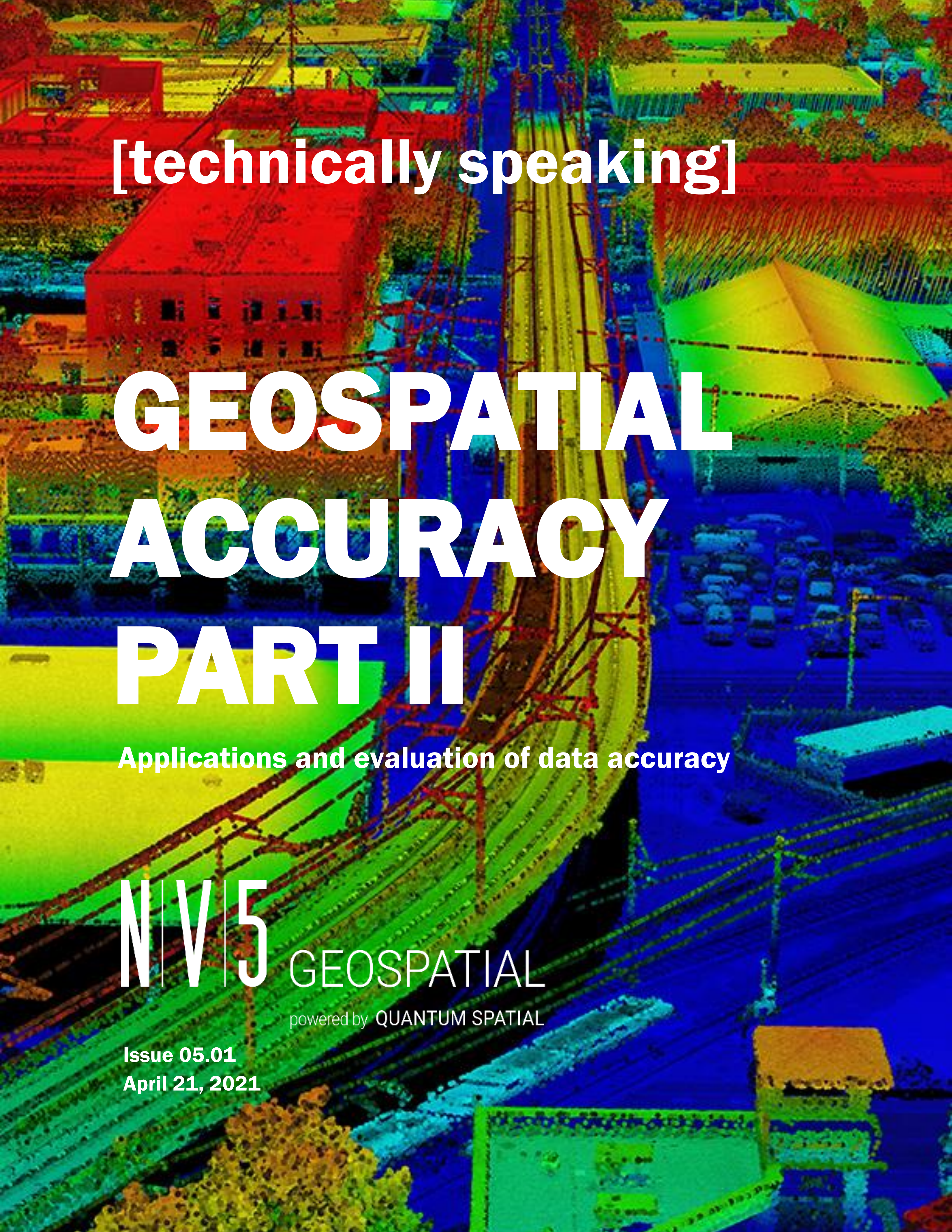

[technically speaking]

GEOSPATIAL ACCURACY PART II

Applications and evaluation of data accuracy

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Introduction

Our internal innovation and development team constantly analyzes new technology and looks for innovative ways to apply it to our client's challenges. Along the way, we ask ourselves many questions and from those develop an understanding of how these technologies might be used to solve new and complex challenges.

