# A REVIEW OF THE ASPRS GUIDELINES FOR THE REPORTING OF HORIZONTAL AND VERTICAL ACCURACIES IN LIDAR DATA

C. Rodarmel[a], A. Samberg[b], H. Theiss[a], T. Johanesen[c]

[a]Integrity Applications Incorporated, 5180 Parkstone Drive, Chantilly, VA 20151 (crodarmel, htheiss)@integrity-apps.com
[b]ASPRS Lidar Committee, 5410 Grosvenor Lane, Suite 210, Bethesda, Maryland 20814 - info@avaproedu.com
[c]National Geospatial-Intelligence Agency 12300 Sunrise Valley Drive, Reston, VA 20191 - Todd.E.Johanesen@nga.mil

**Commission I, WG I.2**

**KEY WORDS:** Lidar, Airborne, Laser Scanning, CAL/VAL, Specification, Standards, Accuracy

**ABSTRACT:**

The American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Committee (ASPRS LC) has developed guidelines titled "ASPRS Lidar Guidelines – Vertical Accuracy Reporting for Lidar Data V1.0 " that provide recommendations on measuring and reporting the vertical accuracy of datasets acquired by means of airborne laser scanning (ALS). The ASPRS LC has also been working on developing a similar document related to the horizontal accuracies associated with lidar data. High Resolution Terrain Information (HRTI), or elevation models containing both high spatial resolution and high accuracies, is often utilized beyond its traditional role in generating Digital Elevation Models (DEM) for applications such as precise geopositioning with rigorous error propagation. ALS is an ideal HRTI source due to its dense post spacing and very accurate elevations. However, in order to use these datasets in non-traditional applications and obtain reliable results, standards are required for file format and error reporting. With minor modifications, the ASPRS guidelines may provide a suitable framework for such specifications. This paper provides an overview of the ASPRS lidar guidelines and makes several recommendations to the ASPRS LC related to the guidelines. The recommendations focus on the implications of adopting the guidelines for non-traditional applications such as the precise geopositioning scenarios. The guideline overview provides a positive review of the ASRPS efforts, but also provides suggestions that if implemented would allow them to be even more universal. Specifically, these recommendations would help assure the utility of lidar data for the widest range of lidar-derived HRTI users possible.

## 1. INTRODUCTION

The collection and use of high resolution Digital Surface Models (DSMs) from non-traditional sources has received much attention and increased emphasis in the remote sensing and geospatial communities in recent years. This is primarily driven by the advent of technologies such as airborne laser scanning (ALS) and Interferometric Synthetic Aperture Radar (IFSAR) which have matured to a point that they provide a viable means to generate high quality DSMs over large portions of the earth. As the technology continues to mature, the resources required for gathering this data—from collection, to processing, to exploitation continues to drop. At the same time, the accuracies of DSMs have improved and the distance between posts has been reduced. Because these DSMs are typically collected at a higher resolution and greater accuracy than currently available Digital Elevation Model (DEM) products, such as the US's National Geospatial-Intelligence Agency (NGA) DTED®, they are often referred to as High Resolution Terrain Information (HRTI).

As this data becomes more readily available, the geospatial community, being a resourceful group, will continue to evolve the use of the data outside of the traditional applications for bare earth and surface modeling. This could include new methods and uses for urban modeling, orthorectification and single ray intersection processes. The variety of uses, however, increases the demand users place on the data sets to support continually evolving needs and the resulting data sets need to be generated rapidly, reliably and accurately. Accurate ALS is an ideal collection tool and method to generate these types of datasets and readily support such calculations. The high resolution elevation data provides additional contextual information to that currently available through a single data collect, and when paired with a high resolution optical image, the necessary ingredients exist for high resolution geospatial processing. However, in order to use these datasets and obtain the reliable results users expect, standards are required for sensor modeling, error reporting and file formatting of the HRTI data.

