Subsonus Performance Evaluation

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1 Revision History

Version	Date	Changes
1.1	22/07/2016	Dynamic positioning results updated, section 3.6 Heading transfer test added, section 4 Laboratory accuracy results updated, section 5.4
1.0	15/03/2016	Initial Release

2 Introduction

Subsonus is a combined USBL system and INS packaged as a single instrument. It is designed to provide a reliable, continuous navigation solution in challenging underwater environments. A pair of Subsonus units are used together instead of differing surface transceivers or transponders which allows for advanced absolute positioning and heading transfer capabilities.

Performance testing of a USBL system can be performed in a number of ways depending on the evaluation criteria.

For acoustic angular accuracy testing, a mechanical positioning mechanism can be used to accurately set the relative angles of two units. This offers valuable angular accuracy data but lacks the complexities of a real world ocean application. Results from this test method are included in Section 5.

For longer track ranges in open water environments a truth system capable of accurately tracking the relative dynamic movement between two instrument locations is required. This test method provides valuable real world example data and is the focus of sections 3 and 4.

Illustration 1: Subsonus operating in a challenging dynamic environment

3 Open Water Dynamic Positioning Test

Testing a USBL system using two fixed and surveyed positions is easy to do, however it does not challenge the USBL to tolerate varying channel conditions, doppler shift and multipath fading. Advanced Navigation's open water dynamic testing platform is designed to test the USBL system in the presence of these performance degrading elements.

The open water dynamic testing platform is pictured in Illustration 2. The platform can be remotely manoeuvred using electric thrusters and has on-board power generation and shore communication systems to enable continuous product testing. Security cameras and monitoring equipment allow for long term deployment in various locations.

Subsea equipment can be positioned in fixed, known locations on the sea floor below. The platform is fitted with an RTK GNSS/INS positioning system which allows direct performance comparison of a USBL system that tracks the platform location relative to the sea floor.

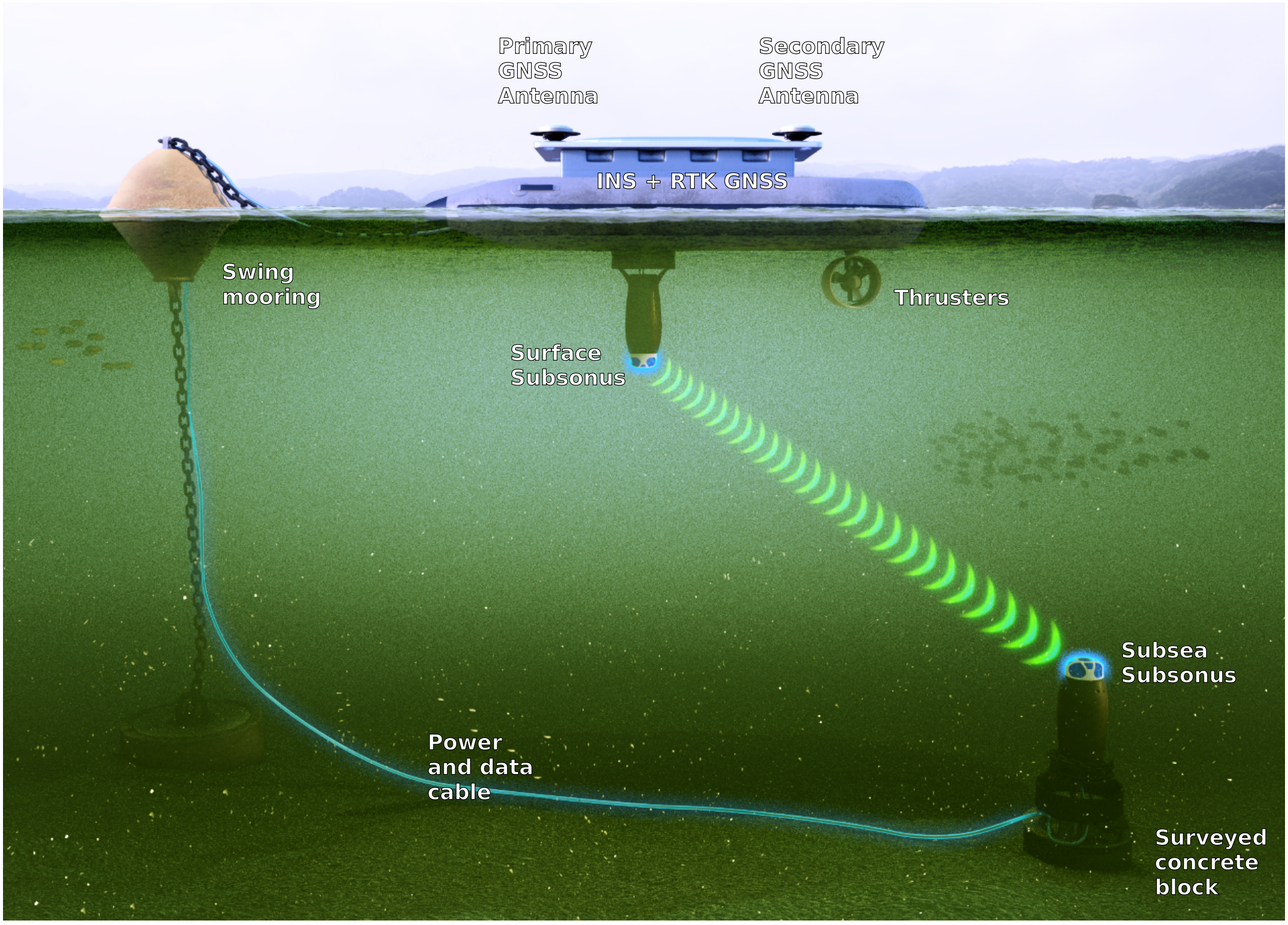

Illustration 2: Diagram of floating platform and subsea equipment layout

3.1 Floating platform

The floating platform is pictured in Illustration 2 and Illustration 3. The structure above and below the water provides accurately measured offsets between critical items such as the GNSS antennas, INS and Subsonus units. The central location of the INS within the platform reduces the length of offsets required. Water sound velocity is continuously monitored using a Valeport ultraSV sensor with an accuracy of ±0.02m/s.