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

Technically Speaking – Geospatial Accuracy Part II

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Geospatial Data Accuracy - Part II

Specific Applications to Geospatial Projects

In December we introduced the topic of geospatial data accuracy and provided a solid background for applying underlying concepts across many different geospatial projects. This quarter we are building upon these basics and diving deeper into actual projects. We will also take a close look at accuracy performance in various land cover classes and look much closer at the concept of normal distribution as it applies to evaluation geospatial accuracy.

Vegetated and Non-vegetated Vertical Accuracy

The US Geological Survey (USGS) has created two general categories for estimating vertical accuracy within collects for their 3D Elevation Program (3DEP). In fact, these requirements have been widely adopted beyond the USGS and are common for most lidar projects completed today, regardless of the client or lidar application.

These classifications recognize accuracy in vegetated areas are expected to exhibit larger, more random errors than those found in open areas. Technically, the non-vegetated vertical accuracy (NVA) includes the land covers where vegetation impacts are minor, and specifically includes areas of bare earth, low grass, and urban areas. Conversely, the vegetated vertical accuracy (VVA) includes areas where vegetation is dominant and likely to be more problematic.

Table 1 below provides a summary of the land cover

"The non-vegetated vertical accuracy (NVA) includes the land covers where vegetation impacts are minor, and specifically includes areas of bare earth, low grass, and urban areas."

Land Cover Class	Reporting
Clear or open, bare-earth, low grass	NVA
Urban areas	NVA
Tall grass, tall weeds, and crops	VVA
Brush lands and short trees	VVA
Forested area, fully covered by trees	VVA

Table 1 – Land cover classes and their reporting relationships in NVA and VVA classes.

information found in Table 3 in the Lidar Base Specification 2020 rev A published by the USGS found at this link. With their migration of the LBS to the web away from print, they added considerable value to the professional community.

As discussed in our introductory document in December, the NVA is typically normally distributed and this simplifies the estimation of the error. The NVA is expressed as a ***95% confidence interval***, which is determined as a multiple of 1.96 times the vertical root mean square error (RMSEz).

This is fundamentally different from the VVA, where errors often are not normally distributed. “In 2004, the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS) both advocated the use of the ***95th percentile error*** to estimate vertical accuracy at the 95% confidence level for lidar data in vegetated land cover categories where errors do not necessarily follow a normal distribution.”

The VVA errors are typically more randomized and larger in magnitude and therefore are not simplified as a multiple of

Figure 1 - The prairie grass at this location provided dense, relatively tall vegetation that posed challenges for lidar modeling

the RMSEz. Here the error is expressed as the 95th percentile error. Excel provides great capabilities for the determination and is as simple as determining the absolute value of all errors, lining them up from smallest to largest magnitudes, and finding the point where 95% of the errors are less than that limit.

The following Excel formula will take care of the math for us:

= percentile (range, 0.95)

Quality Levels

The USGS Lidar Base Specification provides requirements for four levels of “quality” in point clouds and these include requirements for

“The USGS Lidar Base Specification provides requirements for four levels of “quality” in point clouds and these include requirements for the point density and accuracy for both the NVA, and VVA.”

Quality Level	Density	RMSEz	NVA	VVA
QL0	8 ppsm	5 cm	9.8 cm	15 cm
QL1	8 ppsm	10 cm	19.6 cm	30 cm
QL2	2 ppsm	10 cm	19.6 cm	30 cm
QL3	0.5 ppsm	20 cm	39.2 cm	60 cm

Table 2 - The requirements for the various quality levels in lidar. The non-vegetated vertical (NVA) accuracy is expressed at the 95% confidence interval; the vegetated vertical accuracy (VVA) is expressed at the 95th percentile error.

the point density and accuracy for both the NVA, and VVA as shown in Table 2 above. These have been widely adopted for lidar project undertaken by many other organizations around the world.

