Technically Speaking

Geospatial Data Accuracy
Part One

Key information about technology and how it impacts our world

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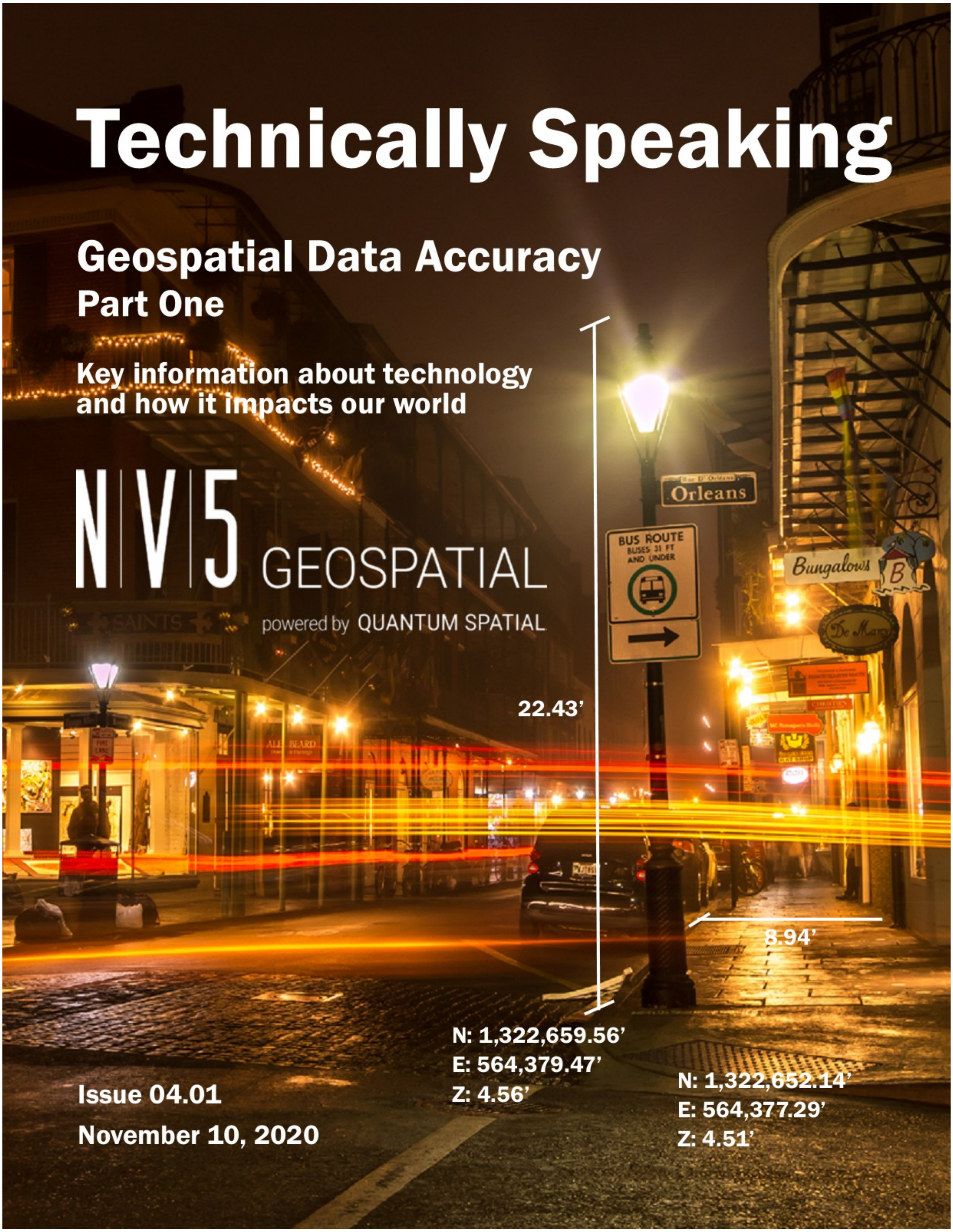

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Introduction

We constantly analyze contemporary topics and look for innovative ways to conduct in depth research and communicate the results internally and externally. Sometimes we focus on new technology. Other times we look at topics that are critically important to the way we value and analyze data and how these data are used by our clients.

