American Society for Photogrammetry and Remote Sensing (ASPRS)

Summary of Research and Development Efforts Necessary for Assuring Geometric Quality of Lidar Data

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Acknowledgement

This document represents a collaboration between industry and government partners through a US Geological Survey (USGS)/ASPRS Lidar Data Quality Working Group, or sometime referred to as the "ASPRS Lidar Cal/Val Working Group". ASPRS and its Lidar Division greatly appreciate the collaboration and effort provided by the community to complete this guidelines document. Any comments, questions or suggestions related to these guidelines, or associated research can be addressed through the ASPRS Lidar Division, lidardivision@asprs.org.

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Summary

To summarize, the US Geological Survey (USGS)/ASPRS Lidar Data Quality Working Group, or sometime referred to as the "ASPRS Lidar Cal/Val Working Group, referred to in the rest of this document as WG, has investigated various factors associated with the geometric quality of lidar data. The WG has noted that while the quality of lidar data have improved tremendously in the past few years, the QA/QC of these data are not standardized including the semantics, processes for measurement and reporting and meta data. Therefore, to ensure the geometric quality of that lidar data required for scientific (statistical error propagation and estimation) and non-scientific purposes (including legal), the WG has recommended several topics for research and development.

To quantify the noise level in the data, the WG recommends research and development efforts towards answering the following questions:

- How should the inter swath "noise" be mathematically defined?
- How should measurements be made to quantify interswath noise?
- How should these measurements be summarized (in terms of mean, median, standard deviation, and spatial distribution, etc.)?

On Inter Swath analysis, the WG further recommends that government agencies, academia and the industry work together towards determining acceptable solutions to the following questions

- Are current thresholds for relative accuracy valid?
- Are the thresholds measurable?
- Should the thresholds be different for different terrain?
- What should be the thresholds for the discrepancy angles?

The WG also recommends a comprehensive error library consisting of systematic errors and their sources be documented and maintained, for current as well as future lidar technologies.

Towards measuring the absolute accuracy of lidar data, the WG recommends that the following studies be undertaken:

- Cost of deploying 3D accuracy assessment targets as a percentage of total project cost, project size, terrain conditions, etc.
- Research on estimation of absolute three-dimensional accuracy of lidar data using latest technologies, including mobile lidar, static lidar, and UAV data.

Towards assessment of national lidar geometric quality and consistency, the WG recommends that research efforts are directed to answer the following topics:

- How should inter project lidar data consistency be mathematically defined?
- How should the data consistency metrics be measured?
- How should must data acquisition be specified to ensure consistency of features across spatial extents of different projects?
- Are there new technologies that can assist in enhancing inter project lidar data quality?

Introduction

Calibration is often called for with a new instrument. However, instrument error can occur due to a variety of factors such as environment, electrical supply, addition of components, process changes, etc. Therefore, calibration should be performed, at a minimum, as directed by the instrument manufacturer either periodically, or based on usage. Calibration should also be performed when an instrument has had a shock or vibration (which potentially may put it out of calibration), any time it is reinstalled on the host platform (e.g., after aircraft maintenance), or whenever observations appear questionable. It is common practice calibration of a partial set of sensor system parameters can be performed in situ (field tests or self-calibration), and it is a standard practice among lidar data providers to perform such a calibration of boresight parameters.

The users of lidar point cloud data require quantifiable means to be assured of the calibration of the lidar data acquisition system. This quality of calibration of lidar systems can be quantified without requiring externally referenced data. These means are Intra Swath analysis of data and Inter Swath analysis of data.

Intra Swath Analysis

The Intra Swath analysis of data quantifies the level of noise present in the lidar sensor (for e.g. due to the range measurements due to jitter). In the current specifications (Heidemann 2014), the intra swath quality of data is in general defined as the repeatability of measurements over a smooth surface, and in particular, repeatability of elevation values over a flat surface.

Inter Swath Analysis

Lidar data for large projects are collected by flying swaths, with overlap between portions of the swaths to prevent data gaps or to ensure the required level of point density. The quality of calibration of a lidar instrument and data acquisition most readily manifests itself in these overlapping areas. The USGS-ASPRS WG has defined several measures to quantify the Inter

Swath accuracy or relative accuracy of lidar data. These measures are termed Data Quality Measures (DQMs).

Table 1 Data Quality Measures (DQMs) or inter-swath goodness of fit measures

Nature of surface	Examples	Data Quality Measures (DQMs)/Goodness of fit measures	Units
Natural surfaces	Ground surface, i.e. not trees, chimneys, electric lines etc.	Point to natural surface (tangential plane to surface) distance	Meters
		Point to surface vertical distance	Meters
Man-made surfaces	Roof planes	Perpendicular distance from the centroid of one plane to the conjugate plane	Meters
	Roof edges	Perpendicular distance of the centroid of one line segment to the conjugate line segment	Meters

The WG have also defined the process of measuring these DQMs and defined how these could be summarized to robustly quantify the lidar point cloud's geometric quality. More details can be found in the "ASPRS Guidelines of Measurement of Inter Swath Geometric Quality of Lidar data.

