Multibeam Calibration: The Patch Test

1 Introduction

The alignment of the Sonic 2024/2022 sonar head to the motion sensor and gyro is critical to the accuracy of the determined depths. It is not possible to install the sonar head in exact alignment with the motion sensor and gyro to the accuracy required (x.xx°). If GPS time synchronization is not used, the latency of the position, as reported by the GPS, must also be measured during the calibration. This being the case a multibeam calibration must be performed to measure the angular misalignment between the Sonic 2024/2022 and the motion sensor and gyro and, if necessary, the position latency; this is called the Patch Test.

The patch test is performed with each new installation or whenever a sensor is moved. In the case of an over-the-side mount, a large number of calibration computations need to be performed to determine how well the pole goes back into the same position each time it is deployed. With more permanent mounting arrangements, a minimum of 5 separate patch tests should be conducted in order to derive a standard deviation that would indicate the accuracy of the derived values.

The patch test involves collecting data over certain types of bottom terrain and processing the data through a set of patch test tools. There are two primary methods of processing the data that are currently used: an interactive graphical approach and an automatic, iterative surface match. Each of these techniques has strengths and weaknesses and the preferred approach is dependent on the types of terrain features available to the surveyor. All modern multibeam data collection software packages contain a patch test routine. Please read the software manual for explicit information regarding the requirements for that software's patch test. The below criteria is, in general, the norm for a patch test.

2 Orientation of the Sonic 2024/2022 Sonar Head

The orientation of the sonar head must be known in order to convert the measured slant ranges to depths and to determine the position of each of the determined depths.

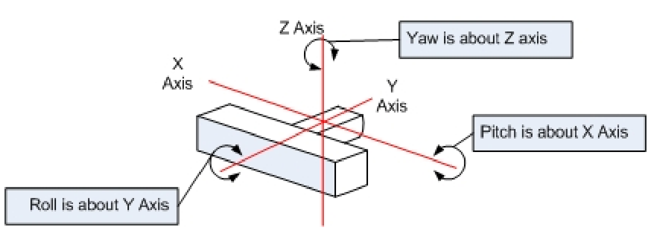


Figure 1: Sonic 2024/2022 axes of rotation

Any error in the measured roll of the Sonic 2024/2022 sonar head can cause substantial errors in the conversion from slant range to depth. A roll error of 1° on a 50 m slant range will cause a 0.6 m error in the resulting depth. Any error in the measured pitch of the Sonic 2024/2022 head will primarily have a detrimental effect on the accuracy of the positions that are determined for each slant range/depth.

A pitch error of 1° will cause an along-track error in the position of 0.4 meter when the sonar head is 25 meters above the seabed.

 C.W. Brennan, Chief Hydrographic Engineer-R2Sonic

3 Patch Test Criteria

The patch test requires collecting sounding data over two distinct types of sea floor topography; a flat bottom is used for the roll computation whereas a steep slope or feature is used for the latency, pitch, and yaw data collection.

Care must be taken that the sonar head covers the same area on both data collection runs, this may not be the same as vessel position, especially with an over-the-side mount or if the sonar head rotated. Only the latency data collection requires a different speed from normal survey speed.

The data collection for Latency, Pitch and Yaw should be done in as deep water as possible. This is particularly true for the pitch computation due to the fact that in shallow water the angle of pitch may not be easily determined due to a lack of resolution.

3.1 Latency Test

The vast majority of installations will incorporate GPS time synchronisation and, as such, no latency is expected in the GPS position. However, it is necessary to complete at least one or two latency tests to prove that the latency, for all practical purposes, is zero. Most patch test programs will not yield zero latency, but the derived value would be so small so as to constitute a practical zero.

For the latency test, data is collected on a pre-defined line up a steep slope or over a well-defined object (such as a rock or small wreck). The line is surveyed at survey speed up the slope, and then surveyed again, in the same direction, but at a speed that should be half of the survey speed. If the vessel cannot make way at half survey speed then the fast run will need to be taken at a higher speed than normal survey speed and this can influence the latency test due to squat or settlement. The main consideration is that one line should be twice the speed of the other.