This document provides a pathway for sharing our findings with the professional community.

Technically Speaking – Geospatial Data Accuracy

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Geospatial Data Accuracy

Part One – The Setup

November 10, 2020

Perfect maps and perfect collections of geospatial data don't exist. Fortunately, perfection isn't a requirement for project success, but inaccuracy and imprecision are certainly problematic and must be avoided. In this document we will discuss accuracy relative to lidar point clouds, digital orthophotos, vector mapping, and in the important answers we derive from these data.

Project success is closely tied to achieving the *right* accuracy – along with other key factors like proper resolution, complete classification schemes, and the right feature collection. Understanding geospatial data accuracy is critically important yet often misunderstood.

There are many expressions of accuracy and many potential sources of inaccuracy and imprecision. Certain topics are critically important:

- The differences between relative and absolute accuracy are especially important to understand
- Errors can be loosely grouped as quantitative and qualitative errors
- Random errors present differently than systematic errors
- Accuracy and precision are related concepts but very different

Let's set the stage for this detailed, two-part discussion of accuracy:

- Absolute accuracy refers to accuracy compared to a known datum; it does not set an upper bound such that every point within a dataset will fit within this limit from its true value
- The American Society for Photogrammetry and Remote Sensing (ASPRS) and the National Standard for Spatial Data Accuracy (NSSDA) define "accuracy" at the 95% confidence interval and 95th percentile levels
- The root mean square error (RMSE) is an important statistical number and is often misused as "data accuracy," however the RMSE is merely a means to estimating accuracy
- Statistical significance, normal distribution of errors, and inde-

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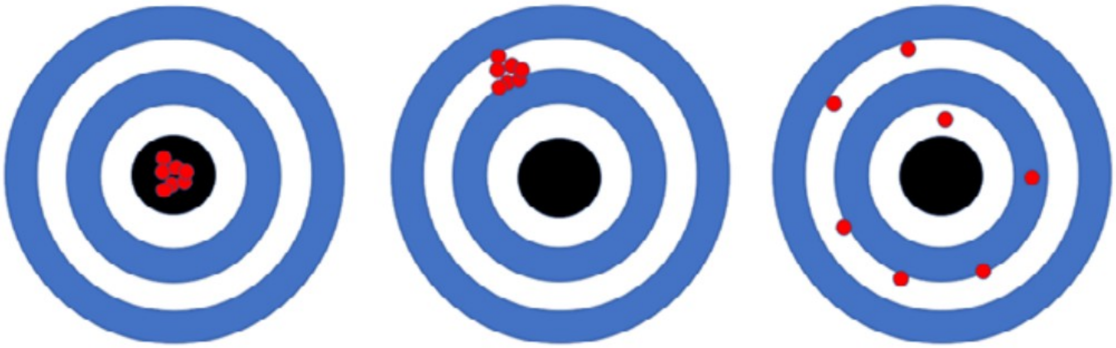

Figure 1 - From left to right above, very accurate and precise; precise but not accurate; and neither precise nor accurate patterning.

pendent sources of higher accuracy for checkpoints are important concepts

Making Wise Project Decisions

There are certain decisions made during project planning that are critical to a project's overall success. Accuracy is key, and typically related to several factors, including:

- Sensor selection and operational settings
- Flying height or observation distance (for remotely sensed projects)
- Calibration – number, location, and accuracy of calibration points
- Collection and processing methods and algorithms
- QC methods and QA testing

Choosing an accuracy standard that is too loose might render the data useless or impair important answers that could otherwise be derived from the data. Selecting a standard that is more stringent than required will increase project costs without adding value.

