MULTIBEAM SURVEYS EXTENDED ABOVE THE WATERLINE

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ABSTRACT

With the increased need to utilize multibeam bathymetry for volumetric surveys both pre- and post-dredging, the ability to apply a cost-effective method for extending the survey above the waterline is of significant value. With the advent of dynamic laser scanning systems deployed from a vessel, surveys can now surpass the detail and accuracy of even the best multibeam sensors. By coupling the sensors together on the same vessel platform, the versatility of this pairing creates an opportunity to perform coastal and inland water body surveys with little regard for the water line relative to the site in question. Surveys using this technology have been recently applied to critical habitat damage assessment, beach cleanup and shoreline surveys and can also include sand traps, pier expansions, beach replenishment, land reclamation and efficient surveys in areas with high tidal variation.

Keywords: Multibeam, bathymetry, laser scanning, habitat damage assessment, shoreline survey, dredging, beach surveys, coastal surveys

INTRODUCTION

Highly detailed and accurate multibeam survey methods are critical in characterizing shallow-water project challenges and estimating associated costs. However, in some cases the area of interest in a project extends above the waterline, where multibeam technology cannot be utilized. Some examples include: dredging projects that require deposition of material both onshore or as sub-surface fill, route surveys for pipeline or cable landing sites or optimizing efficiency in operating in areas with challenging tidal variations. Coupling a mobile laser scanning sensor to a vessel performing the associated multibeam bathymetric survey can remove many of these obstacles and allow for the collection of a comprehensive survey data set that extends above the waterline. Such an application also has the advantage of incorporating a land survey without the need for personnel on the ground, which can be very important in areas that sustain a delicate habitat or expose workers to risks. The resulting data set can typically be treated the same as a conventional multibeam survey but benefits from a significant increase in scope. This paper will discuss several of these applications and reference several real-world applications.

TECHNOLOGY

Multibeam Bathymetry

Hydrographic surveys using sonar technology have been employed for many decades. Sound pulses are fired from a projector through the water column and the return time of the pulse to the sensor is used to calculate the range between the sensor and the ensonified surface (nominally the bottom of the water body). The speed of the sonar pulse is not constant through the water medium due to inconsistencies in the water medium caused primarily by temperature, pressure and salinity. Sound velocity profiles are measured independently in order to compensate for these variations in the environmental conditions and are used to model the travel time of the sonar pulses through the water.

The introduction of multibeam (or swath) bathymetry allows a fan-shaped swath of beams to chart a map in a push-broom manner. This creates rows of observations perpendicular to the direction of vessel travel that cover a wide corridor of area along the route of the vessel. Adjacent passes of the vessel allows for collection of overlapping data, which is valuable for quality assurance while producing a continuous data set below the waterline. There are several variants of multibeam technology on the market today using either discrete beam observations or

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interferometric pulses that are continuous across the swath. Accuracies, ranges, swath width and distance between observations (and thus observation density) all vary depending on the sensor and water depth.

In all cases, multibeam bathymetry requires observation of position and orientation of the sensor in order to produce real-world coordinates for each point. In high accuracy applications which are the subject of this paper, this is typically done using an integrated Global Navigation Sensor System (GNSS – also commonly known as GPS) and Inertial Measuring Unit (IMU – also commonly referred to as Inertial Navigation System (INS)). The GNSS system is used for tracking the precise location of the system and assisting the IMU in tracking the orientation of the system. When tightly-coupling the functionality of these two systems, the resulting trajectory of the sensor is typically very accurate and robust in most environments. The GNSS system is also used to synchronize timing of the sonar device to GNSS time for post-processing.

The final trajectory created using data collected with the GNSS and IMU sensors is processed in conjunction with the range and angle data from the multibeam sensor to create numerous discrete observations typically expressed as XYZ coordinates in the appropriate coordinate system and units for the project.

Since the technology is based upon sound traveling through the water medium, naturally it is not capable of making observations above the waterline. Observations very close to the water surface are suffer degradation in accuracy caused by difficulty in modeling sound velocity so close to the surface and the steep angle from the sensor to the target. In addition, random reflections are also often present. Therefore observations within a few inches of the water surface elevation are typically unreliable.