In 2004, the American Society for Photogrammetry and Remote Sensing (ASPRS), through the work of the ASPRS Lidar Committee (LC), approved a new set of guidelines titled "ASPRS Lidar Guidelines – Vertical Accuracy Reporting for Lidar Data V1.0" (Flood, 2004). The document provides the ASPRS recommendations related to measuring and reporting the vertical accuracy of lidar datasets. Additionally, ASPRS has been working on developing a similar document related to the horizontal accuracies associated with lidar data. Although this guideline has not yet been made public, draft versions are currently under review by the members of the ASPRS LC (ASPRS, 2005b). The ASPRS LC has also been working over the past few years to generate a standard file format (LAS) for the exchange of lidar data (ASPRS, 2005a). This paper provides a brief overview of these guidelines and makes recommendations for future ASPRS LC guidelines, with the goal of accommodating the widest range of lidar-derived HRTI users as possible.

## 2. CASE STUDY: PRECISE GEOPOSITIONING USING HRTI

Airborne imagery provides a good temporal source of data that can be used to remotely locate and identify items of interest. However, in addition to visually locating the item of interest, many users would also like to be able to determine the geoposition (latitude, longitude, and height) of the item.

Several methods can be used to exploit aerial or satellite imagery and geoposition. One of the methods is the single ray intersection. A single ray intersection uses known information about the sensor such as position and orientation to trace the ray passing through a specific image pixel and intersect the ray with a reference surface. The location of this intersection provides the position of the item of interest in a specified reference frame. The advantage of the single ray intersection is that it only requires a single image that shows the item of interest. This eliminates the need for stereo collection, given you have the required digital surface model to provide the height. This of course, leads to the disadvantage-- imagery and associated metadata alone are not adequate input to determine a coordinate. An additional input, the terrain surface, is required.

When using a single ray intersection, the accuracy of the terrain surface has a direct effect on the accuracy of the derived coordinates. A poor elevation in the reference source, used to derive the terrain surface, will result in both horizontal and vertical errors in the derived coordinates. In a similar fashion, if the true terrain features are greatly under-sampled in the reference data, this also leads to both horizontal and vertical errors. Therefore, if the goal is to generate precise coordinates then an accurate reference surface such as a HRTI dataset is required. As mentioned above, lidar or ALS provides the preferred method to generate this HRTI reference data.

There are other benefits to using HRTI data other than as an elevation reference source for the single ray intersection. If the HRTI data is very accurate, then it may also be used as a horizontal control source. Images that have relatively less accurate support data values can be registered to the accurate HRTI data, improving the geopositioning accuracy of the single ray intersection.

All of the applications above require high quality and accurate reference data. Although ALS has been proven to provide such data, guidelines and specifications related to lidar data must be implemented to assure its quality. The use of ALS data in non-traditional applications, such as precise geopositioning, provided the inspiration for the guideline recommendations discussed in this paper.

## 3. THE CURRENT STATUS OF THE ASPRS LIDAR GUIDELINES

Section 2 described the need to control the quality of lidar data being produced through the use of guidelines and specifications. The ASPRS LC is currently developing several guidelines that can be used to help define the required quality control and quality assurance procedures. This section will provide a summary of the ASPRS guidelines.

### 3.1 ASPRS Guidelines for Lidar Vertical Accuracies

The ASPRS Guidelines Vertical Accuracy Reporting for Lidar Data version 1.0 (Flood, M., 2004) identifies the vertical accuracy reporting requirements that are recommended by ASPRS when analyzing elevation data generated using airborne laser scanning technology. This release was published in 2004. These ASPRS guidelines are harmonized with the relevant sections of the Guidelines for Digital Elevation Data (Version 1.0) released by the National Digital Elevation Program (NDEP). The sections on vertical accuracy testing and reporting from the NDEP guidelines have been submitted to the Federal Geographic Data Committee (FGDC) for inclusion as approved revisions to the National Standard for Spatial Data Accuracy (NSSDA). For user convenience the corresponding section references from the NDEP guidelines are cross-referenced and tabulated against section numbers in these guidelines. If cases occur where these ASPRS guidelines are found to be in conflict with the NSSDA, then the NSSDA is the controlling document and takes precedent.

Several key issues are discussed in the ASPRS recommended guidelines. The "fundamental" vertical accuracy is recommended to test in open terrain, specify, and report at a 95% confidence interval. Outside open terrain, the fundamental vertical accuracy is replaced by so-called "supplemental" vertical accuracy, that is vertical accuracy tested using the 95th percentile method (not necessarily normally distributed).