It is important to speak openly with your data provider to ensure the project calls for the right level of accuracy, much like discussing the importance of resolution, classification schemes, or feature lists. In doing so, you should consider all the project stakeholders and all current and potential future uses of the data.

Accuracy versus Precision

Accuracy and precision are very important concepts yet frequently misunderstood. Very simply, accuracy is the closeness of a measurement to its true value, while precision is the closeness of multiple measurements to each other.

The classic example for these concepts is archery. If all arrows fall within the bullseye then the archer was highly precise and accurate. If all the arrows miss the target but are tightly clustered in one location on

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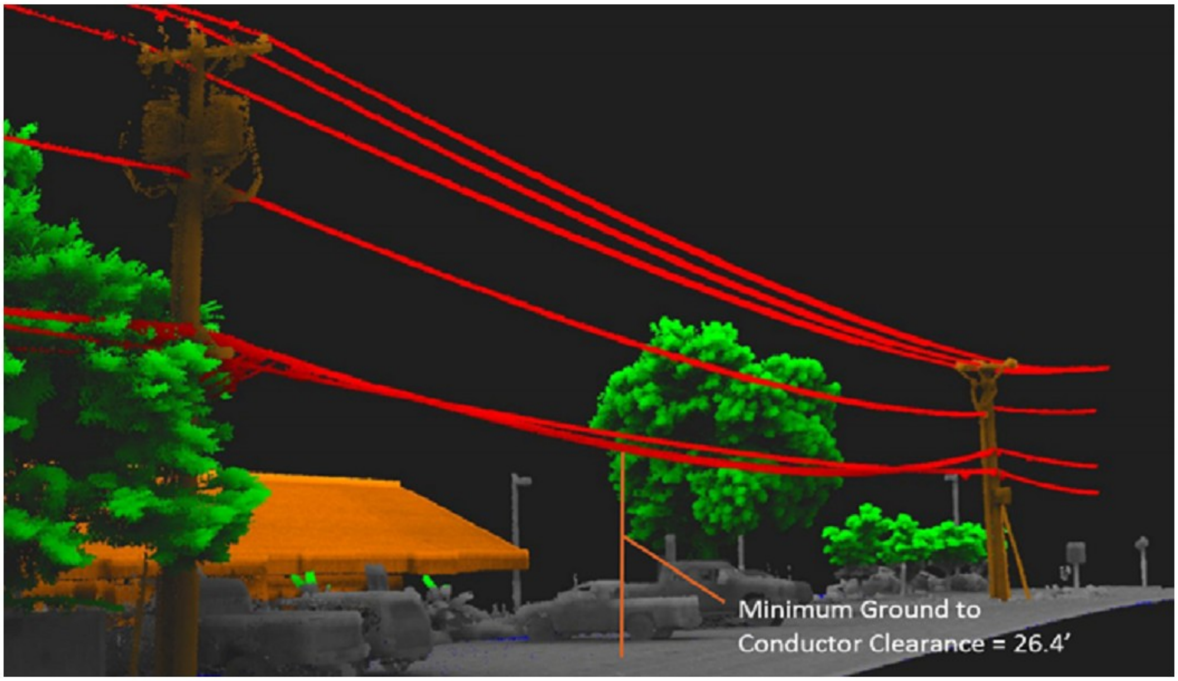

Figure 2 - The accuracy of the elevation difference from the low conductor relative to the ground is extremely important for understanding the safety of this infrastructure. The relative vertical accuracy is a measure of the confidence in the ground to conductor clearance.

the target, these arrows are precise but inaccurate. Finally, if the arrows fall randomly over the target, these arrows would be neither precise nor accurate. This example is perfectly applicable to geospatial measurements and positioning.

Geospatial projects that are both accurate and precise typically benefit from informed planning, top-of-the-line sensors, tight calibration, and skilled production. Precise but inaccurate projects typically result from either poor calibration or systematic errors. Imprecise and inaccurate projects could be a combination of poor planning, noisy sensors, careless calibration, inaccurate checkpoint surveys, or unskilled production.

