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Figure 1 Lynx Mobile Mapper mounted on survey vehicle.





Using the Lynx Mobile Mapper to Survey a Levee

In August 2005, Hurricane Katrina devastated the Gulf Coast of the United States, leaving in its wake an unprecedented loss of life and property damage. Among the critical infrastructure the storm impacted was the levee system that controls the Mississippi River's flow around the city of New Orleans.

In the aftermath of this most destructive storm, a surveying firm was approached by a client seeking a survey of the existing levee system to be carried out with an accuracy standard of 3 to 5 cm. First they sought airborne LiDAR data (surveying the levees from an aircraft flying overhead using an airborne laser scanner), correctly assuming this would be the fastest way to gather accurate topographic position data.

The survey firm informed the client of another option, mobile LiDAR mapping. Like airborne mapping, terrestrial mobile mapping exploits the same technology, LiDAR (LIght Detection And Ranging). But instead of the LiDAR equipment being installed in an aircraft, it is mounted on a ground survey vehicle such as a car, van or truck. Assured that terrestrial mobile mapping would be just

as cost-effective as airborne mapping, they decided to test this method.

Monitoring through LiDAR technology helps engineers to assess the current state of the levee systems. A number of indicators can be checked, such as subsidence monitoring around flood walls. Change-detection in the physical levees is another vital application. Engineering-grade surveys that enable detailed measurement of the levees are critical, and the data required to accomplish this is easily obtained by LiDAR scanning.

Data Collection Test

The survey firm used Optech's Lynx Mobile Mapper™ to conduct the test survey. The Lynx Mobile Mapper was deployed to the New Orleans area to collect spatial data from a 1.3-mile section of levee along the Mississippi River. The total collection time for the 1.3 mile section took one hour. The Lynx was programmed to collect data at a rate of 400 kHz (2 sensors, each operating at 200 kHz). The Lynx data was referenced to an NGS survey point less than one mile from the project location, and no farther than 2.2 miles from the extents of the project limit.

>> By James Wilder Young

TABLE 1:
Profile and survey points along levee

	(m)
Average Dz	-0.002
Minimum Dz	-0.03
Maximum Dz	0.042
Ave mag.	0.019
RMSE	0.024
Std dev.	0.024

Easting	Northing	GPS ground control data (m)	Lynx lidar data (m)	Dz (m)
776583.106	3315512.332	-21.812	-21.77	0.042
776482.977	3316035.837	-18.65	-18.61	0.04
776481.815	3316035.751	-18.59	-18.55	0.04
776480.68	3316035.261	-18.518	-18.49	0.028
776589.905	3315513.815	-22.456	-22.43	0.026
776501.372	3315830.23	-19.544	-19.53	0.014
776608.762	3315517.511	-22.671	-22.66	0.011
776383.998	3316714.09	-18.74	-18.73	0.01
776486.585	3315824.475	-21.032	-21.03	0.002
776531.991	3316043.222	-23.141	-23.14	0.001
776387.068	3316714.58	-18.711	-18.71	0.001
776597.803	3315515.444	-22.91	-22.91	0
776601.931	3315515.648	-22.979	-22.98	-0.001
776603.323	3315516.85	-22.654	-22.65	-0.004
776591.881	3315514.167	-22.424	-22.43	-0.006
776530.485	3316043.036	-23.142	-23.15	0.008
776594.707	3315515.131	-22.558	-22.57	-0.012
776372.596	3316712.887	-22.526	-22.54	-0.014
776385.777	3316714.475	-18.692	-18.71	-0.018
776436.184	3316723.371	-23.651	-23.67	-0.019
776523.518	3315840.038	-20.469	-20.49	-0.021
776545.601	3315849.707	-22.786	-22.81	-0.024
776510.874	3315834.539	-18.653	-18.68	-0.027
776535.454	3315845.038	-21.98	-22.01	-0.03

At the start and finish of the survey, the Lynx operator carried out a static initialization for 10 minutes with the vehicle parked near the GPS base station at the south end of the project. Static sessions are performed at the beginning and end of surveys to allow time for the GPS position data and the sensor's inertial reference data to resolve into fine alignment status. Having fine alignment data from these periods helps in the data post-processing stage, as it can be used to fine-tune occasional coarse alignment data that can occur during the survey as a result of intermittent GPS signal decay or interference.

