Vertical Accuracy Validation of LiDAR Data

Vertical accuracy is the principal criterion in specifying the quality of elevation data, whether it comes from photogrammetry, LiDAR, SAR or any other elevation technology. Determination of vertical accuracy of LiDAR data has always been a challenge in LiDAR projects. The vertical accuracy (absolute) would refer to the accuracy of the point cloud data within the project coordinate system. Normally the accuracy is assessed by comparing the LiDAR point cloud against individual surveyed points measured independently. Such points are commonly referred to as check points/validation points and these points need to be an order of magnitude higher precision than the collected LiDAR.

This paper deals with the evolution of the accuracy validation of aerial LiDAR and also suggests parameters for validating mobile LiDAR data.

Validation of Aerial LiDAR Data

Traditionally, National Map Accuracy Standard (NMAS) used Vertical Map Accuracy Standard (VMAS) to define vertical accuracy at the 90% confidence level. Later on, National Standard for Spatial Data Accuracy (NSSDA) defined vertical accuracy at the 95% confidence level. As the aerial LiDAR technology matured and was operational, it was

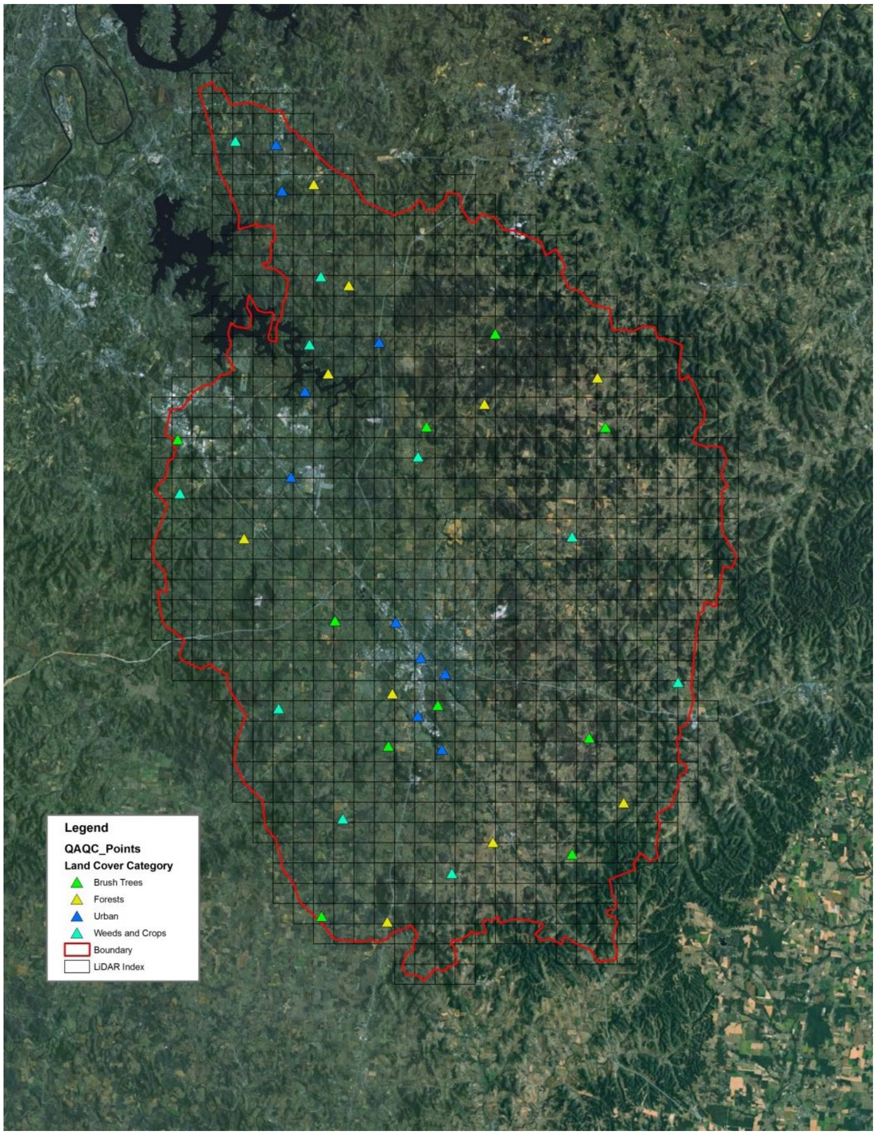

Figure 1: Distribution of Check Points on Aerial LiDAR Project

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observed that the testing of LiDAR derived elevation data has to be performed over various ground cover categories for measurement and reporting purposes. Accordingly, ASPRS guidelines were developed for validating the vertical accuracy of LiDAR data using the validation/check points collected over different land cover categories. These guidelines also defined three parameters to define the vertical accuracy of the aerial LiDAR.

The ASPRS guidelines require a minimum of 20 test points (checkpoints) for each major land cover category representative of the project area to be mapped using a minimum of three categories namely open terrain, weeds and crops, and forested. Other common land cover categories are scrub, brush lands, and low trees urban areas of dense manmade structures; sawgrass; and mangrove. It is essential the points should be well distributed across the project area.