Absolute versus Relative Accuracy

Two other concepts that are critical to this discussion center on absolute versus relative accuracy. Absolute accuracy is how close a measured value is to a known value on a given datum. Relative accuracy is how close a measured value fits a value on relative terms.

A perfect example of absolute accuracy would include the position of a well-defined feature found in the lidar point cloud when compared to its known or true position. Think of identifying where a sidewalk and asphalt driveway meet within a point cloud and comparing it to its true location from a highly accurate ground survey.

"Geospatial projects that are both accurate and precise typically benefit from informed planning, top-of-the-line sensors, tight calibration, and skilled production."

In this case the elevations might be referenced to North American Vertical Datum of 1988 (NAVD 88) and the horizontal position to state plane or UTM projections.

The difference in elevation from the lidar point cloud to the true elevation of that sidewalk corner would represent the error in an absolute sense. Comparing the XY horizontal location of that corner to its true horizontal position would represent the absolute error in the horizontal position.

Perfect examples of relative accuracy include the minimum ground clearance of the low conductor spanning between two transmission structures and secondly, the volume of a stockpile. In both cases we are measuring one feature in a point cloud or image relative to something else in the point cloud or image. In the first, we measure the difference between the elevation on a transmission conductor relative to the elevation of the ground below it. In the second, we measure and report the volume of material sitting above natural ground.

In the first, it is possible to be extremely accurate in measuring that clearance from the ground to the low wire while being highly inaccurate with both elevations when compared to the NAVD 88 datum. Consider the case where the elevation data was placed on an assumed datum that is in error by 150 feet when compared to a true NAVD 88 datum. If the bias is consistent in both elevations measured on the wire and the ground below, then the clearance (elevation difference) measurement is unaffected and perfectly accurate in a relative sense.

Independent Sources of Higher Accuracy Control

Estimating absolute accuracy requires an independent source of high accuracy data that represents true values. This can take many different forms. For example, new orthophotos can be overlaid on existing imagery and offsets quantified. Utility structures can be compared to existing infrastructure positional databases. Or new blind test points can be collected throughout the project area and used as the source of testing.

"Estimating absolute accuracy requires an independent source of high accuracy data that represents true values."

In all three scenarios we are making the assumption the test data represents the true positions of all features tested. If the test data are not of reliable accuracy, then we might confuse inaccuracy of the test dataset with inaccuracy of our project.

In fact, to provide us with confidence in the results, the independent test data should be three times more accurate than the accuracy requirement we are testing against. As a specific example, if we have a vertical accuracy requirement for a lidar point cloud of 0.15' at a 95% confi-

Figure 3 - Global Navigation Satellite System (GNSS) surveys are frequently used for establishing blind checkpoints, but differential levels may be required to establish elevations for the most demanding projects.

dence interval (C.I.) then our vertical test points should be acquired at a vertical accuracy of 0.05' at the same 95% C.I.

It is also important for the test points to be independent of the data being tested. That means blind test points that were not used in the calibration of the new data.

Horizontal Accuracy

In terms of quantitative accuracy, we see requirements for both horizontal and vertical accuracy, which are relatively self-explanatory. The horizontal accuracy is typically evaluated in orthophotos or planimetric maps by evaluating well-defined features and comparing their horizontal position to true coordinates. The vertical accuracy reflects how well the modeled elevations fit their true elevation. Most 3D projects have requirements for both.

In the classic sense, horizontal accuracy testing is quite simple. Features that are easily identifiable in the orthoimage or planimetric map are selected for testing, ground crews dispatched to each of the locations, and "true" positions of the features acquired for comparison to the mapping.