The survey vehicle drove along the top of the levee at a speed of 20 to 35 MPH while the Lynx scanned the surrounding area. The levee test section was driven twice, once northbound, once southbound. Data density was approximately 1,000 to 2,000 points per meter (PPM), and each processed data strip from each LiDAR sensor contained approximately 50 million points. The total size of the data set after processing, including raw and processed data, was 50 gigabytes (GB).

The client's concern with achieving the desired accuracy from a comparatively new technology was addressed

by comparing the Lynx-acquired data with data from the same area acquired by more familiar methods. To do this, the surveyor used survey-grade Trimble GPS equipment to collect a series of ground survey points from a railroad that runs parallel to the levee. This data would be used as a control for comparing the Lynx data. The control data was regulated to achieve sub-centimeter accuracies. The GPS survey control data was not used to develop a transformation for the Lynx LiDAR data in order to

improve the results. Rather, the client was interested in seeing if the Lynx Mobile Mapper could achieve the required accuracies without improving its data by using the survey control information.

Data Processing and Analysis

The spatial data was processed in two hours following the collection. The combined solution of the differential kinematic GPS data yielded separation accuracies of less than 1 cm. The IMU data was reviewed and showed that

TABLE 2: Rail line comparison

Easting	Northing	GPS ground control data (m)	Lynx lidar data (m)	Dz (m)
776436.18	3316723.37	-23.65	-23.63	-0.02
776437.69	3316723.6	-23.64	-23.62	-0.02
776531.99	3316043.22	-23.14	-23.13	-0.01
776530.52	3316042.5	-23.14	-23.15	0.01
776603.32	3315516.85	-22.65	-22.65	0.00

	(m)
Average Dz	-0.008
Minimum Dz	-0.020
Maximum Dz	0.010
Ave mag.	0.010
RMSE	0.014
Std dev.	0.013

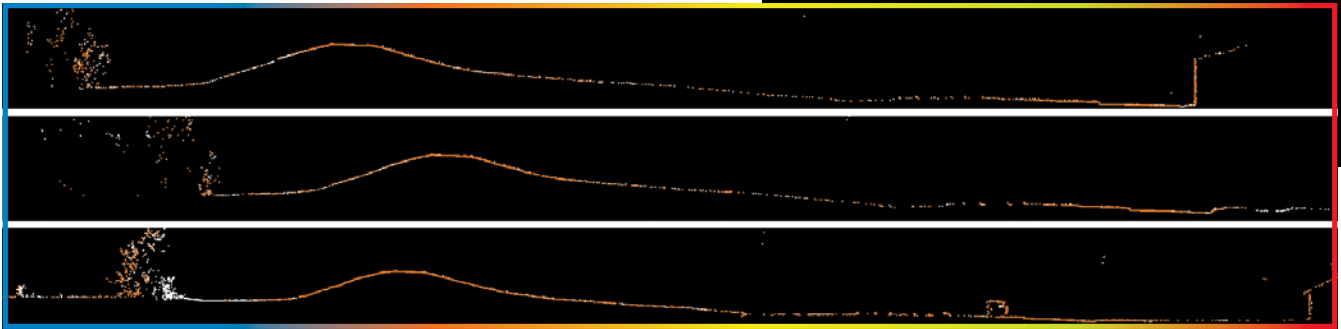


Figure 2 Profiles of scans from both sensors operating at 200 kHz each, for a total of 400 kHz.

there was almost no drift or degradation recorded by the IMU. The two-GPS antenna configuration, plus the addition of a Distance Measurement Indicator (DMI)-the standard configuration in all Lynx Mobile Mappers-facilitated the improvement of the data.

Initial analysis of the accuracy yielded results within 4 cm or better when comparing the Lynx Mobile Mapper LiDAR data to the survey control data (no adjustment), with the RMSE at 2.4 cm. Keep in mind that the Lynx Mobile Mapper data was tied only to one NGS point at the south end of the project area. **Table 1** shows the point accuracy of the profiled data and surveyed points along the levee.

