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DISASTER RESPONSE

AIRBORNE SHOWCASE

Towards Understanding the New Three-Dimensional Accuracy of the ASPRS Accuracy Standards

With the geospatial industry increasingly moving towards three-dimensional GIS and true three-dimensional representation of terrain and infrastructure, it becomes prudent for mapping standards to provide a measure to assess the accuracy of such representations. This measure was defined in the latest American Society for Photogrammetry and Remote Sensing (ASPRS) *Positional Accuracy Standards for Digital Geospatial Data*, published in 2024, in which the term "three-dimensional accuracy" was introduced to complement horizontal and vertical accuracy terms. This article provides users of the standards with practical methods for assessing the three-dimensional accuracy of geospatial data and helps them understand this new term of accuracy.

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Our world in 3D and the challenges in representing it

Whether from space or aerial platforms, advances in lidar, radar, and other mapping and surveying sensors and instruments enable us to view the world in true 3D—revealing what we have never seen before. GIS, environmental, and engineering applications are becoming heavily dependent on 3D point clouds and 3D modeling (see **Figures 1 through 3**). Similarly, new applications like digital twins, BIM, and smart cities push the demands for 3D data to a new level.

Despite the high demand for 3D data, the industry is still behind in dealing with such data in a true 3D environment. We are still evaluating horizontal and vertical accuracy separately owing to the lack of effective tools for visualizing and performing measurements in 3D. Even the most widely used GIS and CAD tools in the industry do not provide such capabilities. What badly need software manufacturers to create a tool that presents 3D models or point clouds in true 3D and provides a terrain-following cursor for 3D measurement capabilities.

The new 3D positional accuracy

The ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) provides the following justification for introducing the new third term of positional accuracy: "Three-dimensional models and digital twins are gaining acceptance in many engineering and planning applications. Many future geospatial datasets will be in true three-dimensional form; therefore, a method for assessing positional accuracy of a point or feature within the 3D model is needed to support future innovation and product specifications.[1]"

According to the standards, the accuracy of the 3D position (X, Y, and Z) of features, with respect to horizontal and vertical datums, is computed using the following formula:

$$RMSE_{3D} = \sqrt{RMSE_X{}^2 + RMSE_Y{}^2 + RMSE_Z{}^2}$$

The $RMSE_X$, $RMSE_Y$, and $RMSE_Z$ of the checkpoints are computed by comparing the coordinates obtained from the map or 3D model to the surveyed coordinates of the checkpoints.

Suggested strategy to quantify the 3D accuracy

The following are scenarios that users may encounter when assessing 3D positional accuracy:

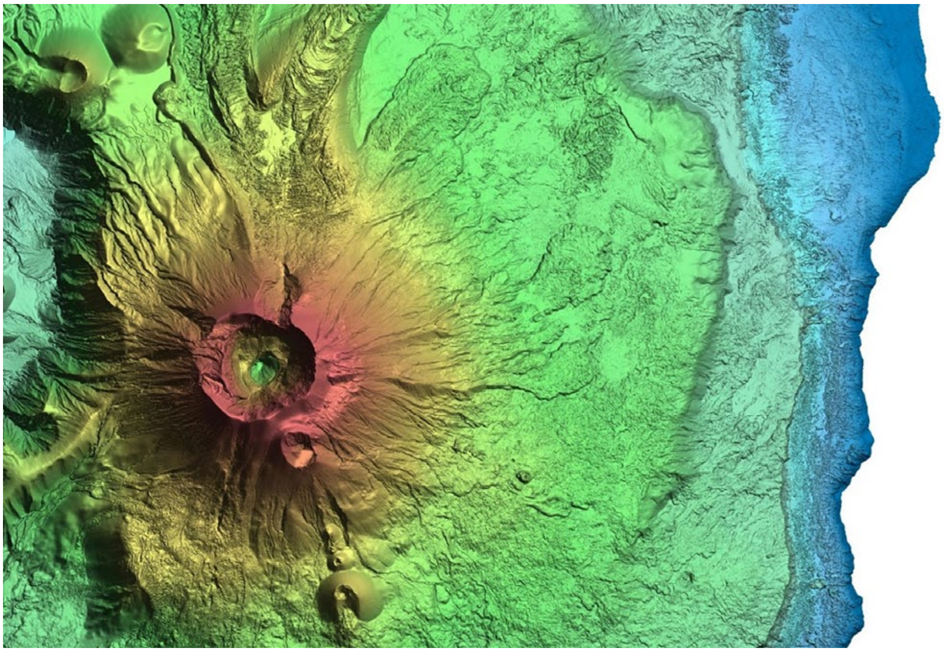

Figure 1: Lidar model of a volcano site in Hawaii
Courtesy of Woolpert and USGS

1. Using checkpoints that are suitable for vertical and horizontal accuracy assessment

These checkpoints are usually referred to as photo-identifiable checkpoints. Users can easily identify and accurately measure these points in imagery or lidar intensity images. They can be paneled targets suitable for imagery or lidar, or existing features in the scene, such as road stripes, parking-space stripes, or corners of utility manholes. Such checkpoints are typically used for photogrammetry, but can also be utilized to assess lidar accuracy. They enable true 3D measurement capabilities if the appropriate software exists. For photogrammetry, a stereoplotter can assess 3D accuracy in a true 3D environment. For lidar data, due to the lack of 3D-enabled software that supports true 3D measurements, horizontal and vertical accuracy can be assessed separately and then combined using the formula provided to compute the 3D accuracy. **Table 1** represents an accuracy computation according to the new ASPRS standards, where all components of horizontal and vertical accuracy exist.