It can be a bit more difficult to complete higher accurate testing of lidar point clouds, especially in lower resolution datasets. Often we

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Span	Actual Length	Modeled Length	Error	$Error^2$
123	214.32′	214.08′	-0.24	0.0576
124	207.18′	207.33′	+0.15	0.0225
125	202.59′	202.48′	-0.11	0.0121
126	212.49′	212.63′	+0.14	0.0196
127	204.73′	204.82′	+0.09	0.0081
Mean $Error^2$				0.0240
RMSE				0.15

Table 1 - The calculation of the Root Mean Square Error (RMSE) of a sample set is relatively straightforward.

can do adequate testing using areas of highly variable intensity – think paint striping, stop bars, markings on tennis courts – or areas with abruptly changing elevation features like distinctive ditches, headwalls, etc.

In order to accurately represent a complex surface, denser data are necessary to capture the surface details for accurate mapping of small linear features such as curbs and micro drainage features."

Vertical Accuracy

Vertical accuracy is typically evaluated in all dominant land cover classes within a project area. Here we group the results as non-vegetated vertical accuracy (NVA - bare earth and urban) and vegetated vertical accuracy (VVA - weeds, tall grass, brush, forests). Lidar typically exhibits a higher accuracy in the NVA class as compared to the VVA. Most project specifications make allowances for these performance differences.

It is also important to compare elevation data accuracy versus elevation data quality. The ASPRS accuracy standards state, "high density lidar data are usually of higher quality than low density data, and the increased quality can manifest as apparently higher accuracy.

Root Mean Square Error

The National Standard for Spatial Data Accuracy (NSSDA) published by the Federal Geodetic Data Committee in 1998 states, "The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points." We will learn later this has been slightly modified in one specific area, but in estimating accuracy, it is key to understand the RMSE.

Table 1 lists the individual errors and their squares in the span lengths between adjacent electric distribution poles and the determination of the RMSE.

"Another critical concept in estimating accuracy is understanding that errors can follow different patterns based on specific project factors and the measurement of points in the data."

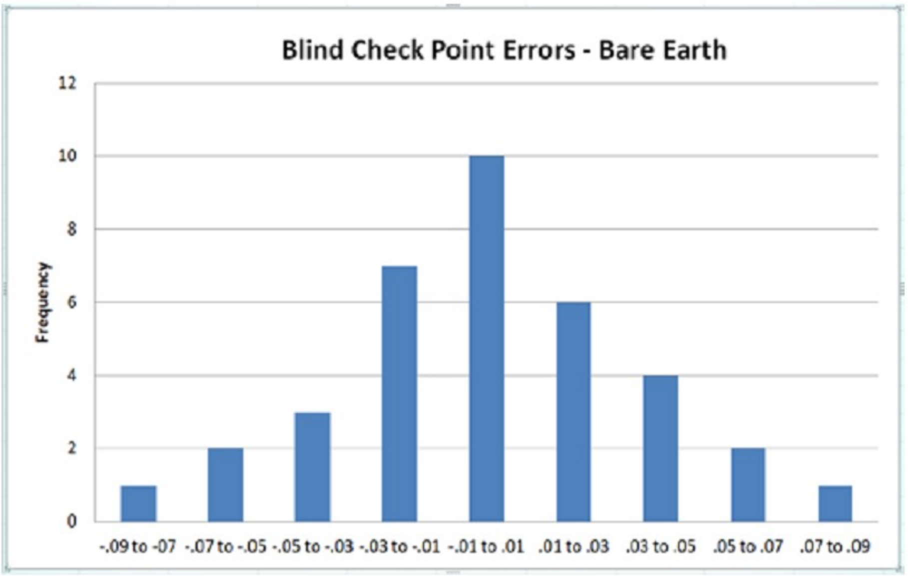


Figure 4 - The vertical errors in this bare earth land cover class exhibit near perfect normal distribution of errors. Notice the bell shape of the errors and the symmetry about the mean.

The sum of the square of the errors is 0.1199 and by dividing that total by 5 (the number of samples) we arrive at a mean square error of 0.0240. The square root of that mean is 0.15', which is the root mean square error, or RMSE of this sample set.