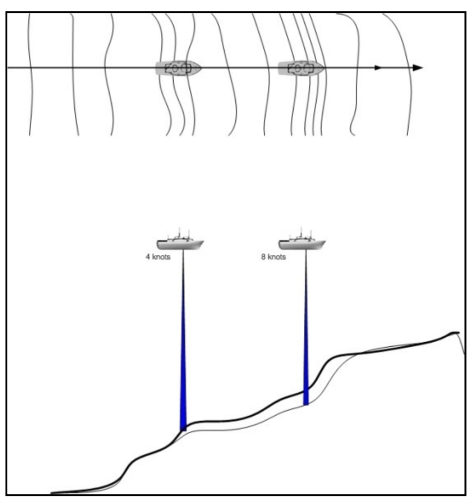


Figure 2: Latency Data collection

3.2 Roll Test

The data collection for roll has to be over a flat sea floor. One line is surveyed twice, in reciprocal directions and at survey speed.

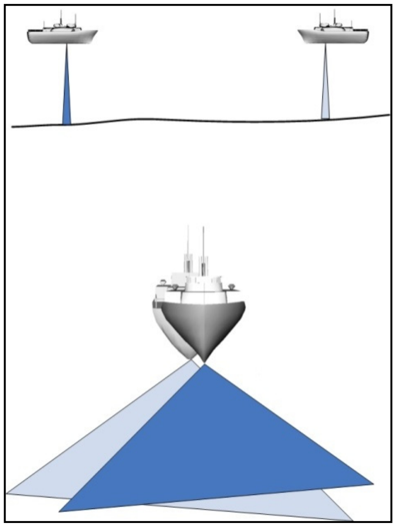


Figure 3: Roll data collection

When the data, from the two data collections, are looked at in profile, there will be two seafloors sloped in opposite directions. Most patch test programs will go through a series of iterations to determine when the difference between the two surfaces is the smallest, and this is the roll offset.

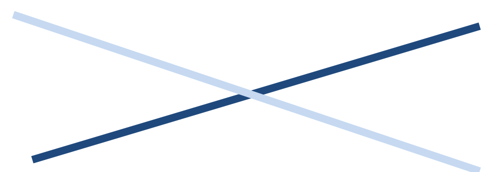
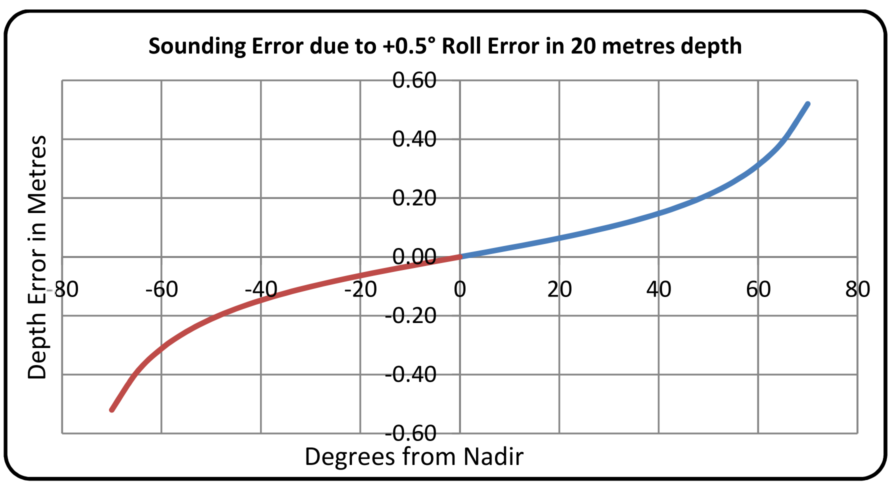


