Surveying from a Vessel Using a Multibeam Echosounder and a Terrestrial Laser Scanner in New Zealand

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Abstract
Shallow water Multibeam Echosounders (MBES) providing high-resolution mapping of the seafloor have been in common use since the 1990's. The technology is now widely used in support of subsea operations including navigational charting, offshore resource exploration, habitat mapping, coastal engineering, dredging and port asset management. Recently Terristrial Laser Scanners (TLS) have become an essential tool in the surveying and mapping industry, providing rapid, high resolution 3D point cloud data, however locally to date, the use of dedicated Mobile Laser Scanners (MLS) or TLS on mobile platforms has been limited.

This paper investigates the potential to acquire and integrate TLS data and high resolution shallow water MBES data simultaneously from a mobile platform. The aim of the trial being to efficiently generate a seamless 3D data set, above and below the waterline.

Keywords: Mobile laser scanner, multibeam echosounder

1. Introduction

High resolution point cloud data is fast becoming the backbone to any construction or maintenance project whether on land or subsea. The ability to digitally model physical structures on the seabed or land improves the planning, design, implementation and maintenance phases of projects. Further, the ability to remotely capture high resolution data efficiently in hazardous environments is seen as a potential benefit to all clients.

Discovery Marine Ltd (DML) has recently been involved in projects where the client's requirement for accurate survey data of structures above and below the waterline but in potentially hazardous locations for personnel could have been readily resolved with the use of a TLS or MLS from a vessel.

2. Background

DML's specialises in providing hydrographic survey services to clients within the littoral zone and inland waterways. These clients are now seeing less of a boundary between water and land and wish to acquire seamless high resolution datasets to manage assets above and below the waterline.

Through the use of MBES systems DML has become extremely proficient in acquiring high resolution bathymetric data below the waterline. Improving the resolution of data gathered above the waterline in order to provide clients with a seamless data set is the goal of this trial. To achieve this DML has been exploring the integration of laser scanning technology with its existing MBES acquisition system. Initially it was envisaged this would involve a dedicated MLS unit that could be fixed to the vessel. Due to costs, timing and logistical issues, attempts to trial a dedicated MLS on a suitable project here in New Zealand have not eventuated.

After further research and discussions with software and equipment suppliers a decision was made to attempt to integrate a TLS in Profile Scanning Mode with an existing Inertial Navigation System (INS) and Real Time Kinematic (RTK) Global Navigation Survey System (GNSS). While the combined use of TLS and MBES on mobile platforms is not new, combining the equipment and software within New Zealand to achieve a local combined mobile 3D mapping system is a first.

2.1 Multibeam Echo Sounders

MBES systems have now become the industry standard for hydrographic surveying in ports for channel monitoring, dredging and dynamic under keel clearance with a growing use in engineering and construction of subsea projects.

MBES's project a swath of sound energy into the water column with energy reflected from the seabed processed into discrete points forming a swath of data. Sonar footprints of between 0.5° and 1° in the across and along track directions are recorded at up to 6 times the water depth. Modern shallow water systems are capable of acquiring high resolution data at frequencies generally between 200 kHz and 400 kHz. Refer Figure 2.

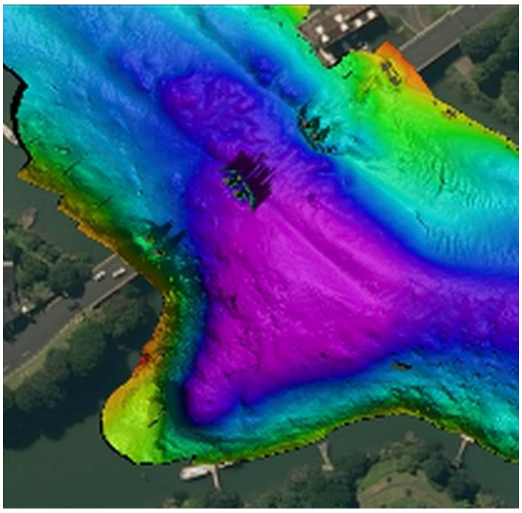

Figure 1 Typical high resolution seabed data acquired by MBES showing road bridge pylons and surrounding seabed.