Normal Distribution of Errors

Another critical concept in estimating accuracy is understanding that errors can follow different patterns based on specific project factors and the measurement of points in the data. Understanding the normal distribution of errors is important to the overarching concept of accuracy. We have all heard of the "bell curve" and likely realize that shape is key to a normal distribution. A perfect normal distribution has:

- Symmetry about the center of the curve
- 50% of the values are less than the mean, and 50% greater
- The mean, median, and mode are equal

With lidar accuracy, the errors typically follow a normal distribution in bare earth and urban areas but often not in other land cover classifications. In estimating this accuracy, we go to numerous well-distributed locations within the project area and use ground surveying techniques to accurately determine the elevations of random points to compare with the elevations from the point cloud.

In the above graph, we have tabulated the number and magnitude of errors determined from the elevation comparisons. In this graph you should see there is one point that exhibited

"Heavily vegetated areas are much more challenging with ground determination and often the errors are not normally distributed. Typically they are more random, larger in magnitude, and can exhibit a bias where the mean errors differ considerably from zero."

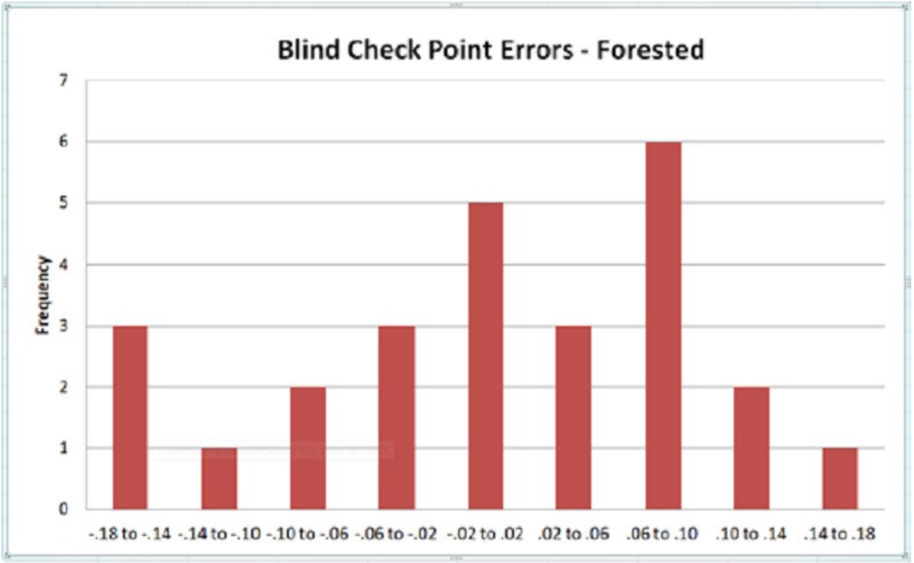


Figure 5 - The vertical errors in the forested land cover class are clearly not normally distributed (no semblance of a bell curve), which reinforces the need to estimate the errors at the 95th percentile.

an error ranging between -0.09 to -0.07 feet, and two points that with errors ranging from -0.07 to -0.05 feet. Notice the general shape of this curve resembles that of a bell, with roughly 50% of the points below 0.00 and 50% above a measured error of 0.00'. These data are both accurate and normally distributed – not perfect but very close.

Compare the previous results in open areas to the results in Figure 5 above with errors found in forested areas. Heavily vegetated areas are much more challenging in ground determination and often the errors are not normally distributed. Typically they are more random, larger in magnitude, and can exhibit a bias where the mean errors differ considerably from zero.

The graph above exhibits all of these traits.

Accuracy at 95%

We mentioned earlier that in its truest form, geospatial accuracy is estimated at either a 95% confidence interval (95% C.I.), or a 95th percentile error. The confidence interval is used when the data have or are expected to have a normal distribution. Vertical errors in lidar point clouds for areas that are open – bare earth and urban areas – typically have a normal distribution and accuracy is reported as a 95% C.I.