It is suggested to specify a different vertical accuracy in different land cover classes, specifying a relatively relaxed vertical accuracy in forested areas, for example, than in tall grass.
If contour maps or similar derivative products are created, then the vertical accuracy in such cases should be specified, tested and reported for each land cover class; i.e. report a fundamental vertical accuracy in open terrain and a supplemental vertical accuracy in each unique land cover class. The accuracy in each class must independently meet the requirements for the desired contour interval.

The ASPRS recommends that vertical accuracy testing always be done in flat and obstacle free areas. In steep sloping areas attempts should be made to keep test points in reasonably low slope and smooth terrain as possible. For example a small but acceptable horizontal shift in the laser data may reflect in an unacceptable vertical error measurement.

### 3.2 ASPRS Guidelines for Lidar Horizontal Accuracies

Despite extensive evaluation of vertical accuracy of airborne laser scanning (ALS) systems, requirements, limitations and recommendations regarding reporting planimetric (horizontal) accuracy have been less studied and reported. The mapping community was very excited when ALS became commercially available worldwide. The primary interest was in obtaining elevation information in order to extend and update existing 2D maps, especially in forested area. However, managing horizontal accuracy is an important issue, too. During the last five years, the ASPRS lidar committee studied the available best practices regarding assessing planimetric accuracy, which could be recommended to the remote sensing and mapping communities.

Often so-called planimetric errors are neglected with the argument that horizontal error components do not much contribute to the surface generated from laser points. This may be true when the scanned area is flat or laser scanning is profiling. However, there are possible areas of applications of laser scanning such as obstacle avoiding, vehicle guidance, and construction engineering, where planimetric errors must be paid more attention when creating an elevation model. Also, there are a lot of places on the earth where topography is rugged. Then assessing planimetric errors would become a primary concern. The problem of assessing planimetric errors is rooted in the fact that laser points do not carry semantic information that would allow their physical identification on the ground.

Due to the lack of interest in more detailed evaluation of techniques that could better describe and improve planimetric accuracy of laser scanning, to the authors' knowledge only one acceptable technique is used so far. It has been designed and developed by the Ohio State University (OSU), USA, and the Ohio Department of Transportation (ODOT), USA (Schenk, 2001). The main idea is the following.

Concerning the elevation, features in aerial images are compared with their counterparts in the laser point cloud. The procedure is so-called backprojecting. Then laser points are backprojected into oriented stereopairs. The developed procedure checks thousands of points, and gives information about discrepancies between the laser points and the visible surface as defined by overlapping aerial images. The same method is also suitable for checking the accuracy of DEMs. Furthermore, planimetric accuracy of laser points can be assessed by extracting linear features which are then compared with their "true" location. Because linear features cannot be easily retrieved from the laser points, it is proposed to segment the laser points into planar surface patches. After that straight lines are computed by intersecting topologically related planes, such as roofs. However, roof ridge may be slightly different to the intersection of the roof planes. This kind of problem can be accounted for by placing very well reflecting characteristic targets on the surface to be scanned. Later those targets are searched for in the aerial images, extracted from the laser data, and compared. Discrepancies are measured.

Recently, assessing planimetric accuracy still requires a help of photogrammetrical means and artificial targets on the object surface. Furthermore, the current draft version of the ASPRS lidar guidelines for reporting horizontal accuracy does not consider terrestrial laser scanning systems, which are on the market, because of the lack of research work in this particular area. Meanwhile, the ASPRS lidar guidelines explain and provide the recommendations regarding carrying the ALS mission such as measuring and managing the angular misalignment between the laser sensor and the navigational and positional systems (the boresight errors). In addition, the requirements of the important flight parameters are defined. For map creation purposes, the classes of planimetric accuracy are presented with respect to RMSE (Root Mean Square Error).