Mobile Laser Scanning

Laser scanning technology (also referred to as LiDAR) is analogous to multibeam technology although it uses light waves (typically in the near infrared spectrum between 1000 um and 1600 um) for surveying above water. Mobile laser scanners use either a zigzag fan pattern (resembling multibeam data) or a 360 degree circular pattern. In cases where a single laser scanning head is used, the scan pattern is generally placed perpendicular to the heading of the mobile platform in the same fashion as a multibeam survey. When two scanning heads are employed, each scanner is generally deployed 30 to 45 degrees off from perpendicular to reduce occlusions.

As with multibeam surveys, position and orientation are critical to producing real-world coordinates for the observations, hence mobile laser scanning systems are always coupled with GNSS/IMU sensors.

Near-infrared light is absorbed or reflected by water; therefore it is not possible for mobile laser scanning units to perform observations below the water surface.

Figure1. Vessel mounted mobile laser scanner (single sensor).

Sensor Integration

Since both technologies are limited in their field of view on the opposite side of the water medium, they are well suited to work together. In most applications, the technologies are deployed from the same vessel platform although in some cases, moving the laser scanner to a ground based vehicle can offer additional perspective views for capturing data that is not visible from the vessel. This might include features such as the back side of a levee or building, downstream face of a dam where water conditions might prevent vessel access or the upper deck features of a bridge or pier structure. For water-based surveys, the choice of vessel platform is largely contingent on water depth and the draft of the vessel and/or its seaworthiness. Vessels with significant draft are not suitable for shallow water; similarly a small vessel may not be sufficiently seaworthy to carry out survey work in the open ocean. Most projects have specific requirements that will dictate the appropriate platform.

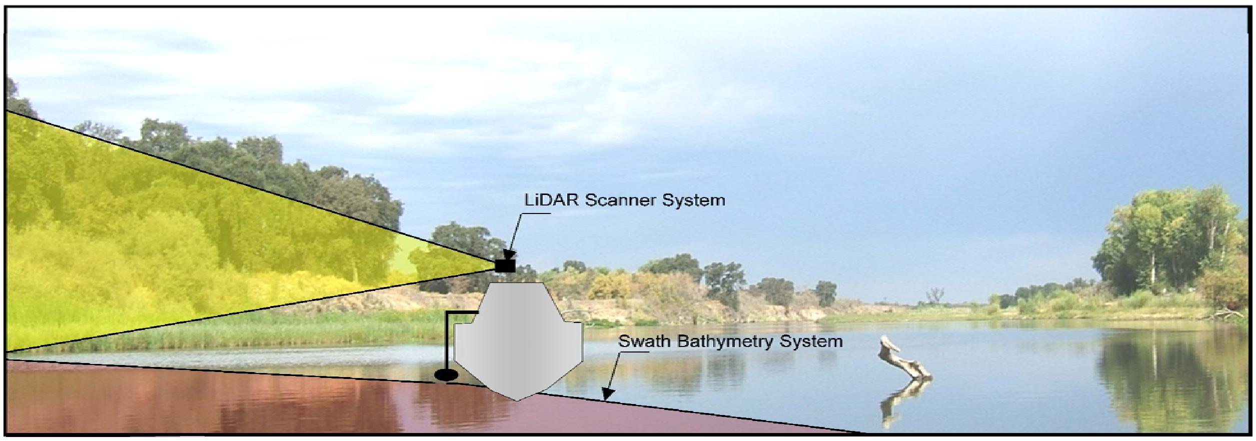

Figure 2. Integrated multibeam bathymetry and laser scanning systems.