For one-dimensional accuracy that is consistent with elevation accuracy, the NSSDA defines the 95% C.I. as a

"With lidar accuracy, the errors typically follow a normal distribution in bare earth and urban areas but often not in other land cover classifications."

multiple of the $RMSE_z$:

$$95\%\ C.I. = 1.96 \times RMSE_z$$

Other examples of linear or one-dimensional errors might include a span length for utility conductors or depth of cover for an underground utility.

For two-dimensional accuracy, which is typical of horizontal accuracy, we use a circular error at a 95% confidence interval (CE 95), which reflects both the X and Y (Easting and Northing) errors together. The CE 95 is the radius of a circle such that there is a 95% probability that the horizontal error resides within the circle. Said another way, if we overlay that circle centered about a well-defined point in a map, there is a 95% probability that the true position of that point falls within the circle.

The NSSDA defines the CE 95 as a multiple of the radial $RMSE_r$, which considers both the $RMSE_x$ and $RMSE_y$ in the calculation. The $RMSE_r$ is determined from the following:

$$RMSE_r = Sqrt\ [RMSE_x^2 + RMSE_y^2]$$

And the value of CE 95 is computed from that as:

$$CE\ 95 = 1.7308 \times RMSE_r$$

This is valid under the assumption that the values of $RMSE_x$ and $RMSE_y$ are similar. If there is considerable difference between the two, consult the NSSDA for alternate ways to estimate the horizontal accuracy.

Vertical errors in point clouds in the more challenging vegetated land

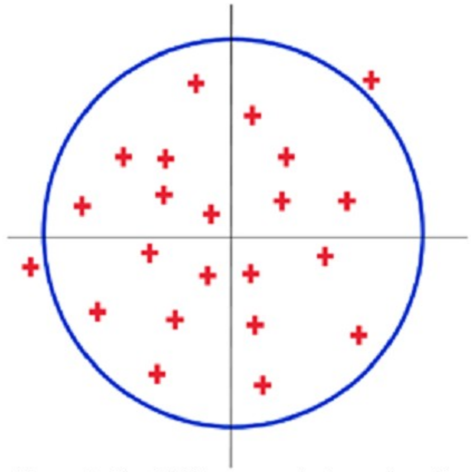


Figure 6 - The CE 95 represents the radius of a circle that contains 95% of two-dimensional errors, or in this case a horizontal error.

cover classifications like forests or tall grasses often exhibit a bias, are more random, and are not typically normally distributed. For these areas, we report accuracy at a 95th percentile error.

The 95th percentile error is measured from the actual errors found in the data. Here the absolute values of the errors are tabulated and ranked by magnitude. The value that represents the point at which 95% of the errors fall at or below that value is determined, which becomes the 95th percentile error.

Statistical Significance

When we analyze geospatial data, it is important to know if our findings are "significant" and have confidence that the results of our analysis aren't due purely to chance. To do this we need to analyze a large enough sample of test data to provide that confidence. With large enough sample sizes, we greatly reduce the

"For two-dimensional accuracy, which is typical of horizontal accuracy, we use a circular error at a 95% confidence interval (CE 95), which reflects both the X and Y (Easting and Northing) errors together."

possibility of having results that reflect randomness.

