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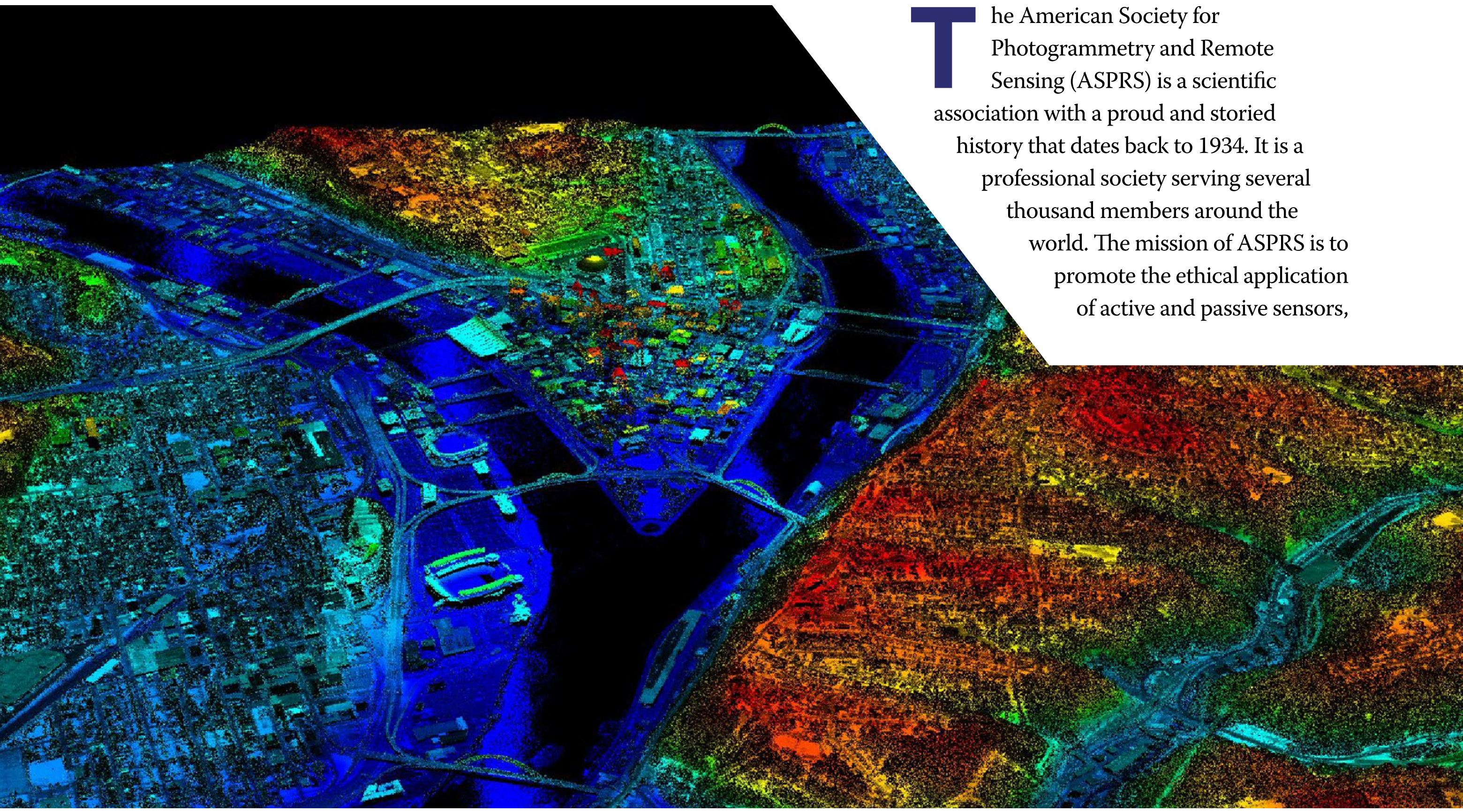
SENSOR FUSION

HOW **ASPRS** HELPS GUIDE THE LIDAR INDUSTRY

The American Society for Photogrammetry and Remote Sensing (ASPRS) is a scientific association with a proud and storied history that dates back to 1934. It is a professional society serving several thousand members around the world. The mission of ASPRS is to promote the ethical application of active and passive sensors,