Data Integration

Although both sensors produce point cloud data sets, there are challenges to overcome in merging them. The raw multibeam data has higher variance in positional accuracy than laser scanner data due to the complex nature of the water medium relative to air. Multibeam points near the water surface are also subject to more propagated uncertainty near the waterline. This is the result of both steep observation angles from the sensor head and more variance introduced in shallow water (i.e. above the depth of the sensor head) which is caused by less reliable sound velocity modeling and potential signal multi-path. Manual editing, employment of sophisticated algorithms or sacrifice of this transition zone data is necessary before merging with laser data. The laser scanner data also is subject to signal multipath as it impacts the water, creating false data below the waterline. Removal of this data again requires manual editing or sacrifice of this transition zone data is required. Because both sensors perform at their weakest at the transition zone, it is highly advantageous to utilize tidal variation (where possible) to collect overlapping data.

APPLICATIONS

Dredging

Due to the substantial cost of dredging projects where costs are based upon volumetric quantities of material moved, very accurate and detailed surveys protect both the dredging operator (compensated on quantity) as well as the contracting party responsible for payment. Multibeam surveys have been used for precisely this purpose for more than a decade; single beam surveys (crossing profiles) are not commonly employed for this task simply due to the ratio of cost between the survey and the cost of error in volume. Multibeam surveys produce dense point clouds where data sets can be orders of magnitude more dense and detailed compared to single beam (profile) surveys (depending on sensor chosen and water depth). The survey produces overlapping strips of point clouds which are used to generate Triangulated Irregular Networks (TIN) and/or Digital Elevation Models (DEM) frequently of onemeter or even sub-meter resolution. This is a drastic improvement over the considerably wider spacing created using single beam survey techniques.

However, a problem remains when the dredging site or the material deposit site crosses the waterline. Since multibeam technology cannot cross the waterline, this technology alone is not suitable to provide the same comprehensive survey above the waterline. The common remedy has been to employ traditional pole-mounted GNSS surveys, total station and/or grade staking to provide cross-sections for these spoil deposit areas above the waterline. One disadvantage to this method is the requirement for deploying personnel into the deposited and potentially hazardous material. Another disadvantage is the inferior detail of cross section surveys compared to that provided by the accompanying multibeam survey.

Utilizing mobile laser scanning from the same platform conducting the bathymetry survey can often overcome both of these obstacles – reducing HSE exposure while collecting superior resolution data. In some cases, it may still be necessary to deploy the laser scanner from a ground based vehicle if the land area is not fully visible from the vessel.

In harbor channels and other navigable waters, material accumulation in certain areas can occasionally be a by-product of activity above the waterline, such as sediment accumulation from dumping, build up created by vessel activity or debris from erosion or landslides. Inclusion of laser scanning in surveys in areas that have unexpected material deposits can offer valuable context as to the source of the deposition.