Figure 4: Roll data collections

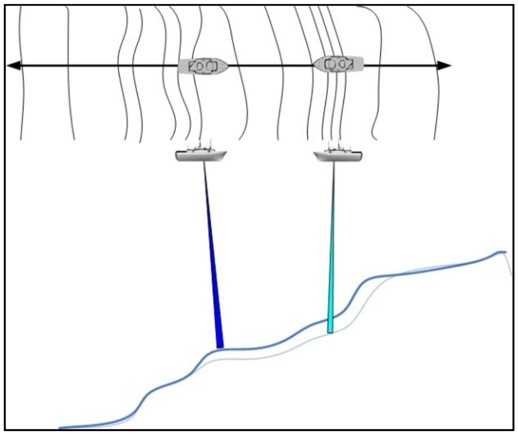
Roll is perhaps the most critical value in the patch test routine as an error in roll will result in an error in sounding depths. However, the computation to determine the roll misalignment is usually the easiest and most consistent.



Graph 1: Depth errors due to incorrect roll alignment

3.3 Pitch Test

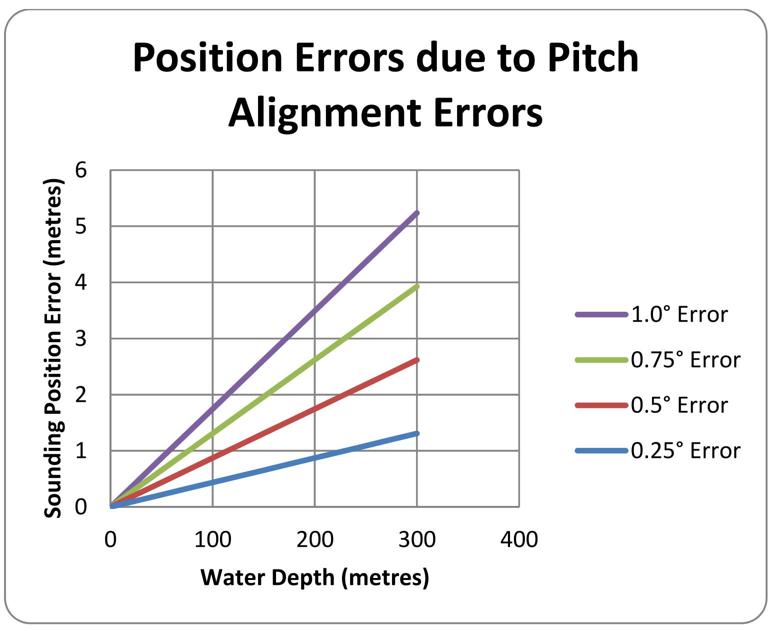
The pitch data collection is over the same type of sea floor as the latency data collection, i.e. steep slope or feature on the sea floor. One line is surveyed, twice, in reciprocal directions at survey speed. It is very critical that the sonar head passes over the same exact part of the slope on each run.



A profile of the data will show two different slopes, which represent the reciprocal data collections. The patch test software goes through a series of iterations of pitch angle corrections until the difference between the two surfaces reaches a null. Whatever the angle of correction, which results in the minima or null, that angle will be reported as the pitch misalignment.

Figure 5: Pitch data collections

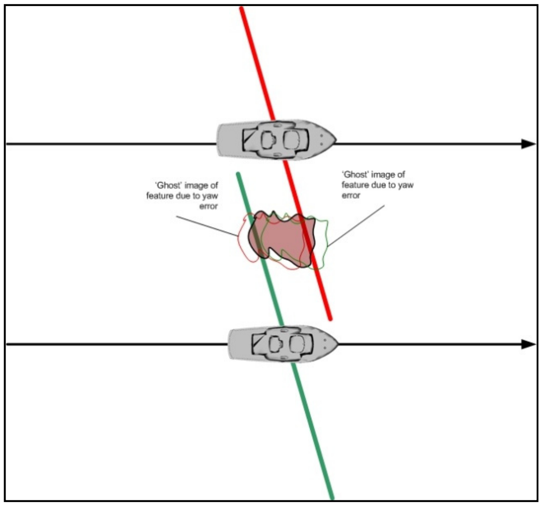
A pitch error will result in a an along –track position error, which increases greatly with depth



