AN APPRAISAL OF MULTIBEAM ECHOSOUNDER CALIBRATION

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ABSTRACT

One of the most impressive hydrographic technique developed over the past few decade is multibeam sonar systems. Sounding data from these systems is a result of processing information from several data sources. Among them, positional data from Global Positioning System (GPS), vessels heading and attitude data from gyrocompass and motion sensor systems, vertical reference data from tide gauge and sound speed data, in addition to the multibeam data itself. There must be a good coordination between these systems in order to obtain reliable data. To determine this, a proper and thorough field calibration procedure has to be carried out on the system as a whole. This process begins with measurement of static offsets between each sensor system with reference to a fixed point on the vessel. Preferably, the point of centre of gravity (COG). Then the patch test is carried out to determine the mounting offsets and GPS latency and lastly a performance test to verify whether the data meet the accuracy requirements for the survey. This is achieved through a comparison of data with a reference surface. This paper discusses the theoretical aspects, steps involved and results of the calibration procedures for multibeam sonars, using RESON SeaBat 8124 multibeam system. Finally, a summary of multibeam sonar calibration criteria is also presented showing the methodology involve which include when to perform each test and applying corrections.

Keywords: *multibeam echoounder, calibration, reference surface.*

1.0 Introduction

One of the latest advancement in hydrographic surveying technology is multibeam echosouder system (MBES). It is capable of covering a larger area of seabed in a single sweep. The coverage is a function of water depth. Normal multibeam transducer comprises of 30-120 beams covering 40-160 degrees swath angle. However the outermost beams will not be useful in some cases due to the lack of accuracy. Even though, MBES is increasingly being employed in almost all kind of hydrographic surveys in whole over the world, from channel and harbour surveys to dredging surveys etc.

2.0 Why Calibration?

The final bathymetric data from the MBES is a result of processing information from various individual sensors or units like GPS receiver, motion sensor unit, gyro compass, sound velocity probe (SVP), tide gauge etc, acting as a single large hybrid system. Normally, these sensors are installed in different locations in the survey vessel. The positional data is accomplished by using the GPS unit, vessel motion like pitch, roll, and heave from motion sensor and heading from gyrocompass. The time synchronization between all these components is critical. The relationship in terms of their location with respect to each other is also important. Therefore, the final accuracy is comprised not only of the multibeam system accuracy, but also of the accuracy of the various components that makes up the total system. This can be achieved only by a proper calibration procedure.

The standard procedure in calibrating the MBES is the alignment or offset measurements of each sensor, the patch test and finally the performance test.

2.1 Offset measurements

This is to establish the mathematical relationship between each sensor with respect to the vessel reference system. Normally, the reference point is selected as the vessels centre of gravity (COG) or a point closer to it, which is easily accessible. This can be found by referring to the vessel's blue prints or verify from the engineer onboard. Once it is located, the physical distances (x, y, z) to each sensor is measured by using a tape or a total station. The standard sign convention is shown in Figure 1. The positive direction of X-axis is starboard; positive Y-axis is towards bow and positive Z-axis is directly upward from the reference point. These values have to be feed in to the data collection software. All these measurements must be done when the vessel is on a stable position (on a trailer or on blocks). Each distance to be measured from the reference point to the centre point of the sensor; which can be easily found in the manufacture's specifications.

The water level mark (draft) on the boat is also measured with respect to the sonar head, once the vessel is afloat. This is very important in accurate depth determination. It should be closely monitored during the survey and measured at least twice a day before and after the survey. During that period here any fluid or load transfer occurs, the draft should be measured before and after the transfer.

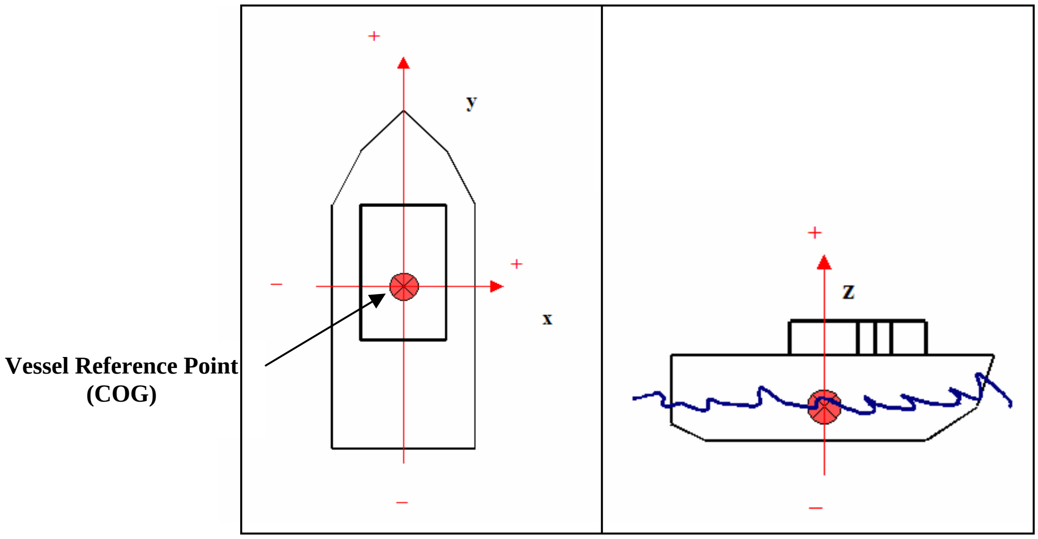

Figure 1: The vessel sign convention.