Fundamental Vertical Accuracy (FVA) is determined with checkpoints located only in open terrain where there is a high probability of having LiDAR return from the bare-earth ground surface and where errors are expected to follow a normal error distribution. Fundamental vertical accuracy is calculated at the 95-percent confidence level as a function of RMSE(z).

Supplemental Vertical Accuracy (SVA) is the result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by FVA.

Consolidated Vertical Accuracy (CVA) is the result of a test of the accuracy of vertical checkpoints consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95th percentile, CVA is always accompanied by FVA.

It should be noted that the SVA value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. However, the CVA value is a requirement that must be met, regardless of any allowed "busts" in the SVA(s) for individual land cover types within the project. **Figure 1** shows the distribution of checkpoints in an aerial LiDAR project.

It is to be noted that the vertical accuracies of the aerial LiDAR are linked to the appropriate contour interval that is generated from the data and the nominal pulse spacing that is needed to meet the vertical accuracy requirement. The relationship between NPS, FVA and contour interval are shown in **Table 1**.

Table 1: NPS and expected FVA.

NPS	RMSE	FVA	Contour Interval
1 m	12.5 cm	24.5 cm	2 ft
2 m	24.5 cm	49.5 cm	4 ft

Irrespective of the application of the LiDAR data, the nominal pulse spacing and the needed contour interval will dictate the vertical accuracy of the aerial LiDAR data. However, efforts are on to define accuracy thresholds for digital elevation data independent of contour interval.

Validation of Mobile LiDAR Data

Mobile terrestrial LiDAR was the logical progression from aerial LiDAR systems, by employing recent technological

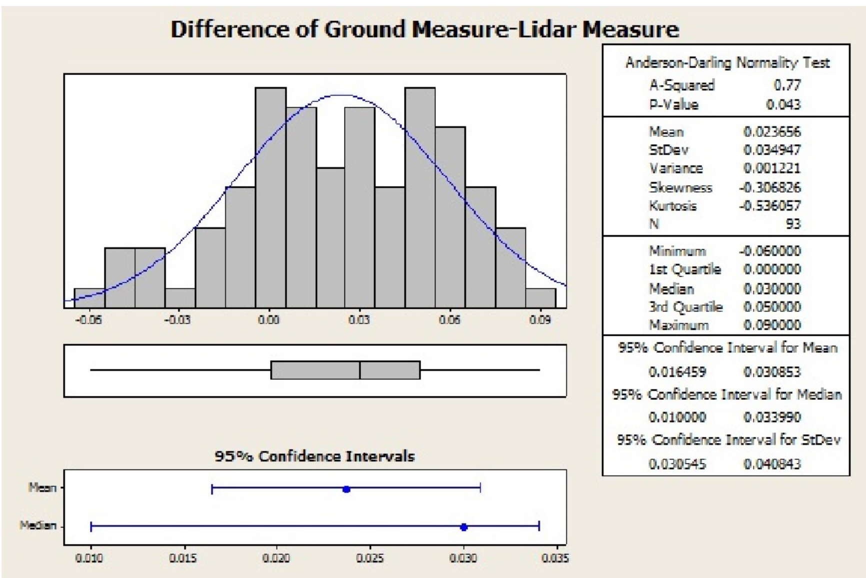

Figure 2: Difference of Ground Measure-LiDAR Measure (Hard Surface)

evolutions in sensor design that facilitate data capture from a vehicle travelling at highway speeds. The mobile LiDAR technology capitalizes on enhanced sensor designs that facilitate increased point densities, greater precision, and the ability to produce survey-grade accuracies. The standards for quantifiable vertical accuracy requirements for mobile LiDAR are still evolving.