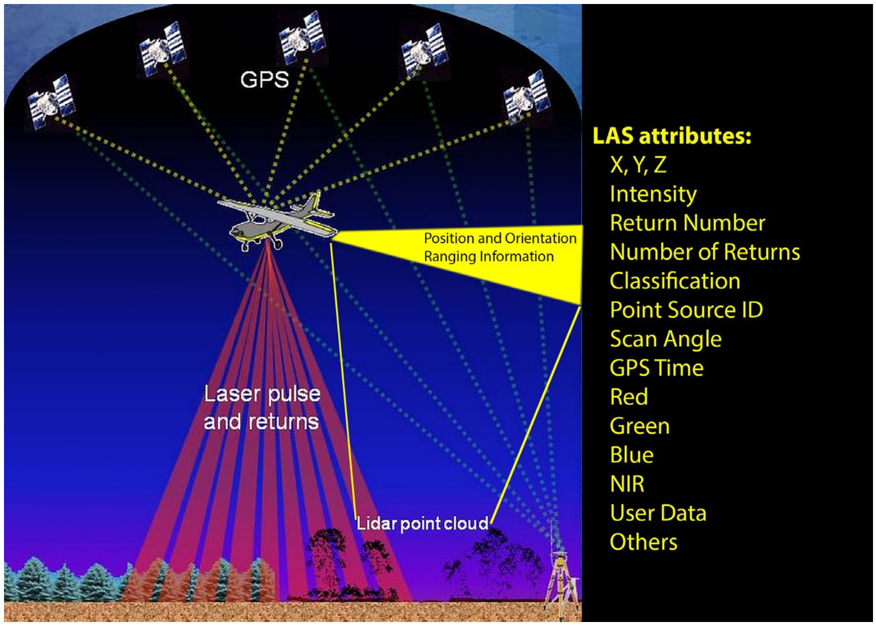
The LAS file format enables views and use of massive amounts of point cloud data across a wide range of software platforms. (Lidar over Pittsburgh, Pennsylvania)
Source: USGS

BY DR. JASON **STOKER**

the disciplines of photogrammetry, remote sensing, geographic information systems, and other supporting geospatial technologies; advance the understanding of the geospatial and related sciences; expand public awareness of the profession; and promote a balanced representation of the interests of government, academia, and private enterprise. ASPRS is organized to be responsive to the various types of remote sensing and mapping technologies, and currently has seven technical divisions: the GIS Division; the Lidar Division; the Photogrammetric Applications Division; the Primary Data Acquisition Division; the Professional Practice Division; the Remote Sensing Applications Division; and the Unmanned Autonomous Systems Division.

The Lidar Division was established by the ASPRS Board of Directors at its May 5, 2011 meeting in Milwaukee, Wisconsin. The Division is focused on all aspects of kinematic laser scanning (e.g. the entire sensing platform is in motion). The mission of the Division is to provide a forum for collection, development and dissemination of information related to the best practices in developing, maintaining and operating kinematic laser scanners and associated sensors. The Division currently comprises two committees and one working group:

- **Airborne Lidar Committee:** This committee develops best practices by soliciting input from the broad airborne laser scanning industry and from academia. Best practices are disseminated in both working papers and more formal specifications (such as the Vertical Accuracy Specification).
- **Mobile Mapping Systems Committee:** This committee is a parallel committee to airborne but with the focus being land/water-based kinematic laser scanning systems.
- **LAS Working Group:** The LASer (LAS) Working Group maintains and updates the LAS kinematic laser data standard.



Source: USGS

Figure 1: Conversion of lidar instrument information into a LAS point cloud dataset. Information from laser pulses and their associated returns is combined with location (GNSS) and attitude (IMU) to create clouds of XYZ points (lower right).

The role of ASPRS in standards

As part of its mission, ASPRS maintains a leadership role in the development of guidelines, standards, specifications and calibration processes for those sensors and activities of primary importance to the membership. The ASPRS Board of Directors has the responsibility for ASPRS standards and has chartered the ASPRS Standards Committee to oversee the ASPRS Standards Program: the committee has defined responsibilities and procedures for developing, maintaining, and approving standards authored by ASPRS. An ASPRS standard is one developed wholly by ASPRS for use by the geospatial community and ASPRS members. It is a goal of the ASPRS Standards Program to ensure the broadest acceptance and implementation of ASPRS standards within the geospatial community of interest by working with recognized Standards Development Organizations (SDOs) and Standards Setting Organizations (SSOs) to move ASPRS standards forward for further SDO and/or SSO processing.