Illustration 3: Remotely operated floating platform

3.2 Reference system

The RTK GNSS/INS fitted to the platform is a Spatial FOG Dual model, manufactured by Advanced Navigation. When operating with an RTK fix it offers position accuracy of 0.008m horizontal and 0.015m vertical. Spatial FOG Dual receives low latency RTK corrections from a station with an 11km baseline.

Spatial FOG Dual’s multi-constellation GNSS receiver ensures high satellite availability regardless of the time of day. This allows the system to reliably maintain a fixed RTK navigation solution. The twin Antcom G8 antennas are fitted with large 250mm ground planes to exclude multipath signals reflected from the water surface.

3.3 Surface Subsonus

The surface Subsonus unit is mounted on a rigid frame which is fixed to the under side of the floating platform, see Illustration 4. This structure is effectively a USBL pole which places the Subsonus array head approximately 1m under the water line.

The INS inside this Subsonus unit has its reference point configured to offset the navigation data stream to the physical location of the RTK GNSS/INS reference system installed in the platform above. This allows direct comparison of the navigation data from both units as Subsonus automatically compensates for the platform motion to correct its output data to the new location.

Illustration 4: Surface Subsonus (and spare unit) installed on frames underneath the floating platform

3.4 Subsea Subsonus

The Subsonus unit on the seabed is installed on a tripod which is mounted to a large concrete block, see Illustration 5. The block location has been surveyed so its location and orientation is known very accurately. The Subsonus unit has been set to stationary mode which is recommended for applications with fixed mounting.

Power and data for Subsonus is sourced from the platform above. Subsonus supports the Power over Ethernet specification which allows a single cable length of up to 100m to provide both power and an Ethernet network connection.

The location selected for this test has a water depth of 15 metres. The track range between the two units varies between 14 and 26 meters as the platform moves around the swing mooring.

