LiDAR – The Hopes and Dreams Versus Reality

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Light Detection And Ranging - LiDAR

LiDAR (Light Detection And Ranging) is an active sensor, similar to radar, that transmits laser pulses to a target and measures the time delay between the transmission of the pulse and the detection of the reflected signal. LiDAR measures properties of the scattered light to find range or other information of a distant target. This technology is currently being used for high-resolution topographic mapping by mounting a LiDAR sensor to the bottom of aircraft and measuring the pulse return rate to determine surface elevations. As LiDAR advances, it is becoming more popularly integrated with Global Positioning System (GPS) and Inertial Measurement Unit (IMU) technology.

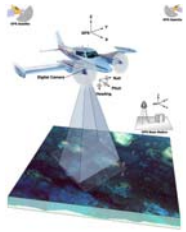


Figure 1. Graphic of a plane with LiDAR sensor

Figure 2. Timeline graphic showing how LiDAR technology was beginning to develop in the late 60s. In 1993, the first commercial LiDAR topographic mapping system was being used.

Real Time Kinematic (RTK) Data Collection

All field elevation and positioning surveying was conducted using a Trimble 5700 RTK- receiver system (with a Trimble HPB450 External Radio Base and a Trimble TSC2 Controller). The Trimble 5700 has the potential of horizontal and vertical accuracies of ± 5 to 10 mm, while in static measurements surveys controlled by NGS bench marks (Trimble, 2007). During static surveys, a base station is set-up on a primary control point (a vertical point of reference (VPR) or benchmark), while a "rover" is then set-up on the point of interest. The base station collects satellite data relative to its known fixed position and radios that information (through a Trimble HPB450 External Radio Base) to the rover which utilizes this positioning and distance information, in addition to its own satellite positioning, to determine the position of the point of interest. Millimeter accuracy can be easily attained through second to minute long surveys, depending upon the distance from the base station. The greater the distances involved between stations, the more observation time is needed.

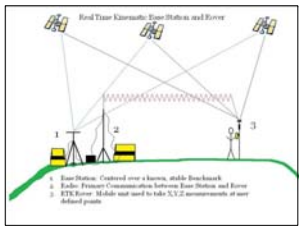


Figure 3. Real Time Kinematic Schematic

Blackbird Landing Road – Townsend, De

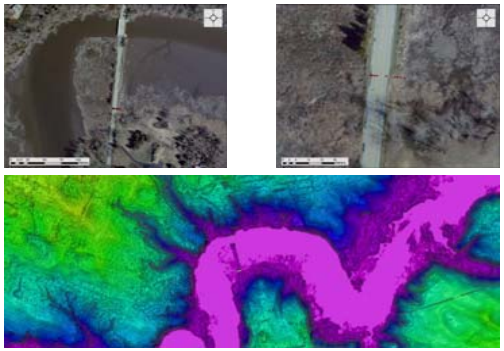


Figure 7. (Top) RTK survey points across Blackbird Landing Road (Bottom) Raster image of LiDAR

