LIDAR Basemaps Come of Age

Greg Lennon, QOC

Ever wondered about better ways to create basemaps? Three years ago, long-time QOC member Chuck Ferguson, now USOF President, posted a message on the O-Map Yahoo! discussion group in which he suggested that the O community ought to look into a hi-tech approach using Light Detection And Ranging (LIDAR) to make basemaps. Well, we've now followed up on this, and guess what? He was right! We've found that LIDAR derived basemaps are probably going to be a great asset to orienteering clubs around the world, and in the spirit of getting this ball rolling, we'd like to share our initial observations and experiences with this fascinating – and potentially cheap, fast, and high quality – way of making basemaps. Furthermore, and in the long run perhaps most importantly, the process of making digital basemaps, whether by LIDAR or other remote sensing means, is the cornerstone for creating a digital map collection that can be more easily maintained, updated, and modified to serve an orienteering club's needs in the future.

But first: where would we be without a disclaimer? Although this article was helped by comments from several professional LIDAR engineers, any errors are mine, and I don't claim to be the LIDAR guru. I have enjoyed helping create and fieldcheck my share of B-meet orienteering maps over the years, though, and my interest in LIDAR stems from a drive to find better mapping methods that can be widely used.

Now, what is LIDAR? Although best known as an alternative to radar for ticketing speeding cars, the use we are interested is – at least for the moment - airborne rather than ground based. The basic principle is simple (Figure 1); an airplane or helicopter with sophisticated electronics monitoring its position and motion through the air beams 100,000 or so pulses per second of near infrared light down towards the ground from a height of around 3000 ft, and a record is captured of the time it takes for every portion of the beam's energy to bounce off of the objects encountered. Multiplying the speed of light by half of the time taken to bounce back to the receiver gives you the distance to each object from the transmitter in the airplane, which, given the angle of the pulse and the exact coordinates in space of the transmitter at the time the pulses were released, allows one to define a large number of x,y,z (latitude/longitude/elevation) datapoints representing all the objects encountered. Objects also vary in their ability to reflect more or less of the energy in the pulse, and the more modern receivers capture these intensity values in addition to the x,y,z geographic coordinates for each datapoint. Although varying widely depending on survey goals, typical point densities at the moment in the US for LIDAR surveys are around 1 point per square meter, and an x,y,z ASCII text file (including intensity values) for all the points gathered over 1 square kilometer (about 250 acres) at this density will be around 20-30MB.

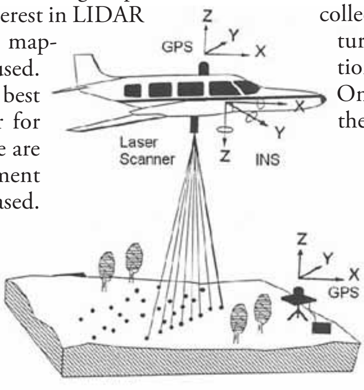


Fig. 1: Basic schematic of airborne LIDAR surveying. Adapted from USGS source.

The first objects encountered produce the file of datapoints called the First Returns (FR), and as you might expect, these points could be reflections off almost anything: birds in mid-air, electrical wires, any part of a tree, cars, buildings, or bare ground. As the pulses continue downward they stand an increasing chance of reaching the actual ground, and therefore the last object returning a reflection is more likely to be representative of the surface near the ground. This Last Return (LR) file is the most important file for topographic use, but it should be noted that some of these datapoints represent the surfaces of objects likely to be attached to the ground but not actually at ground level: buildings, elevated roads, rock outcrops, even densely growing corn or other vegetation. Depending on the intended use, LIDAR data collection can occur during either leaf-on or leaf-off seasons in forests with deciduous trees, and can be done at night. Some instruments collect multiple (intermediate) returns in separate files in addition to the first and last returns. Once all this data is in hand, the fun really begins.

Generally the first step in creating orienteering basemaps is the creation of a detailed contour map. If you're lucky, and we often have been, the LIDAR data you're able to obtain includes a processed version of the Last Return data known as the Mass Point ("MP"; or, Bare Earth) data. This file is created by skilled technicians using semi-automated software plus experience in interpreting LIDAR point clouds. Basically, many (perhaps a third to a half) of the last return points are deleted because they are judged to not truly be representative of "bare earth". This MP file is the correct substrate from which a surface model of the terrain should be derived, although the LR file can be used with appropriate caution. The surface model is created using algorithms that 'connect the dots'; common fast algorithms include nearest neighbor and triangulation methods. Once a model (such as a grid or triangulated model) is created, contours can be calculated for any specified contour interval, and with varying degrees of smoothness depending on the software used. The contours are then generally exported to a format compatible with the next type of software to be used in creating the orienteering basemap; for example, if the contours are exported as a layer in .DXF format, both OCAD and Adobe Illustrator as well as many geographic information system (GIS) software packages are able to import them.