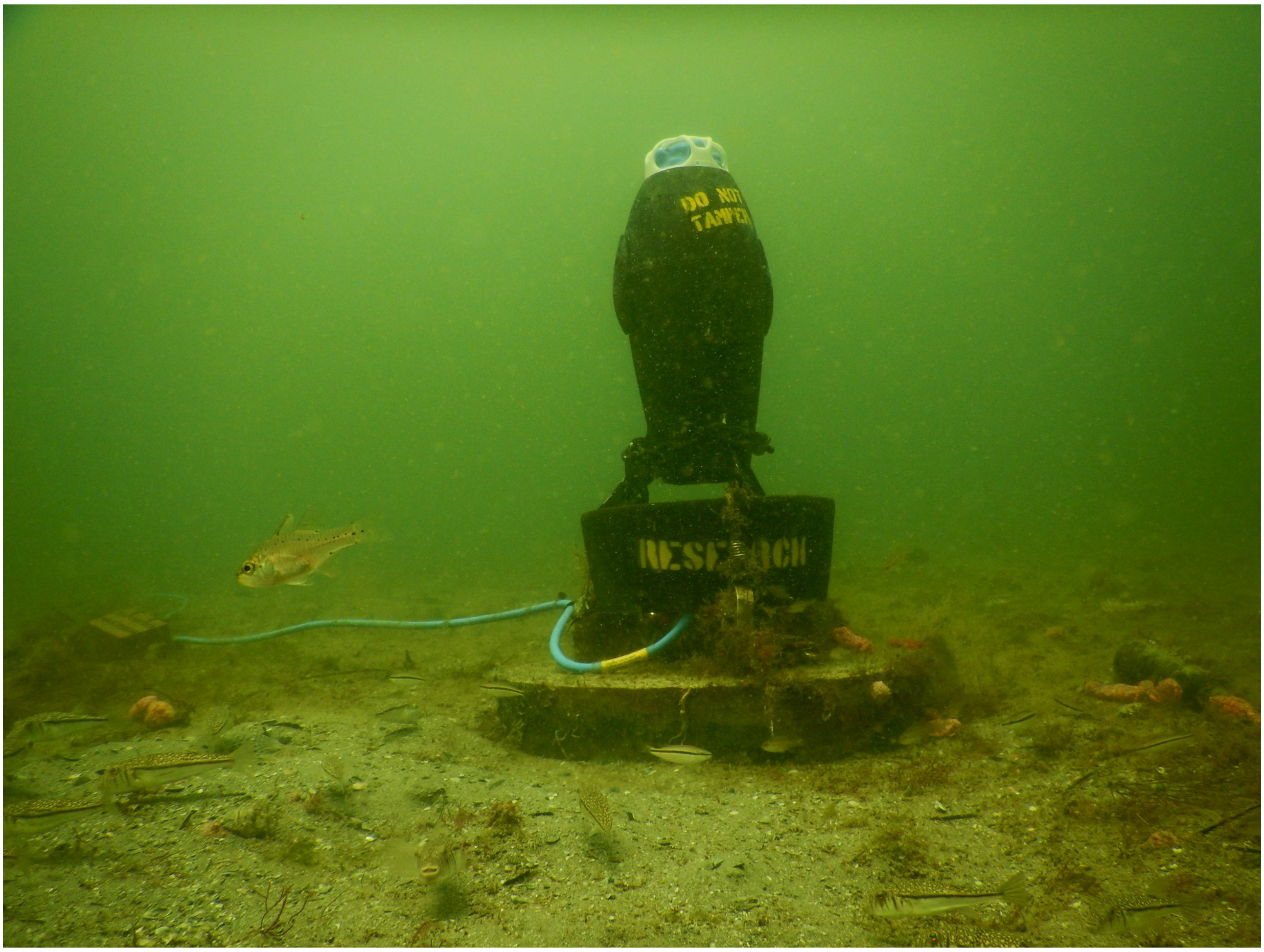

Illustration 5: Subsonus unit installed on a frame and concrete block in a fixed, surveyed seabed location

3.5 Movement profile

The only constraint on the floating platform's movement is the bow chain connection to a swing mooring. During the data collection period the platform was remotely driven around the mooring at an arc radius of approximately 5m, see Illustration 6 and Illustration 7. The duration of the test is 7 minutes.

The light blue circles in Illustration 6 and Illustration 7 show the raw acoustic positions derived by Subsonus. The darker blue line shows the position output by Subsonus after this raw acoustic position data is fused with inertial and pressure depth data in the built in INS. The INS in Subsonus considerably increases the accuracy and allows for continuous high update position and velocity output through acoustic outages.

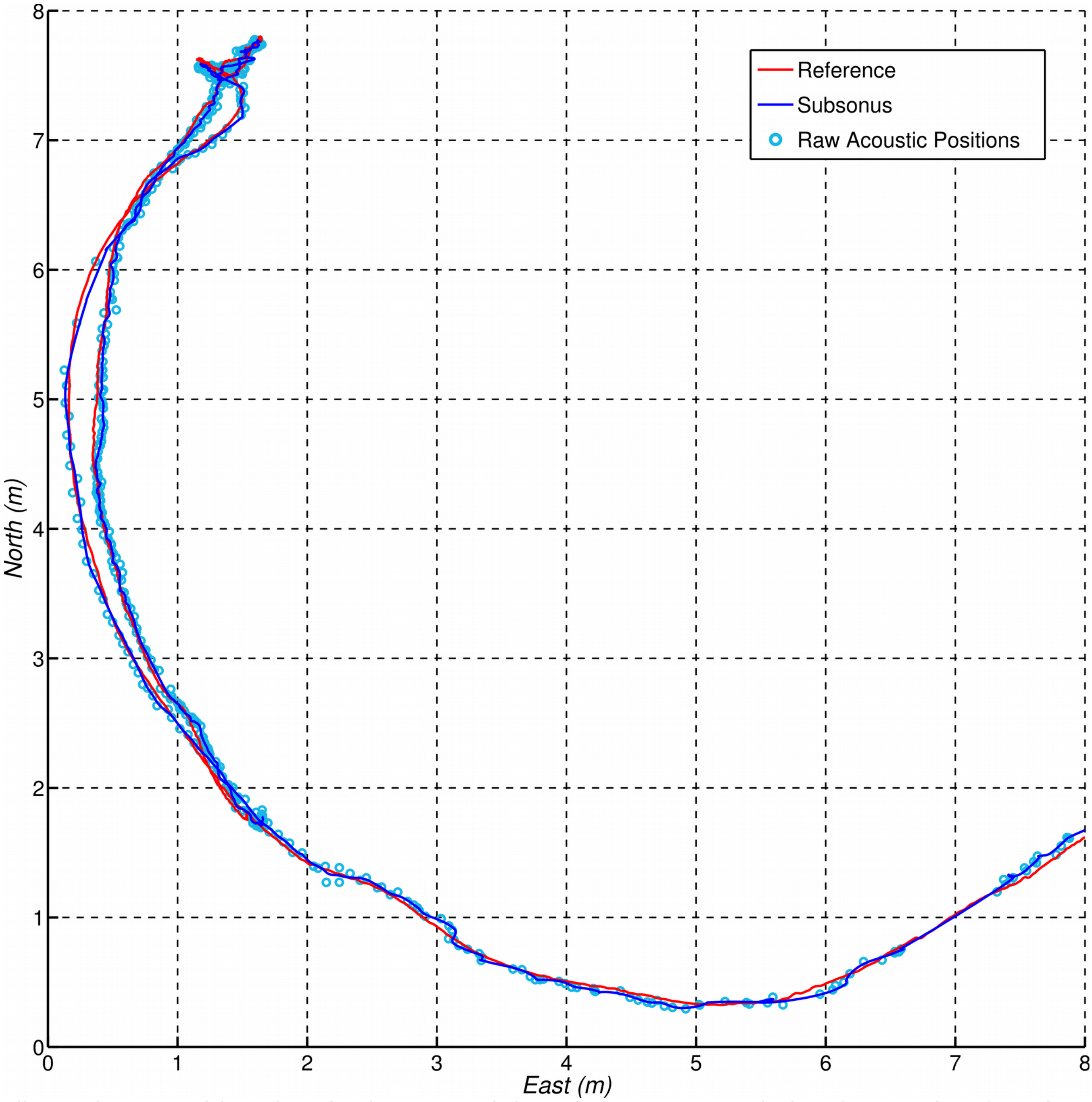

Illustration 6: Position plot of Subsonus and the reference system during the test duration of 7 minutes

Illustration 7 below shows a magnified view of a short, 2 minute section of the test. During this time the direction of the platform movement was reversed using the electric thrusters, creating a complex movement profile that sees the platform motion dwell momentarily and then perform five different direction changes in quick succession. During this manoeuvre the platform also changes heading considerably due to the altered thrust vector which further challenges the navigation system. Note the scale of the chart.