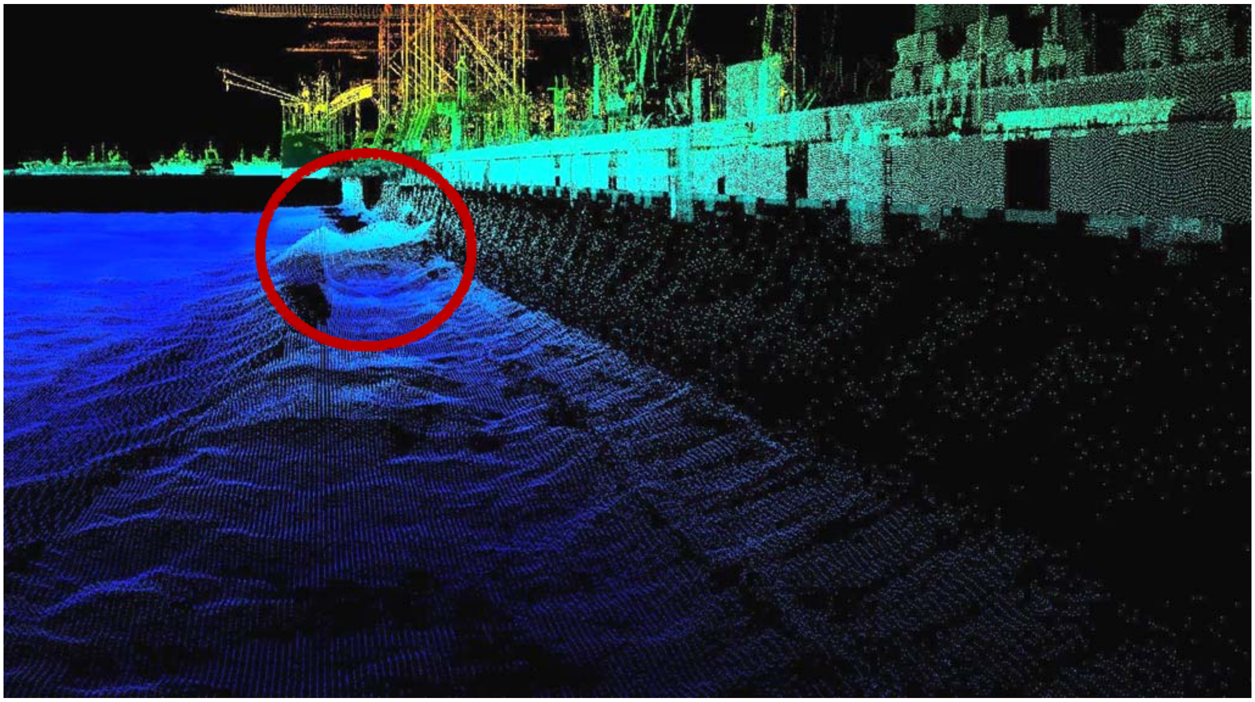

Figure 3. Berthing site – sediment accumulation caused by vessel activity.

Beach Landing Sites

Many infrastructure projects such as pipelines or subsea cables require landing sites for the infrastructure to cross the waterline. These sites are often difficult to access and because they are engineered long after the survey, there is a significant advantage to having very detailed, comprehensive surveys which allow engineers greater latitude during the design phase. Conventional topographic GNSS RTK surveys are exponentially more time consuming with expansion of the area of interest – consequently, the surveys are typically limited in scope to no more than is deemed essential. However, laser scanning can cover several miles of shoreline in a single day, which can be of significant value to the engineer during design. This can also be valuable if issues arise with concern to landowner permission, safe access to the site or risk of endangering the habitat. It should be noted that surveys of this type that have significant vegetation or building obstructions within the area of interest will commonly require supplementing the survey from the land.

The bathymetric survey is a common element to most landing site surveys today; however there are frequently overlooked advantages to utilizing multibeam sensors. Wide-angle multibeam systems can increase the field of view from the vessel. When the sensor head is tilted towards the shoreline, it can often allow survey to the shoreline which might eliminate the use of lead lines or GNSS RTK surveys by personnel standing in water. Using these technologies together can allow general increases in scope to have a much smaller impact on the overall cost of the survey.

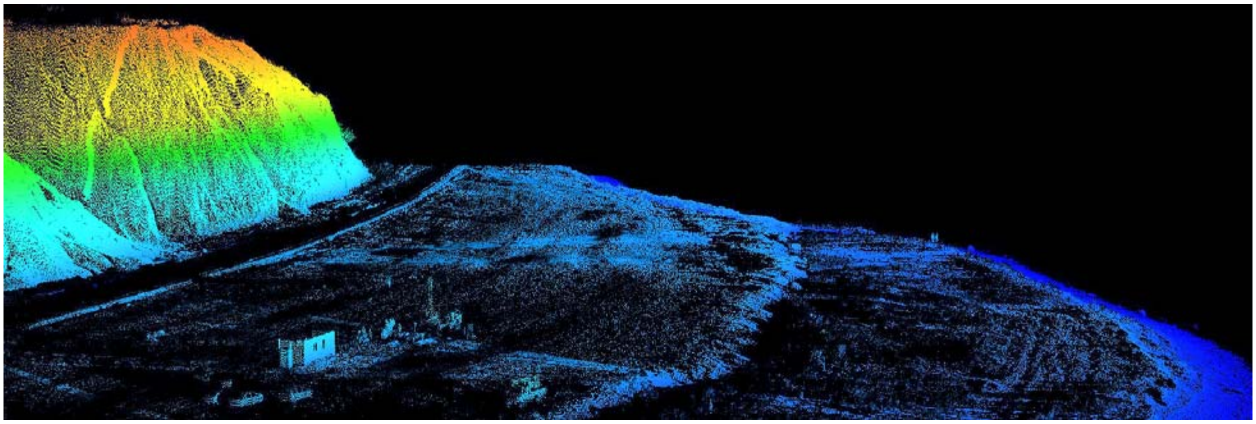

Figure 4. Beach/shoreline survey in Izmit, Turkey.