2.2 Patch Test

Once all the sensors are installed on the vessel and physical offsets being measured, it is not possible to get them in perfect alignment. Especially the sonar head, it is not possible to perfectly align with the reference system. Patch test is designed to precisely determine the static configuration of the sonar head (i.e. pitch, roll and yaw) and the latency remaining between the reception of the GPS fix and its integration by the acquisition system. This involves collection of data over a specific type of seabed and processing using specially designed software.

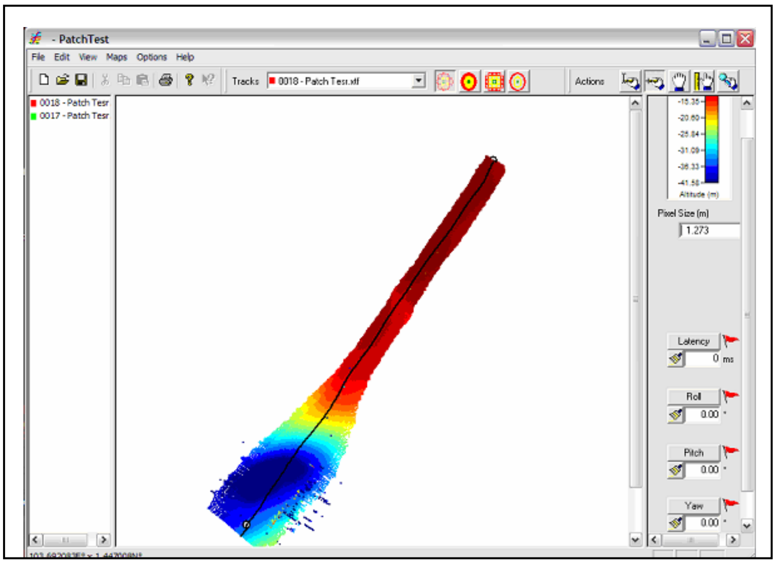

Figure 2: RESON patch test software

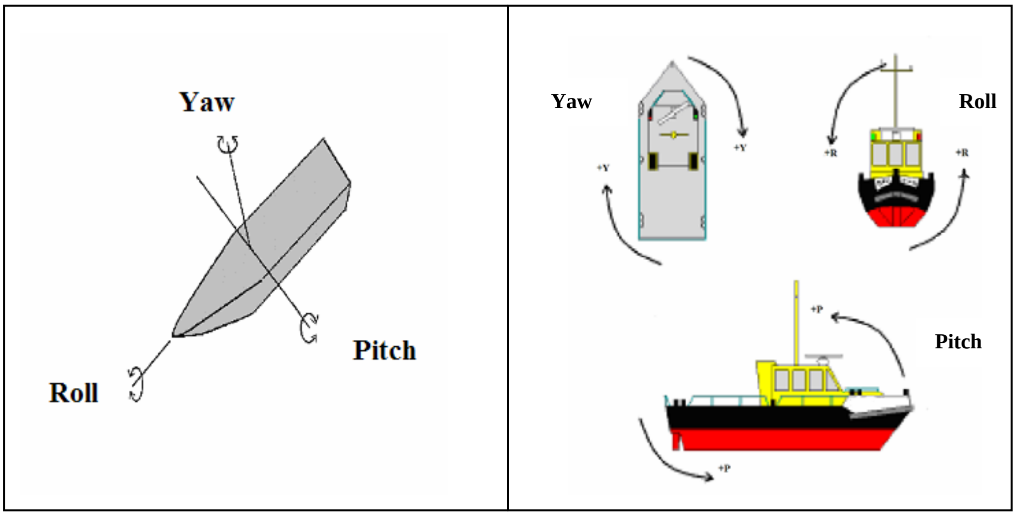

Figure 3: Vessel Rotation

2.2.1 Latency

Latency is the time difference between the time of the reported position being valid and the time of the message is output over the serial interface to the processing system. This depends on the modal and the mode of the GPS receiver. Incorrect latency causes positional errors along track and the effects are greater with higher vessel speeds. To determine the latency of the system, the same survey line has to be run in the same direction in different speeds over a feature or a sloppy seabed. Preferably one line has to run in a minimum speed and the other one as twice high as the previous line. Here only nadir beams should be used in processing in order to minimize the effects of other offsets which is yet to be determined.