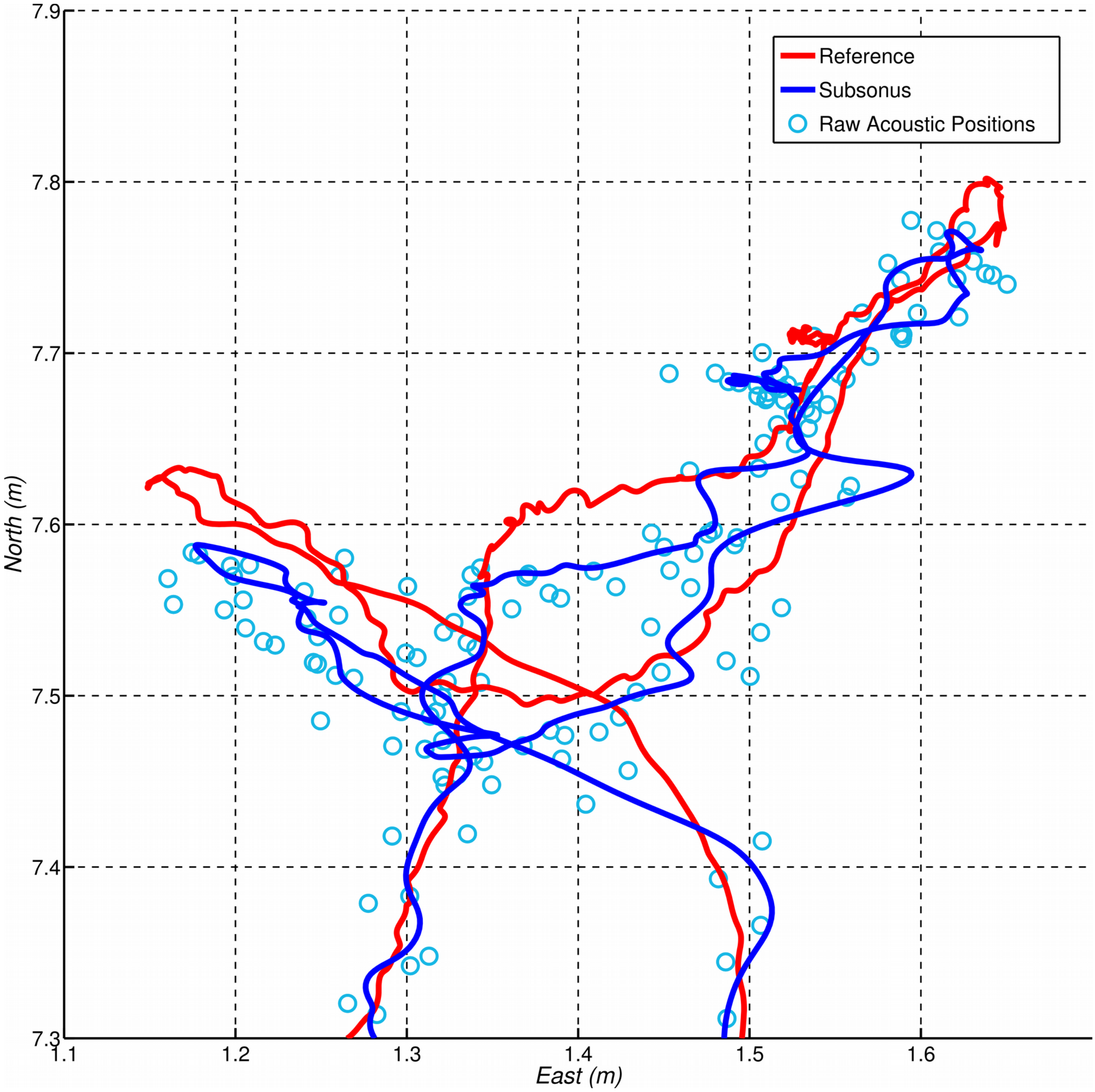

Illustration 7: Magnified view of position tracks during the platform direction change section of the test

3.6 Results

Illustration 8 below shows the error in the absolute position solution from the Subsonus data and RTK GNSS/INS reference system data. The 1 sigma standard deviation for the absolute position error between the two data sets is 0.089 metres.