Blind Check Points

Estimating accuracy in geospatial projects requires a statistically significant number of blind check points to be withheld from the mapping. Much like ground calibration points, it is critically important for the 3D position of these points to be considerably more accurate than the mapping that is being produced and tested. In fact, the ASPRS Positional Accuracy Standards for Digital Geospatial Data states, "the independent source of higher accuracy for checkpoints shall be at least three times more accurate than the required accuracy of the geospatial data set being tested."

As an example, lidar point clouds produced to meet QL1 requirements of 10 cm expressed as an RMSEz or 19.6 cm at the 95% confidence interval would require calibration and blind check points accurate at 3.3 cm expressed as an RMSE or 6.6 cm at a 95% confidence interval. For projects completed at higher accuracies such as mobile mapping and low altitude airborne lidar projects, the accuracy of the check points is more exacting. For example, mapping accuracies for an RMSEz of 0.05', equaling a 95% confidence interval of 0.10', require vertical calibration and check points at an RMSE of 0.017' or a 95% confidence interval of 0.034'.

The accuracy requirements for these two projects call for very

"Estimating accuracy in geospatial projects requires a statistically significant number of blind check points to be withheld from the mapping."

Project Area		Static 3D Checkpoints		
Km^2	Mi^2	NVA	VVA	Total
<500	<193	20	5	25
750	290	25	15	40
1,000	386	30	20	50
1,500	580	40	30	70
2,000	773	50	40	90

Table 3 – Requirements for static 3D checkpoints used for blind QA points in lidar projects, covering both NVA and VVA locations

different surveying methodologies to ensure project requirements are met. In the first, careful GNSS observations can provide the vertical accuracies needed at 6.6 cm in terms of a 95% CI. The second requirements at 0.034' in terms of a 95% CI preclude the use of GNSS to meet these requirements. Here differential level runs between high-accuracy benchmarks are likely the best method of developing elevations.

Number and Placement of Blind Check Points

Now that we know the accuracy needed for all the blind check points, the next question is how many points are needed to properly estimate the accuracy and where should the points fall within the project area. Expectations vary by client but USGS and ASPRS specifications are often used by many clients.

The table above provides a summary of the requirements for several project sizes:

The prevailing thought is that a minimum of 20 points is required to have a statistically significant sample size to estimate the non-vegetated vertical accuracy.

In terms of placement, the checkpoints should be well distributed throughout the project area. Providing most or all of the points concentrated in a single location or two does very little to promote overall confidence in the accuracy. Moreover, the vegetated points should represent the vegetation cover types found within the project area. If half the vegetated area of a 386 mi^2 project is forested, and the remaining half is divided equally among tall grass and shrubs, then a division of 30 points in bare earth and urban areas, coupled with 10 points

"Moreover, the vegetated points should represent the vegetation cover types found within the project area."

in forests, 5 in tall grass, and 5 in shrubs would be ideal.

Project Analysis

Let's apply our knowledge to estimating the horizontal and vertical accuracy for a lidar project. In full transparency, we are using some data from an actual project and supplementing that with synthetic data to help us illustrate all the concepts we have discussed.

Consider a large, wide-area lidar project that covers a project area of 580 square miles. There are large expanses of open areas with bare earth and low grasses; a highly urbanized city center; areas of tall grass and weeds; and areas of brush lands and short trees. The project area has only minor areas with a grouping of tall trees. The contract calls for a typical QL1 collect, which requires a nominal point density of 8 ppsm, an RMSEz of 10 cm, a FVA of 19.6 cm, and a VVA of 30 cm.

Table 3 provides us with recommendations for 3D blind QA points for a project area of 580 square miles at 40 NVA and 30 VVA points. Since the project area is dominated by areas with bare earth and low grasses, we elect to acquire 25 blind QA points in that land cover and 15 points in the city center, roughly mirroring the makeup of the project overall. Assuming the vegetated areas of tall grass and weeds and brush and short trees are somewhat equal in dominance we split the vegetated QA points evenly at 15 in each of the two classes.