The sampled locations where DQMs are measured be categorized as functions of slope of terrain: Flat terrain and slopes greater than 10 degrees. For higher slopes, the DQM errors are further categorized as belonging to slopes along track and across track. The WG recommends that the Inter Swath quality may be reported in three parts for flat areas:

a. The distance of each sampled location from the mean centerline of overlap is measured.

b. The discrepancy angle at each sampled location is measured.

c. The summary statistics for the discrepancy angles is recorded. For high quality data, the discrepancy angles must be close to zero, and the standard deviation must also be low.

The Discrepancy Angle (DA) is a measure of systematic errors present in the lidar point cloud, and is a direct indicator of the geometric quality of the data.

Recommendations for Further Research

To quantify the intra swath noise level in the data, the WG recommends research and development efforts towards answering the following questions:

- How should the intra swath "noise" be mathematically defined?
- How should measurements be made to quantify intra swath noise?
- How should these measurements be summarized (in terms of mean, median, standard deviation, and spatial distribution, etc.)?

On Inter Swath analysis, the WG further recommends that government agencies, academia and the industry work together towards determining acceptable solutions to the following questions:

- Are current thresholds for relative accuracy valid?
- Are the thresholds measurable?
- Should the thresholds be different for different terrain?
- What should be the thresholds for the discrepancy angles?

It is also recommended that a comprehensive error library consisting of systematic errors found in lidar data and their source be maintained by the ASPRS.

QC of Lidar System Calibration and Data Acquisition using Absolute Accuracy Measurements

Introduction

The absolute accuracy of lidar data ideally must consider the accuracy of all three dimensions of the data. Due to the legacy of lidar data being used primarily for Digital Elevation Models, only the vertical accuracy of the data are generally reported. Another reason could be that in the initial years of the development of the technology, the point spacing of the data was low, and hence it was difficult to identify planimetric features from the data with certainty.

However, the applications of lidar data have grown tremendously since the early days. It is not limited to being an input to DEMs, and the data are used in solving many problems which require their accuracy be known in all three dimensions. Also, with the increasing use of return intensity data, development of 3D feature extraction algorithms, increasing point density, as well as increased computational resources, it is possible to measure the accuracy of all three dimensions of the data. Currently, the vertical accuracy of the data is measured on mostly flat, clear and open areas. However, these measurements do not provide any quantifiable estimate of the horizontal accuracy of the data set. However, there are very few studies that have attempted to provide standardized processes to measure the absolute accuracy. Some of these are mentioned below. These studies propose the use of specially designed 3D targets or intensity identifiable targets. In Figure 2 below, example targets are shown and identified, as such; the first row shows targets developed by the Ohio State University for the Ohio Department of Transportation; the second row depicts targets developed for Indiana Department of Transportation and the third row depicts a 3D pyramid shaped target designed by Jason Stoker of USGS and retro reflector based on targets designed by the National Geospatial-Intelligence Agency. However, deploying targets can be expensive. Few, if any, of the studies have focused on the cost of deploying such targets, which are assumed to be high based on current costs of obtaining ground control points. Targets deployed beforehand can also be inadvertently moved or tampered with.

