LiDAR – So Much More Than A Pretty Picture. An Introduction to the Analytical Capabilities of Topographic and Hydrographic LiDAR Survey Data.

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Abstract

Survey methods using Light Detection and Ranging (LiDAR) have become more common for both terrestrial and hydrographic surveys. This rapid survey method provides unprecedented detail over large, even regional areas, and has demonstrated great potential for a variety of uses by coastal engineers and scientists. Until recently, the analysis of LiDAR data presented a great number of challenges, and some types of analysis were impractical without expensive high-end computer workstations and software. However, recent advances in standard desktop computer hardware and software now facilitate the analysis of LiDAR data and provide a new level of analytical capabilities and information. Information from this analysis ultimately allows researchers and managers to gain a better understanding of coastal processes, make better decisions, and save costs. This paper provides a summary and example of present capabilities for the end-user.

Background

For coastal surveying and monitoring in Florida, engineers and scientists have employed a variety of survey methods. Probably the most common survey method has been rod and transit surveys collected in conjunction with single-beam hydrographic surveys. Beginning at reference monuments placed in or behind the dune and typically continuing out several hundred to several thousand feet, shore perpendicular survey transects typically occur along 500- to 1000-foot intervals along the beach. A rod and level survey documents landward features out to wading depth, and then the hydrographic survey overlaps the wading survey and continues seaward. Depending on the near-shore beach and sand bar features, the end-area method to calculate volumes can introduce significant errors the survey interval increases along the shoreline (Irish et al., 2004).

The U.S. Army Corps of Engineers (USACE) employ another coastal survey method called the Coastal Research Amphibious Buggy (CRAB). The rolling 35-foot tripod survey station features instrumentation to survey transects from the dry beach out to approximately 25 feet of water (USACE, 2002).

For bathymetric surveys, multi-beam hydrographic surveys use sonar instrumentation towed behind a vessel collect data in a swath. Overlapping the survey lines can ensure a complete survey at a specified density and therefore provide excellent detail. Given the swath width (approximately four times the water depth), this method may require numerous passes to survey the shallow, near-shore coastal areas.

LiDAR systems employ an aircraft mounted laser system that measures the reflection of laser pulses emanating in a swath over the ground or sea floor. Advances in laser technology facilitate extraordinarily detailed survey data at amazing speeds of up to 100,000 pulses per second for terrestrial systems and 3000 pulses per second for bathymetric systems (Optech, Inc, 2006 and Wozencraft & Millar, 2005). These systems can survey over 20 square miles per hour. Depending on the application, point-based bathymetric survey data can collect and provide data in two to five meter spacing.

While numerous terrestrial LiDAR systems presently operate in the U.S., only two companies make hydrographic surveys commercially available. Tenix LADS, Inc. — an Australian based company — employs the Laser Airborne Depth Sounder (LADS) system; Fugro Pelagos Inc. employs the Optech Inc. Scanning Hydrographic Operational Lidar Survey (SHOALS) system.

The USACE uses a LiDAR system under the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX). JALBTCX, which has collected data throughout the U.S., presently employ a modified SHOALS laser system developed by. Optech Inc. termed Compact Hydrographic Airborne Rapid Total Survey (CHARTS). This system consists of a bathymetric LiDAR, a topographic LiDAR, and a digital camera. Recent modifications include the addition of a spectral imager to facilitate the simultaneous collection of hyperspectral data for mapping the benthic habitat and coral reefs (Wozencraft, 2005). The National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, LiDAR Data Retrieval Tool (LDART), provides access to much of the data the USACE has collected.

While LiDAR presents an appealing survey method with impressive capabilities, several considerations and limitations attend this method. For hydrographic surveys, water clarity becomes an important factor because the laser penetrates approximately two to three times the secchi disk depth (Fugro Pelagos, 2006). Turbidity, wave activity, and algae blooms can affect water clarity and, as such, limit the depth of the survey. For the terrestrial survey, the laser returns reflect from vegetation and other structures. While the application of algorithms during data processing may provide “bare earth” survey data, the algorithms rely on some laser penetration getting to the ground. In the coastal region, areas of very dense vegetation may not yield accurate measurements.