What point density is needed to get contours good enough for orienteering basemaps? As it happens, FEMA (the U.S. Federal Emergency Management Agency) has helped establish standards indicating that collecting points at a density of around 1 per square meter is sufficient to derive a surface model with nodes every 2m, and that can satisfy contour accuracy of at least 2 feet in relatively flat terrain or 4 foot contour accuracy in hillier terrain. In our experience to date, basemaps produced from densities of 0.5 to 1 point/sq m are sufficient to create contours from our typical terrains (forests in Maryland or Virginia) that are easily equal to or superior to the contours created by traditional photogrammetric means. In the examples shown, we compare a USGS 10 ft contours with contours derived from LIDAR data (Fig 2a,b), and contours our club derived earlier by photogrammetry and fieldchecking with contours recently derived from LIDAR data for that

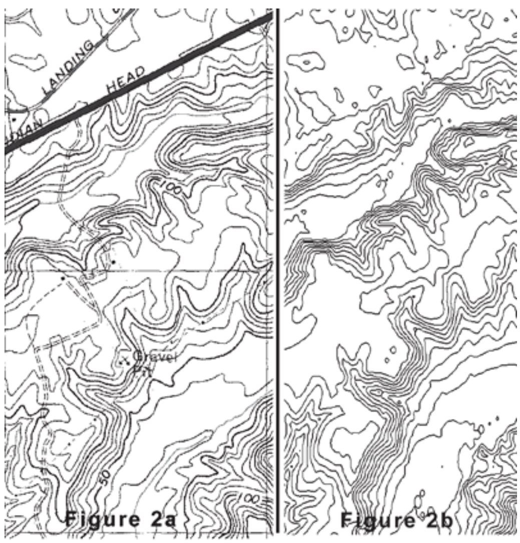
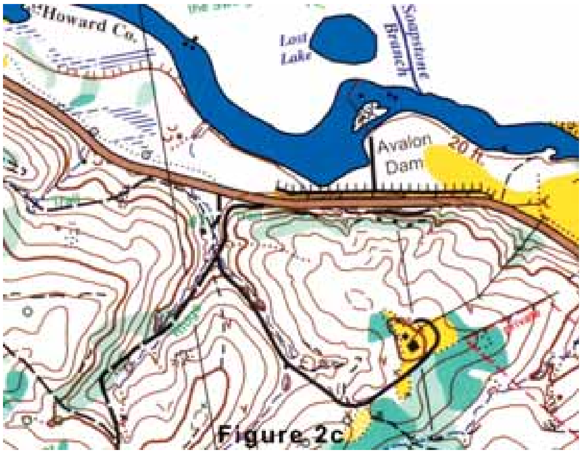


Fig 2a,b: Chapman State Forest, MD. (a) USGS topo, 10 m contours, (b) corresponding LIDAR contours, 2.5m.