Drawn from government, academia and the private sector together, members of ASPRS create not only standards, but best practices and guidelines that are shared throughout the community. This community approach

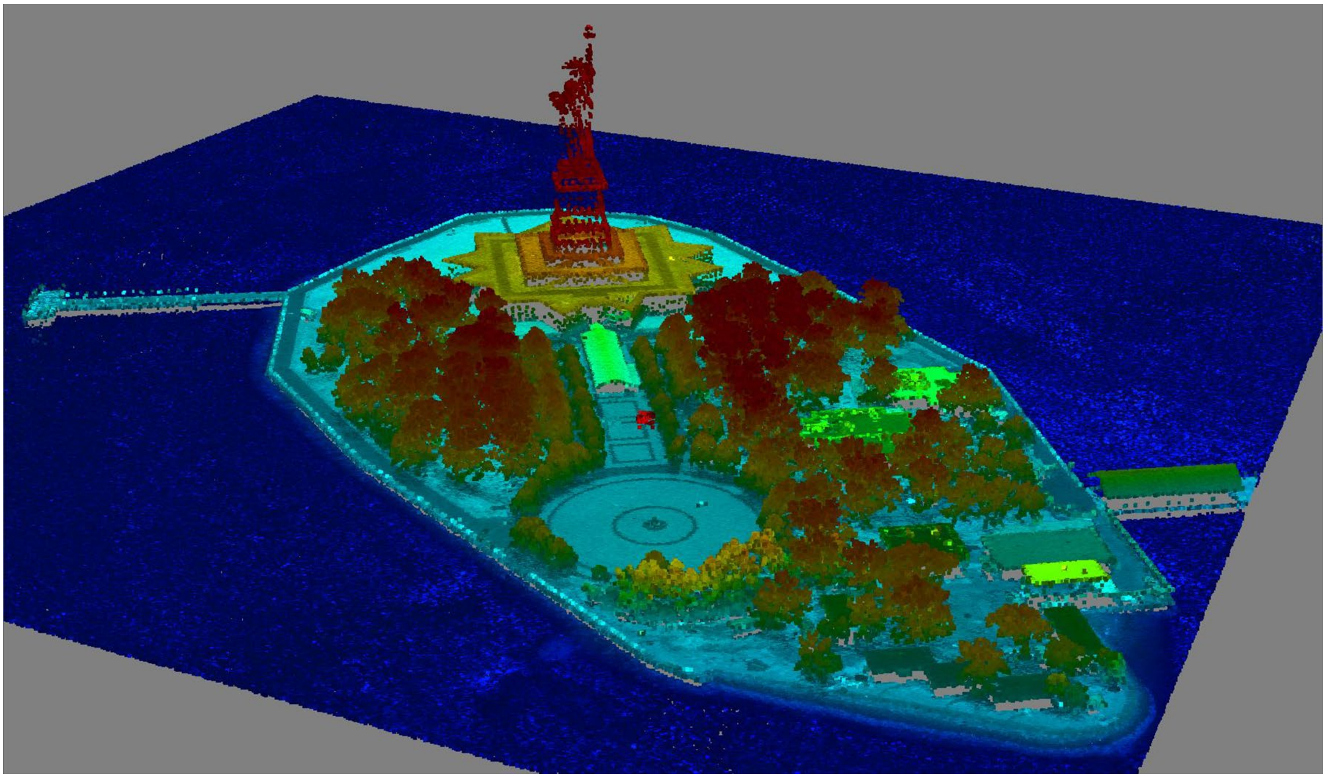


Figure 2: Calibration is critical when combining swaths of data to image objects such as the Statue of Liberty.

helps hardware manufacturers, software developers and end users to develop tools, methods and standard processes that move the industry forward in many beneficial ways. Working through ASPRS allows people to link proprietary and open source methods together, to the benefit of the end user and the community at large.

Standards developed by ASPRS are based on an open, consensus process. The Board of Directors is responsible for ensuring that all applicable requirements, including due process and consensus, have been met. Consensus is established when, in the judgment of the ASPRS Board, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

As it relates to the Lidar Division, two efforts have had immense impact on the industry. These are the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* and the *LAS Common Data Exchange Format Activity.* For example, both of these efforts helped the U.S. Geological Survey (USGS) develop its Lidar Base Specification, a document that dictates how data needs to be delivered to the USGS in order to be part of the 3D Elevation Program (3DEP). Accuracy information correlates with how the ASPRS has defined many aspects of accuracy and a fully populated LAS 1.4 file is now a required deliverable to 3DEP.

The LAS file format is a public file format for the interchange of three-dimensional point cloud data between data users. Although developed primarily for exchange of lidar point cloud data, this format supports the exchange of any three-dimensional x,y,z tuplet. This binary file format is an alternative to proprietary systems or a generic ASCII file interchange system used by many companies. One issue with proprietary systems is that data cannot always be easily taken from one system to another. There are two major problems with ASCII file interchange. The first 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 lidar data, such as instrument configurations and designs, is lost. The LAS file format is a binary file format that maintains information specific to the lidar nature of the data while not being overly complex (**Figure 1**).