In addition to collecting points in all the dominant land cover classes, we want representative coverage throughout the vast geography of the project. We have good transportation and ready access in all the project area, so we will make sure no areas are left out. Our survey plan calls for all points to be collected on public rights of way, eliminating the challenges of gaining permission for access to private property. Our survey planners also select areas easy to drive to where ground crew safety is always of importance. That includes areas out of high traffic roadways and locations with ample parking.

Since the required vertical accuracy is 10 cm in terms of an RMSEz, our target vertical accuracy for the blind QA points is 3.3 cm, or better given our 3X requirement (the accuracy of blind points should be three times better than the accuracy

"In addition to collecting points in all the dominant land cover classes, we want representative coverage throughout the vast geography of the project."

of the surface tested). We know that we can achieve this accuracy with carefully planned static GNSS surveys. The plan is complete and the survey crew dispatched to the project to acquire the 70 points needed.

NVA Evaluation

The NSSDA states "the reporting standard in the vertical component is a linear uncertainty value, such that the true or theoretical location of the point falls within +/- of that linear uncertainty value 95-percent of the time."

We used GNSS static surveys to collect the 70 blind check points in the project area and grouped them according to their land cover classification. We used the horizontal (XY) location of each of the surveyed points and interpolated the modeled elevation from the point cloud at each of those locations. The error or elevation residual at each was determined as the difference in the surveyed versus modeled elevation and recorded.

We are presenting two graphs that represent the error distribution. The first is for the bare earth and low grass along with the urban points. Together these represent the NVA points. Note two important characteristics of this distribution. The overall shape of the distribution is consistent with a bell curve with tails at each end and a concentration of errors about the center of the curve. Moreover, it appears there are about the same

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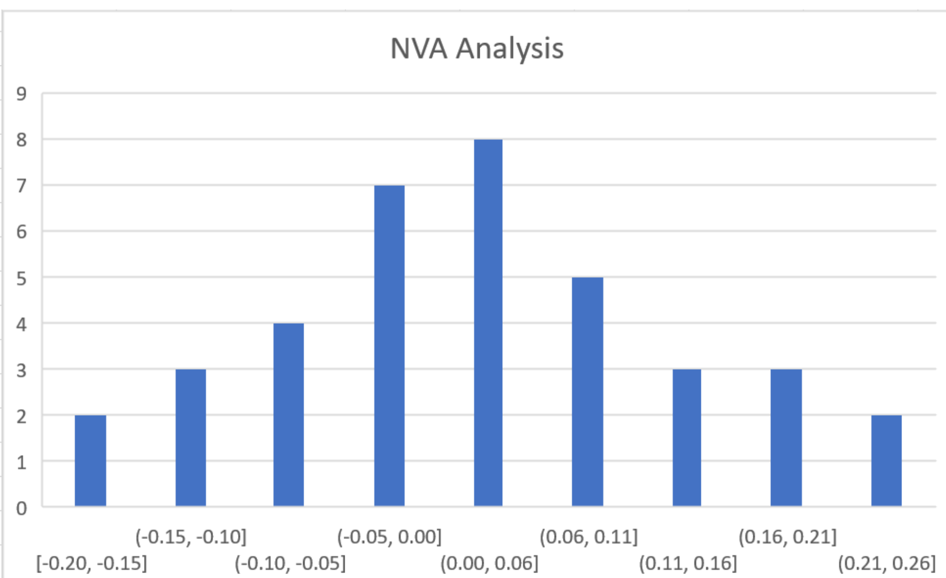


Figure 2 – The NVA errors have a bell shape with good symmetry about the mean and very little bias.

number of residuals left of center as there are right of center. This provides the immediate impression this is a normal distribution of errors, which we expect for the NVA classification. It isn't perfect, but it is close, which validates our assumptions.