When comparing the Lynx data to the control data along the railroad it was determined that the Lynx measured the rail to within 2 cm or better, with a RMSE of 1.4 cm, based on the control survey rail elevations (**Table 2**).

Two Heads Are Better Than One

There are advantages to using two sensors instead of one. The relative accuracy of each sensor can be verified by the other, which provides confidence in the operation and stability of the system. Also, using two sensors in different locations reduces the occurrence of laser “shadowing,” a phenomenon related to LiDAR’s line-of-sight principle. For example, the sensor “sees” the north and east facades of a bridge support because it was aimed in this orientation as it scanned; the south and west facades of the support, however, are not captured because they were not in the sensor’s line-of-sight. The dual-sensor configuration minimizes laser shadowing as each sensor optimizes the line-of-sight least accessible to its companion. In post-processing, range, angle and intensity

data are combined from both sensors to produce a much more complete and accurate 3D model.

Figure 2 shows profiles of levee data that the Lynx collected from three different locations. The point data in the profiles was captured in scans from both sensors during one pass along the levee. Points from sensor 1 are color-coded white; points from sensor 2 are brown.

Note that in the bottom strip there is a predominance of brown points on the left side of the profile which come from sensor 2 on the passenger’s side of the survey vehicle. Similarly, there is a cluster of white points on the right side which come from sensor 1 on the driver’s side. This distribution of points, seen clearly in the visual rendering of the profile, illustrates how operating two sensors greatly reduces the level of shadowing that could occur if only one laser was used.



Figure 3 Crack in surface pavement of levee rendered visible after sampling data down to surface level.