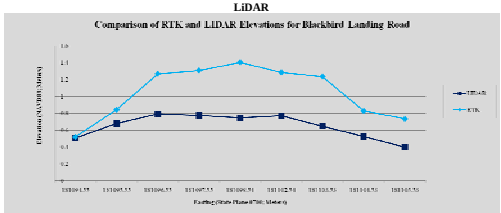


Figure 8. Comparison of elevation data

Variations in LiDAR Over the Surface of the Marsh

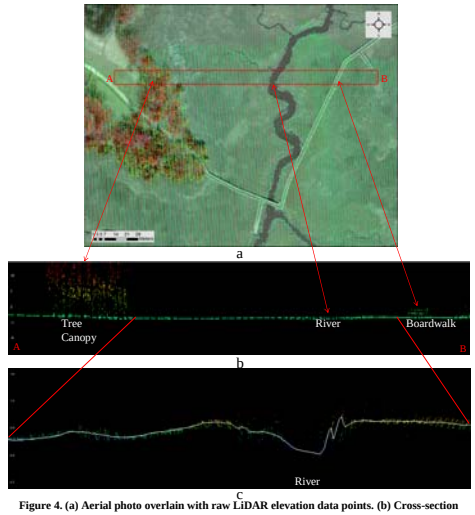
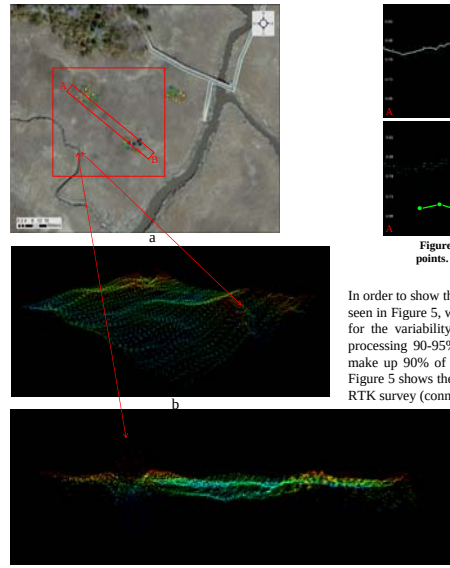


Figure 4. (a) Aerial photo overlain with raw LiDAR elevation data points. (b) Cross-section of area showing variation in data over several surfaces. (c) Cross-section of wetlands with a vertical exaggeration to highlight variation in LiDAR data.



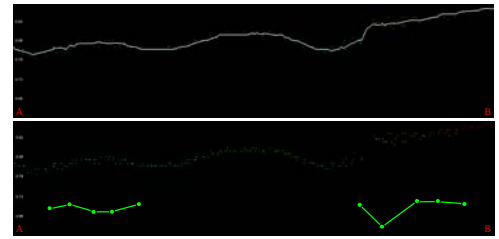


Figure 5. (Top) Bare-Earth line of best fit (white line) through raw LiDAR elevation points. (Bottom) Comparison of RTK elevation data (connected green points) and raw LiDAR elevation points.

In order to show the variation in LiDAR data, it was viewed in several ways in ArcMap. As seen in Figure 5, when constructing a bare-Earth model, a line of best fit is used to account for the variability of the data. The problem with the bare-Earth model is that during processing 90-95% of non-ground points are removed. The remaining 10% of points make up 90% of the budget for the model (Nayegandhi, 2007). The bottom graphic of Figure 5 shows the true elevation of portions of the cross-section A-B, as determined by an RTK survey (connected points). These values show an average offset of about 10 centimeters (cm) between the true elevation (RTK) and the LiDAR data. Certain portions of Figure 5 show a spread of nearly 4 cm at one point. Figure 6 shows undulations in the marsh surface at both oblique (b) and planar (c) views. As seen in 6-c, the vertical spread of points becomes much greater along the river banks, than that of areas of shorter vegetation, due to areas of taller vegetation

Figure 6 (left). (a) Aerial photo showing RTK points. (b) 3-Dimensional oblique view of raw LiDAR data to show undulation in red square seen in 3-a. (c) 3-Dimensional planar view of area in 3-b.

Errors During Processing of LiDAR

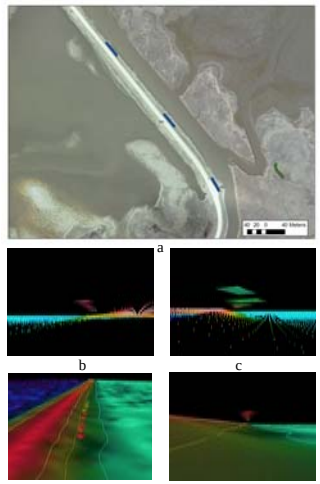


Figure 13. RTK survey and LiDAR at Bombay Hook National Wildlife Refuge

A series of points (a) along the road in Bombay Hook National Wildlife Refuge were collected using an RTK rover and compared to LiDAR elevation data (b & c). The RTK points appear to float above the LiDAR data due to a rounding error incurred during the processing of LiDAR data. In order to contour the area in a way more pleasing to the eye for presentations, the LiDAR data was "smoothed" to reduce the slope leading up to either side of the centerline of the road. Therefore, the LiDAR underestimates the elevation along the edges of the road. The RTK data represents the true elevation of the area. This can also been seen when creating a profile across a road as seen on Blackbird Landing Road (Figures 7 & 8).