The costs for LiDAR surveys largely depend on the size of the subject area and mobilization costs. Terrestrial LiDAR surveys, per square mile, cost substantially less than hydrographic surveys. This cost difference likely results from the lower cost of the terrestrial laser systems as well of as the pressures of marketplace competition. While hydrographic surveys cost more, the widespread application of the data presents opportunities for cost sharing. The same opportunities apply to mobilization costs for large-scale surveys.

Once collected, processed, and cleaned of errors, the terrestrial LiDAR data arrive to the end user as ‘first return,’ which includes the elevation of structures and vegetation, or ‘bare earth.’ The survey data typically appear as XYZ coordinate point data in ASCII text files in the horizontal and vertical reference of choice. Due to the high density of these surveys, the files commonly contain tens of millions of data points, consume gigabytes of storage, and can present challenges for the end user wishing to visualize and analyze the data.

Typically, the point data is converted into a surface, or Digital Elevation Model (DEM). The DEM, comprised of a grid, can be fine or coarse depending on the application and density of the data. Having flexibility for the end user to create DEM’s of various scales is beneficial.

Once a surface is created, analysis can be performed including cross sections, contour analysis, and volume calculations. If there are data collected over the same area at different times, the surfaces can be compared and change analysis can be performed.

While we have not tested all surface modeling programs, experience suggests that some of the most commonly used surface modeling software, including ESRI’s ArcMap with 3-D Analyst and Golden Software’s Surfer, seem to struggle with the processing of more than several hundred thousand data points. High-end software applications, including IVS 3D’s, Fledermaus, are very effective at visualizing, processing and analyzing millions of data points but are expensive (approximately $10,000 US). Competitively priced, Applied Imagery’s QT Modeler software provides excellent visualization and analysis tools using millions of data points.

The ability for the user to visualize and analyze large data sets over extensive areas provides a variety of terrestrial and hydrographic uses. The petroleum, utility, and transportation industries employ Terrestrial LiDAR surveys to evaluate land change and development. Hydrographic LiDAR surveys are being used for nautical charting, navigation projects, coastal mapping, sea floor feature classification, storm and damage response, and subsurface object detection (Optech, Inc., 2006). For coastal engineers and scientists, the ability to conduct analysis over large areas with unprecedented detail helps to further the understanding of coastal processes and events, and therefore facilitates better decision making.

Example - Coastal LiDAR Data Visualization and Analysis

To demonstrate the present capabilities of coastal LiDAR data visualization and analysis for the end-user, the following provides an example using USACE data collected in 2004 with the CHARTS system.

In April 2004, the JALBTCX group was testing the newly upgraded CHARTS system along several coastal regions in Florida (Culpepper, pers. com, 2005). Then, following Hurricanes Frances and Jeanne in September of 2004, the JALBTCX group returned in November to resurvey some of the storm-affected areas. Both surveys covered approximately 33 miles of coastline within Palm Beach County on Florida's southeast coast. Data extended approximately 2000 feet landward of the shoreline to approximately 4000 feet for the April survey, and 1000 feet landward and 2000 feet seaward for the November survey. The point data from these surveys was downloaded with NOAA's LDART system.

The visualizing and analysis of the data for this example was performed with Applied Imagery's QT Modeler software version 5.0 on a Dell Precision 670 Workstation with a 2.8 GHz Xeon processor, 2 GB of RAM, an NVidea Quadro FX500 video card, all running under Microsoft Windows XP Professional (SP2) operating system.

The April 2004 data set comprises over 26.2 million data points with roughly two foot point spacing on the land portion and six foot spacing on the bathymetric portion. The ASCII text files for these data points consume over 400 MB of storage. Data files of this magnitude must arrive in a standard format in the preferred horizontal coordinate system and vertical datum, because manipulation of the raw data is challenging at best. The November 2004 data consists of less dense point spacing on the terrestrial portions and did not extend as far landward and seaward. This data set contains 11.1 million data points in a 380 MB text file.