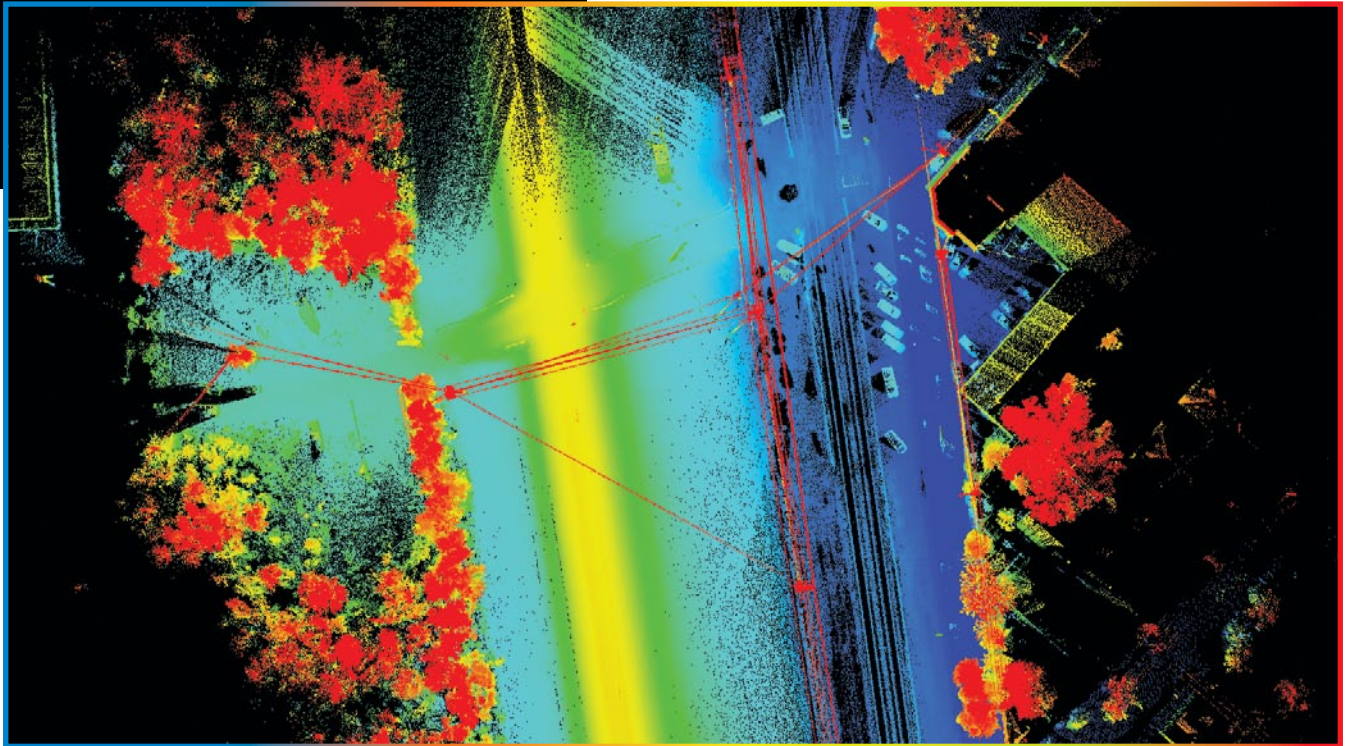


Figure 4 Point cloud visualization (plan view) of the levee from two scans, one from each Lynx sensor.

Results

Of the total 3,086 samples used in this analysis, 1,146 (37 percent) registered a difference of 0 (i.e., showed no difference between scans). A total of 170 samples (5 percent) measured values of 3 cm, either negative or positive. Therefore, it can be deduced that 95% of the samples were within 2 cm of each other. This difference is ascribed to the sensor measuring to the top of grass growing on the levee surface rather than to the ground below. To verify this conjecture, the data was sampled down to only those points on the top pavement of the levee. When sampling down to this level, an example of the detail that the Lynx Mobile Mapper captures can be seen in the crack along the levee surface pavement shown in **Figure 3**.

Overall, the Lynx Mobile Mapper performed very well, especially considering the fact that the data was referenced to only one NGS point, and no adjustment or transformation was applied to fit the data within the survey parameters.

If the data was transformed to the survey points, it would be reasonable to expect an overall result of less than 1 cm.

Figure 4 shows a point cloud of the levee derived from Lynx Mobile Mapper data and output through QT Modeler visualization software. The visualized data is the product of two scans, one

from each sensor and both scanning in the same direction. The density and detail of the point cloud are striking: cars parked along the street in the upper-right corner, railroad tracks to the left of the cars, tree foliage and overhead power lines are all clearly delineated.

The accuracy of this visual rendering is particularly impressive, given that objects such as the railroad tracks are 50 meters away from the area of interest.

Future Applications

The client was very impressed with the results of this test survey. The client's required accuracies were 3 to 5 cm, and the approach to the project was based on these specifications. It was demonstrated that 3-cm or better accuracy can be achieved using the Lynx Mobile Mapper. It is understood that accuracies better than 3 cm are not always achieved for all data with this approach, and that other projects may require additional ground survey control to achieve engineering-grade results. Therefore, planning the survey project in close accord with the required specifications is essential to ensure successful mobile mapping projects.

Monitoring subsidence is important to ensure that the levee walls and pilings are rooted sufficiently deep in the subsurface; change-detection analysis

can reveal whether they are shifting. This is a proactive measure that should be taken to detect where failures could occur, and thereby, rectify detected problems. This will not only assist in building stronger flood walls and pilings, but could also save property—and more importantly—lives, if the New Orleans area experiences another hurricane of Katrina's magnitude.

In addition to producing accurate and rich data sets, the Lynx Mobile Mapper is far more time- and cost-effective than traditional survey methods. An average data collect requires a driver and operator to drive the route plan in about one hour, and then prepare the data for post-processing. Compared to traditional monitoring methods, the Lynx Mobile Mapper also aids in worker safety by eliminating the need to work very close to the water and its attendant risks: turbulence, exposure to subsurface hazards and—in south Louisiana—potentially harmful predators such as snakes and alligators. *AS*

James Wilder Young is currently the LiDAR Solutions Specialist for Aerometric, Inc. He has more than 17 years operational and management experience in the mapping industry, 15 years of which have been with LiDAR.