Graph 2: Position errors as a result of pitch misalignment; error can be either negative or positive

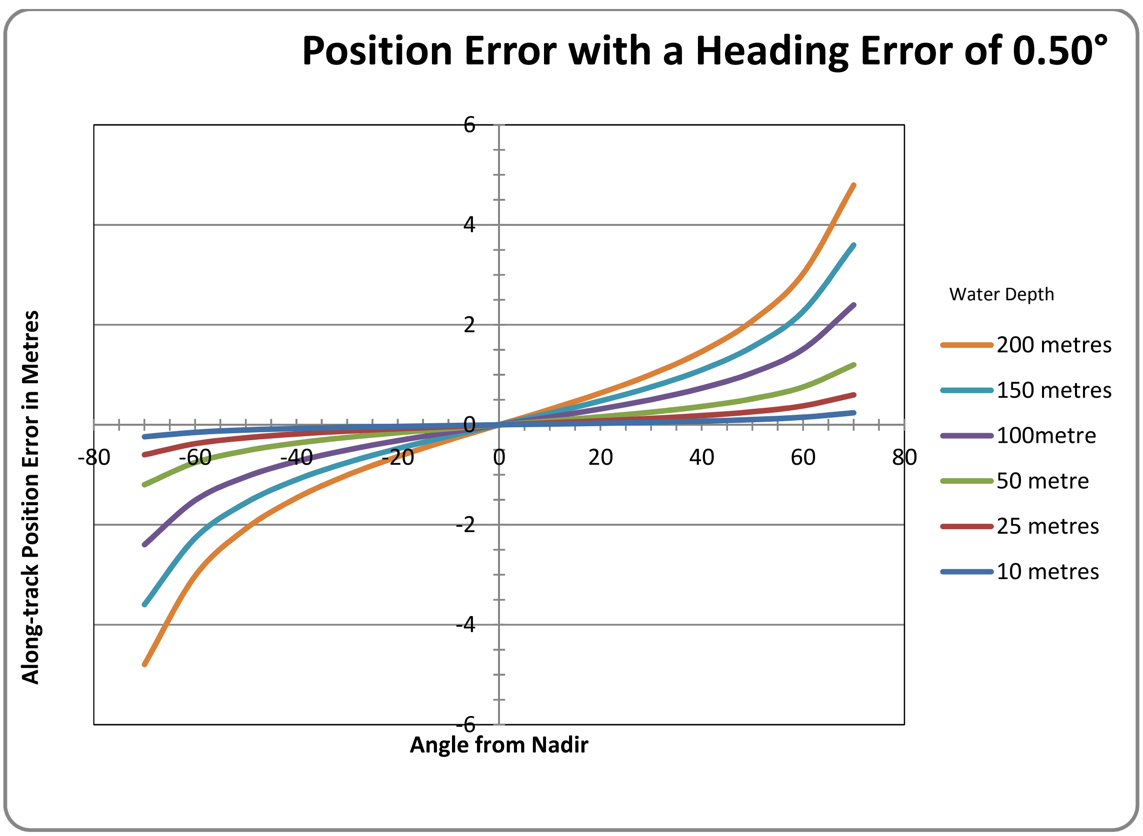
3.4 Yaw Test

The yaw data collection and subsequent solving for the yaw offset is usually the most difficult of the 4 tests that comprise a patch test. This is especially true if a slope is used for the yaw computation; a feature generally works much better. The reason for this is that the area that is used for the computation is not directly under the vessel, but in the outer beams and the slope may not be perfectly perpendicular in relation to the course of the vessel.