We easily calculate the RMSEz of the distribution by squaring each of the individual errors, determining the mean or average of the squares, and taking the square root of that value. Our 95% confidence interval is determined as 1.96 times this value. For this project the average error was only 0.02 feet and the RMSEz came in at 3.3 cm (0.11 feet). This provides a 95% confidence interval of 6.6 cm (0.22 feet). We are well within the project requirements for QL1 at 10 cm and 19.6 cm for the RMSEz and 95% confidence interval, respectively.

VVA Evaluation

The second represents the tall grass and weeds, and shrubs and short trees. Together these represent the VVA points for this project area. A few important points should be readily apparent. First, the shape of the curve is more random and has a concentration of errors that are not centered about zero (indicating an elevation bias). The average error was +4.6 cm,

"The second represents the tall grass and weeds, and shrubs and short trees. Together these represent the VVA points for this project area."

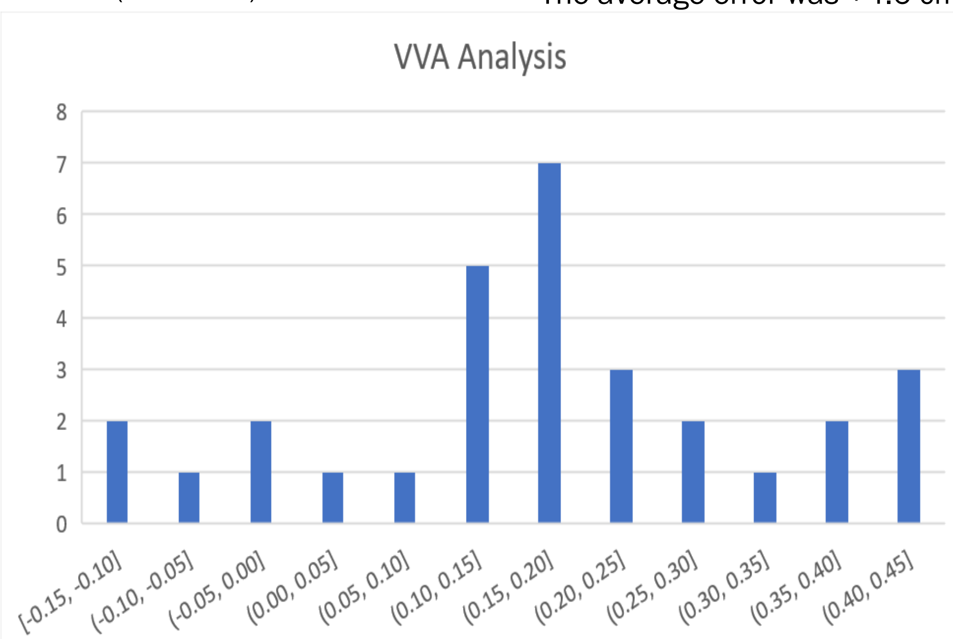


Figure 3 – The VVA errors were much more random, had considerably more errors with a positive value, indicating a bias of the modeled surface above natural ground, and were considerably larger when compared to the NVA analysis.

indicating a bias within our lidar model with the lidar point cloud

consistently above the elevation of the surveyed check points. Also, the errors are larger than those seen in the NVA class.

Our assumption was the VVA would be more random and not normally distributed and that assumption is true for these points.

To determine our accuracy at the 95th percentile we need to evaluate the actual data and find the point where 95% of the errors fit. We first start by taking the absolute value of each of the errors. Excel provides the ability to determine the accuracy for this as discussed earlier. In this case the absolute value of our 30 VVA errors are found in cells G51 to G80. The following formula provides the accuracy:

=percentile(G51..G80,0.95)

For this project there was a considerable bias of 0.18 feet, with the lidar surface consistently above the surveyed elevations. Our VVA analysis provided a 95th percentile error was 13.6 cm (0.45 feet), which again was well within the requirements for the project.

A Tale of Two Anomalies

One final thought - anomalies in data analysis are defined as, ”rare items, events or observations which raise suspicions by differing significantly from the majority of the data.” There are times that limited anomalies can be excluded from the accuracy determination.