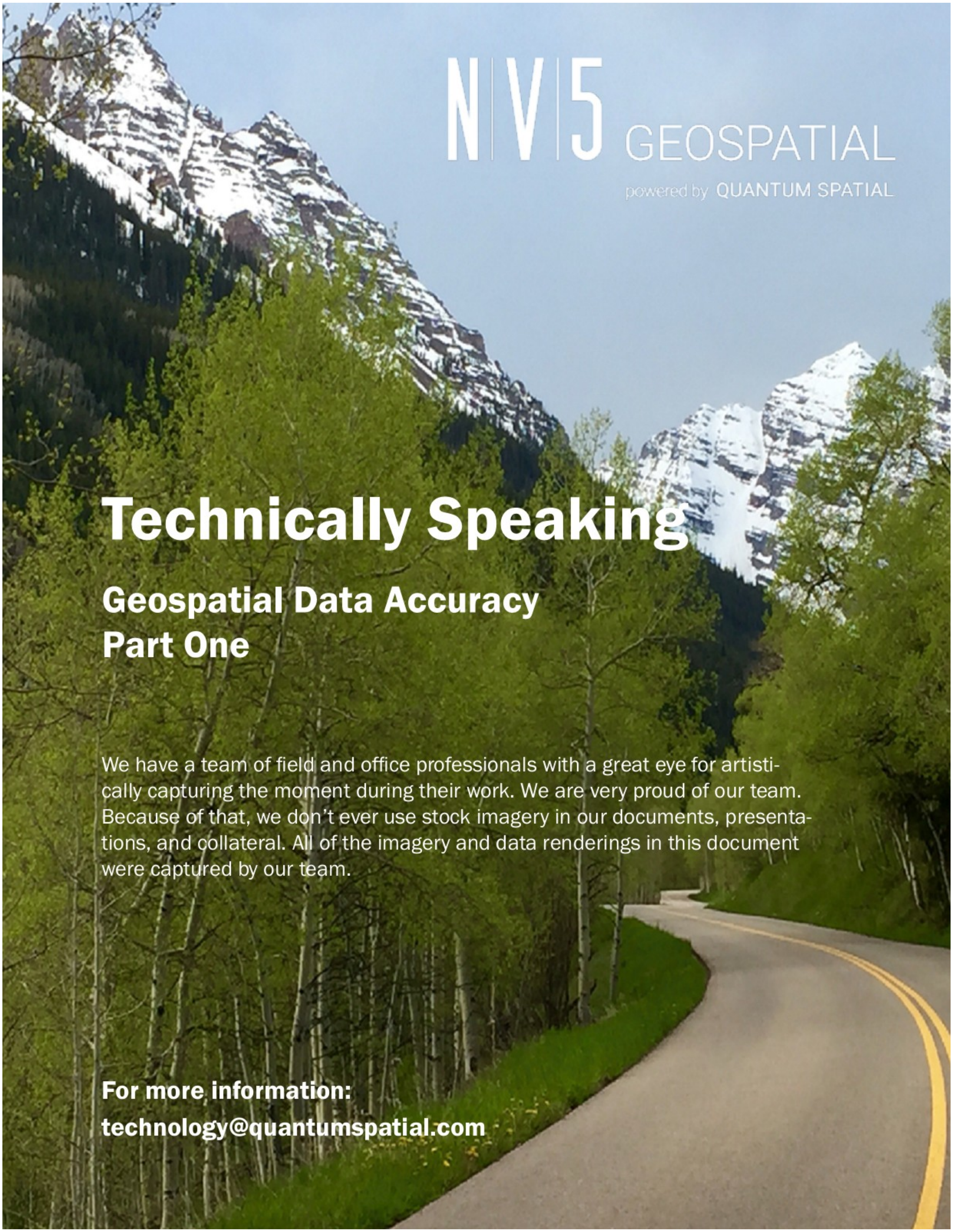
Of course there is a cost component to statistical sampling, so it is important to find a level of testing that provides the right balance of confidence and cost.

The 2014 ASPRS Accuracy Standards for Digital Geospatial Data provide good recommendations for the minimum number of horizontal and vertical checkpoints based on project area. These can be found in Table 7 of the document. They require a minimum of 20 check points for horizontal accuracy tests for small project areas and the numbers grow as project areas increase.

These same standards provide requirements for vertical accuracy testing. For the non-vegetated vertical accuracy, the requirements start at 20 independent locations and increase as the project areas grow. These are implemented uniformly by many clients. However, vegetated vertical accuracy requirements may differ somewhat based on clients and project locations, so be sure to check specific project requirements.

Conclusion

Estimating and reporting accuracy in geospatial data is quite complex and very important. This introduction sets up our next discussion in Part Two, where we will depart from the basics of geospatial data accuracy and do a deep dive into specific applications of example projects. Look for Part Two in a few weeks.



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