2.2 3D Laser Scanners

2.2.1 Terrestrial 3D Laser Scanners (TLS)

The first commercial terrestrial 3D TLS were released in 1998. Since then advancements in scanning speed, software processing, decreasing cost of equipment and training have led to the wide adoption of the technology in the survey and engineering industry.

A TLS consists of a scanning head that rotates 360° in both horizontal and vertical planes, from a fixed position. Scan data is logged to the on board memory and downloaded for processing and visualisation in dedicated point cloud or CAD software packages.

The New Zealand market is serviced by a number of manufacturers offering products that vary in accuracy, resolution and cost. Refer Figure 4.

Figure 2 Terrestrial 3D laser scanners.

2.2.2 Mobile Laser Scanners (MLS)

Dedicated MLS units consist of 1 or 2 scanning heads coupled with a high accuracy RTK GNSS positioning system and an Inertial Measurement Unit (IMU) or INS. The scanning heads rotate 360° on one axis generally orientated near to 90° to the along track movement of the scanning unit. Refer Figure 5.

MLS use in New Zealand has been limited with units hired from Australia or Singapore. While manufacturer demonstrations have proved popular in New Zealand suppliers have struggled to make the systems available due to the high purchase and/or lease costs relative to project size.

Figure 5: Typical MLS units available to the New Zealand market

3. TLS Trial

3.1 Combined Vessel Setup

The aim of the trial was to mobilise a vessel capable to capturing MBES data and TLS data simultaneously. The survey system included the integration of MBES, TLS and INS data within the QPS QINSy hydrographic survey acquisition software package.

The benefit of this configuration is that seabed and structures in the marine environment can be mapped to a common horizontal and vertical datum quickly and safely.

Figure 6 Fresh water dam riser above the surface.

It is envisaged a fully calibrated system will capture data above and below the water line to a similar density in areas that are difficult or slow to measure with traditional techniques e.g. wharf & bridge piles, under wharf batter slopes, dam faces, water intakes, breakwaters and seawalls etc. See Figures 6 and 7.

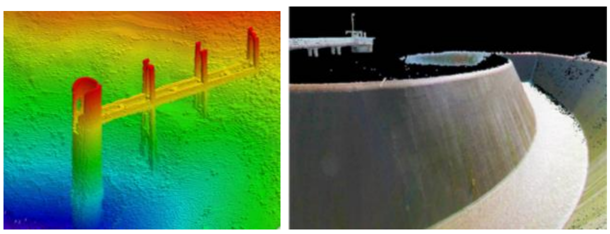

Figure 7 Submerged fresh water dam riser surveyed with a MBES and a TLS as two discreet surveys.

3.2 Location

After completing bench testing of the configuration settings between the Leica P20 and QINSy software at the Global Survey Ltd office, an on water trial was completed around West Haven

Marina, Wynyard Wharf and the Auckland Harbour Bridge on 20th May 2015.

3.3 Platform

DML's dedicated inshore survey vessel '*Pandora II*' was used for the trial. The 7.3m Kingfisher Boats 705HT Power Cat is a highly stable survey platform. The vessel is configured to operate predominately around New Zealand's waterways including the coastal margins, ports, harbours, rivers lakes and dams. It is fitted with both MBES and Single Beam Echo Sounder (SBES) survey systems.

The typical equipment configuration for this survey vessel is shown at Table 1 *Pandora II* specifications.

Table 1 *Pandora II* specifications

Vessel	*Pandora II*
Type	Kingfisher Boats 705HT Power Cat
Year Built	2014
Hull	Alloy
Propulsion	Twin Yamaha 115HP 4 Stroke
Electrical	12V DC and 230V AC
Survey Systems	R2Sonic MBES Applanix POSMV Wavemaster Reson Navisound 210 SBES QINSy Survey Acquisition and Processing software Trimble R6 RTK GNSS
Survey Class & Limits	Survey for 6 Pax – Inshore Limits

3.4 Equipment/Software

3.4.1 Terrestrial Laser Scanner

A Leica P20 ScanStation was supplied by Global Survey for the trial. The P20 is considered an industry standard TLS with a number of units sold to the surveying, engineering and construction industry in New Zealand. See Table 2 for specifications.