The first step of analysis is to import the ASCII data into the software program and examine the raw point cloud of the data to understand the coverage and potential anomalies (Figure 1). Statistics on the survey data can be obtained that show the limits of coverage and the average point spacing. The spacing of the data is important in determining the maximum detail of the Digital Elevation Model (DEM), which can create false surfaces from areas lacking data and can provide misleading results.

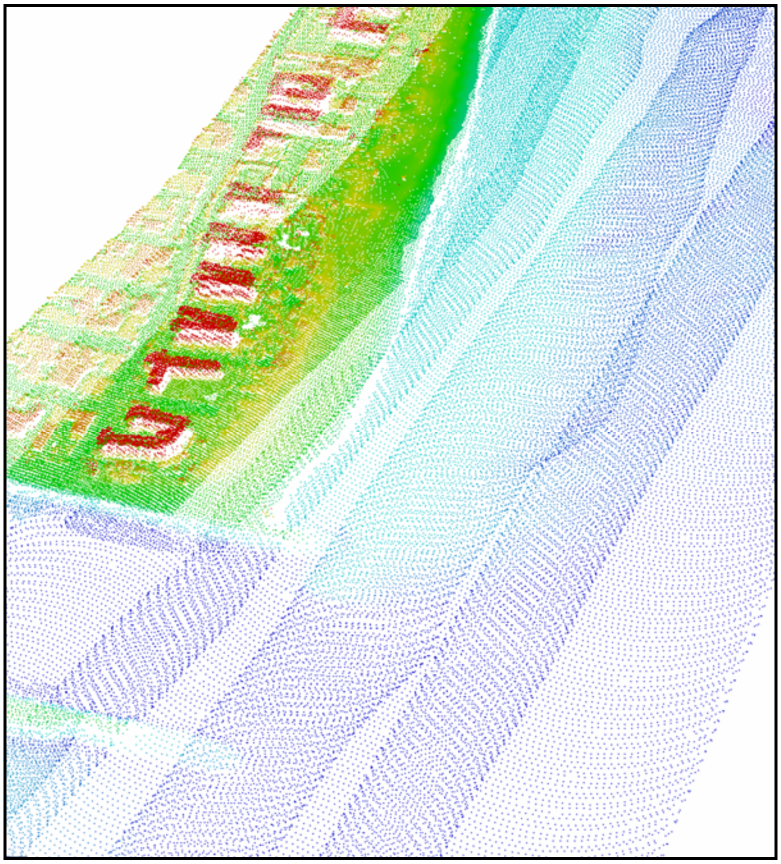

Figure 1. Point cloud rendering of LiDAR USACE data collected with the CHARTS system along Palm Beach County, Florida.

The next step in the visualization and analysis process involves generating a surface, or digital elevation model (DEM), from the point data. The QT Modeler software accomplishes this by first creating a Triangulated Irregular Network (TIN) from the data and then generates a grid surface model (or DEM) based on the TIN. Depending on the software application and the number of data points, this process can take many hours or even days to compile. However, the powerful QT Modeler software generates detailed DEM's from millions of data point in minutes.

In this example, the data from the April 2004 data set (30.7 million data points) was compiled into a surface with a grid size of six (6) feet in 5 minutes 53 seconds. Once created, the surface grid contains 26.2 million vertices, consumes 609 MB of storage, but loads in approximately 17 seconds. Once loaded the user can rotate, pan, zoom in and out, and "fly" through the surface model.

The smaller November data set, containing 11.2 million data points, was compiled into a six foot grid surface in 2 minutes 16 seconds. This surface grid contains 14.2 million cells and consumes 473 MB of storage.

In order to prevent the software from generating a surface without data, one must apply a triangulation filter during the creation of the surface model. This filter limits the length of a triangle side when the software connects the points. While the filter may result in voids in the surface model where the data are sparse, it may be preferable to creating false surfaces. In this example, a triangulation filter was set to 60 feet, or ten times the grid size.