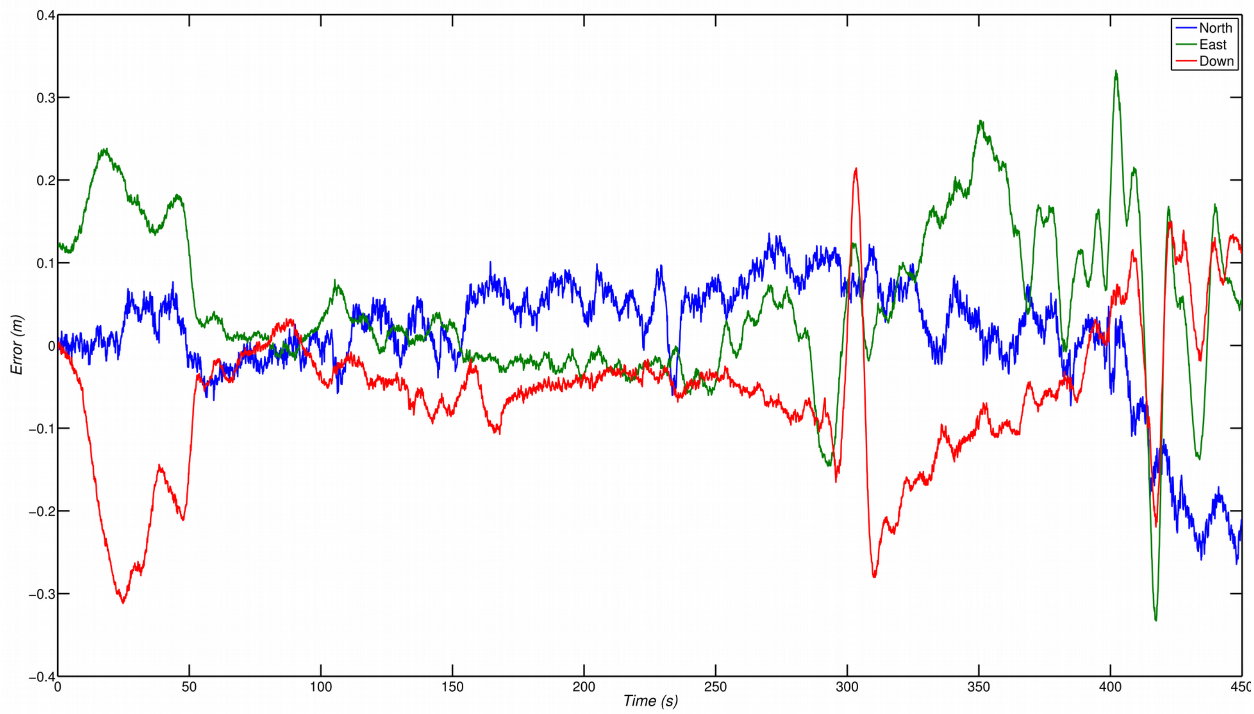

Illustration 8: Graph of relative position error in metres between Subsonus and the reference system

This test presents a challenging environment for Subsonus to perform in with many natural sources of error present. These include:

- Multipath interference reflected off the sea floor and the water surface.
- Strong natural water channel thermoclines in the area of the test.
- Varying salinity at different depths in the area of the test.

Subsonus is able to mitigate all 3 of these errors to a large extent through its multipath mitigation technology and continuous velocity of sound measurements.

There are some additional sources of error present in the data which Subsonus cannot remove. These include:

- Errors in angular alignment and measured offsets between the different instruments on the floating platform.
- Small amounts of flex in the floating platform when waves impact the hull.
- The small but expected position error (0.008 m) of the RTK GNSS/INS reference system.

3.7 Test Conclusions

The close correlation between the navigation track from Subsonus and the RTK GNSS/INS reference system demonstrates excellent performance of Subsonus when operating in a real-world, dynamic environment.

4 Heading Transfer Test

A unique feature of Subsonus is its ability to acoustically transfer heading from a surface unit to a sub-sea unit. This is performed by taking angular acoustic measurements in both track directions, allowing computation of the sub-sea unit's heading from the known heading of the surface unit.

Performance testing of Subsonus's acoustic heading transfer was carried out using the same open water dynamic testing platform used in section 3. In this test the heading transfer system was operated in the reverse direction to resolve the floating platforms heading from the known, fixed heading of the sub-sea unit mounted on the concrete block. This allowed for comparison of Subsonus's acoustic heading solution with the dual antenna GNSS/INS reference system on the floating platform.

During the test the floating platform was driven around in a complex pattern with several full heading rotations in both directions.

4.1 Results

Illustration 9 shows the angular heading difference between the Subsonus acoustic heading and the GNSS/INS heading during a seven minute test.