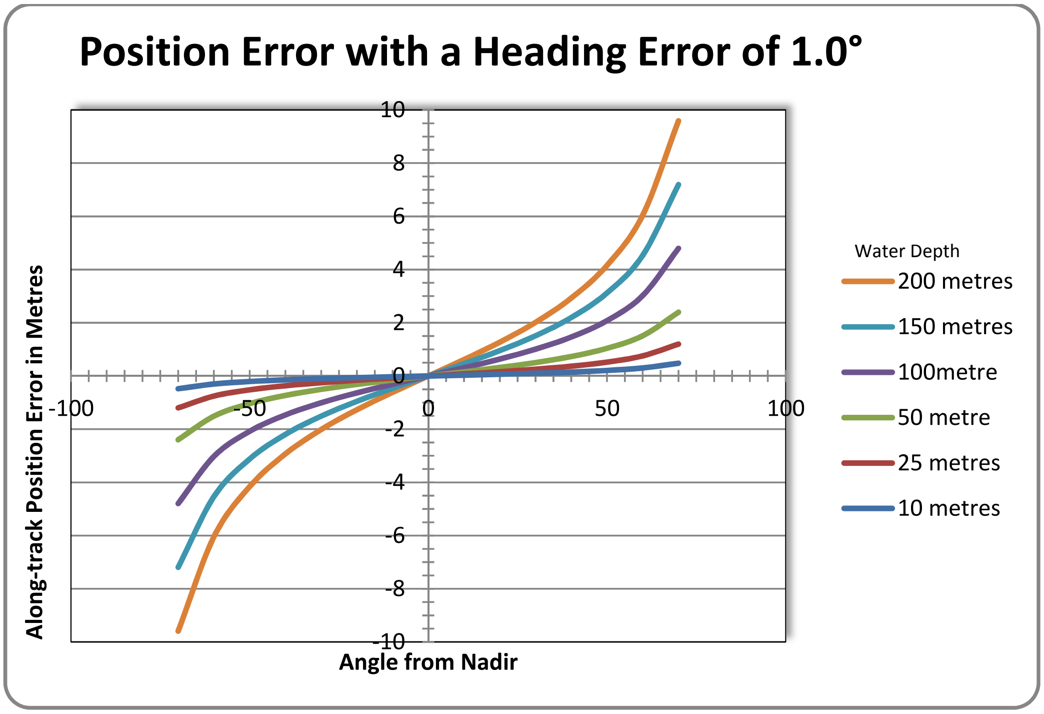
For the Yaw data collection two parallel lines are used, with the vessel surveying in the same direction on those lines. The lines are to be on either side of a sea floor feature or over a slope. The lines should be approximately 2 – 3 times water depth in separation. A yaw error will result in a depth position error, which increase with the distance away from nadir.

Figure 6: Yaw data collection



Graph 3: Along track position error caused by 0.5° error in yaw patch test

 C.W. Brennan, Chief Hydrographic Engineer-R2Sonic



Graph 4: Along-track position error caused by 1.0° error in yaw patch test error

4 Solving for the Patch Test

Depending on the data collection software that is employed and how it solves for the patch test, there will be a distinct order that the tests will be solved for, but this does not influence the data collection for the patch test. In general, latency will be solved before pitch; roll will be solved for before yaw. It is not uncommon that a larger than expected error in one of the tests will make it necessary to go back and resolve for all previous values. This can be the case with a large yaw offset, as this will influence to a greater degree the accuracy of the latency and pitch computations if done using a slope.

The resultant patch test values are corrections that are entered in the data collection software and not in the Sonic 2024/2022 software, as the values are used for process data.

4.1 History

Since the advent of commercial multibeam echosounders there has been the need to measure the angular offsets between the multibeam sonar head and the auxiliary sensors that provide attitude and heading information. Another measurement is made to determine the latency, in the GPS receiver. Multibeam data is collected that is used to determine (1) latency, (2) roll offset, (3) pitch offset and (4) heading or yaw offset

What has been developed is called the Patch Test; this is the multibeam calibration. During the development of the data collection criteria, for the Patch Test, there has only been a basic description for the manner of the data collection; providing little, if any, directions that would help create a high degree of confidence in the results of the various tests. This section will address those very directions that will help create a highly accurate and statistically viable result from the Patch Test.