The user can color the surface models according to the elevation of the surface and can manipulate the color ramp to emphasize areas of interest in the model (Figure 2). The user can drape orthorectified imagery over the model for additional visual reference.

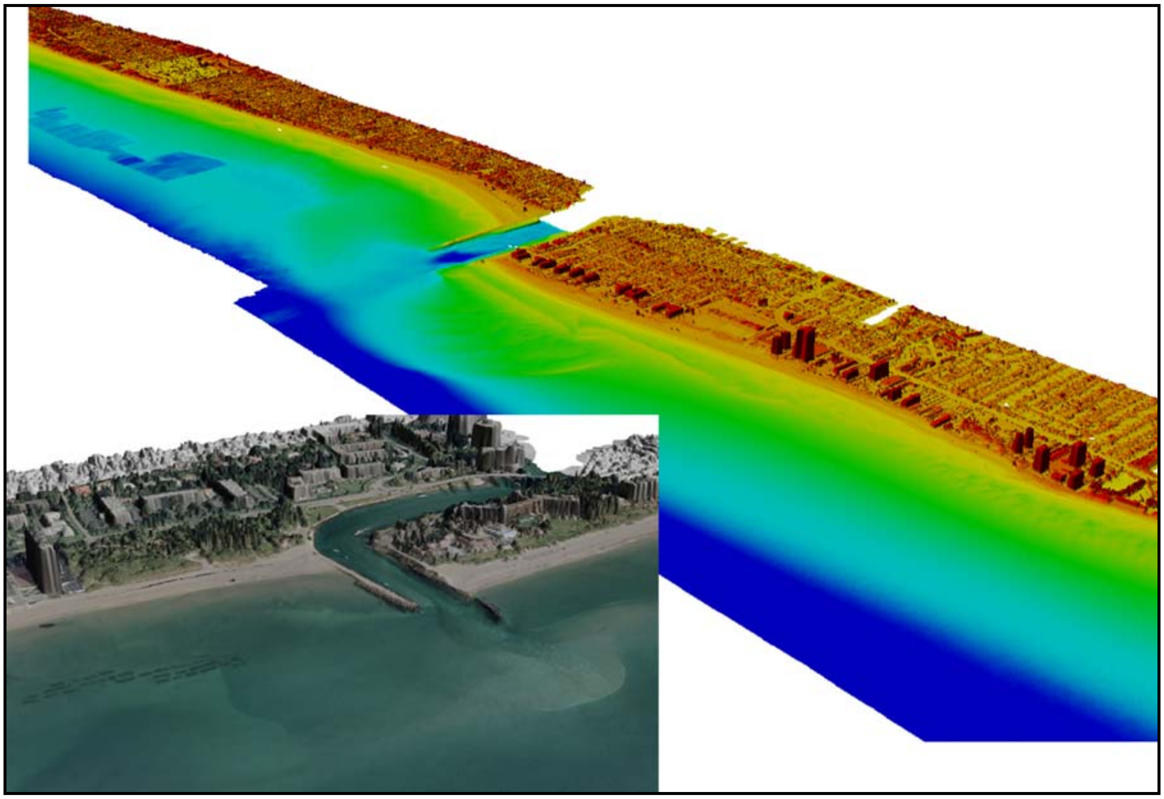

Figure 2. Colored and orthophoto draped Digital Elevation Model (DEM) of LiDAR data collected in April 2004 by the U.S. Army Corps of Engineers CHARTS system along Palm Beach County, Florida.

In order to exclude the landward portion of the data for analysis, the shoreline was digitized along the heavily vegetated or armored sections of the beach. This selection polygon was used to crop the April and November surface models so that only the seaward portions of the models remained for analysis.

The user can perform a variety of analyses on these surface models including contour line generation, flood analysis, volume calculations, change analysis, and profile analysis on multiple models simultaneously.