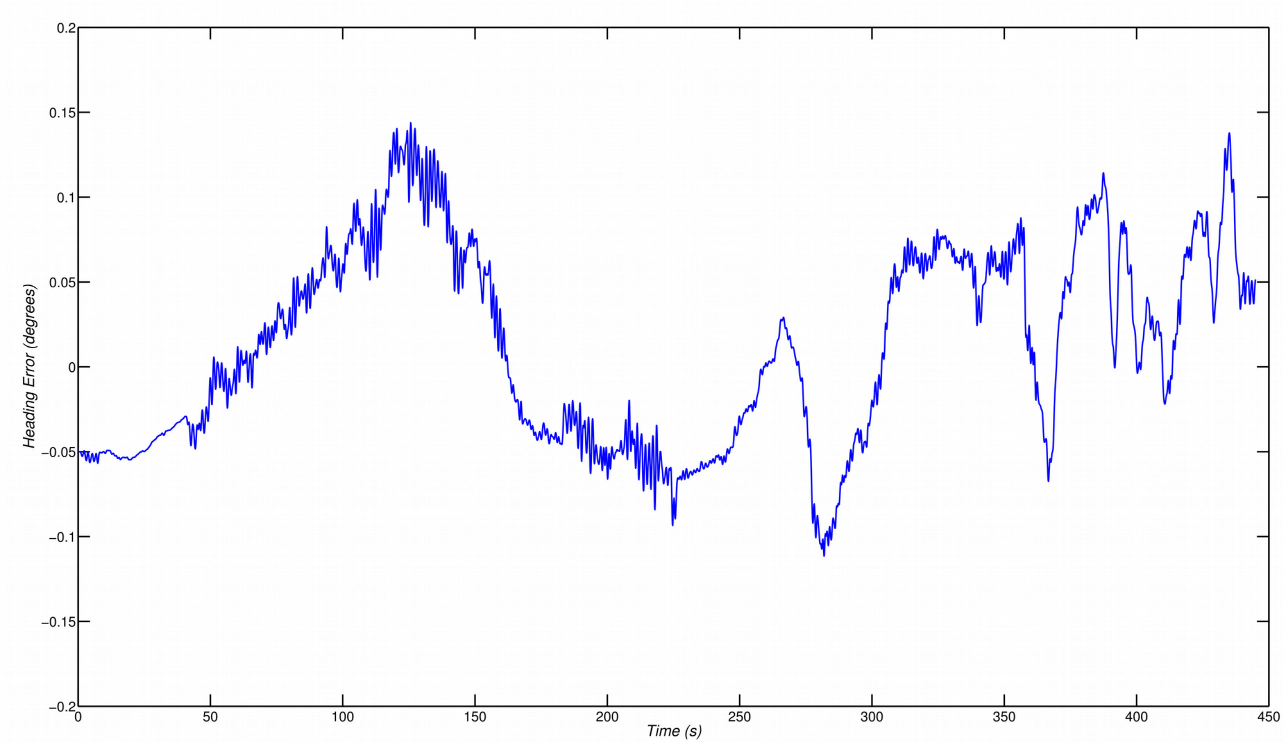

Illustration 9: Graph of heading difference between Subsonus's acoustic heading and the reference navigation system.

4.2 Test Conclusions

The results of this test show that Subsonus can provide high accuracy heading data to the sub-sea vehicle at a fraction of the cost and physical size of a traditional gyrocompass system.

5 Laboratory Tank Accuracy Test

Advanced Navigation uses a two axis CNC underwater positioning system for recording high accuracy measurements of its acoustic products, see Illustration 10. The machine is installed in an indoor research tank and is capable of repeating axis movements to an angular accuracy of 0.0013 degrees.

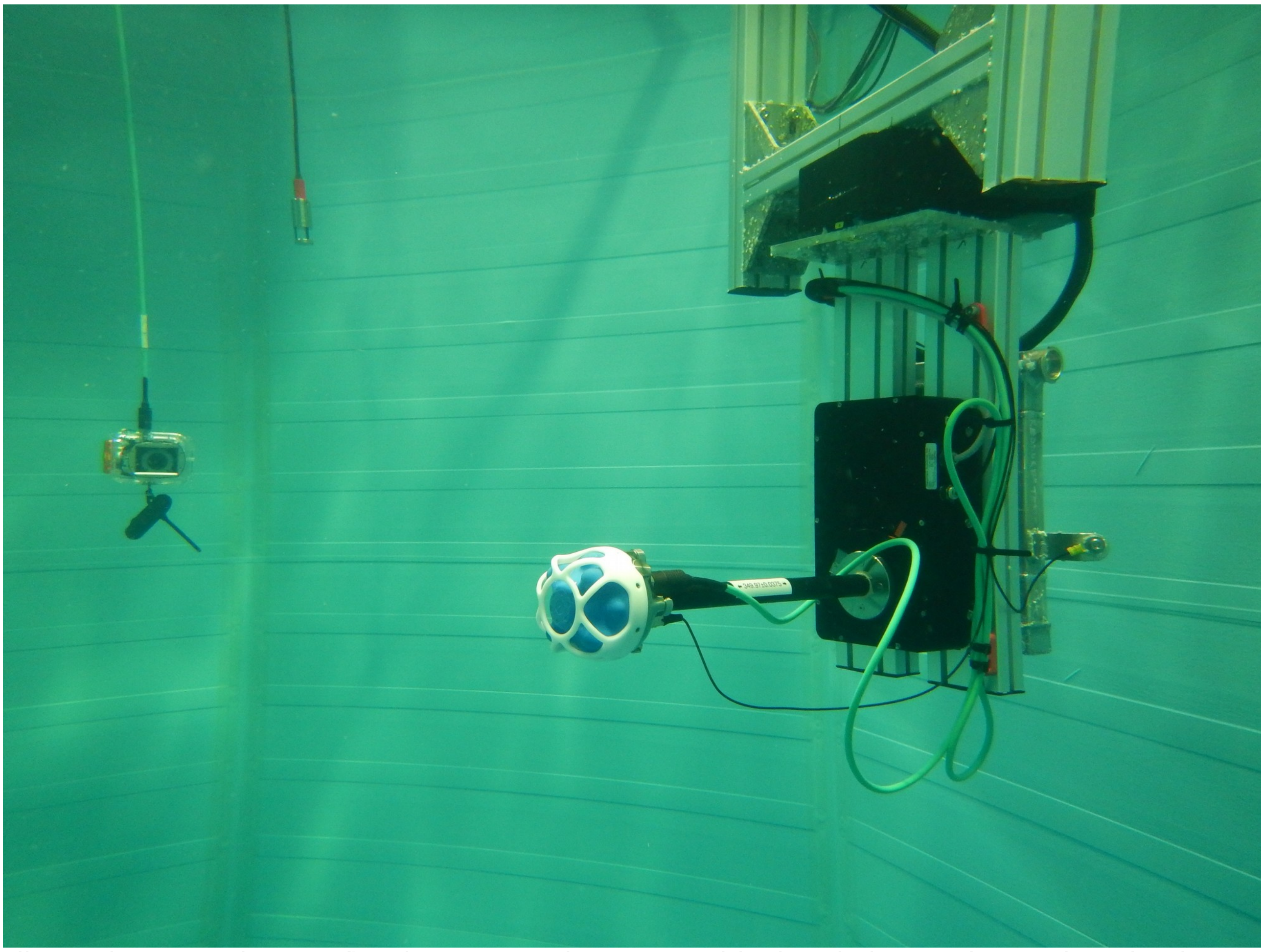

Illustration 10: Subsonus fitted to a two axis servo positioning rig in an Advanced Navigation research tank