Shoreline/Riparian Habitat Monitoring, Beach Replenishment and Land Reclamation

Similar to beach landing sites, shoreline surveys to investigate erosion effects, beach replenishment planning or land reclamation programs can be completed very efficiently compared to traditional or GNSS survey methods, covering several miles in a single day. In the same way that volume is a critical cost element in dredging projects, it is also typically a critical cost element in projects requiring beach replenishment and/or land reclamation and therefore the same benefits apply to these programs. Shoreline areas and marsh vegetation edges are often restricted from anthropogenic access due to fragile wildlife habitat, land ownership issues, hazards caused by chemical spills or the presence of hazardous waste. Therefore non-standard survey methods must be implemented to collect and capture critical topographic features, such as shoreline erosion, scarp line, exposed root mass, vegetation wrack line, and pollutant residues. The combination of sensors again allows capture of data on both sides of the waterline. The primary limitation in such examples arises in non-tidal zones where it is difficult to collect data that seamlessly spans the waterline. Where sufficient tidal change is present, this can be overcome.

Coastal Slope Stability and Hazard Surveys

Coastal property is prime real estate for residential, commercial as well as infrastructure development, yet it is commonly at very high risk due to erosion effects of the ocean, landslides, tsunamis and earthquakes. These sites are also typically difficult to access safely. Engineering geologists are often called upon to identify sites that are likely to fall victim to damage caused by slope failure, yet without suitably detailed survey information regarding the conditions of the site, it is very difficult to provide an empirical model of the actual risks. Mobile laser scanning from a vessel can provide exceptional detail of the slope, characterizing the slope angles of different facets, identifying scarps and landslide debris while limiting exposure of personnel to hazards at the site. Bathymetric survey data plays a valuable role in providing forensic evidence of historic land slide events which may be hidden below the waterline. Some laser scanners have more limited range than others and in many of these projects the approach of a vessel to the site may be dangerous, preventing use of short-range laser scanners in these applications.

Coastal Engineering Applications

Piers, offshore platforms, bridges and similar structures that have piles/footings embedded below the waterline frequently undergo structural challenges caused by sediment transport (scour) and are episodically affected by events such as tsunamis or earthquakes. Multibeam bathymetric surveys can quickly capture structural details in a relatively short period of time and help identify areas of structural concern to be further investigated by underwater dive inspections. The integrated survey technique becomes very cost effective by limiting diver deployment and diver exposure to hazardous conditions such as high water turbidity, extreme currents and swell. Where diving proves necessary, the collected data can be valuable in providing divers with pre-site reconnaissance in poor visibility conditions. The utilization of underwater multibeam equipment helps leverage field resources for Smart-Diver Deployments and eliminates over utilization of lengthy underwater dive inspections. With the combination of underwater multibeam and above water laser scanning, a full 360 degrees visual data set can complement bridge height clearances surveys, erosion and scour assessments, and infrastructure planning and improvements. Multibeam and laser scanners can help coastal engineers and environmental planners assess damage to infrastructure due to both natural and man-made disasters, they also provide cost-effective means for periodic studies to monitor land and vegetation loss/gains. This quantification of damage may be used for litigation purposes, and help provide objective data sets to be used for comparative analysis with future surveys performed in the same manner.