Table 2 Leica ScanStation P20 specifications

Instrument Type	Ultra high speed pulsed laser scanner
Accuracy	3D Position: 3mm at 50mm; 6mm at 100m
	Linearity error: <1mm
	Angular accuracy: HZ:8", VT: 8"
Wavelength	808nm (invisible)/658 (visible)
Laser class	1
Beam Diameter (at front window)	< 2.8mm
Range	Up to 120m; min range 0.4m
Scan rate	Up to 1,000,000 points/s
Field of view	Horizontal: 360^0
	Vertical: 270^0
Scanning optics	Vertically rotating mirror on horizontally rotating base.
	Up to 50 Hz with internal battery
	Up to 100 Hz with external power supply

An accurate dimensional control survey determining 3D positions of all existing sensor locations within the Vessel Reference Frame (VRF) had been completed previously. Utilising an existing mounting location within the VRF, the TLS was fixed to the starboard side of the vessel roof. Data transfer and accurate timing cables were run to the Applanix POS MV inertial navigation system through a ventilation hatch in the roof.

When integrated with the existing survey systems, the TLS operates in 2D profiling mode controlled by the QINSy survey software. The scan mirror rotates around the horizontal axis only, scanning at 90° to the forward motion of the vessel. To restrict the scanner rotating around the vertical axis, the P20 was fixed rigidly to an alloy mounting plate welded to the roof of the vessel, see Figure 8.

Figure 3 Leica ScanStation P20 mounted on *Pandora II*.

3.4.2 Multibeam Echo Sounder

DML currently has an R2Sonic 2022 MBES deployed on *Pandora II*. The 2022 is a light weight high accuracy hydrographic survey grade echo sounder capable of gathering bathymetric data up to 6x water depth. See Table 3 for equipment specifications.

Table 3 R2Sonic MBES specifications

Operating Frequency	Broadband 200 to 400 kHz
Depth Range	100m (400kHz) 300m (200kHz optional)
Maximum Swathe Angle	10^0-140^0
Beam Forming (along track transmit & across track receive)	256 beams (1^0 x 1^0 at 400kHz)
Roll Stabilisation	Real Time
Maximum Ping Rate:	60Hz
Depth Resolution	6mm

The MBES sonar head can be retrieved through the moon pool, and raised well clear of the water, for transits.

Figure 4 R2Sonic sonar head deployed via the moon pool.

3.4.3 Inertial Navigation System
The Applanix POS MV Wavemaster is an Inertial Navigation System (INS) that blends accurate GNSS data with angular rate and acceleration data from an Inertial Measurement Unit (IMU) and heading from a GNSS Azimuth Measurement System (GAMS) to produce a robust position and orientation solution.

The Applanix POS MV calculates the 3D vessel position of *Pandora II* using RTK positioning corrections received from a GNSS base station via a UHF radio. The Applanix POS MV combines IMU and GNSS sensor data to provide an integrated real time centimetric navigation solution.

The Applanix POS MV data is also used to provide accurate heading and motion compensation to all collected MBES and TLS data. The IMU generates attitude data in three axis. Measurements of roll, pitch and heading are all accurate to ±0.02° or better, regardless of the vessel latitude. Heave measurements supplied by the Applanix POS MV maintain an accuracy of 5% of the measured vertical displacement or ±5 cm (whichever is the larger) for movements that have a period of up to 20 seconds. More accurate delayed heave can be applied in post processing which further increases the vertical accuracy.

The high frequency rate of position and orientation data provided by the POSMV is a crucial element to achieving accurate geo-referenced laser point cloud data from a mobile platform. See Table 4.