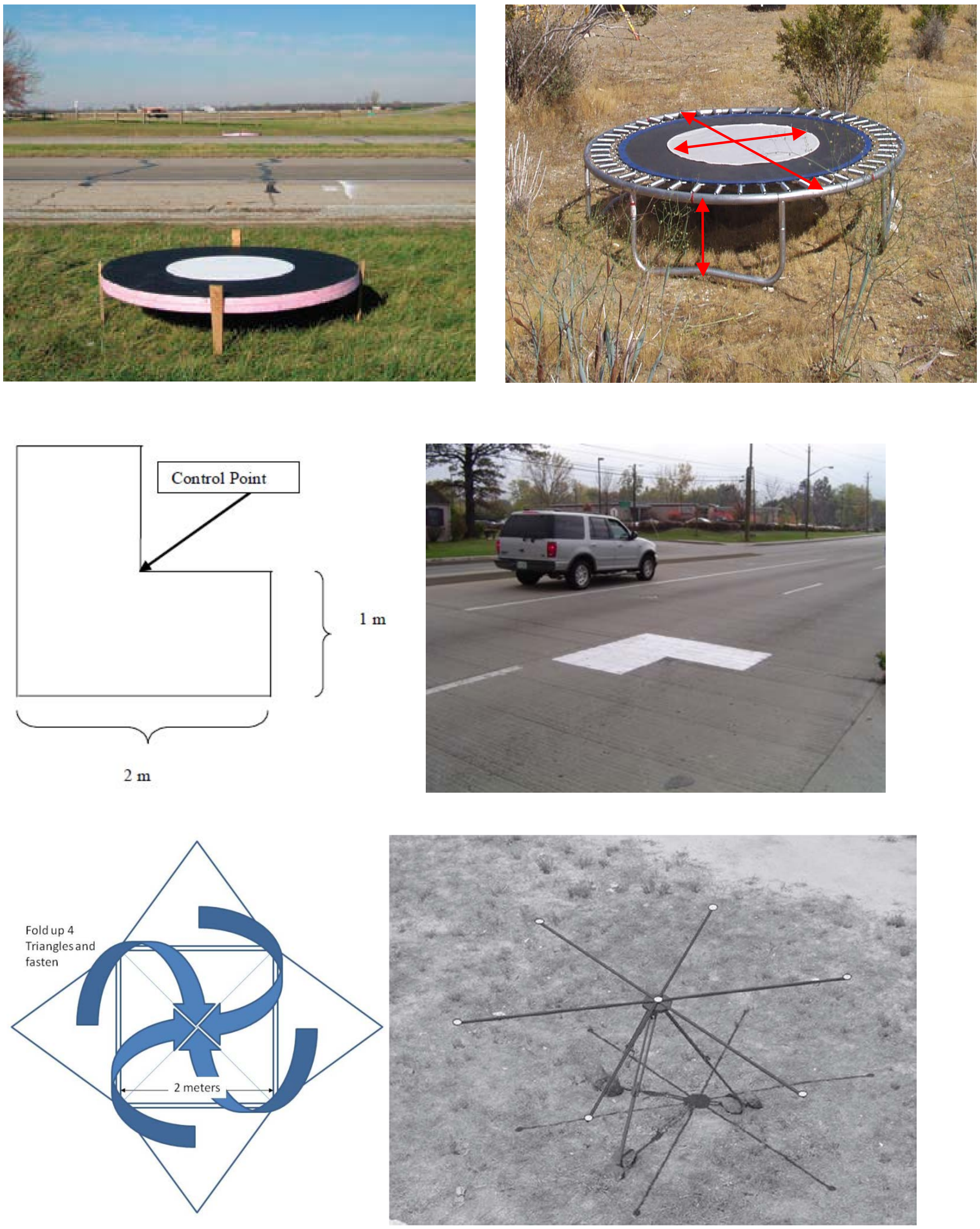

Figure 1 Targets used in planimetric and vertical elevation assessment of lidar data.

Recommendations for Further research

The WG recommends that the following studies be undertaken:

- Cost of deploying targets as a percentage of total project cost, project size, terrain conditions, etc.
- Research on estimation of absolute three-dimensional accuracy of lidar data using latest technologies, including mobile lidar, static lidar, and UAV data.

QC of Lidar data for National Lidar Projects such as 3DEP

Introduction

National projects including the 3D Elevation Program (3DEP) are envisaged to support national and pan-regional scientific and engineering goals. Many of the lidar acquisition projects have scientific goals that are regional or sub-regional in scope. Their geometrical quality assessments are also limited in their spatial extent. Lidar data for scientific projects; such as, river systems analysis, carbon sink assessments, interstate road networks, watersheds, etc.; require data assessments that are similar in scope, i.e. across projects. In practice, individual projects are executed by USGS with other federal and local partners in a more ad-hoc (spatially) manner.

Many features; such as streams, roads, forests, etc., will span multiple collections or projects. It is important to the scientific community that these features are represented in a consistent manner by the lidar data, even though the data may be acquired by different vendors, using different sensors, and at different times. The consistency between adjacent datasets must be quantified and documented in the metadata.

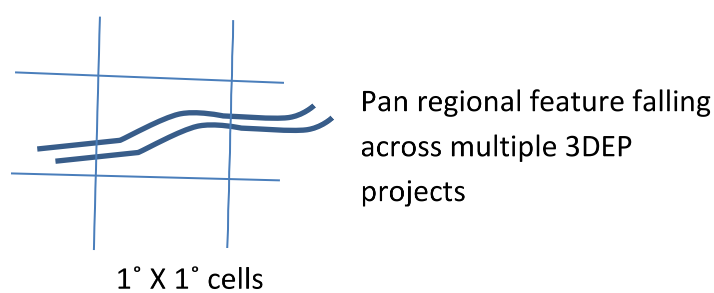

Figure 2 Illustration of pan regional features of scientific importance that require quantification of inter project geometric alignments

Recommendations for Further Research

The WG recommends that government, academia and the industry stakeholders research and develop methods for inter project lidar data consistency. The specific questions that are required to be answered include

- How should inter project lidar data consistency be mathematically defined?
- How should the data consistency metrics be measured?