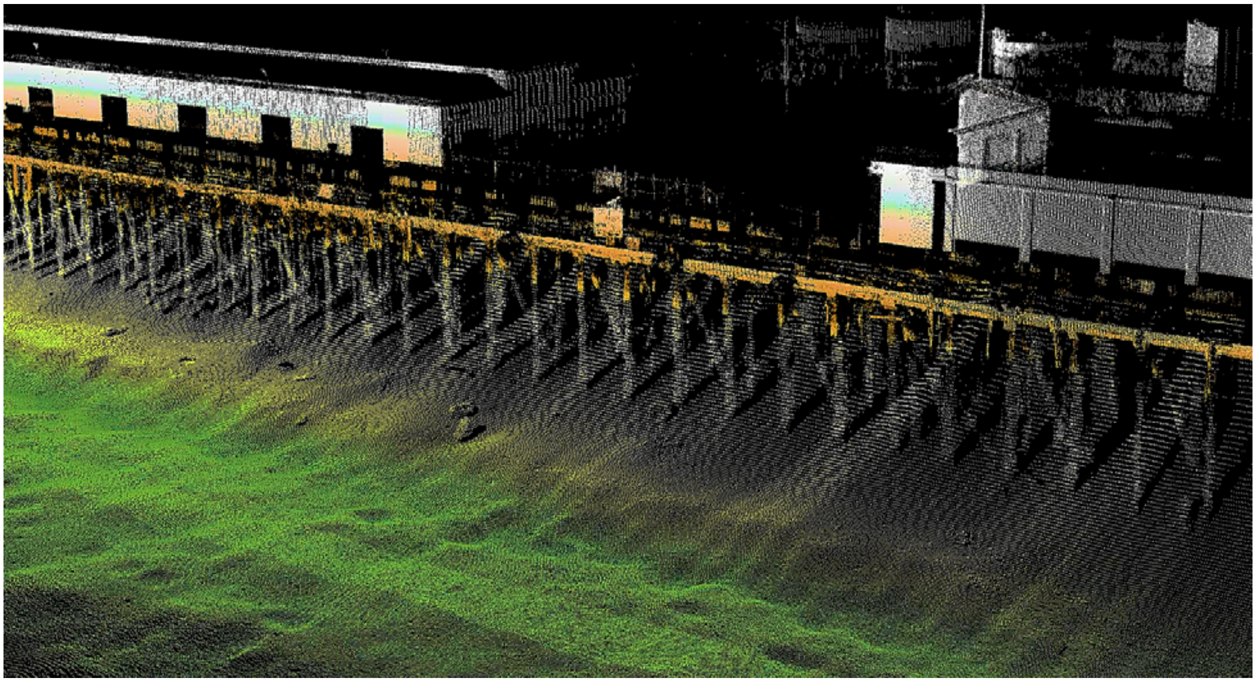

Figure 5. Multibeam bathymetry and laser scanning of pier facility in Los Angeles, California.