4.2 Basic data collection criteria

Patch test data collection does not have to be in any set order, but the order that the values are computed, in the data collection or processing software, will be in a distinct order. Normally, Latency is the first value that is computed, followed by Roll, Pitch and Yaw (or heading). The solving order is important, as will be seen below.

4.3 Patch Test data collection error areas

There are many common errors, or mistakes, made during the patch test data collection.

4.3.1 Positioning

The accuracy of the positioning system is a common area where errors arise. DGPS has, at best, a variability of ± 0.50 metres, whereas RTK variability is ±0.05metres.

A recent article, by Mike Brissette, (MosaicHydro LTD, Canada) in *Hydro International* ('Stop Using DGPS'; Hydro International; Volume 16, Issue 7; Oct 2012) documents this issue very well:

http://www.mosaichydro.com/papers/M%20Brissette%20-%20Stop%20Using%20DGPS.pdf

The article fully details the errors that can occur by using DGPS, instead of highly accurate positioning for the Patch Test data collection. The error increases inversely with the water depth,
i.e. the shallower the water, the larger the error that can be induced by using DGPS over more accurate positioning.

However, many users do not have any better positioning capabilities than DGPS; how can they still obtain valid patch test results without having centimetric accurate positioning? This is, in large part, what this paper is concerned with. However, even with centimetric position, the following should be followed.

4.3.2 Feature chosen for test

Where at all possible, for latency, pitch and heading data collection, a feature should be used rather than a slope. Slopes tend to be too variable as opposed to a well-defined feature such as a wreck, rock outcrop or pipeline.

One of the other issues, with using a slope, is that many times the shallow end of the slope does not allow sufficient area or depth for the vessel to come about and line up for the reciprocal run; this does not allow sufficient time for the motion sensor to settle down nor for the helmsman to find a steady course.

It has been found that when using a slope, for the pitch calibration, that the heading angular offset can have a large influence. If the sonar head does not track exactly the same route, up and down the slope, the heading offset will affect the pitch angular result.

4.3.3 Water depth

The deeper the water, the better the result. In shallow water, DGPS wobble (as noted in the Brissette paper), creates more relatively severe position errors. A corollary to this is that the subtended angle is larger in shallow water, which can blur the definition of the object used, be it a feature or slope. The shallower the water, the larger the subtended angle; the deeper the water, the smaller the subtended angle and, therefore, the better the definition of the object or slope.

4.3.4 Use predefined survey lines

The most important positioning issue is having the sonar head pass over the same exact location in both of the survey data collections. This is especially true when using a highly variable slope. One way to assist the helmsman is to give the helmsman a defined line to navigate by. Just trying to go over the same track, without a line reference, does not work, as it is the sonar head that has to pass over the same exact point; this accuracy cannot be obtained just by using the grid display to steer the vessel.

When setting up the survey software, make sure that the sonar head is the steered reference for all offline measurements. It does no good to have the vessel on the survey line, if the sonar is mounted on the side of the vessel; it is the sonar that should be on the survey line.

4.3.5 Speed

When doing the latency data collection, the fast run should be at survey speed where, if there is squat or settlement, it should have been previously measured and can be applied. Many times, the fast run survey line is at a speed that is greater than the normal survey speed and induces unknown squat and settlement errors into the computation.

4.3.6 Vessel line up

In order for the angular measurement to be accurate, the vessel should have sufficient time to come on line and allow the motion sensor to ‘settle down’. Sufficient lead/run in should also be allowed in order for the helmsman to find the proper heading so that vessel can maintain as straight a course as possible.

4.3.7 Pole variability

The other issue, which is often overlooked, is the variability in the repeat position of a deployable hydrophone pole. With any moveable mounting arrangement the pole should be recovered and redeployed a few times, during data collection, to determine if it does, indeed, go back into the same aspect every time that it is deployed. (It is a good idea, after redeploying the head, to do a few figure 8 manoeuvres.)

