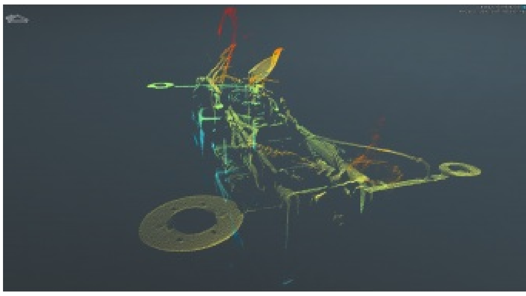
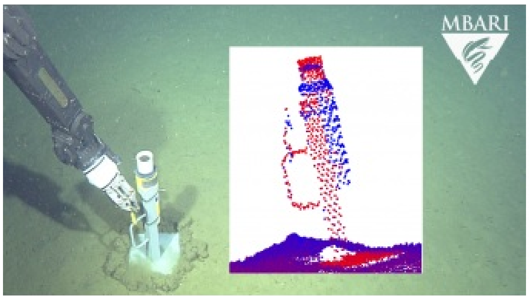
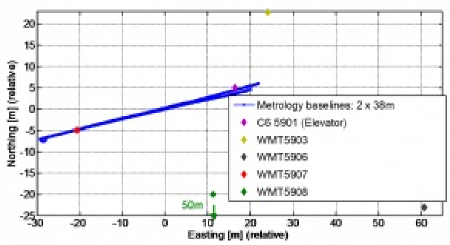
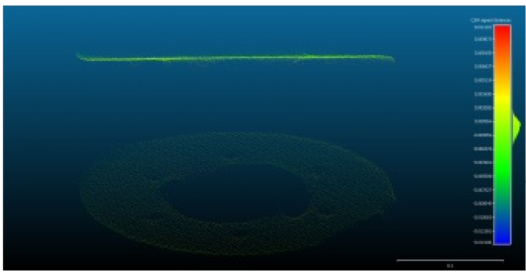
FAST 3D SUBSEA MOBILE MAPPING AND CONTACTLESS METROLOGY

Acoustically Aided INS and Lidar









[Aerial mobile mapping]() using Lidar and [GNSS-aided inertial navigation]() has revolutionised the efficiency of land and shallow-water bathymetric surveying. Now, fast ultraâ€‘high resolution subsea mobile mapping is approaching.

Millimetre-resolution Lidar sensors have emerged in parallel with major advances in tightly integrated subsea inertial navigation. Wideband Doppler velocity navigation (DVL), Long BaseLine (LBL) observations, Simultaneous Localisation And Mapping (SLAM), automatic calibration and forwards-backwards post-processing, join with Acoustically Aided INS (AAINS) to provide robust dynamic subâ€‘millimetre relative accuracy and centimetric-level accuracy over wide areas.

Successful deepwater ROV trials in the Monterey Canyon, California, USA, have demonstrated the extremely efficient dynamic future of robust high-accuracy subsea survey and contactless metrology.

Introduction

The combination of multibeam echo sounders (MBES) and (loosely coupled) AAINS on ROV/AUVs has been successful for demanding subsea applications such as pipeline Out Of Straightness (OOS) surveys. Since the advent of wideband acoustics, LBL acoustic positioning has provided centimetric level static accuracy over wide areas and is the long-standing trusted reference for subsea metrology.

Commercial subsea Lidar and Laser line/camera triangulation sensors (jointly referred to as 'Laser sensors') with millimetre level precision are available from several vendors including; 2G Robotics (Canada), 3D at Depth (USA), Cathx Ocean (Ireland) and Fugro (Netherlands).

Static Scanning

Laser sensors are used in two different modes of operation; static scanning and mobile mapping. In static scanning, the sensor is placed on the seafloor (e.g. on a tripod) and mechanically rotated to scan the local area. Use in a confined area is relatively simple since no navigation is required. However, variable turbidity introduces the risk that planned coverage is not achieved. Wide area use becomes impractical due to the need for complex and time consuming scanning and merging of data from multiple locations. Scanning of horizontal and elevated features is difficult since the sensor is tied to the seafloor.

Mobile Mapping

Laser sensor mobile mapping is similar to well known MBES surveying but provides dramatically higher resolution. Mobile mapping is inherently faster than static scanning and can cover wide areas. Risk from turbidity is reduced since the sensor can be moved along the optimal path for mapping e.g. close to and directly above a structure. This can be a critical advantage when measuring hub/flange orientations for metrology.

Tight INS Integration of Raw Wideband Acoustics

Full utilisation of Laser sensor resolution in subsea mobile mapping has, to date, been constrained by navigation accuracy. Developed with these sensors in mind, this is set to dramatically change with the next generation of higher performance tighter integrated AAINS. Direct INS integration of raw two-way travel time measurements allow dynamic vehicle positioning over wide areas to the centimetric level of accuracy known previously only from static wideband LBL. Similarly, direct integration of the raw measurements from the individual beams of a state of the art wideband Doppler Velocity Log (DVL) robustly achieves millimetric level relative accuracy. Time efficiency, accuracy and robustness are further enhanced by a host of techniques; Sparse SLAM LBL array calibration, forward-backwards post-processing, miniature wideband transponders, mechanically integrated sensors and auto-calibration. The boost in relative dynamic accuracy enables fast contactless measurement of target orientation to tiny fractions of a degree.