One of our recent projects provided a really interesting look into and explanation of two significant vertical anomalies in a lidar point cloud. In addition to typical mapping of a roadway for the Oklahoma Department of Transportation (ODOT), we also performed two other independent lidar missions to test other sensors and acquisition platforms over the same roadway.

ODOT provided 395 blind high-accuracy check points for our use in evaluating the accuracy of the data. Many of these points were established about four months after the acquisition of the airborne lidar data.

As we evaluated the data, two points stood out because of their large elevation residuals. The large elevation differences of more than 1 foot when comparing the surveyed

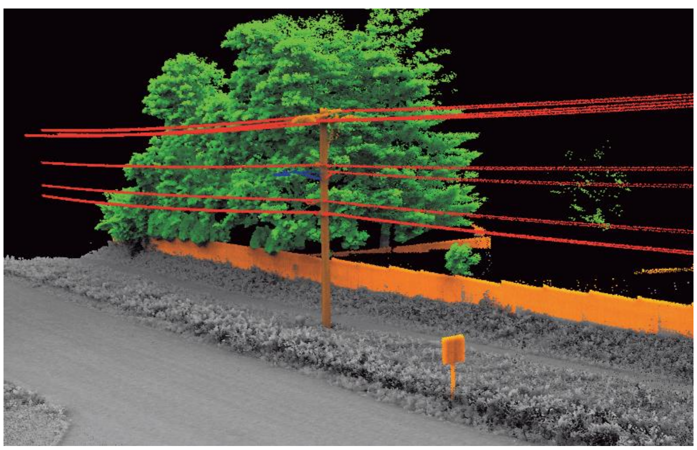
“To determine our accuracy at the 95th percentile we need to evaluate the actual data and find the point where 95% of the errors fit.”

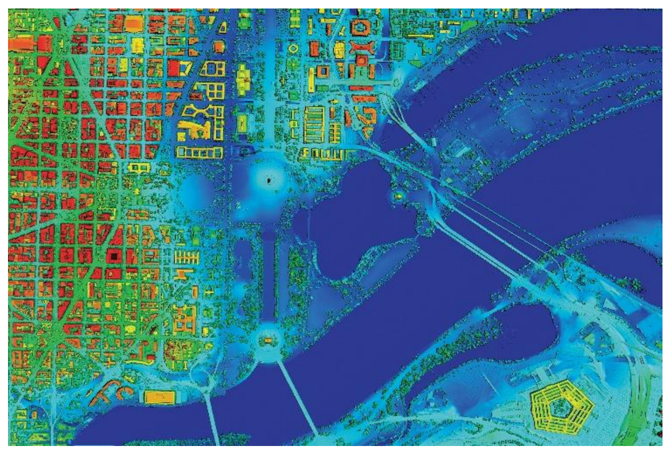
elevations to the lidar model disappeared when comparing the elevations of the three independent lidar surfaces to each other. The latter differences ranged from 0.01’ to 0.13’. It is almost certain that changes in the actual ground took place between the acquisition of the airborne data and the ground control.