5 Improving the Patch Test and Patch Test results

Section 11.7 described areas that should be addressed to improve the results of the patch test when collecting the data. Further improvement will come with the number of data collections and the manner in which the patch test is computed.

5.1 Need to collect sufficient data

Too many times, surveyors will collect just a few lines of data for each test. One of the major issues, detailed above, is the variability of the position accuracy of DGPS. Another issue, detailed above, is the steering of the vessel during the data collection and the relationship of the sonar head to the feature or slope on each data collection.

In order to overcome the variability of the DGPS positioning and vessel steering, it follows that the more tests that are performed, the greater will be the reliability of the test results. Below, is an example of a multibeam calibration, which included five data collections for each test.

ROLL	PITCH	YAW
0.73	-0.73	1.02
0.73	-0.99	0.90
0.76	**-2.16**	0.81
0.76	-1.07	**2.26**
0.74	-0.83	0.94

Pitch mean with erroneous value = -1.16 (SD = 0.58); without erroneous value of -2.16 = -0.91 (SD = 0.13) Yaw mean with erroneous value = 1.19 (SD = 0.61); without erroneous value of 2.26 = 0.92 (SD = 0.08)

Consider the above patch test and what the result would have been if only two collections were made and those were the ones that contained the highlighted values, which can clearly be seen to be outside of the trend. Having more data to work with, a more reliable result can be achieved.

The more data collected, the more evident will be any out of trend values that may reflect a DGPS wobble, a steering issue, or variability of the positioning of the pole. Enough data should be collected to provide a reliable statistical result, i.e. mean and standard deviation. Collecting enough data to compute six of each test, allows the exclusion of any one 'out of trend' result to yield a mean and standard deviation derived from five computations; this would be a statistically viable sampling.

5.2 Individually solving values

No matter what the solving order may be, each value should be computed independently. All tests should be based on the mean of the previous test(s).

It is important to understand why a certain solving order is used in all survey software. Each computation is based on the previous test result. This is the reason that latency is computed before pitch and roll is computed before heading; the primary test (latency or roll) has a large influence on the result for the secondary test (pitch and heading). The roll computation can also have an influence on the pitch computation, primarily if the position of the sonar head, of the reciprocal runs, was not coincident. The heading offset will also have an influence on the pitch computation for the same reason.

Generally, multibeam surveys are conducted with very accurate time synchronisation using GPS time and the Pulse Per Second. In this case, the latency test is used to prove the lack of latency or that is sufficiently small enough so as to be of no consequence. Using accurate timing, it is not necessary to collect more than two latency collections. This paper will concentrate on the angular offset computations. However, if accurate timing is not used there should be the same number of collections as with the other tests.

With a good number of individual tests, solve for one computation (i.e. only roll) and derive a mean and standard deviation for that one test. Determine if the standard deviation is within acceptable accuracy requirements, then use that derived mean to solve for the next computation (i.e. pitch). As an example, using the results on page 7, the first step would be to solve for Roll first, derive a Roll mean and then use that mean in all of the Pitch computations. Find the mean and standard deviation for Pitch. Use the mean Roll and Pitch values to determine the Heading offset.

In the above example, the roll mean, of the five tests, is 0.74°, with a standard deviation (δ) of 0.01°. The roll mean would now be used when determining the value for pitch. Use the roll mean and solve all of the pitch computations; the pitch mean is -0.91° (excluding the out of norm value), δ = 0.13°. The roll and pitch computed means are now used to solve for the heading offset. The solved heading offset is 0.92°, δ = 0.08°.

If the heading offset had been 1.5° or greater, it would be advisable to re-compute the pitch offset, using the computed heading offset value. This is due, again, to the fact that if the sonar head did not track the same exact position in the reciprocal runs, the heading offset will have an influence on the pitch offset result.

5.3 Truthing the patch test

After deriving the values for roll, pitch and yaw, the values should be entered into the appropriate areas in the data collection software. Ideally, find a singular object that can be boxed in (running data collection lines, on all sides of the object) and process the data. The object depiction, with all survey lines, should not vary from the object depiction from any one line.