For the accuracy assessment session presented in **Table 1**, it is assumed that the checkpoints were surveyed using standard RTK-based GNSS surveying practice, where the survey accuracy is assumed to be around 2.0 centimeters (or 0.066 feet) horizontally and vertically. Knowledge about survey accuracy is required to compute the final product accuracy according to the new standards.

The first component of errors in **Table 1** is computed from the product fit to the checkpoints provided in the three rightmost columns:

$$RMSE_{3D_1} = \sqrt{RMSE_X{}^2 + RMSE_Y{}^2 + RMSE_Z{}^2}$$

Or:

$$RMSE_{3D_1} = \sqrt{0.553^2 + 0.590^2 + 0.254^2} = 0.848 \text{ ft.}$$

1 publicdocuments.asprs.org/PositionalAccuracyStd-Ed2-V2, page 8.

Table 1: Geospatial product accuracy computations example

Point #	Surveyed Coordinates			Map Coordinates			Error Values (ft.)		
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Error in Easting (ft.)	Error in Northing (ft.)	Error in Elevation (ft.)
CP_1	2447813.666	320999.277	1091.290	2447813.745	320999.886	1091.041	-0.079	-0.609	0.249
CP_2	2447783.731	321113.799	1095.153	2447783.872	321114.131	1094.945	-0.141	-0.333	0.208
CP_3	2447759.165	321215.297	1098.398	2447759.805	321216.064	1098.148	-0.640	-0.767	0.250
CP_4	2447733.079	321308.624	1101.503	2447734.077	321309.328	1101.232	-0.997	-0.704	0.271
CP_5	2447700.757	321419.045	1105.196	2447701.039	321419.393	1104.925	-0.282	-0.348	0.272
CP_6	2447674.817	321511.857	1108.295	2447675.068	321512.646	1108.004	-0.251	-0.789	0.291
CP_7	2447653.663	321604.458	1111.250	2447653.973	321604.580	1110.852	-0.310	-0.122	0.398
CP_8	2447626.292	321705.399	1114.654	2447627.196	321706.205	1114.357	-0.904	-0.807	0.297
CP_9	2447596.353	321793.142	1117.680	2447596.445	321793.785	1117.340	-0.091	-0.642	0.339
CP_10	2447571.460	321890.393	1120.912	2447571.985	321890.750	1120.860	-0.524	-0.357	0.053
CP_11	2447546.661	321995.976	1124.451	2447547.164	321996.487	1124.188	-0.503	-0.511	0.263
CP_12	2447526.557	322083.359	1127.236	2447526.923	322083.384	1126.979	-0.366	-0.025	0.257
CP_13	2447500.261	322166.601	1130.190	2447501.255	322167.463	1129.896	-0.994	-0.862	0.294
CP_14	2447466.423	322281.229	1134.034	2447467.060	322282.134	1133.836	-0.637	-0.905	0.198
CP_15	2447308.665	322248.522	1138.270	2447308.853	322248.748	1138.075	-0.188	-0.226	0.195
CP_16	2447344.717	322148.450	1134.550	2447344.809	322148.749	1134.343	-0.092	-0.299	0.207
CP_17	2447365.379	322069.094	1131.729	2447366.118	322069.380	1131.606	-0.739	-0.286	0.124
CP_18	2447397.698	321961.434	1127.951	2447397.923	321961.772	1127.802	-0.225	-0.338	0.149
CP_19	2447432.470	321852.655	1124.165	2447432.820	321853.379	1124.070	-0.351	-0.724	0.095
CP_20	2447461.110	321756.112	1120.759	2447461.289	321756.306	1120.491	-0.178	-0.193	0.268
CP_21	2447488.289	321668.755	1117.655	2447488.705	321669.220	1117.306	-0.416	-0.464	0.349
CP_22	2447517.838	321559.055	1113.819	2447518.485	321559.832	1113.544	-0.648	-0.777	0.275
CP_23	2447551.427	321449.022	1110.043	2447552.148	321449.791	1109.801	-0.721	-0.769	0.242
CP_24	2447574.256	321367.151	1107.080	2447574.808	321368.040	1106.854	-0.551	-0.889	0.226
CP_25	2447603.184	321268.437	1103.592	2447603.749	321268.847	1103.287	-0.565	-0.410	0.306
CP_26	2447630.643	321182.130	1100.562	2447631.516	321183.004	1100.299	-0.873	-0.874	0.263
CP_27	2447746.661	322195.976	1126.451	2447747.164	322196.487	1126.188	-0.503	-0.511	0.263
CP_28	2447956.698	322520.434	1129.951	2447956.923	322520.772	1129.802	-0.225	-0.338	0.149
CP_29	2447658.148	321084.483	1097.144	2447658.603	321085.080	1096.927	-0.455	-0.597	0.217
CP_30	2447691.264	320973.009	1093.237	2447692.172	320973.591	1092.907	-0.909	-0.582	0.330
						Number of Check Points	30	30	30
						Minimum Error	-0.997	-0.905	0.053
						Maximum Error	-0.079	-0.025	0.398
						Mean Error	-0.479	-0.535	0.243
						Median Error	-0.479	-0.547	0.260
						Standard Deviation	0.282	0.252	0.076
						RMSE	0.553	0.590	0.254
						First Component of Horizontal Positional Accuracy $RMSE_{H1}$	0.809		
						First Component of Vertical Positional Accuracy $RMSE_{V1}$	0.254		
						Enter Survey Horizontal Accuracy $RMSE_{H2}$	0.066		
						Enter Survey Vertical Accuracy $RMSE_{V2}$	0.066		
						Final Product Horizontal Positional Accuracy $RMSE_{H}$	0.811		
						Final Product Vertical Positional Accuracy $RMSE_{V}$	0.263		
						Final Product Three-dimensional Positional Accuracy $RMSE_{3D}$	0.853		