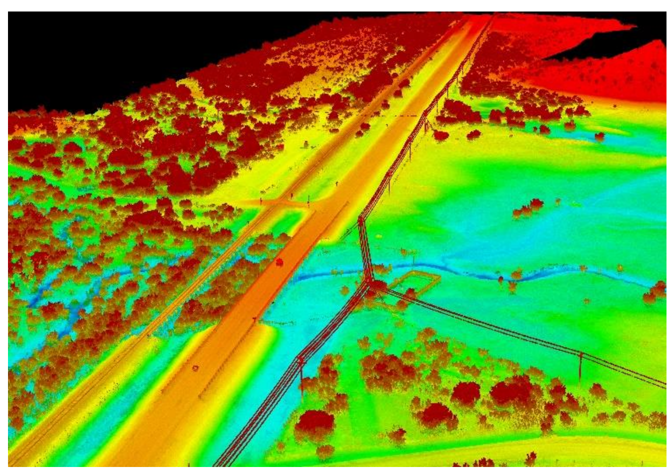
Conclusion

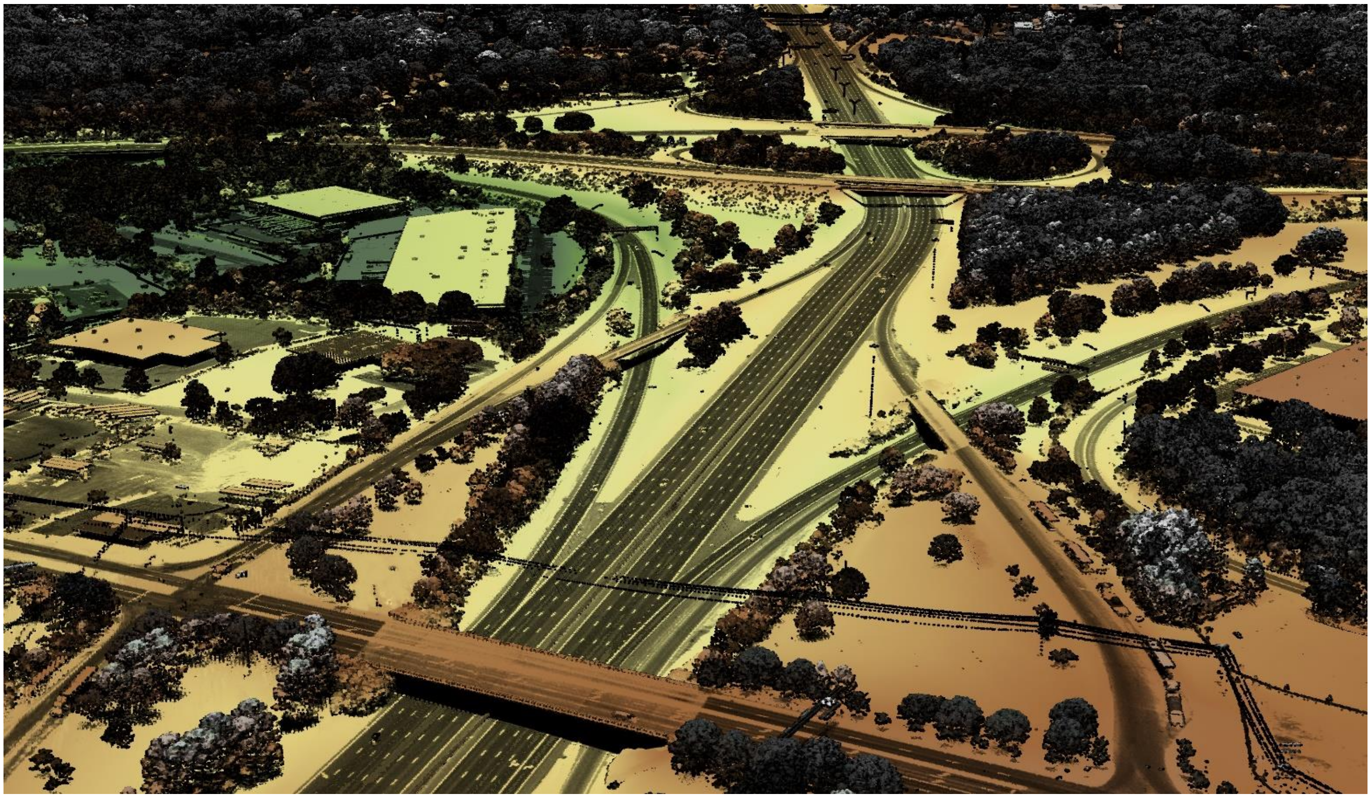
The estimation of accuracy for geospatial data is critically important. While the overall analysis can be complex, the individual components are straightforward:

- Develop a statistically significant set of ground truth points
- Establish these at an accuracy at least 3 times better than the expectations for the data to be evaluated
- Cover all areas of the project geographically
- Ensure all variations in the project area are evaluated; this may include varying land cover or other factors









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