- How should data acquisition be specified to ensure consistency of features across spatial extents of different projects?
- Are there new technologies that can assist in enhancing inter project lidar data quality?

QA of Lidar data using Sensor Model based Geometric Processing Methods

Introduction

Geometric processing of raw data (GNSS, IMU, range, etc.) to (X, Y and Z) point cloud uses parameters derived from laboratory and self-calibration methods. The geometric process often involves adjusting boresight and other parameters using overlapping data and in conjunction with ground control points, such that the resulting point cloud are internally consistent and externally match the GCPs. The traditional procedure is a manual adjustment process based on the operator's expertise to minimize error. However, the geometric processing parameters are often correlated and it is easy to misinterpret the source of errors. These procedures also implicitly assume that the other geometric correction parameters hold their previously computed values, which may not be the case. The results depend on individual skill, experience of the operator, and are exhausting, time-consuming and expensive. Traditional methods also have the following drawbacks:

- They do not allow estimation of error in the generated data.
- Data sets generated by different users cannot be easily compared to each other.
- The processes cannot be traced to an accepted standard; i.e., the calibration is not conducted using a measure of higher accuracy.

It is recommended that manufacturer provided automated geometric processes be followed to the extent possible.

Rigorous geometric processing methods

Rigorous geometric processing methods are based on determining parameters that describe the sensor model completely (including the provision of expected magnitudes of error). The parameters include boresight parameters. Since many parameters associated with a complete sensor model are proprietary, software to perform rigorous geometric processing should be provided by the instrument manufacturer. Alternately, sensor manufacturers are encouraged to make their sensor models open. Conceptually, the rigorous geometric process relies on minimizing discrepancies between tie features using redundant observations (data). These tie features must be features that can be reliably extracted from point cloud data. Possibly the easiest feature that can be reliably extracted from a point cloud are planes. Breaklines can be treated as the intersection of two planes, and points can be treated as intersection of at least three planes. Most manufacturer provided rigorous geometric processes have focused on extracting (sloping) planar features (e.g. roof planes, etc.) from the overlapping portions of point cloud, including those obtained from flying opposite directions, cross-strips and from different altitudes. Each point lying on the planar feature forms an observation equation (using the complete sensor model), and a constraint equation is used for points that are known to lie on the same plane. The parameters of the sensor model are estimated by minimizing the errors (e.g. least squares). Other methods of calibration that use extracted breaklines and points have also been successfully implemented (Habib et al., 2010)

Quasi-rigorous calibration methods

Quasi-rigorous geometric correction methods are very similar to the rigorous methods in terms of their use of planar and other features as tie features towards geometric processing of data. However, these methods do not have access to the actual sensor model, or all the parameters involved in the sensor model. These methods therefore use a generic sensor model substituting proprietary or unknown sensor parameters with generic sensor parameters. Examples of a generic sensor model include the Universal Lidar Error Model (ULEM, Rodarmel et al., 2015), now renamed as the Generic Point Cloud Model (NGA, 2015). Some methods also use a limited set of parameters (e.g. using trajectory information, but not the range). However, the geometric correction process is the same as the rigorous methods, i.e. these methods also use planar patches, extracted planar features or combine extracted planar features to make measurements on derived features such as breaklines and points (Habib et al., 2010).

Recommendations for Further Research

The Sensor Model based calibration methods are essential for the success of error propagation models that estimate the error present in the lidar data point cloud. The WG recommends that

- The possibility of expressing error in terms of generic sensor models be investigated further.
- Isolating the contribution of generic subsystems towards the total error budget be studied further. In particular, the errors introduced in the point cloud data due to errors in sensor trajectory must be further investigated

References

1) Habib A, Kersting A. P., Bang K. I., and D. C. Lee. 2010. "Alternative Methodologies for the Internal Quality Control of Parallel LiDAR Strips," in IEEE Transactions on Geoscience and Remote Sensing, vol. 48, no. 1, pp. 221-236, Jan. 2010.
doi: 10.1109/TGRS.2009.2026424
2) Heidemann, H. K., 2014, Lidar base specification version 1.2, U.S. Geological Survey Techniques and Methods, Book 11, Chapter. B4, 63 p.
3) Rodarmel, C.; Lee, M; Gilbert, J.; Wilkinson, B.; Thiess, H.; Dolloff, J; O'Neill, C; "The Universal Lidar Error Model". Photogrammetric Engineering and Remote Sensing, July 2015, Volume 81, Issue 7; pp. 543-556.
4) National Geospatial-Intelligence Agency, 2015, The Generic Point-cloud Model (GPM): Implementation and Exploitation, NSG Standards Documents. Available online: https://nsgreg.nga.mil/doc/view?i=4197.