Change analysis provides a visual representation of elevation increases and decreases. The analysis is particularly useful for coastal engineers and scientists as areas of erosion and accretion in a coastal system can be easily and quickly identified. The software computes the difference in the elevation at each overlapping vertex in the grid models. It then creates a new vertex coloration that represents the result of the difference calculation (Figure 3). In the resulting grid, colors corresponding to the calculated values of change highlight areas of erosion and accretion (Figure 4). In this example, the change detection computation takes approximately 6 seconds.

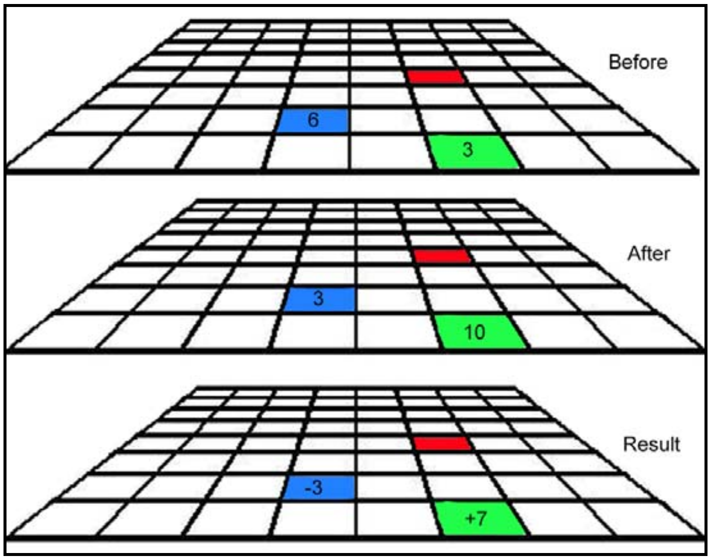

Figure 3. Simplified representation of the change analysis computation on overlapping cells of a Digital Elevation Model (DEM).

