Does LiDAR Satisfy Your Data Requirements and Budget Constraints?

LiDAR is an acronym for **Li**ght **D**etection **a**nd **R**anging, an emerging active remote sensing technology that uses pulses of laser light to measure distances and characterize features. This white paper will describe one major component of the technology, specifically Airborne LiDAR as applied to digital surface mapping and elevation modeling. The intent of this paper is to help you decide if LiDAR products, accuracies and costs make it the right tool for your needs.

The Airborne LiDAR System – An Integration of Several Technologies

A LiDAR system begins with a laser source that projects a beam of light at a target. An airborne LiDAR laser scanner is mounted in the bottom of an airplane (similar to an aerial camera) along with an Inertial Measuring Unit (IMU) and airborne Global Positioning System (GPS). The IMU and GPS are necessary to accurately position the LiDAR unit, which is used in conjunction with surveyed ground-based locations in the project area. The LiDAR system projects thousands of laser pulses per second, thus creating a dense swath of laser points on the Earth's surface. The reflected (returned) laser pulses are detected by the system which then, based on the time of travel and the aircraft position (GPS) and attitude (IMU), computes the x, y and z position of each reflection point. These points may be the bare ground or intermediate objects such as buildings or vegetation. For a more detailed description on how airborne LiDAR works please go to http://www.usace.army.mil/publications/eng-manuals/em1110-1-1000/c-11.pdf.

Processing LiDAR Data into Information

Modern LiDAR systems are able to record up to five returns per laser pulse, giving the ability to distinguish not only the canopy (trees and buildings) and bare ground but also surfaces in between. For example, if parts of a laser pulse reflect off of tree branches or foliage at several levels and the remainder reflects off the ground, the elevation of the branches, foliage and ground can all be measured. This capability is very important when trying to map ground topography beneath vegetation. The 'last returns' for each pulse are those from the lowest features and thus are more likely to be reflections from the ground. Post-processing algorithms and manual interpretations identify or classify the data into canopy, intermediate and bare earth returns. The use of bare-earth only LiDAR points to model surface topography is the most mature application of airborne LiDAR data. However, considerable work is ongoing to exploit the information in the other returns. First return data can be used to map building footprints (although possibly compromised by roof overhangs) and heights, and vegetation height, canopy density, and biomass. Intermediate returns can identify forest understory structure. Figure 1 below shows LiDAR first-return mass points, colored by elevation. One can clearly see the buildings and trees. Figure 2 shows a bare-earth terrain model and contours, derived from the same data after processing to remove the buildings and trees. The ravines present in wooded