Table 4 Applanix POS MV specifications

Roll, Pitch Accuracy	0.02° (1 sigma with RTK)
Heave Accuracy	5cm or 5% (whichever is greater) for periods of up to 20s
Heading Accuracy	0.03° (1 sigma with 2m baseline)
RTK Positioning Accuracy	HZ: ±10mm +1ppm VT: ±20mm +1ppm
Velocity Accuracy	0.05m/s horizontal

3.4.4 QINSy Survey Software
QPS QINSy Survey v8.1 is an integrated hydrographic data acquisition, navigation and processing software package. The suite of applications can be used for various types of surveys from simple single beam surveys to complex surveys requiring multi senor data acquisition and geo-located point cloud data.

QINSy Survey is able to compute, visualise and store up to 500,000 points per second, allowing it to combine real time GNSS data, INS data, precise timing, MBES data and TLS data simultaneously. QINSy also allows the importing post processed trajectory data from INS or GNSS systems.

In 2009 QINSy added support for real time laser scanner data acquisition and in early 2014 began supporting the Leica P20 ScanStation operating in Profile Scanning Mode.

The driver allows QINSy to visualise and record a real time geo-referenced attitude and height corrected DTM, including point cloud data, on the fly from the P20's scan data.

3.5 Patch Test Calibration Method

In order to collect accurate TLS and MBES data both systems must be calibrated prior to the start of a project.

The calibration routine, known as a Patch Test requires data to be collected on a number of lines covering particular features or seabed gradient. Data from each survey line is compared to determine the orientation of the TLS head or MBES head, in the three axis of roll, pitch and yaw relative to the IMU. These three angular offsets must be determined to produce accurately corrected and repeatable TLS and MBES data. See Figure 10.

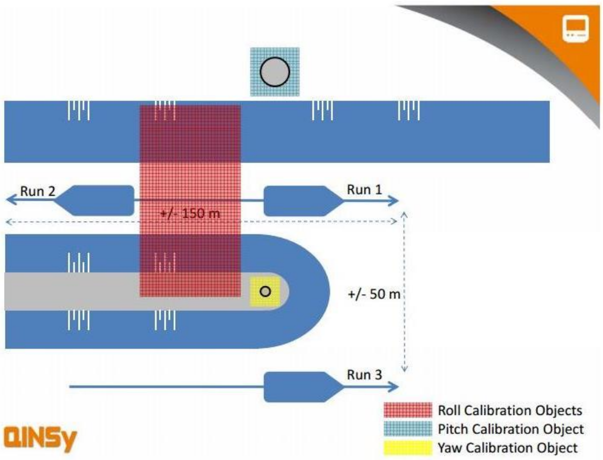

Figure 10 Laser calibration routine

Pitch and roll for both the TLS and MBES head are measured relative to the vertical axis of the IMU and the heading (yaw) of the sonar head relative to the horizontal axis of the IMU.

When the data acquisition software is not synchronised to GNSS time using a 1PPS system, it will also be necessary to determine the latency of the positioning system. Installation offsets are usually determined in a fixed sequence: latency (if required), roll, pitch and yaw.

Once the data has been collected, it is processed using the Patch Test tools in QINSy to determine the value to be applied.

3.5.1 MBES Calibration
Existing calibration parameters for the MBES were used as determined by Patch Tests from a previous project.

3.5.2 Terrestrial Laser Scanner
The topography and features around Westhaven marina provided a number of suitable areas for completing a patch test of the scanner.

Reciprocal lines for the roll calibration were navigated through the western entrance to the marina collecting data along a concrete wall on the western side and the end of the northern break water.

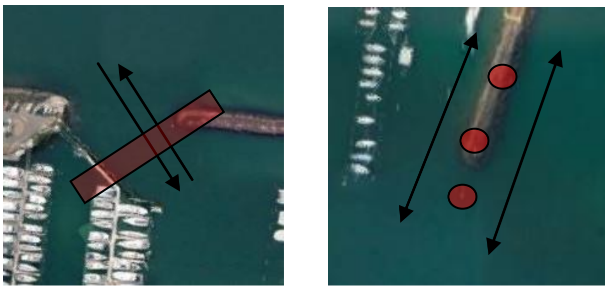

Figure 11 Patch Test routines

Pitch and Yaw calibration runs were collected along the eastern breakwater of the marina, with a free standing pile to the south of the breakwater used as the feature as well as signs and poles on the breakwater. See Figures 10 and 11.