Mobile Mapping and ‘Contactless’ Metrology

Subsea metrology is the post-installation measurement of relative position and orientation differences between the hubs/flanges of two or more subsea structures. Results are used for onâ€‘land manufacturing of rigid interconnecting sections of pipe and both accuracy (5â€‘10cm, <<0.5deg) and quality control (QC) requirements are therefore stringent [2]. Modern LBL acoustic based metrology provides the best level of accuracy and QC and is the reference against which all other methods are compared.

‘Contactless’ AAINS mobile mapping inherits the fundamental accuracy of LBL acoustics but by-passes any need for precision ROV handling of equipment on the structures and is therefore potentially extremely fast. LBL transponders are deployed at flexible locations on the seafloor and provide bounded accuracy and strong QC. Transponder count and calibration time is reduced via SLAM sparse LBL techniques incorporating accurate reliable transponder to transponder baseline measurements where possible.

Monterey Canyon Trials, November 2015

Deepwater ROV mobile mapping trials were first performed in 2014 and then again in November 2015 onboard the R/V *Western Flyer* through cooperation with the Monterey Bay Aquarium Research Institute (MBARI) [1]. Figure1 depicts a ‘subsea elevator’ prepared with flanges of varying diameters to constitute a metrology target. The red Sonardyne Compatt 6 (C6) transponder was used as both scanning target and LBL position reference.

MBARI’s ROV ‘Doc Ricketts’ was equipped and navigated using state of the art SPRINT 700 AAINS, 6G Wideband Syrinx DVL (600kHz) and ROVNav 6 LBL transceivers and a precision pressure sensor. The calibrated and trusted LBL reference array included four additional rapidly deployable miniature Wideband Transponders, see Figure 2. Array baseline calibration residuals (‘C-O’) were 2.7cm RMS (root of mean square). The Compatt 6 had pressure and sound speed sensors for automatic tidal compensation, processing redundancy and QC via periodic acoustic telemetry. The LBL array layout and two ROV metrology baselines performed in opposite directions are shown in Figure 3. The two transponders constituting each metrology baseline were excluded from use in navigation.

2G Robotics ULS-500 and Eiva NaviSuite

The ULS-500 works by emitting a line of laser light onto the target surface where it is observed from an offset camera. Through image processing, the offset camera determines the angle to 1400 points along the laser line and then calculates the location of intersection between the laser line and the target surface. By then passing the ROV over the target of interest, adjacent profiles are captured to build a complete 3D point cloud model of the environment.

Dependent on altitude and ROV speed (0.1â€‘0.5m/s) resolution was as good as a few millimetres. Eiva’s NaviSuite supports the ULS-500 and was used for 3D real-time visualisation, data recording and offline for merging with post-processed navigation to generate accurately geo-referenced 3D point clouds from which metrology results were derived. Operation was optimised for metrology speed rather than image clarity. Figure1b is the result of a single ~20 second overhead pass by the ROV and yet resolution and quality is clearly sufficient for metrology use. Animated 3D point cloud mobile mapping data and more information is available from the vendors own website. See references [3], [4] and [5].

Metrology From	**To**	**AAINS/Laser Baseline [m]**	**Ref. Acoustic Baseline [m]**	**Difference [m] (“C-O”)**
5907	5901 (Elevator)	38.472	38.466	0.006
5903	5906	58.634	58.610	0.024
5906	5901	52.543	52.499	0.044
5901	5907	38.453	38.467	-0.013
5907	5903	52.695	52.694	0.001
5903	5901	19.459	19.403	0.056
RMS			**45.28m**	**3.11cm**

Table 1: *Measured baselines: AAINS/Laser mobile mapping vs calibrated LBL acoustic reference. Baselines were measured from the generated 3D point cloud and compared to the calibrated LBL acoustic baseline reference.*

Results and Conclusion

Results from six metrology baselines are shown in Table 1. The RMS of all baselines is just over 3cm with a single baseline error marginally above 5cm. It is likely that the calibrated LBL reference contributed slightly to the observed differences. Flange/hub orientations are determined via point cloud matching to the known geometry. Accuracy is robustly below metrology tolerances (<<0.5deg) - see Figure 4. This is due to the combination of AAINS dynamic relative accuracy and the sub-millimetre precision of the laser scanner (2G Robotics ULS-500).

All six metrology baselines where mapped by the ROV within a single 1 hour 45 minute time frame. Prior deployment of the four miniature wideband transponders took less than 30 minutes and fewer transponders would be used in an operational scenario. With realistic streamlining for commercial operations, AAINS mobile mapping technology will support single dive, contactless metrology in considerably less time than any other known method. Moderate turbidity is required which will not always be present subsea so more traditional forms of metrology will still be important.

Highly time efficient mobile mapping with reliability, accuracy and resolution proven to metrology standards is generically valuable for a host of other subsea survey, inspection and construction applications.

Acknowledgements

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Further Reading

- [1] www.mbari.org, MBARI, Moss Landing, CA, US, was founded by David Packard and is recognised as a world centre for advanced research and education in ocean science and technology.
- [2] IMCA (International Marine Contractors Association) S019 Rev 1, 2012 “Guidance on Subsea Metrology”. http://www.imca-int.com/
- [3] www.2grobotics.com, 2G Robotics Inc. Waterloo, Ontario, Canada
- [4] www.eiva.com, Eiva A/S, Skanderborg, Denmark
- [5] www.sonardyne.com, Sonardyne International Ltd, Yateley, Hampshire, UK