### 3.3 The ASPRS Lidar File Exchange Format (LAS)

Historically, the ASCII file format had been used for data exchange between various hardware vendors, software developers, data providers, and end users in the field of remote sensing and mapping. With the introduction of commercial laser scanning systems it was realized that there are two major problems with the ASCII file. The first problem is performance because the reading and interpretation of ASCII elevation data can be very slow and the file size can be extremely large, even for small amounts of data. The second problem is that all information specific to the LIDAR data is lost. In May 2003, the first version of the LAS was released by ASPRS (1.0). The LAS file format is a public binary file format that maintains information specific to the LIDAR nature. In March 2005, ASPRS released the second version of the LAS, 1.1 (ASPRS, 2005a). The ASPRS LC maintains the LAS format through its LAS Working Group where GeoCue Corporation (former NIIRS10), USA, plays a leading role. The LAS Working Group is now working on a full version update of LAS to version 2.0. Topics to be covered in version 2.0 include optimisation and revision of the existing format, inclusion of additional data such as RGB values, the potential for waveform encoding, the extension to cover other diverse data formats such as manufacturers' comprehensive outputs and the potential to have the LAS format cover lidar data from terrestrial (ground-based) laser scanners as well. At the request of the US's NGA, the LAS Working Group is also investigating the potential use of the Advanced Authoring Format (AAF) as a wrapper for the LAS data.

The current version 1.1 of the LAS binary data format consists of the following blocks: a header block, variable length records, and point data. As it is defined in the LAS specification version 1.1 from March 2005, all data is in little-endian format. The header block consists of a public block followed by variable length records. The public header block contains generic data such as file signature, GUID data 1-4, version major and minor, and coordinate bounds. The variable length records contain variable types of data including projection information, metadata (i.e. user ID and record ID), and user application data. Point data consists of information about X, Y, Z, Intensity, Scan Direction Flag, Edge of Flight Line, and Classification, for example. Georeferencing for the LAS format uses the same mechanism as in the GeoTIFF standard.

## 4. RECOMMENDED CHANGES AND MODIFICATIONS TO THE ASPRS GUIDELINES

In the sections above, Section 2 described one application that has a need for accurate lidar datasets while Section 3 described efforts currently underway within ASPRS to develop guidelines that will help to assure quality data collections for DEM generation. The ASPRS guidelines could also have an effect on the future of lidar data collections performed to support geopositioning and single ray intersections. However, due to the precise nature of the geopositioning and the desire for implementing rigorous error propagation techniques, several additional items should be considered prior to implementing the ASPRS guidelines. With some minor modifications these guidelines may better suit the needs of the geopositioning community. This section will describe the recommendations.

### 4.1 Recommendations on the Vertical Accuracy Guidelines

One item that should be addressed in the ASPRS Lidar Vertical Accuracy Reporting Guidelines is relative vertical accuracy. These guidelines currently discuss relative vertical accuracy but do not require that it be reported because of the difficulty in measuring it. However, many applications may be very interested in relative vertical accuracy. In some of these applications the relative position between two objects may be much more important than the absolute location of either object. Some applications of precise geopositioning fall into this category. Therefore a relative vertical accuracy should be measured and reported for future HRTI data collections. One possible method that could be used to measure the errors in the data and therefore predict the relative accuracy would be to employ a least squares based strip adjustment technique between adjoining strips (Vosselman, 2002).

One interesting method to display the relative error would be to bin the relative vertical accuracies based on the distance between points. Then the relative error could be plotted versus distance. This information could be used to investigate the relationship between the relative vertical error and other time dependent factors such as the number of flight lines involved, the distance from a GPS base station, etc.

A second recommendation would be to suggest the development and recording of a quality for each individual lidar data point. It would be beneficial to have some measure of quality for each lidar data point. This measure of quality could be developed from information related to the quality of the GPS/IMU solution, the sensor settings (i.e. scan rate and pulse rate), the collection geometry (i.e. altitude and scan angle) and other known factors. This information could be fed into a rigorous sensor model to develop a variance/covariance matrix for every point. Researchers have worked on developing error budgets for the various system components (Huising, 1998) and there has also been work on developing lidar sensor models (Filin, 2001). This proposal is to take this work one step further and develop real-time error estimates per point.

Although the implementation of such a quality measure may require a lot of additional storage, providing covariance matrices for every point would have many benefits in the future. It would provide a method for "intelligent thinning" of the data so that out of the many points that might fall within a given radius, only the point with the highest weight (inversely proportional to variance) would be saved for future calculations. In a similar fashion, it could be used during the gridding process to increase the accuracy of the interpolation by applying a weighting scheme to the points. It would also provide extra information when examining trends in datasets. Finally, providing covariance matrices for each point would allow for rigorous error propagation to determine the accuracy of a coordinate of interest when the data is used for applications such as single ray intersections and other production.