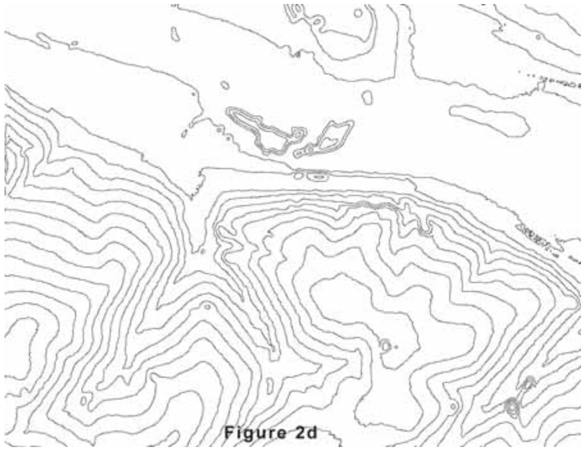


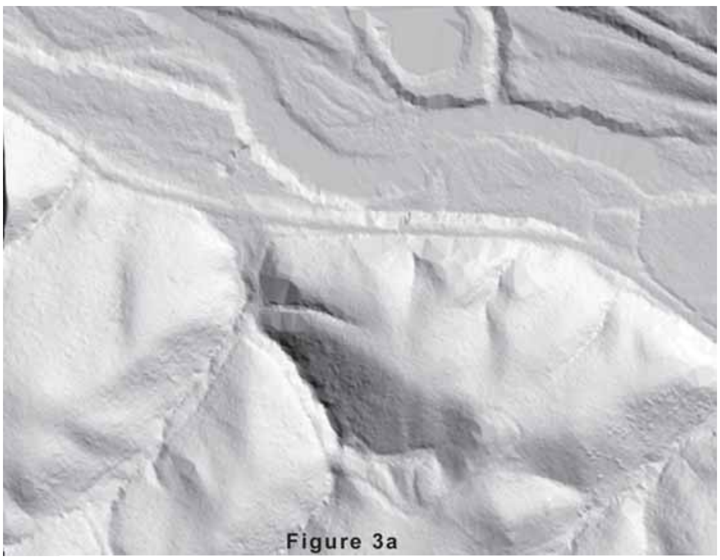
Fig 2c,d: Avalon area, Patapsco Valley SP, MD. (c) O map 20ft contours, (d) LIDAR contours, 5m.

same area (Fig 2c,d).

Once you have an excellent topographic basemap in hand, you can decide whether to start fieldchecking right away or only after extracting additional features from LIDAR as well as other datasources such as aerial photographs. [Map boundaries formed by roads or water features can readily be added from LIDAR files, other GIS sources or aerial images.] Ultimately we believe that many feature types will be semi-automatically extracted from LIDAR datasets, each into its own exportable layer, once we gain more experience training ourselves and our algorithms for specific types of terrains and the features found within them. Currently, though, we have found that at least in our hands it's important to assess the cost/benefit ratio of extracting a given type of feature at the computer compared with just heading right out into the terrain to fieldcheck it directly.

Features that can currently be readily mapped and exported into GIS-like layers with high accuracy from LIDAR data beyond contours include open vs. forested terrain, linear features such as ditches, earth or stone walls and some trails, and buildings. For example, mapping of clearings is readily accomplished from either the FR file itself, or in a more sophisticated manner by subtracting the surface model derived from LR or MP datapoints from the FR model (Fig 3a,b). Intensity measurements associated with FR datapoints can also yield surface model images that are surprisingly like photographs (Fig 4). Linear features such as stone walls and other ground-based features are best extracted from LR data (Fig 5). Beyond extracting the MP dataset, the main use of image processing is in general noise reduction and in the removal of outliers. Overall, though, two generalizations capture our current thinking with regard to feature extraction.

First, almost regardless of how sophisticated the image filter you apply, in order for features to be detectable they must have been 'pinged' by enough LIDAR pulses to stand out in comparison to their surroundings. Depending on the terrain, this could be at least 10 to 20 pulses, which at an average density of 1 per sq meter, means the feature must have an area of at least 10-20 sq meters. A cube-shaped boulder of 2m per side, while large by orienteering standards, is unlikely to stand out from its surroundings if the average point density implies there will be very few if any datapoints directly on top of it, whereas a ditch that is 2m deep and 50m long has a much better chance of being noticeable. [Note that the 60m wall detected in Fig. 5b had over 100 LR datapoints directly "on top" of it.] A 50 sq m clearing on an otherwise forested slope with some overhanging canopy may get 20 LR pulses, putting it on the margin of being visible. However, some methods that combine LR or FR elevation returns with their corresponding intensity returns can help bring out smaller fea-



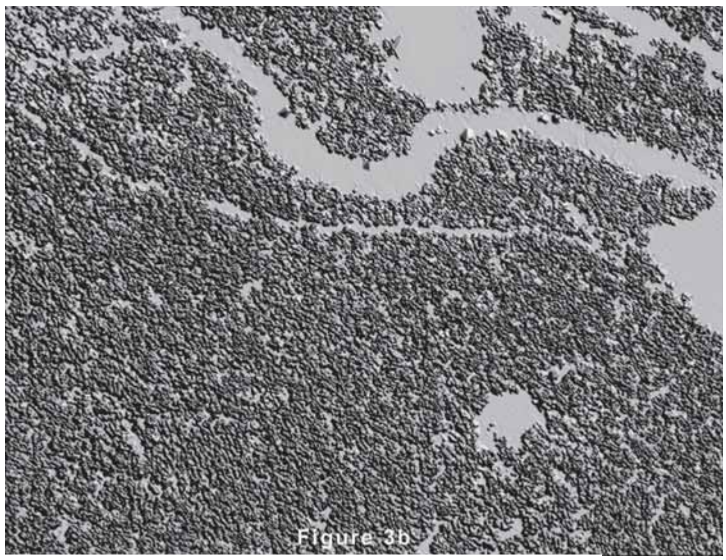


Fig 3a: Mass Point (MP) LIDAR surface shown in shaded relief, corresponding to Fig 2c.
Fig 3b: Boundaries resulting from (FR minus MP) LIDAR-derived surfaces; for earlier Omap version of clearing shown in lower right, see open (yellow) area in Fig 2c. Note also shrinking of large clearing towards the middle of the right edge.