Figure 2: 3D model of an industrial complex
Courtesy of Woolpert

The second component of positional error is the error in the survey of the checkpoints:

$$RMSE_{3D_2} = \sqrt{RMSE_{Hsurvey}{}^2 + RMSE_{Vsurvey}{}^2}$$

Or:

$$RMSE_{3D_2} = \sqrt{0.066^2 + 0.066^2} = 0.093 \text{ ft.}$$

The final 3D product accuracy is computed as follows:

$$RMSE_{3D} = \sqrt{RMSE_{3D1}{}^2 + RMSE_{3D2}{}^2} = 0.853 \text{ ft.}$$

2. Using checkpoints that are suitable for only vertical or horizontal accuracy assessment.

In the lidar industry, checkpoints are usually acquired to assess vertical accuracy. Horizontal accuracy of lidar data is rarely assessed by users. Checkpoints suitable for assessing vertical accuracy may not be suitable for assessing horizontal accuracy, as they are often not identifiable in the intensity image. In this scenario, however, we will assume that vertical and horizontal accuracy are assessed using separate sets of checkpoints. The accuracy assessment in this case is straightforward: vertical accuracy is assessed separately from horizontal accuracy and they are then combined to compute the final 3D accuracy. Assuming the final horizontal accuracy ($RMSE_H$) is computed, from **Table 1**, to be 0.811 feet, and the final vertical accuracy ($RMSE_V$) is found to be 0.263 feet, the 3D accuracy is computed as follows:

$$RMSE_{3D} = \sqrt{RMSE_H{}^2 + RMSE_V{}^2} = \sqrt{0.811^2 + 0.263^2} = 0.853 \text{ ft.}$$

3. Using only vertical checkpoints to assess 3D accuracy of lidar data

This is the most common industry practice today, as checkpoints for lidar data are usually surveyed to assess vertical accuracy. 3D accuracy can be assessed even without checkpoints suitable for assessing horizontal accuracy. The new standards in section 7.6 provide the following equation to reliably estimate the horizontal accuracy of lidar datasets:

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

The horizontal accuracy of lidar data estimated from the above equation is a function of the following main contributors to the error budget in lidar:

- Flying altitude above mean terrain (in meters)
- GNSS positional errors derived from published manufacturer specifications or processing reports (in meters)
- IMU errors derived from published manufacturer specifications (in degrees)
- To illustrate the use of this equation, assume a lidar project was flown with the following specifications:
- Flying altitude above mean terrain: 2500 m
- GNSS positional errors: 0.07 m
- IMU roll or pitch errors: 10 arc seconds
- IMU heading errors: 15 arc seconds

Figure 3: Imagery-based 3D model of the National Museum of the United States Air Force, Dayton, Ohio
Courtesy of Woolpertand the United States Air Force

Using the above equation, the estimated horizontal accuracy ($RMSE_H$) of the lidar point cloud that was produced from the aerial acquisition mission flown with the above parameters and instruments is 0.23 meters (or 0.75 feet). To calculate 3D accuracy, use the following equation, assuming the vertical accuracy of 0.263 meters computed in **Table 1**:

$$RMSE_{3D} = \sqrt{RMSE_H^{\,2} + RMSE_V^{\,2}} = \sqrt{0.75^2 + 0.263^2} = 0.853 \text{ ft.}$$

Since the horizontal accuracy ($RMSE_H$) is estimated based on the sensor model, we did not incorporate the survey errors in deriving it, as they did not play a role.

Final remarks

As the industry adopts the latest version of *ASPRS Positional Accuracy Standards for Digital Geospatial Data*, more emphasis will be placed on the new 3D accuracy term. This is true for federal programs such as the USGS 3DEP. This article helps users calculate 3D accuracy for their projects under different circumstances of checkpoint availability.

Download the ASPRS standards document using the following link tinyurl.com/dhp3tert or QR code:

Purchase a printed book of the standards using the following link: tinyurl.com/4radm237.

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