Issues and Answers in Quality Control of LIDAR DEMs

Gary W. Thompson
North Carolina Geodetic Survey

David F. Maune
Dewberry & Davis LLC

INTRODUCTION

“Quality control” is defined as those steps necessary to ensure that delivered products satisfy client expectations for accuracy and utility. It is important that potential LIDAR (light detection and ranging) users understand the terminology, capabilities, and limitations so that client expectations are realistic and achievable. This paper addresses the key issues, regardless of whether the final deliverables are uniformly-spaced digital elevation models (DEMs), triangulated irregular networks (TINs), or digital contours. The ongoing North Carolina floodplain mapping initiative is a major testbed for the ideas discussed herein.

QUALITY/ACCURACY ISSUES

Expected vertical accuracy is the first issue to be addressed. LIDAR technology is cost-competitive with photogrammetry when the accuracy of the data is comparable to contours with an interval of 1 or 2 feet. With 5-foot contours, photogrammetry is normally more cost-effective. The break-over point is somewhere between 2-foot and 5-foot equivalent data, where LIDAR becomes cost-competitive with traditional methods for generating digital topographic data.

High-accuracy raw LIDAR data are obtained by using LIDAR systems that are calibrated frequently, preferably daily, during peak acquisition periods; flying at lower altitudes; using a narrow scan angle and/or using only the data near the center of the scan; acquiring data with a dense point spacing; planning flight lines that have a heavy sidelap; limiting data acquisition to times when there is strong GPS (global positioning system) satellite geometry (i.e., having a low positional dilution of precision, normally 3 or below); and using differential GPS base stations that are within 20-25 miles of the LIDAR aircraft at all times during data acquisition. It is also important that the data be acquired during leaf-off conditions and when waters are within their normal stream banks.

High-accuracy processed LIDAR data are obtained by using additional ground control points to process the bare-earth elevations; by using sophisticated computer algorithms to perform automated post-processing for removal of last-return LIDAR data that hit rooftops and/or failed to penetrate dense vegetation; by using digital orthophotos produced from recent imagery to assist in manual post-processing and quality control; and by using experienced personnel to perform the manual post-processing to both check the accuracy of the automated procedures and to clean (remove) artifacts that remain.

The vertical accuracy of LIDAR data is normally expressed in terms of the vertical root-mean-square-error, computed by comparing dozens of survey check points on flat or gently sloping terrain with elevations estimated from the LIDAR bare-earth dataset, interpolated by using inverse-distance weighting for the LIDAR points that surround the check points.

DATA FORMAT ISSUES

Do you need DEMs, TINs, or digital contours? What computer hardware and software will you use? What data formats do you need (e.g., ESRI Grid float, TIN, ASCII, BIL, state plane or UTM)? Which vertical datum do you need? Do you need breaklines along the tops and bottoms of stream banks? Either digital orthophotos or stereo photogrammetric procedures are needed to develop 2-D or 3-D breaklines, respectively. TINs are preferred for hydraulic modeling where breaklines form natural TIN edges. Furthermore, TINs more accurately reflect the true shape of the terrain. DEMs are easier to store and use, but they result from interpolation procedures that reduce accuracy slightly and generalize the shape of the terrain.

The raw LIDAR data are irregularly spaced and are normally acquired to achieve an average desired point spacing; the raw data are post-processed into a TIN dataset. The desired average point spacing impacts the costs. Point spacing is narrowed by flying slower and with a narrower scan angle; thus the dataset is denser, will probably improve the overall accuracy of the end products, but is also more costly. Similarly, with uniformly spaced DEMs adequate for hydrologic modeling, the point spacing should normally be equal to or greater than the average point spacing from the irregularly spaced raw data.

Finally, do your data need to be “hydro-enforced”? Hydro-enforcement removes the natural undulations in the terrain and forces the drainage lines to flow downstream. Contour lines will hug the shorelines, even under bridges. When data are not hydro-enforced, there will be islands of higher points along stream lines. DEM and TIN points will be retained on bridges and contours will go up and over those bridges, making it appear as though water cannot flow through. Normally, hydraulic modeling requires hydro-enforced TINs but with elevations on bridges, culverts, and dams removed to a separate file.

LIDAR ADVANTAGES COMPARED WITH PHOTOGRAMMETRY

The accuracy of photogrammetric data is inversely proportional to the flying height, while LIDAR accuracy degrades less significantly with increased flying height. Photogrammetry requires two different lines of sight to both see the same points on the ground from two different perspectives, but LIDAR only needs a single near-vertical laser pulse to penetrate through the trees to measure the ground beneath. This means that LIDAR will have far fewer areas where the terrain is obscured by trees that block the lines of sight.

LIDAR can be collected from both first- and last-returns, with up to 50,000 pulses per second, so as to semi-automatically map the elevation of the tree canopy as well as ground elevations with high density, high accuracy data. Photogrammetry can generate high-density elevation points also, but only by processes that are either more expensive or less accurate than LIDAR.

LIDAR data are acquired both day and night, whereas aerial photography is acquired only during limited daylight hours when the sun angle is optimum.

LIDAR DISADVANTAGES COMPARED WITH PHOTOGRAMMETRY

LIDAR pulses are routinely absorbed by water, and water returns are unreliable. Normally, digital orthophotos are used to determine the limits of water boundaries, and LIDAR returns within those boundaries are discarded.

LIDAR data are poorly suited for breakline generation. If LIDAR pulses have a nominal point spacing of 5 or 10 meters, for example, it is difficult to determine the location of breaklines at the tops and bottoms of stream banks that fall somewhere between the elevation points, especially when data in the stream itself are also unreliable. Thus, 2-D breaklines estimated from digital orthophotos or 3-D breaklines compiled photogrammetrically are used to augment the LIDAR data as needed for hydraulic modeling.

LIDAR is a relatively new technology, and standard procedures have not yet been developed to yield data with predictable accuracy comparable to that from photogrammetry where flying height, focal length, and established procedures consistently yield predictable results. A LIDAR working group within the American Society for Photogrammetry and Remote Sensing is acting in 2001 to develop draft guidelines for LIDAR surveying and mapping.

Whereas aerial cameras are normally calibrated every 3 years or so, LIDAR system manufacturers normally specify laboratory recalibration after perhaps 500 hours of use. Others specify routine on-site calibration. For the North Carolina floodplain mapping initiative in 2001, the North Carolina Geodetic Survey specified daily LIDAR system calibration, and results indicated this was a wise requirement when one of the systems suddenly started acquiring unusable data that would have gone undetected throughout the entire data acquisition period if not for this calibration requirement.

SUMMARY

In conclusion, LIDAR represents an exciting new technology in the toolbox of the floodplain management community. The ongoing North Carolina floodplain mapping initiative includes evaluation of of the issues discussed above. This project will serve as a major pioneering project for LIDAR technology, with lessons learned for the benefit of users worldwide.