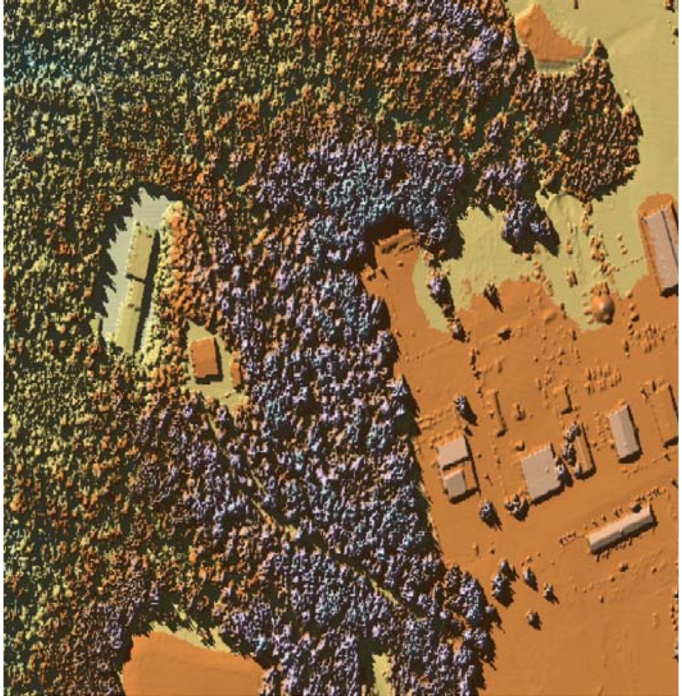

Figure 1

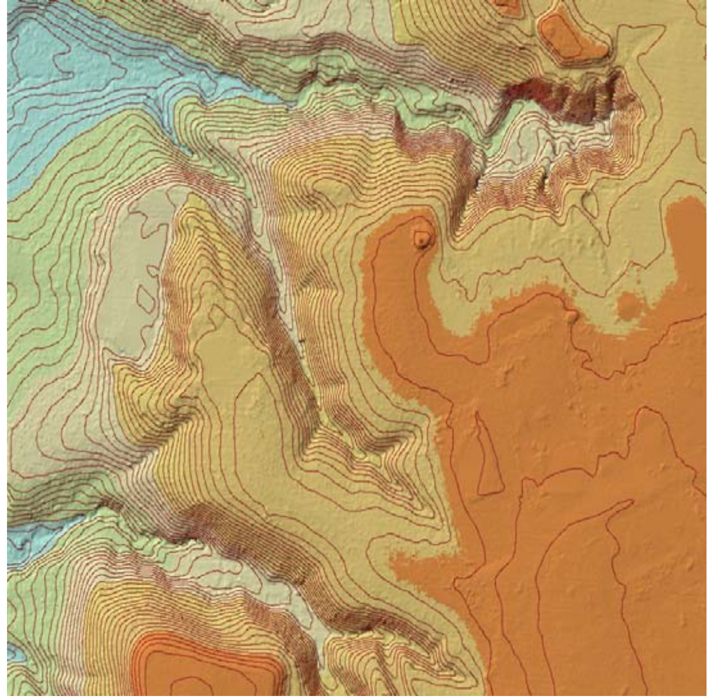

Figure 2

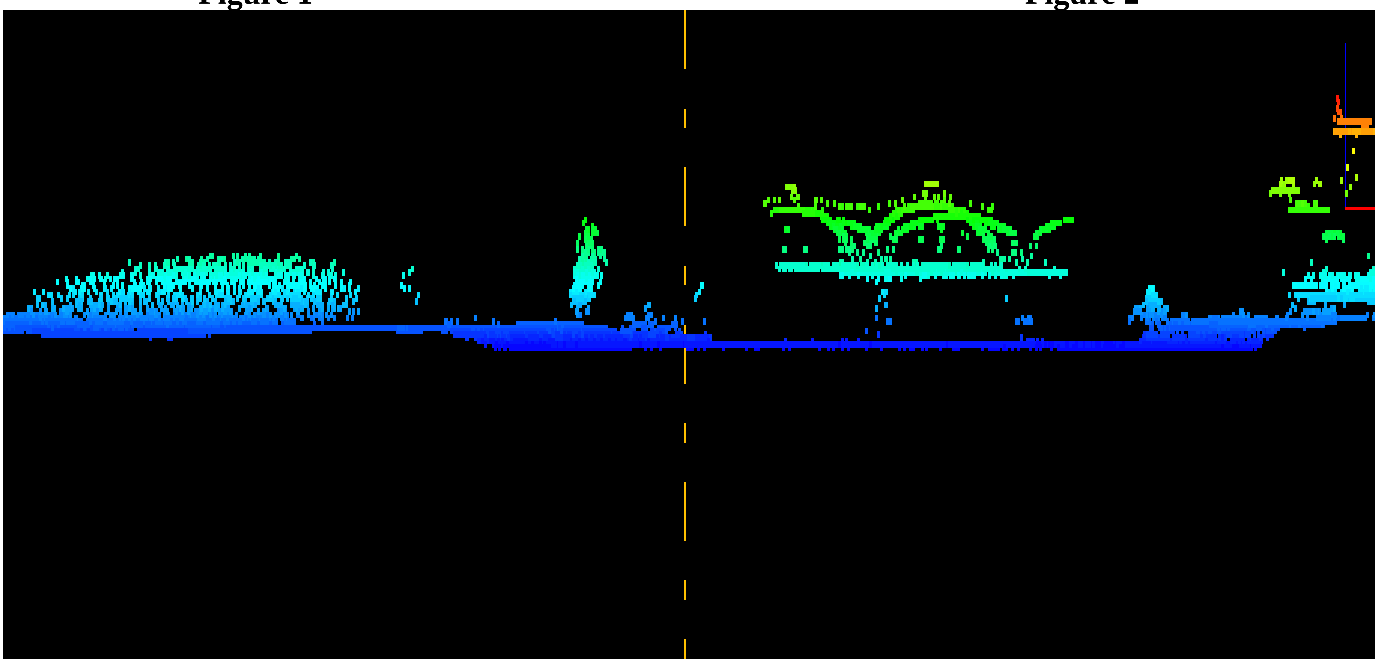

Figure 3

areas are accurately depicted from the subsequent returns that penetrated the upper tree canopy. Figure 3, a different LiDAR data set, shows a cross-section of all returns colored by elevation, illustrating the information available about the mid-canopy and understory in vegetated areas, as well as a bridge's structure and buildings nestled among trees.

LiDAR systems also capture the intensity of reflectance data. Reflectance percentage values differ depending on the type of surface they hit (e.g. snow may reflect 90%, black asphalt 5%), and are called "LiDAR intensity". These data may be processed to produce a geographically-referenced raster file which is ortho-metric and looks somewhat like a conventional aerial image. These images are useful as ancillary data for post-processing and in limited cases may substitute for coarse-resolution aerial photography.

Advantages of LiDAR-derived Topographic Mapping

Topographic mapping has traditionally been achieved using stereoscopic pairs of aerial photographs to map spot elevations at intervals required to model landscapes to the desired accuracy. Source photography