The survey team usually measures the elevation of the actual ground, while the lidar point cloud measures the tops of the leaves, debris, and grass overlaying the ground. Such discrepancy in the measured elevations undermines the assessed VVA.

The forest floor is dynamic in nature: Forest floor debris moves with wind, water runoff, and animals disturbing the soil. In addition to the error vegetation already introduces, it also transforms in height and shape over time, which can pose serious problems, especially if the field ground survey is not performed at the same time as the airborne survey.

Finally, the advanced sensor technology on the market produces highly accurate point clouds: It is therefore appropriate to base data acceptance or rejection on the accuracy of the data over bare earth, where the ground is not obscured from the sensor. This was done for decades in photogrammetry when under-tree area contours were drawn as dash contours to indicate a low-confidence area where accuracy was not guaranteed.

The Power of the Six Addenda

For the first time, ASPRS standards contain best practices and guidelines for use. The information included in these addenda is not easily found in a textbook or a technical paper. It is a collection of science and practical experience authored by professionals possessing decades of surveying and mapping practice. The following is a brief description of these addenda:

Addendum I: General Best Practices and Guidelines

This addendum provides information on the following topics:

- Reporting notes for delivered geospatial products.
- Error normality testing and reporting.
- Understanding accuracy statistics and errors mitigation.
- Lidar data quality versus positional accuracy.
- Lidar system classification and grouping.

Addendum II: Best Practices and Guidelines for Field Surveying for Ground Control Points and Checkpoints

This addendum is a valuable addition that details everything users need to know about conducting safe and successful field surveys. No person should start a survey in the field for projects that must meet ASPRS standards without first consulting this addendum.

Addendum III: Best Practices and Guidelines for Mapping with Photogrammetry

This addendum walks users through all aspects of photogrammetric mapping, from planning to aerial data collection, to production and accuracy assessment. It is a great resource for practitioners as well as those just starting their career in photogrammetric mapping.

Addendum IV: Best Practices and Guidelines for Mapping with Lidar

Lidar is becoming the backbone of our industry and the money-maker for almost all mapping businesses. This addendum provides information similar to the information addendum III provided for photogrammetric mapping but with a focus on lidar, lidar sensors, and operations.

Addendum V: Best Practices and Guidelines for Mapping with Unmanned Aerial Systems (UAS)

While UAS is taking our industry and other aspects of life by storm, this addendum provides everything needed to create a successful production line out of UAS operations . It contains two sections—one focuses on photogrammetric operation and production while the second focuses on UAS-based lidar operation and production.

Addendum VI: Best Practices and Guidelines for Mapping with Oblique Imagery

The market lacks good information about best practices in oblique imagery operations. That was the motive behind adding this addendum which contains information about oblique imaging acquisition and production that is difficult to find anywhere else.

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This article will be published concurrently in Lidar Magazine.

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ASPRS would like to welcome the following new members!

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