References

Nayegandhi, Amar. "Lidar Technology Overview". US Geoligical Survey. Airborne Lidar Technology and Applications, June 20-21, 2007.

"Dead Zone" Effect of *Spartina* Marshes in Delaware

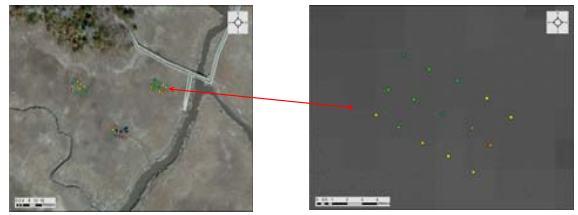


Figure 9. (Left) RTK survey points on marsh in the St. Jones watershed (DE) (Right) Zoomed view of a plot of RTK points (large points) against LiDAR bare-Earth layer with scattered raw LiDAR points (small points)

Source of Error	Approximate Error (cm)
Laser ranging accuracy	1-5
GPS positioning error	5-100
Attitude system error	3-15
Terrain type (vegetation "noise")	***1-100***
Coordinate / Datum conversions	1-10
Rasterizing (Gridding)	??
Time synchronizing errors	??
Total Error	**11-230**

Figure 10. Error Budget for potential induced LiDAR vertical error (Nayegandhi, 2007)

Since the initialization of LiDAR, it was determined it contained an inherent, known error. When using LiDAR in areas with vegetation, this error can become greater than the known error of about ~11 cm, according to Figure 10. The error depends on a number of factors including vegetation "noise" and several other sources. The range of terrain-type error can be from a few centimeters in open canopies to several meters in closed canopies (Nayegandhi, 2007). As seen in Figure 10, vegetation "noise" alone can account for almost an entire meter of error. It can be argued that a *Spartina alterniflora* marsh has a relatively closed canopy, due to greater stem densities, and, therefore, gives the marsh an error greater than the minimum. When creating a bare-Earth model of the LiDAR, it is more difficult to determine elevations for the model under short grasses creating the "dead zone" effect (Nayegandhi, 2007). The "dead zone" effect is caused by limitations of the sensor to detect small vertical variations between successive reflections from a transmitted pulse, frequently related to short vegetation in coastal wetlands.

When analyzing the error of the highlighted RTK plot (image on the upper right) in Figure 9, an error of 22.360 cm was calculated when comparing the RTK to the Raster LiDAR (Figure 11). In *Spartina* marshes like this, it is most commonly found that the LiDAR elevation is overestimated, or much higher than the true value. However, in terrestrial, grassy areas LiDAR elevations are underestimated as seen in Figure 12. In the grassy meadow, the LiDAR is underestimated by an average of 11.3 cm (minimum error estimated by Figure 10), well within the standard or normal range of error.

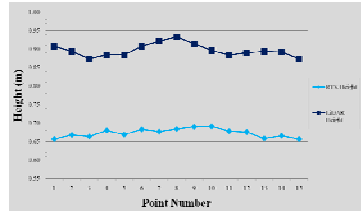


Figure 11. Comparison of Raster LiDAR and RTK elevation values in the St. Jones watershed, DE.

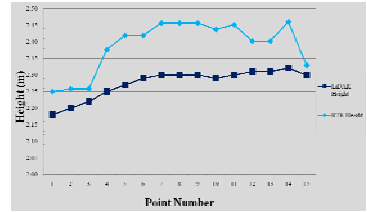


Figure 12. Comparison of Raster LiDAR and RTK Elevation in a grassy meadow at Bombay Hook National Wildlife Refuge, DE