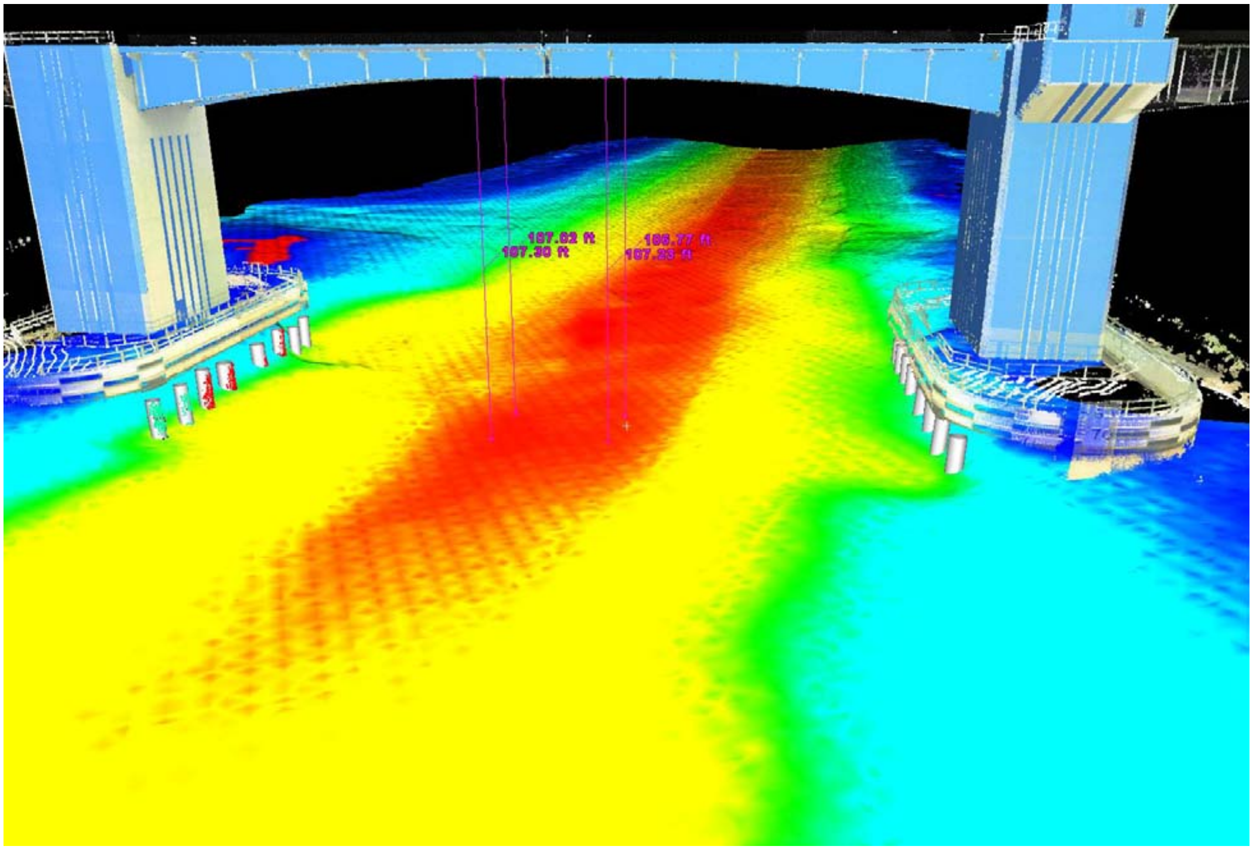

Figure 6. Multibeam bathymetry and laser scanning of Cypremort Point Bridge, Louisiana

Working in High Tidal Variation

Multibeam bathymetric surveys cover significantly more area in deeper water since the sensors field of view is angular in nature and the fan-shape of the swath expands in distance the further it travels. Although an increase in distance translates into a reduction of density of detail, many projects benefit more from reduced cost over level of detail. In regions where tidal variation is very great (as in far northern or southern latitudes), the efficiency of a survey can be greatly hindered by significant reduction in the area covered during a bathymetric survey due to low tide. Adding to the complexity are nearshore areas which may become exposed to air when the tide drops, making bathymetric survey very difficult, dangerous or perhaps impossible due to short time windows for conducting the survey and the risk of grounding the vessel.

In these near-shore cases where a site is no longer covered by water, the laser scanner again offers the opportunity to capture this type of such a site efficiently and with minimal risk.

SELECT PROJECT EXAMPLES

Coastal Near-Shore Infrastructure Surveys

On multiple occasions Fugro Consultants has carried out surveys using an Optech ILRIS laser scanner and either an R2Sonic 2024 or GeoAcoustics GeoSwath multibeam bathymetric survey system for surveying coastal near-shore infrastructure including breakwaters, pier structures and harbor facilities in Southern California and in Cape Town, South Africa. The coastal nature of the projects suits optimizing tidal conditions to produce overlapping data from the two sensors. Dangerous risks associated with deploying personnel on the breakwater for a conventional survey (typically the primary driver for these projects) were avoided. Capture of details about the underside of piers is the primary advantage of this application.

Beach Surveys

In summer and fall of 2010, John Chance Land Surveys carried out two surveys mobile laser scanning surveys were conducted in southern Louisiana in order to investigate beach conditions and the presence and health of vegetation during one survey and calculating sand volumes in another project. Both projects used an Optech ILRIS laser scanner deployed from a vessel or from a ground-based ATV. These techniques allowed efficient surveys of these areas of interest without disturbance.