The LAS file format was originally published on May 9, 2003, and has become the *de facto* standard file format for airborne lidar. LAS has also been widely used for other 3D point cloud data, including point clouds generated from photogrammetry, ground-based lidar, and structure-from-motion processing of imagery acquired from UAVs. There have been several revisions to LAS over the years. LAS 1.1 was published on May 7, 2005[1]; LAS 1.2, September 2, 2008[2]; LAS 1.3, October 24, 2010[3]; and LAS 1.4 was approved in November 2011[4]. LAS 1.4, the most recent approved version of the document, was also approved by the Open Geospatial Consortium (OGC) as a community standard in 2017. In July 2013, the Lidar Division created the ability to customize the LAS file format to meet application-specific needs. The mechanism that makes this possible is the LAS Domain Profile, which is a derivative of the base LAS v1.4 specification that adds (but does not remove or alter existing) point classes and attributes. For example the Topo-Bathy Lidar Domain Profile[5] adds point classification values for bathymetric point (e.g., seafloor or riverbed; also known as submerged topography), water surface, derived water surface, submerged object, IHO S-57 object, and bottom-not-found depth data. Extra Byte Variable Length Records (EXTRA_BYTES or Extra Byte VLRs) are added for pseudo-reflectance, uncertainty, water column depth, figure of merit, and processing specific flags[6]. We anticipate the release of additional domain profiles in the future; proposed additional domain profiles should be provided utilizing the LAS Domain Profile Description Template.

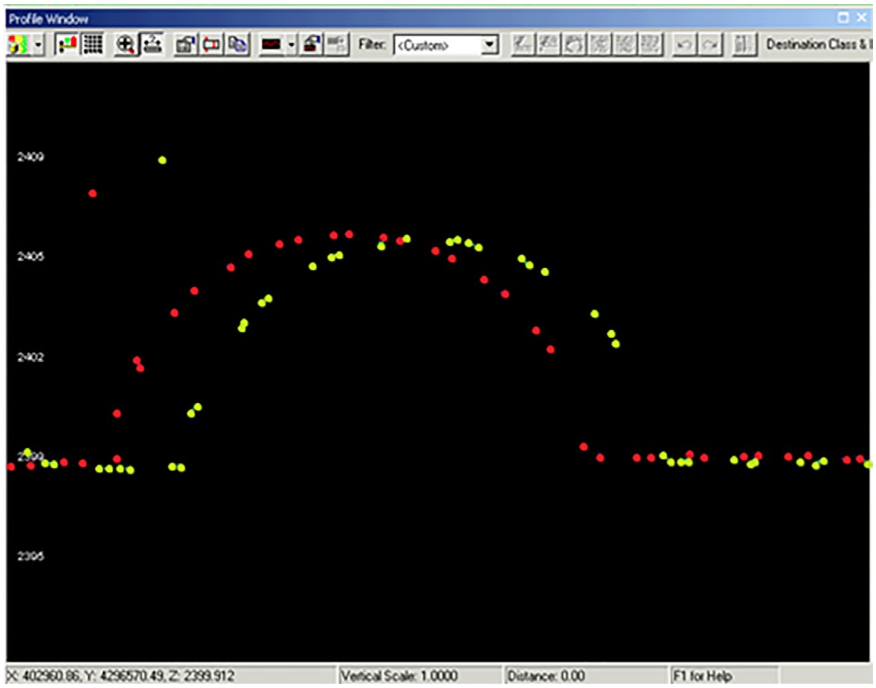


Figure 3: An example of misalignment between swath 1 (red) and swath 2 (green).
Image courtesy of Dr. Aparajithan Sampath, Stinger Ghaffarian Technologies, Inc. (SGT), contractor to USGS

New ASPRS Research and Development Topics for Assuring Geometric Quality of Lidar Data

The new ASPRS *Guidelines on Inter-Swath Geometric Accuracy of Lidar Data* and *Summary of Research* and *Development Efforts Necessary for Assuring Geometric Quality of Lidar Data* guides were developed through collaboration between the private sector and government partners via a USGS/ASPRS Lidar Data Quality Working Group (WG), sometimes referred to as the "ASPRS Lidar Cal/Val Working Group". Operating under the aegis of the ASPRS Lidar Division and its Airborne Lidar Committee, this group has investigated various factors associated with the geometric quality of lidar data. The WG has noted that while the quality of lidar data has improved tremendously in the past few years, the quality assurance and quality control (QA/QC) of data are not standardized, including the semantics, processes for measurement and reporting, and metadata. Therefore, to ensure geometric quality of lidar data that is required for scientific (statistical error propagation and estimation) and non-scientific purposes (including legal) (**Figure 2**), the WG has recommended several topics for research and development in a Summary document. In addition, the WG created guidelines on quantifying the relative horizontal and vertical errors observed between conjugate features in the overlapping regions of lidar data. The effort has been supported by the USGS National Geospatial Program (NGP) and the Land Remote Sensing (LRS) program.