5.1 Acoustic Source

The Subsonus unit is installed on the positioning rig receives acoustic signals transmitted from an accurately located source transducer fixed to the same rigid frame as the positioning components. The source transducer has an ideal beam pattern for the range of valid positioning rig movements.

5.2 Clear Water

The acoustic transmit length and receive window are selected to ensure measurements are only taken from signals travelling in clear water. This means the signal has not yet encountered reflections from the surface, tank boundaries or other objects. Subsonus does operate well in high multi-path environments, however the purpose of this test is to demonstrate acoustic angular accuracy in an open water location.

5.3 Movement profile

A computer program drives the machine axis through a three dimensional movement profile and triggers Subsonus to make a position measurement at increments of two degrees in each axis.

5.4 Results

Illustration 11 below shows the angular error between the Subsonus measured arrival angle and the machine reported encoder angle. The distinguishable patterns in the data are related to the unique geometric arrangement of the eight elements in the Subsonus hydrophone array.

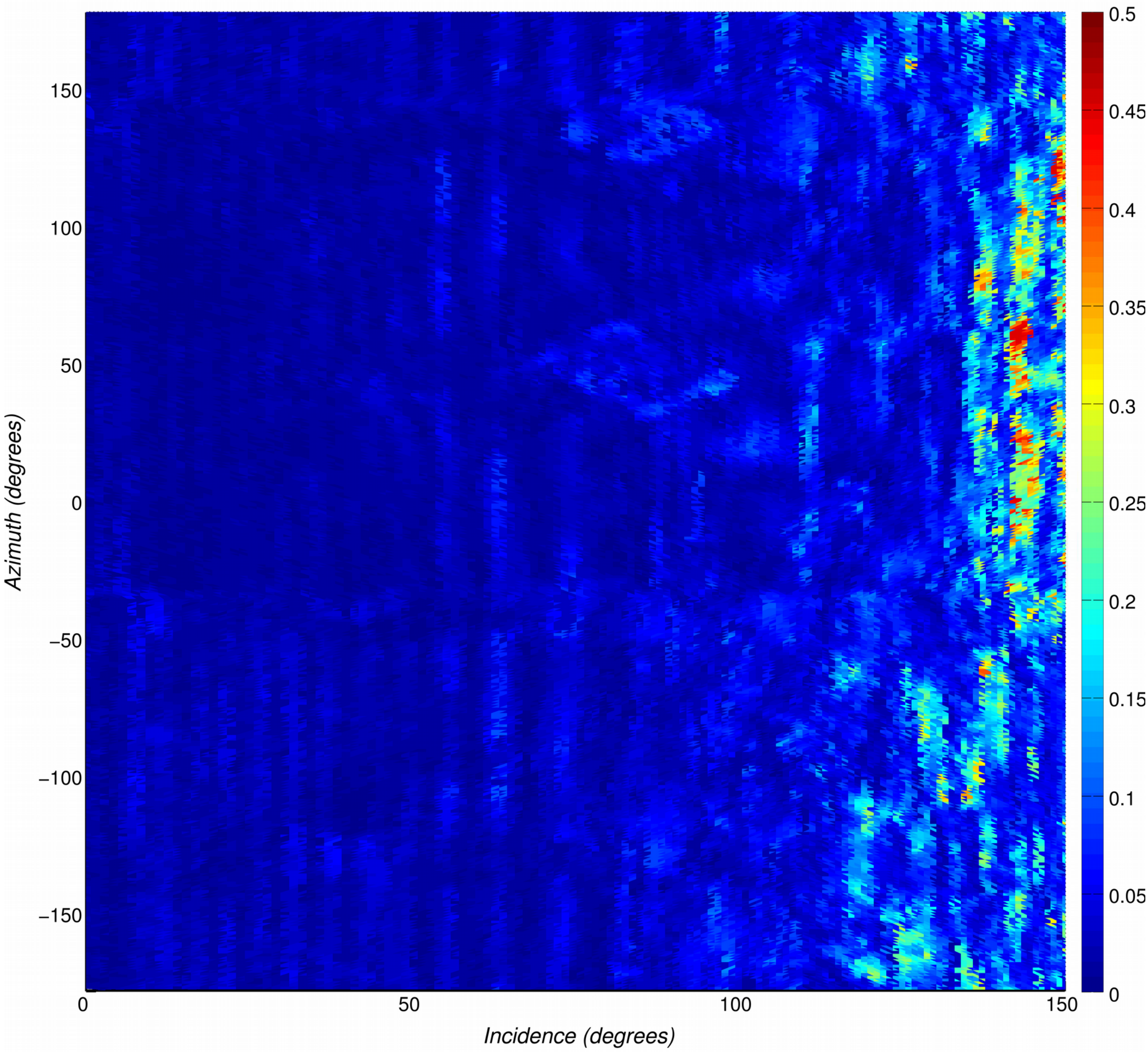

Illustration 11: Graph of Subsonus acoustic measurements angular error across azimuth and elevation

Subsonus uses an array of 8 directional hydrophones to receive acoustic signals and produce an overdetermined solution for range and angles. The positioning of these elements has been optimised for best accuracy during long range or deep water positing tasks while maintaining very wide acoustic coverage (300 degrees) for shallow water operation.