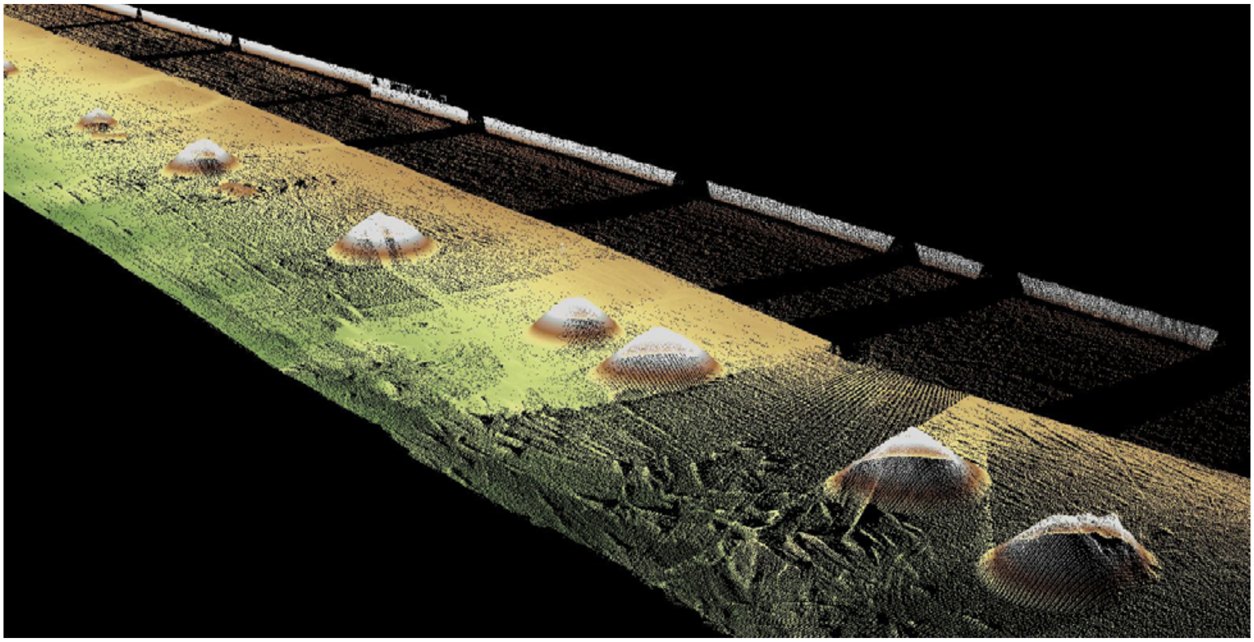

Figure 7. Beach survey in Louisiana.

CONCLUSIONS

Advantages

The utilization of various advanced technologies working in tandem can be applied to several survey disciplines. Reducing field time while improving detail and functionality of collected data, expediting the manner in which the data is collected and the increase of both the amount of data collected and the accuracy in which it was collected have been key drivers for development of this technology pairing. However, increasing the safety of working conditions for all field personal, minimizing the more intrusive nature of conventional survey field methods and limitation the subjectivity of captured data have also been advantages realized by employment of this technique since its development.

Disadvantages

Obstructions to the field of view of either sensor caused by above-surface features such as vegetation, buildings, piers, infrastructure or vessels impede the ability to collect data beyond the obstacles creating data voids. It is highly advantageous to collect data in a manner that takes into account obstructions and to avoid them where possible or to supplement data collection from different aspects to ensure inclusion of all necessary features. Interpolation of data across occluded data voids is possible but not necessarily desirable. Planning the survey around the absence of mobile obstructions is also advantageous in terms of data processing time.

As covered earlier, both sensors perform more poorly at the water line. In tidal areas, this can be overcome by taking advantage of tidal swing to collect overlapping data. However in non-tidal areas, it is not typically possible to produce seamless data unless the laser and bathymetry surveys are carried out when seasonal variations change the water elevation.

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