The Patch Test computed angular misalignments between the IMU and Leica P20 3D laser scanner. These values are then entered into the acquisition software for real time correction of the scans.

3.6 Estimated Accuracies

"A Priori" estimates of point accuracy have been computed using QINSy's real time Total Propagated Uncertainty (TPU) calculator. The TPU for each point is the interval about a given point that QINSy estimates will contain the true 3D position at a given confidence level. Each value in the TPU calculation indicates either limitations of the measurement sensors or the statistical fluctuations in the measured data from that sensor.

A major source of uncertainty in the TPU calculation for the laser scanner data appears to come from the INS. Standard deviations for the computed Patch Test results plus the RTK GNSS positioning and attitude data all contribute to the final uncertainty of position.
The vertical component of the TPU during this trial indicated laser scan data collected at around 100m to 120m to have a vertical uncertainty of 4-5cm with the horizontal component around 10cm. Further refinement of the values entered into the TPU calculation for the TLS should reduce the A Priori values.

It is anticipated that applying post processed trajectory data will further improve both horizontal and vertical A Posteriori accuracies. Further work will be undertaken to ground truth the TLS data using an RTK GNSS to positon clearly visible features within the data.

3.7 Data Validation and Post Processing

The QINSy processing suite and Fledermaus was used for data reduction and quality assurance. Final imagery and results were compiled using Fledermaus 3d Editor. See Figure 12.

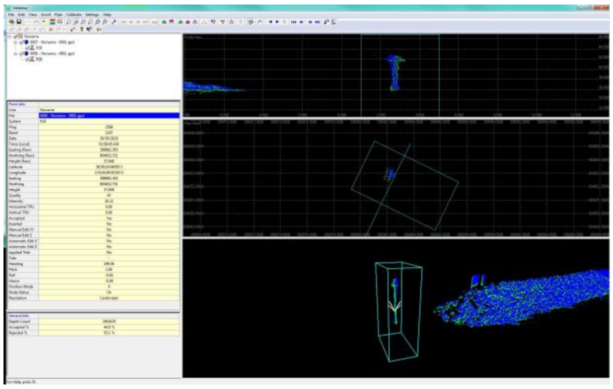

Figure 12 TLS data editing.

4. Results

TLS data was collected around the Wynyard Wharf area and Westhaven Marina for calibrations and general assessment of laser range and resolution.

Final point cloud results show good repeatability between overlapping and crossing scans, indicating good calibration values. Data resolution is impressive at all ranges around the seawall with some limitation due to line of sight and shadowing behind wharf piles. See Figures 13 and 14

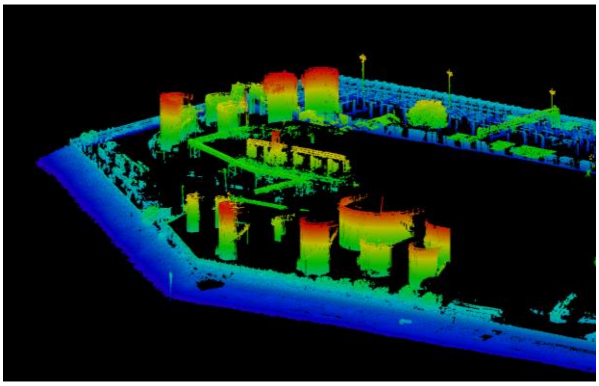

Figure 13 West Haven Marina, Tank Farm and seawall.