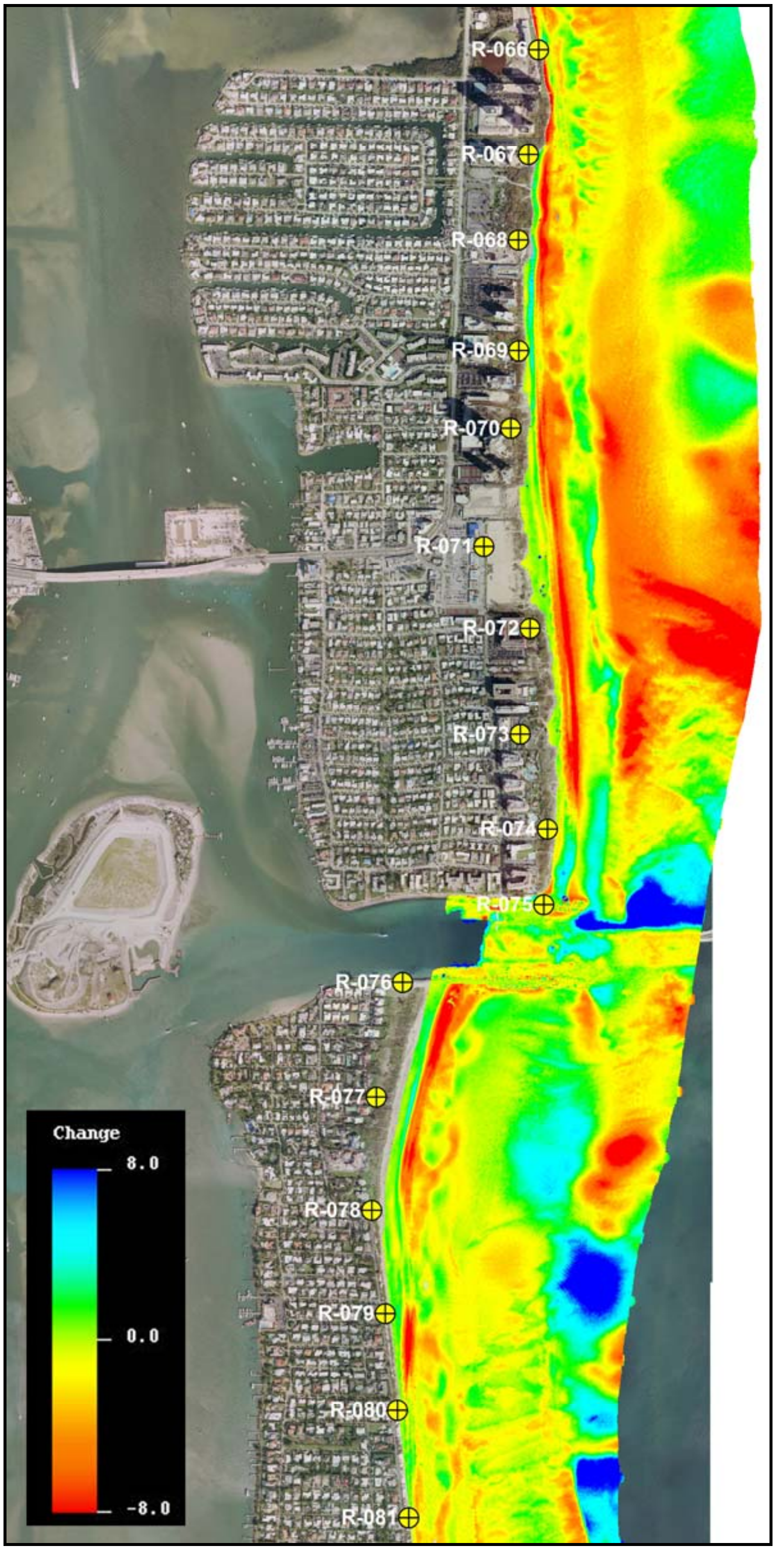

Figure 4. Sediment change analysis visualization based on surface models created from the U.S. Corps of Engineers LiDAR survey in April 2004 after hurricanes Frances and Jeanne in November 2004 in Palm Beach County, Florida. Red colors indicate areas of erosion of 8 feet, blue colors indicate accretion of 8 feet, and light green indicates no change in elevation.

Volume analysis tools can quickly detect changes and provide very accurate quantification because the tools consider each cell of the model in the computation. In the example, the tools can compute the net change in volume. This volume calculation took approximately 6 seconds to show that roughly 6.1 million cubic yards of sand was lost from the 22 mile section of coastline and near shore area analyzed.

Considering the overlap in the models to a depth approximately -30 feet of water, these findings of sediment transport following the hurricanes is noteworthy. While the erosion effects on the beaches after a storm may appear obvious, engineers and scientists must know the fate of the eroded material so that they can best predict how the shoreline might recover. In this case, large volumes of sand have likely moved offshore.

Summary

Advances in LiDAR technology, PC computing power, and software have delivered an unprecedented level of analytical capability to coastal engineers. These new capabilities will result not only in better understanding of coastal processes, faster storm impact assessment, and more accurate project monitoring, but also in cost savings and better decision making.

References

Fugro Pelagos, Inc., 2006, http://www.fugro-pelagos.com/.

Irish, Jennifer L., Lillycrop, W. Jeff, and Parson, Larry E., 2004. Accuracy of Sand Volumes As a Function of Survey Density in Proceedings of the 25th Conference on Coastal Engineering, American Society of Civil Engineers, New York, NY.

Optech Inc., 2006, http://www.optech.ca/.

Tenix LADS, Inc., 2006, http://www.tenix.com/Main.asp?ID=30.

U.S. Army Corps of Engineers, 2002. Chapter 18 - Coastal Engineering Surveys *in* Engineering Manual EM 1110-2-1003.

Wozencraft, Jennifer & Millar, David, 2005, Airborne Lidar and Integrated Technologies for Coastal Mapping and Nautical Charting *in* Marine Technology Journal, Vol 39, Number 3, Fall 2005.