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Planning, Understanding, and Validating Lidar Accuracy

By Brian Raber and Doug Jacoby

"Fast is fine, but accuracy is everything," according to Xenophon, the Greek historian. That comment is as applicable today as it was in 400 BC, especially in airborne lidar data acquisition and delivery.

With the increasing demand for airborne-acquired lidar data, the need for speed of acquisition and data delivery to the end user has increased. This demand for rapid turnaround compounds the complexities of accuracy as firms push the envelope to meet clients' unique requirements for valuable, timely, and applicable topographic databases. A thorough knowledge of where error can occur and how the positional accuracy of the database will be validated is a necessary component for a successful lidar mapping project.

The compounded effects of inaccuracy are becoming well known to practitioners with advanced technical abilities in this field. However, a thorough understanding of the production steps in the project where error can occur allows stakeholders to have realistic expectations for accuracy. It also allows the team to be completely knowledgeable about the procedures, timeframe, and resources needed to validate and publish the accuracy results.

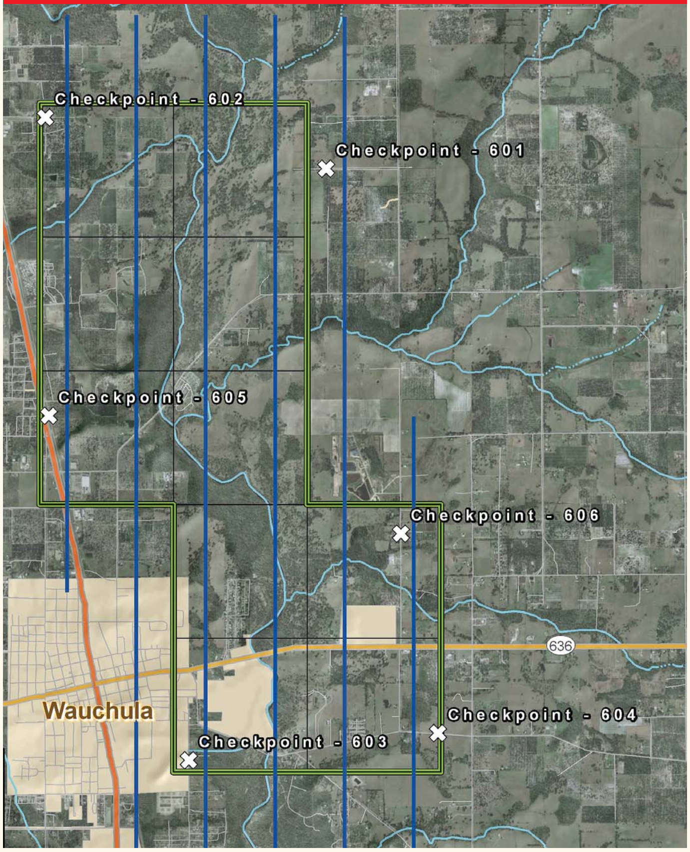
Building accuracy into a project is accomplished through understanding the lidar technology and development of a detailed plan by the lidar consultant. The overall project plan should be augmented by individual technical plans that mitigate potential issues in three specific areas: 1) on the survey ground support, 2) during the airborne lidar data scoping and acquisition, and 3) during the lidar data post-processing. As part of the process, the consultant and client should agree to use the best validation methods affordable to verify that the accuracy goals are met.

Overall Project Planning

The overall plan should:

- identify the predetermined accuracy specifications and guidelines,
- ensure that client/team communications, methods, and plans are established,
- make sure adequate project procedures and documentation needs are defined and understood,
- define schedule milestones and clarify budget constraints,
- contain plans for office data management, quality control, accuracy assessment, and safety,
- identify a comprehensive list of deliverable products, and
- include a resource allocation plan to ensure that all stakeholders have an adequate number of trained and experienced professionals to support the project.

Because acquiring airborne lidar data is a complex undertaking, it pays to know all the nuances that can affect accuracy.