Illustration 12 below shows the equivalent number of hydrophones used in range and angle calculations across azimuth and elevation. The colour axis shows the scale relative to the maximum sensitivity of a single receiving hydrophone on its directional axis. At elevations higher than 90 degrees the acoustic source is actually coming from behind Subsonus. The unit would never typically be operated in this configuration.

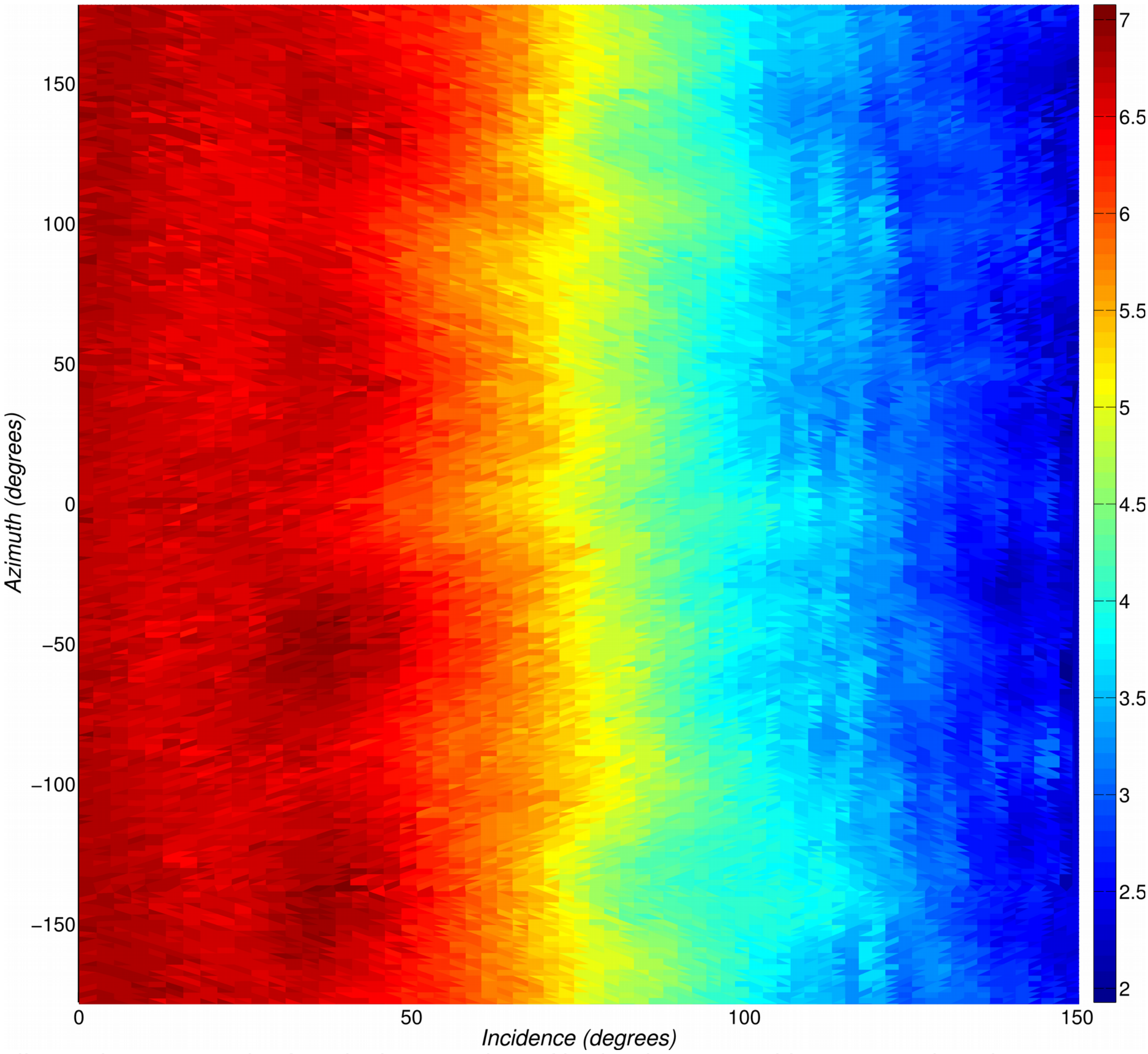

Illustration 12: Graph of equivalent number of hydrophones used in range and angle calculations across azimuth and elevation

5.5 Test Conclusions

Subsonus is the only USBL system on the market that produces overdetermined acoustic solutions using 8 hydrophones. Most USBL systems have 3 to 5 hydrophones and use only the best 3 hydrophones to calculate a solution. A correlation between acoustic accuracy and number of hydrophones used in the solution can be seen through the comparison of Illustration 11 and Illustration 12.

The results presented demonstrate Subsonus's very high acoustic angular accuracy across the full azimuth and elevation. Degradation of angular accuracy can be seen at the very high angles of incidence where signals are actually being received from behind the unit (above 90 degrees). This however is still quite remarkable since most competing USBL systems either do not work at all in this region or do not publish a performance specification for it.

The accuracy of these results can be attributed to the extensive factory calibration that is stored inside every unit, Subsonus's unique hydrophone array and the advanced signal processing architecture.