A third recommendation relates to the confidence interval used in the reporting of the vertical accuracies. Currently, the ASPRS guidelines specify that the accuracies will be reported at the 95% confidence interval. However some applications, including many geopositioning applications, typically use a 90% or 50% confidence interval instead of the 95% level. Therefore it would be beneficial if the ASPRS guidelines would allow flexibility in the confidence interval. Rather than require 95%, the guidelines could discuss the method to be used to calculate the accuracy and allow the user to determine the proper confidence interval.

### 4.2 Recommendations on the Horizontal Accuracy Reporting Guidelines

The ASPRS guidelines on reporting of lidar vertical accuracy provided a section related to the horizontal accuracy, but did not require that the accuracy be measured or reported. They discussed the difficulty in selecting distinct ground points in the dataset. However, planimetric errors in lidar data can be several times larger than the height errors in lidar data (Vosselman, 2002). This indicates that these errors should be measured and reported. In controlled situations where a "reference" DEM is available, brute force techniques can apply numerous global horizontal translations to an "evaluation" DEM and select the translation vector which minimizes the standard deviation of the vertical differences between post heights in the reference versus evaluation DEMs. As a refinement to the brute force technique (or as an alternative if the translation is not too large), a least squares adjustment can be performed to solve for the translation vector such that the standard deviation of the vertical discrepancies are minimized. Although this would not be possible in every collection, it would provide the opportunity to characterize sensors in certain instances. Also, the ASPRS guidelines ignore the fact that most current lidar systems provide an intensity image. With an intensity image it becomes more feasible to select specific points in a lidar dataset. This method would be more feasible on every project. There have been publications indicating that a least squares based strip adjustment technique could be used on overlapping strips of data to identify systematic errors and measure relative accuracy (Vosselman, 2002 and Filin, 2004).This technique made use of both the height and the reflectance data. Therefore, a modified version of the ASPRS guidelines should be applied to HRTI datasets requiring the contractor to measure and report both an absolute and relative horizontal accuracy.

As discussed in Section 4.1, rigorous error propagation should be used to compute predicted horizontal errors on a per point basis. Current systems are capable of providing sufficient metadata to provide such error estimates to the users of the data. These error estimates are very important stochastic input to geolocation processes including both single ray intersection and registration of a single image, with approximate support data, to a dense DEM.

The first draft of the ASPRS guidelines on reporting horizontal accuracy provide good insight into existing accuracy specifications within the mapping community. However, it is seems that these guidelines should provide more information about methods to be applied for measuring the horizontal accuracy of laser points. The guidelines could answer many important questions. What should be used as control points? Are there specific targets that the contractor should use or do they use existing features? Are the "control" point locations measured in the elevation data itself or in the intensity images? What type of target should be placed at the required six control points? The Ohio State University, USA has been performing tests to design lidar specific targets (Csyani, 2004). How is the size of control targets related to post spacing? Do there need to be horizontal accuracies reported for various land-cover types like ASPRS suggests for the vertical accuracy? Although the horizontal accuracy should be less dependent on land-cover, it would still affect the ability to measure terrain.

### 4.3 General/Interdependent Guideline Recommendations

The two lidar requirement documents that ASPRS is currently developing have many interdependencies and overlap between them. This section will describe some of those relationships.

Some interdependency relates to the close relationship between the vertical and horizontal errors in lidar data. This interdependency is described in the guidelines for reporting horizontal accuracy. It is possible that a horizontal bias will exist in the dataset that can be identified and eliminated. However, adjusting for a horizontal error will change the results of vertical accuracy calculations. Therefore it must be stated during the error reporting whether the vertical errors being reported were calculated before or after a horizontal adjustment; or results from both cases should be reported.

A second interdependency relates to sections in the horizontal errors reporting guideline that discuss recommended collection protocols. They describe best collection practices that would insure both accurate horizontal and vertical results. Therefore it seems that these recommendations should either be placed in a second collection protocol document or that the horizontal and vertical reporting documents should be combined into one master ASPRS document.