Fig 4: Color shaded relief intensity map of portion of Chopawamsic Creek map, Quantico Marine Base, Quantico VA. Note ability to see single buildings, trees and even vehicles.

tures. A second generalization is that image processing is useful in revealing "true positives", i.e. features that upon fieldchecking will turn out to be bona fide, even if the exact type of feature is unknown until fieldchecked, but it will also inevitably miss many small features ("false negatives") that will only be found through fieldchecking. Ultimately, we believe that it will be possible to use multiple return LIDAR profiles down through vegetation between 0-2 meters above the ground to indicate likely boundaries between forested areas with varying runnability. This is likely to require somewhat higher LIDAR point densities as well as the development of custom algorithms or even near-horizontal, near-ground (i.e. non-airborne) LIDAR surveys.

Better basemaps may make fieldchecking easier, faster, and therefore less expensive, but fieldchecking will always be necessary and will probably remain the major effort in creating any final orienteering map. Having a georeferenced and digital basemap though also allows various features to be mapped through the use of handheld GPS units. Trails, some vegetation boundaries, and many point features can be localized to high accuracy with such units and their positions overlayed onto subsequent versions of the map. Unfortunately it's often the case that the same types of steep, heavily forested terrain that confound all types of airborne measurements can't access enough satellites to give good GPS readings, and in these cases the use of local reference stations may be necessary.

It's also worth noting that as subsequent LIDAR (or other remote sensing) surveys in later years cover terrains mapped from earlier digital surveys, we anticipate performing 'change analysis' at the computer to readily identify areas on a map where major features have changed over time. Fieldcheckers can then be directed to these areas.

How do you obtain LIDAR data, and what types of software can best manipulate these large files? Unless you're in Switzerland – home of OCAD and where recently the entire country has been LIDAR mapped at 1 point/m2 resolution – your best bet is to contact your local public GIS office. Within the US, most states and counties have a GIS office that can tell you if publicly available LIDAR data exists for some or all of that state or county. The National Oceanic and Atmospheric Agency (NOAA) also maintains a portal (called LDART) for selected LIDAR data, primarily from coastal states. The data from these sources can be downloaded for free. Large LIDAR surveys can cost customers $1-4/acre to have flown, so it's probably not economically feasible for most orienteering clubs to hire a LIDAR flight service to collect a custom dataset. However, by contacting local LIDAR flight service vendors, it may be possible to piggyback a small club project at much lower cost onto a flight plan being flown anyway as part of a larger project. As for software, it's an entire topic unto itself, but both free and relatively low cost packages are mentioned in the webpage designed to supplement this article with more details about all aspects of applying LIDAR for orienteering mapping at URL http://www.lidarbasemaps.org/.

So where do we stand at the moment? Basically, several factors have converged such that it's now feasible for O mappers to consider the ease and speed of generating basemaps using LIDAR technology in a manner replacing or at least complementary to stereo photogrammetric techniques. These factors include the improvements in LIDAR technology itself, the widespread use of GPS georeferencing, the lifting of restrictions on GPS accuracy, the increased ability of personal hardware and software suitable for working with and interconverting large quantities of data, and the increasing availability of free LIDAR data from public sources. We have now used LIDAR data to create basemaps and we've been very pleased with their quality. We hope that mappers interested in using these types of approaches will collaborate and share ideas, data and software in an open source manner to facilitate making improvements useful for everyone. It would also be possible for organizations such as the IOF or USOF to facilitate through organizational and financial support the inevitable transition to digital map enterprise systems in general.

In the long run, georeferenced map collections that are digitally based and capable of interacting with GIS databases, regardless of what wavelengths are used in their collection, will be easier and cheaper to update and expand. This will help keep down the significant portion of an orienteering club's budget that is devoted to mapping while increasing the overall quality and utility. What more could you want ... other than an abundance of great fieldcheckers, of course!

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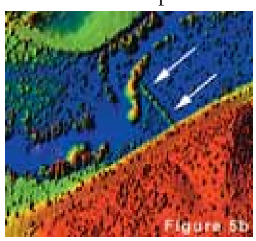

Fig 5a: Photo of stone wall (old dam), Avalon area of Patapsco Valley State Park, MD.
Fig 5b: Pair of arrows indicate stone wall as seen in colorized version of corresponding LR LIDAR dataset. Note that this wall can not be seen in either the MP (Fig 3a) or FR-MP (Fig 3b) data.