Current specifications are not adequately able to quantify geometric errors (particularly horizontal and systematic geometric errors). This is mostly because the methods to quantify systematic and non-systematic errors have not been investigated sufficiently. Measuring only vertical accuracy also potentially underestimates the inter-swath errors, including the presence of systematic errors in lidar data (**Figure 3**). Hence they pose a risk to the user in terms of data acceptance (i.e. a higher potential for accepting potentially unsuitable data). For example, if the swath's overlap area is too small or if the sampled locations are close to the center of overlap, or if the errors are sampled in flat regions when there are residual horizontal errors in the data, the resultant Root Mean Square Differences (RMSD) can still be small. To avoid this, the following are suggested to be used as criteria for defining the inter-swath quality of data:

A. Median Discrepancy Angle
B. Mean and RMSD of Horizontal Errors derived from measurements on sloping surfaces
C. RMSD for uniformly sampled locations from flat areas to define vertical errors (defined as areas with less than 10 degrees of slope)

The recommendations are a result of discussions within the WG as well as the results of testing on sample datasets.

Associated Software

The recommendation from the WG was to implement the process defined in the guidelines in the form of software and test it on several datasets. The software was tested on datasets including swath data from both historical and recent projects available from 3DEP. The software was designed by the USGS's Earth Resources Observation and Science (EROS) Center and is currently being tested for implementation under operational QC conditions of the USGS's National Geospatial Technical Operations Center (NGTOC). The software and documentation can be downloaded from https://edcftp.cr.usgs.gov/project/rst/DQM/. The contents are:

- DQManage.exe and DQMeasure.exe: executables that need to be stored in same folder
- DQMAnalysisFun_Horizontal.py and DQMOutputAnalysisHorizontal.py: python scripts that should be in the same location
- LidarInterswath_CleanCopyASPRS.docx: explains the theory and motivation behind the DQM algorithms
- LidarResearchGuidelines_CleanCopyASPRS.docx: explains further work that needs to be done for ensuring lidar data quality
- DQMDocumentation.docx: help document for use of the programs
- DQM_Operational_Testing 2017-2-7.pptx: PowerPoint presentation made at ILMF 2017 on DQM implementation.

The software and documentation have been provided to ASPRS and will be managed by ASPRS Lidar Division and Standards Committee with support from USGS.

Conclusions

Since its inception in 1934, ASPRS has helped guide the photogrammetric, GIS and remote sensing industries into the future. As new technologies such as lidar mature and develop, ASPRS will continue to be a critical organization that bridges government, academia and private sector developments with a cohesive set of guidelines, best practices and standards. The LAS file format has helped increase the adoption of lidar data across an amazing array of sectors in the industry by standardizing a file format used across many software platforms. The Lidar Division of ASPRS looks forward to continuing to help guide the industry in ways that enable improved data collection, dissemination quality. Tools such as *Guidelines on the Inter-Swath Geometric Accuracy of Lidar Data* will help improve the accuracy and precision of lidar data into the future, a key contribution in our ever growing 3D mapping and place-based location and intelligence world.

[1] asprs.org/wp-content/uploads/2010/12/asprs_las_format_v11.pdf

[2] asprs.org/wp-content/uploads/2010/12/asprs_las_format_v12.pdf

[3] asprs.org/wp-content/uploads/2010/12/LAS_1_3_r11.pdf

[4] asprs.org/wp-content/uploads/2010/12/LAS_1_4_r12.pdf

[5] asprs.org/wp-content/uploads/2010/12/LAS_Domain_Profile_Description_Topo-Bathy_Lidar.pdf

[6] asprs.org/wp-content/uploads/2010/12/LAS_Domain_Profile_Description_Template.docx

Dr. Jason Stoker is a US Geological Survey Physical Scientist and is the Chief Scientist for the USGS 3D Elevation Program. Jason is also the former Director of the ASPRS Lidar Division.