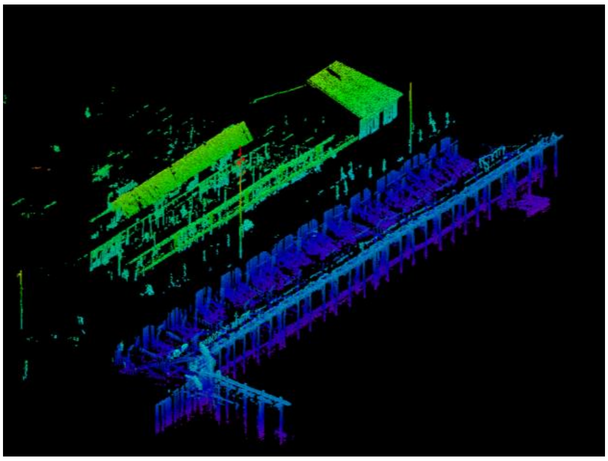

Figure 14 Wharf Piles. Wynyard Wharf

To create a seamless above and below water data set, combined MBES and TLS data was collected around the Auckland Harbour Bridge. The TLS data was collected on a single north to south pass on the eastern side of the bridge around 80m offset from the bridge centreline. MBES data was collected separately and covers a seabed area approximately 80m either side of the bridge.

The data was then combined during processing and validated to create a single high resolution point cloud data set containing both seabed depths and bridge heights, referenced to a common vertical and horizontal datum. See Figures 15, 16 and 17.

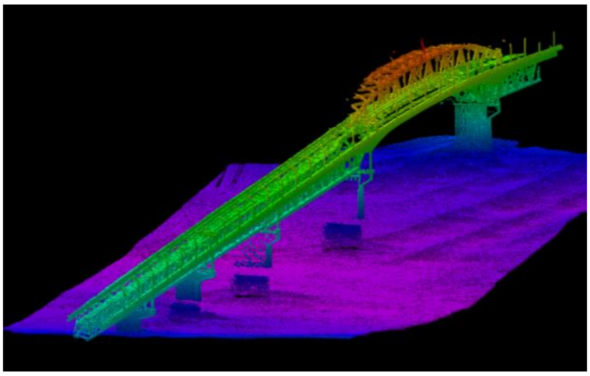

Figure 15 MBES & TLS data, Auckland Harbour Bridge

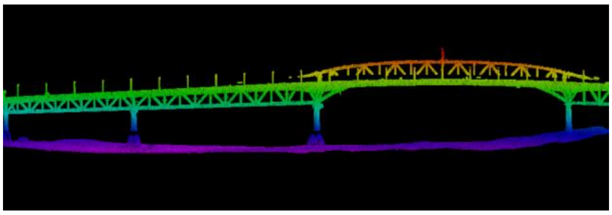

Figure 16 MBES & TLS data, cross section of Auckland Harbour Bridge

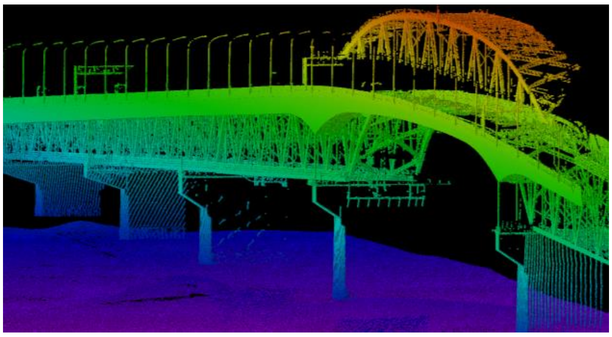

Figure 17 MBES & TLS data, detail of Auckland Harbour Bridge

Initial analysis of the results proves that TLS data can be gathered from a vessel using the method described.

5. Conclusion

The combined TLS and MBES trial has provided a workflow for the system integration required to acquire a seamless point cloud dataset above and below the water. Improvements were identified during the trial to increase point accuracy and repeatability. With further refinement seabed and submerged structures can be mapped simultaneously.

DML believes the method described in this paper could be applied to a land based vehicle for mobile mapping projects.

6. Acknowledgements

The authors would like to acknowledge the valuable contribution of Bruce Robinson (Global Survey Ltd) for the use of the Leica P20 ScanStation during this trial.

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