must be leaf-off to map through trees and other vegetation and if not, vegetated areas may have to be interpolated or generalized. Even using the latest advances in softcopy photogrammetry, topographic mapping of this type is labor-intensive and expensive. For smaller areas and those requiring higher accuracy, field surveying for elevations is still required. These methods are even more labor-intensive, expensive and are limited by accessibility to the area.

Airborne LiDAR technology offers the opportunity to quickly collect points of incredible density (typically 1-3 feet spacing) and to collect on steep slopes, vegetated and shadowed areas and otherwise inaccessible areas. Figure 4 represents the relative density of data for photogrammetrically derived points (on left) and LiDAR mass points (on right). Because of the point density, breaklines are not as critical to accurately model the terrain. Arguably, breaklines are still required to identify man-made changes to drainage patterns such as bridges and culverts for hydrologically-enforced elevation models.

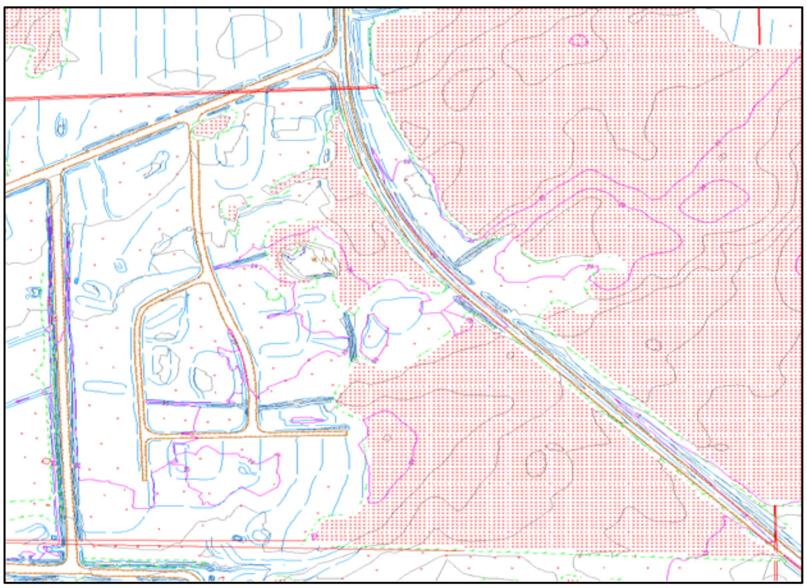

Figure 4

See http://www.ncgia.ucsb.edu/ncrst/research/ncgia.html for a more complete discussion comparing LiDAR and traditional photogrammetry for topographic mapping.