The GPS guidelines section also spans both horizontal and vertical accuracies. One specific item from this section to consider is rewording the statement that the GPS network is "completely free from errors". A better way to state this may be "adjusted using a rigorous least squares solution". Like any other surveying system, a GPS network always has some errors associated with it due to the random distribution (usually standard normal) of measurements. However, blunders can be avoided and measurement residuals can me minimized using a robust least squares adjustment.

If the document is going to provide guidelines on collecting quality GPS data, should it also provide a section on collecting quality IMU data? IMU collection definitely has limitations and recommended practices, and all of these items will have an effect on the quality of the data collected both in the horizontal and vertical directions. So, if collection protocols are to be discussed, then IMU collection should be included in the specification.

### 4.4 Recommendations on the LAS File Format

The ASPRS LC has worked on developing the LAS file format. The LAS is supposed to meet various user needs. The current version 1.1 allows storing some of the parameters which are needed to perform a per point error propagation and a sigma value of XYZ coordinates of each laser point. One expectation is to directly have the information about a full covariance matrix inside the LAS standard.

## 5. FUTURE WORK

Customers, or users of lidar data, have many vendors from which to choose to provide their services. Oftentimes each of these vendors claims to be superior to the others in delivering the most accurate lidar product. Continuing to clearly define the accuracy reporting standards will involve a significant amount of work in the near-future. Beyond establishing standards, the geopositioning community needs to develop innovative validation techniques that would allow an independent party to perform testing to determine whether or not a vendor has met the level of accuracy that it claims.

Further development of the lidar guidelines is necessary. The ASPRS will continue to refine their guidelines for error reporting, and the specification of the LAS file format. In order to achieve the best results, the end users must provide their feedback to the ASPRS LC more actively. Therefore, we the users must continue to identify what items are important for our specific applications and express this to the Lidar Committee. In this way, the ASPRS Lidar Guidelines will continue to improve and become more universally accepted.

## 6. CONCLUSIONS

The ASPRS has been proactive within the ALS community over the past decade trying to generate the lidar guidelines that would improve the quality of laser data. Although these guidelines have been helpful to the remote sensing and mapping communities, they have also been primarily focused on the use of lidar in traditional mapping applications. This paper provides a positive review of these guidelines, but also provides suggestions that if implemented would allow them to be even more universal. Specifically, these recommendations would help assure the utility of lidar data for a variety of geopositioning applications.

## REFERENCES


ASPRS, 2005a. LAS Specification Version 1.1 , 2005 http://www.lasformat.org/documents/ASPRS%20LAS%20Format%20Documentation%20-%20V1.1%20-%2003.07.05.pdf

ASPRS, 2005b. The 1st draft of the ASPRS Lidar Guidelines on Reporting Horizontal Accuracy (2005) (in review)

Csyani, Nora, C. Toth, 2004. *On Using Lidar Specific Ground Target.* ASPRS Annual Conference Proceedings May 2004, Denver, Colorado

Flood, M., 2004. ASPRS Guidelines Vertical Reporting for Lidar. http://www.asprs.org/society/divisions/ppd/standards/Lidar%20guidelines.pdf

Filin, Sagi 2001. *Recovery of Systematic Biases in Laser Altimeters Using Natural Surfaces.* International Archives of Photogrammetry and Remote Sensing, Volume XXXIV-3/W4. Annapolis, MD Oct. 2001.

Filin, Sagi 2004. *Adjustment of Airborne Laser Altimetry Strips*. ISPRS Conference Proceedings, Commission 3, Istanbul 2004.

Huising, E.J., Gomes Pereira, L.M., 1998. *Errors and accuracy estimates of laser data acquired by various laser scanning systems for topographic applications*. ISPRS Journal of Photogrammetry and Remote Sensing 53 (5) 245-261.

Schenk, T. et al. *Accuracy study of airborne laser scanning data with photogrammetry*. International Archives of Photogrammetry and Remote Sensing, volume XXXIV-3/W4, Annapolis, MD, USA, 22-24 Oct. 2001, pp. 113-118

Vosselman, G., 2002. *On estimation of planimetric offsets in laser altimetry data*. International Archives of Photogrammetry and Remote Sensing 34, 375-380.