Currently, the California Department of Transportation (CALTRANS) has developed a set of specifications that explicitly addresses the required information and data quality that should be provided with mobile LIDAR surveys. CALTRANS has suggested a two part classification system for mobile LIDAR surveys based on the accuracy requirements also known as Type A and Type B. Type A covers topographic surveys involving engineering topographic surveys, as-built surveys and surveys involving structures and bridge clearance, deformation surveys, and forensic surveys. Type B covers earthwork and low-accuracy topographic surveys involving corridor study, planning surveys, asset inventory, management surveys, and environmental surveys.

The Florida Department of Transportation (FDOT) also provided guidelines similar to the CALTRANS guidelines with the difference being FDOT guidelines added Type C in addition to Type A and Type B. Type C corresponds to planning, transportation statistics, and general asset inventory surveys, which requires lower accuracy. Currently, ASPRS is also developing mobile mapping standards involving quantifiable vertical accuracy standards. It is clear that the accuracy requirements for Type A, B, and C projects will be different so there should be different threshold limits for vertical accuracy requirements in Type A, B, and C projects.

Table 2: Classification of Surfaces

Surface Category	Surface Type
Hard Surface	Pavement Centerline
Soft Surface	Edge of Pavement Edge of Concrete Back of curb

It is a normal practice to place and measure High Accuracy Targets (HATS) throughout the project area. Normally these targets are generally located along mainlines, ramps, and arterials and should be well distributed in the project area. The targets are normally located horizontally using RTK GPS. High-accuracy elevations are established on the targets using either differential leveling and/or total stations. The number and distribution of HATS needed for mobile LiDAR project is still evolving.

Absolute Accuracy Validation

Like aerial LiDAR projects, it is proposed to collect validation points over two different surface categories namely hard surface and soft surface. Table 2 shows the classification for hard and soft surface. It is likely additional surface types can be added.

For the purpose of validating the vertical accuracies of mobile LiDAR data, it is suggested collecting high accuracy targets on both the hard surface and soft surface. It is expected that the mobile LiDAR will provide better vertical accuracy on a hard surface compared to a soft surface. A set of new parameters is proposed for mobile LiDAR similar on the lines of aerial LiDAR. The vertical accuracy is to be tested by comparing the elevations obtained from mobile LiDAR on the hard surface and soft surface separately with elevations of the same points as determined from the control survey.

Fundamental Vertical Accuracy Hard Surface (FVAHS)

FVAHS is determined with checkpoints located only in the hard surfaces and where errors are expected to follow a normal error distribution. FVAHS is calculated at the 95-percent confidence level as a function of RMSE(z).

Fundamental Vertical Accuracy Soft Surface (FVASS)

FVASS is determined with checkpoints located on the soft surfaces namely edge of pavement, edge of concrete, and back of curb. It is proposed that FVASS is calculated at the 95 percent confidence level as a function of RMSEz though it is likely that FVASS may have to be computed on 95th percentile.

Analysis of the Minimum, Maximum and Desired Differences between the Checkpoints and the LiDAR points

The vertical accuracies of the mobile LiDAR can also be validated by measuring the minimum, maximum, and desired differences between the checkpoints and the LiDAR derived elevation value. Again, the desired differences will be different for hard and soft surface.

An example of the statistical summary of checkpoints and LiDAR based elevation for hard surface is shown in **Figure 2**.

Conclusion

An attempt has been made in this paper to define the potential parameters which will validate the vertical accuracy of the mobile LiDAR data. The parameters have been defined based on the experience gained in working on various mobile LiDAR projects and if the parameters are agreeable, these parameters can be suggested for consideration in the ASPRS mobile LiDAR guidelines.

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