Limitations or Disadvantages of LiDAR-derived Topographic Mapping

LiDAR file sizes are huge and can be difficult to process and serve to users. ASCII-formatted x,y,z data covering 1 square mile is about 80 megabytes (MB), while a 1-meter raster grid of the data is about 30 MB. Derivatives are not a one-size-fits-all, especially if serving a mix of GIS and CAD users. Application softwares have not kept up with the LiDAR industry to handle the large file sizes, formats and to easily produce derivatives. This is especially true in regards to exploiting the first return and intensity data.

Of most concern with LiDAR topographic mapping – is it accurate enough? The accuracy of LiDAR data is a function of flying height, laser beam diameter (system dependent), the quality of the GPS/IMU data, and post-processing procedures. Accuracies of ±15cm (horizontally) and ±15cm (vertically) can be achieved. It is important to contrast overall accuracy, averaged across the project area, with accuracies for different landscape/surface condition combinations. One should specify the upper limit of acceptable accuracy (e.g. not to exceed ± 40 cm on hillsides with vegetation) as well as overall accuracy, as determined by an independent surveyed assessment. LiDAR accuracy is also limited by site condition, including high water, snow and leaves. Best results are achieved when water levels are at normal or below, leaves are off and no snow covers the ground.

Cost

The variables affecting cost of airborne LiDAR data collection and processing include size and shape of project area, density of LiDAR postings, accuracy requirements of derived products and formats/number of derived products requested. Economies of scale make LiDAR topographic mapping more cost-effective than traditional photogrammetry for areas exceeding about 10 square miles. Due to flight patterns, the squarer the area is in shape the more cost-effective. Processing the "raw" LiDAR data for removal of vegetation and buildings to produce bare-earth terrain models, and the accuracy required of that processing, are large cost factors. All of these variables make citing dollar estimates for LiDAR projects risky. However, to give some ballpark figures, if the processed LiDAR data will yield 2-foot contours to national mapping standards for a typical Missouri county, the cost per square mile should fall in the $200-400 range. More site-specific projects (around 10-20 square miles) might fall more in the $750-1000 range.

Data Currently Available for Missouri

Acquisition of airborne LiDAR in Missouri has progressed in a piecemeal fashion. Likely, no one agency or organization is aware of all data available. The following counties have LiDAR-derived terrain mapping: Carroll, Cass, Chariton, Clay, Jackson, Lafayette, Linn, Platte, Saline, Taney, Warren and partial Sullivan and St. Louis. Smaller project areas include St. Louis City, portions of the Missouri and Mississippi floodplains, Taum Sauk reservoir and the City of Nixa. A map showing Missouri LiDAR data is at the end of this document. The lead agencies for collecting and/or distributing these data are listed in the legend of the map. Each project has different products, accuracy and distribution policies; therefore, it is best to contact the agency regarding availability and use of the data. Contacts are listed below.

If you are aware of additional LiDAR mapping projects, please notify Elizabeth Cook for updates to the map and document.

Contracting for LiDAR and Collaboration Opportunities

Many organizations and agencies are expressing an interest in acquiring LiDAR data. However, piecemeal acquisition does not take advantage of economies of scale and resulting data may be of variable quality and formats. The Missouri GIS Advisory Committee Data Development subcommittee is taking the following actions to assist potential LiDAR customers:

- Produce this document with overview information
- Maintain a status map of LiDAR data in the state and facilitate multi-agency aquisitions

- Host regional LiDAR workshops
- Pre-qualify LiDAR firms through state or federal contracting procedures to short-cut LiDAR purchases by individual customers

Websites for Further Information

Many websites contain valuable information about airborne LiDAR topographic mapping. A sample listing, focusing on non-commercial sites, is given below:

http://lidar.cr.usgs.gov/index.php
http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm
http://www.lidarmap.org/
http://www.iowadnr.gov/mapping/lidar/
http://www.asprs.org/society/committees/lidar/

Contacts for Further Information

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Elevation Mapping Project Areas from Airborne LiDAR