Typical project boundary, flight line plan, and control layout diagram.

Once these overarching project needs are included, the plan must address the project's technical aspects, including:

- accurately identifying and digitally documenting the project boundaries,
- defining the desired projection, horizontal and vertical datums, and units that serve as the basis of the project coordinate system,
- ensuring correct conversions and translations (e.g., the use of U.S. coordinates versus international coordinates),
- ensuring that the correct lidar point spacing (a.k.a. as ground sample distance—GSD) is adequate to meet accuracy expectations,

- anticipating flight line breaks for extreme elevation changes,
- identifying the optimum laser pulse rate and/or scan rate for the flying altitude,
- identifying the appropriate field of view to provide adequate beam penetration in vegetation and urban areas, and
- ensuring a sufficient side overlap for each flight line so data is not missed.

1) Ground Control Support Planning

A ground control support plan should be developed in conjunction with a qualified registered land surveyor who understands the unique characteristics of the local survey networks and conditions. This should include:

- avoiding erroneous horizontal or vertical reference stations,
- keeping the Global Positioning System (GPS) baseline-flight line distance under a maximum of 20 miles,
- planning for equipment malfunctions and always carrying an additional GPS receiver,
- mitigating GPS base station problems including insufficient satellite configuration (PDOP), incorrect antenna height measurement, battery failure, vandalism, etc.,
- preparing for any post-processing errors including poor constraint network, lack of local control knowledge, datum transformation, monuments at ground elevation, etc.,
- accounting for operator error, and
- identifying the quantity and type of land cover survey points that will be used to check accuracy.

2) Airborne Lidar Acquisition Planning

For the acquisition planning, the well-known saying "measure twice and cut once" comes into play. Accuracy in acquisition is contingent on navigational route accuracy, and this is contingent on input from a boundary file typically provided by the client. While it appears simple, when developing flight plans that cover the appropriate area, "measure twice" to ensure that the aircraft is flying the correct route.

It's also necessary to anticipate technical difficulties such as a laser and/or inertial measurement unit (IMU) malfunction or airborne GPS (AGPS) problems through an on-board antenna offset or system failure, an aircraft electrical problem, or operator error. Also make sure that pre- and post-mission calibrations are always performed.

3) Lidar Post-Processing Planning

The post-processing of lidar data is computer intensive and highly automated. However, intimately knowing the project's accuracy goals as well as the local terrain and land cover characteristics help define the data processing workflow. For accuracy, the post-processing plan should incorporate many checks and balances including:

- understanding the project bore sighting specifications as they relate to the predefined accuracy goals,
- using a proven process for validating the horizontal and vertical survey adjustments or shifts,
- calibrating each flight line to adjacent lines,
- ensuring that breaklines reference lidar data during compilation, and
- watching for manual classification issues that can generate too many artifacts or misclassified data and automated classification issues that can be over aggressive and eliminate important terrain features.

Accuracy Assessment Data Sources

Once the data is acquired and post-processed, the question becomes, "Does the lidar data conform to the planned positional accuracy criteria?" Many sources exist for independently comparing the lidar data to real-world coordinates, and often this important process is under-budgeted. In a best-case scenario, the client has the appropriate expertise to work closely with the lidar consultant or an independent firm to create an accuracy assessment plan that would include:

1) *Individual check points:* These are typically single GPS locations, surveyed in open and flat locations, with x, y, z values as the result. They are surveyed at the same time the lidar is flown to eliminate the possibility of changed conditions that could affect validation and to assist the consultant in internal calibration validation.
2) *Surveyed cross sections:* Using traditional total station and digital level surveying equipment, a string of elevation points are measured in a loop or linear pattern, typically under tree canopy where GPS equipment cannot operate.
3) *Area surveys:* When validating using as-built and engineering drawings and other existing data as a resource, use caution, as they may not truly represent current conditions.
4) *Ground truth surveys:* The Federal Emergency Management Agency (FEMA) has guidelines for cover class surveys that include urban, bare ground, short grass, brush, and forest and that specify a minimum of 20 survey points per land cover category. Using these detailed land cover/land use classifications allows the team to compare the accuracy of the lidar to points in and under various types of vegetation conditions.
5) *Existing survey points:* When mining for existing survey data that could be used to test the lidar accuracy, proceed with caution. Red flags include: older vintages may not truly represent present conditions, not understanding the survey basis (i.e., datums), and knowing the technology used to collect the original information.
6) *Horizontal accuracy checking:* Be sure to check horizontal accuracy by comparing to lidar-visible planimetric features, contours in flight line overlap areas, and contours on buildings.

Several accuracy standards are being used, so prior to publishing a request for proposals, we recommend that you identify the project's guiding standards. Factors to consider are the desired accuracy of the lidar points, interpolated contour lines, procedures for validating the different products, and how obscured areas are to be assessed. Several interim standards created by FEMA and the American Society for Photogrammetric and Remote Sensing (ASPRS) provide the best set of knowledge about accuracy. The ASPRS sources include

« *Lidar behaves differently in various land cover situations. In surveying positions under the tree canopy and in highly reflective sandy soils, it is important to understand the overall accuracy of densely foliated locations such as this one found in Tallahassee, Florida.*

Horizontal Accuracy Reporting for LIDAR Data, Sensor Calibration and Reporting, Vertical Accuracy Reporting for LIDAR Data, and *Laser Eye Safety*.

Using Independent Quality Control

Often, the client's internal teams are over-tasked, and the accuracy and acceptance of the lidar information becomes a secondary priority to schedule adherence. As most new clients learn, lidar data products and survey validation methodologies, accuracy assessment formulas, and compliance interpretation of data comparison are complex. To address this and other project management responsibilities, clients may choose to retain an independent quality control source to perform systematic visual reviews for adherence to data acceptance and accuracy assessment criteria. Several reputable firms such as Dewberry and Jones Edmonds & Associates have industry-recognized experts, well-established management procedures, and software processes for automated data assessment that can make hiring an independent firm affordable and practical.

With lidar becoming common for both public and private sector organizations, it's important to completely understand the value of positional accuracy. From over 10 years of lessons-learned experiences, we offer several takeaways from this article to help new and existing users of lidar.

First, developing internal and external (client and consultant) plans for each major step of a project formally documents expectations and becomes the basis for quantitatively and qualitatively measuring the success of the project.

Second, underestimating the amount of time it takes to successfully manage the many aspects of a project is common. Dedicated and frequent lines of communication between the client and consultant allow for rapid resolution of issues as they arise.

Third, engaging the expertise of a registered land surveyor familiar with various survey methods, local conditions and problems, control point data mining procedures, and data accuracy testing is a huge asset to the project team.

Last, producing accurate lidar data requires many automated and technologically advanced systems, and the process goes well beyond bolting a lidar system to an aircraft. Considering all the possibilities for error, when retaining lidar consultants clients should request a proven demonstration of their knowledge of the many complexities of lidar planning, acquisition, processing, and accuracy validation.

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Additional Resources

FGDC Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy (NSSDA), 1998.

Appendix A, Guidelines for Aerial Mapping and Surveying, to FEMA's "Guidelines and Specifications for Flood Hazard Mapping Partners," April 2003.

Guidelines for Digital Elevation Data, version 1.0, National Digital Elevation Program (NDEP), May 10, 2004.

ASPRS Guidelines: Vertical Accuracy Reporting for Lidar Data, version 1.0, May 24, 2004.

Digital Elevation Model Technologies and Applications: The DEM Users Manual Edited by David Maune, PhD, CP, 2nd Edition 2008.

LIDAR Guidebook: Concepts, Project Design, and Practical Applications, Urisa Quick Study Series, authors Raber and Cannistra, published by the Urban and Regional Information Systems Association (URISA), Park Ridge, Illinois, 2005.