Latency is resolved by measuring the along-track displacement of soundings from a pair of coincident lines as mention above. Same line direction will minimize the pitch errors. The equation to calculate the latency is:

$$L = \frac{\Delta a}{(Vh - Vl)}$$

Where, L = Latency in seconds
Δa = Along track displacement
Vh = Higher speed
Vl = Lower speed

Figure 4 shows the effects of incorrect latency measurements. This effect is called feature twinning.

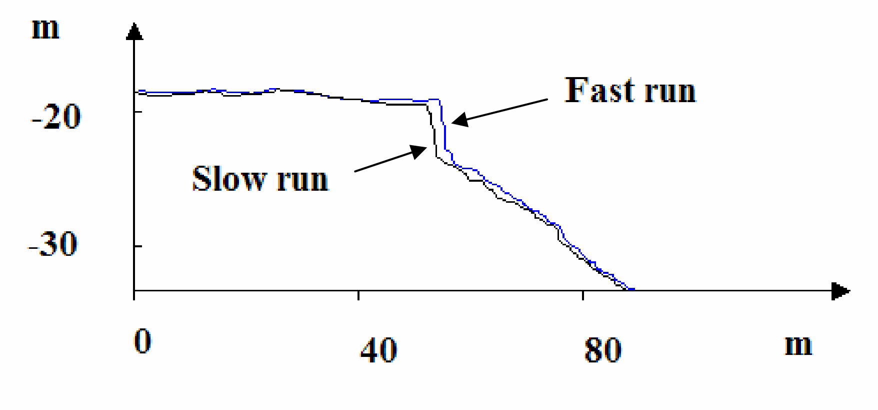

Figure 4: Latency effects on a slope

2.2.2 Roll

Roll is the misalignment of the transducer in Y-axis direction (Figure 3). This effects the depth and the effects get wrest for the outer beams of the swath and with the water depth (Figure 5).

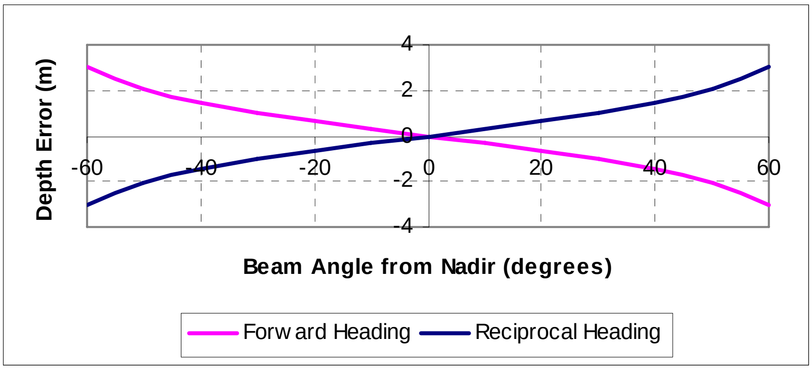

Figure 5: One degree roll error effects for 100 m depth.

To determine this offset, same survey line has to run in both directions with the same speed over a flat sea bottom. Then the cross-sections are compared.

The equation for this comparison is:

$$R = \frac{tan^{-1}(\Delta d / \Delta a)}{2}$$

Where, R = Roll in degrees
Δd = Depth difference
Δa = Across-track distance

2.2.3 Pitch

This is the misalignment of the sonar head in X-axis direction (Figure 3). This effects on position and the effects increases with the depth (Figure 6).

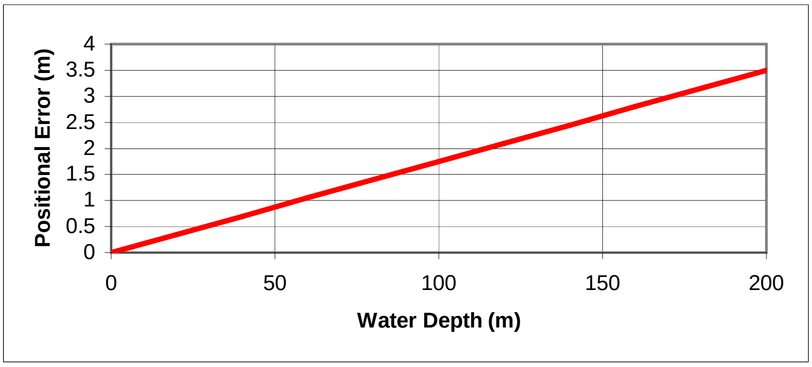

Figure 6. Positional errors from one degree pitch error.

Pitch can be calculated by two reciprocal lines run in both directions in the same speed over a sloppy or featured terrain. The equation is:

$$P = \tan^{-1}\left(\frac{\Delta a / 2}{d}\right)$$

Where, P = Pitch angle in degrees
Δa = Along-track displacement
d = Depth

2.2.4 Yaw

Yaw or azimuthal offset results from the misalignment of the transducer in z-axis (heading line or gyro compass rotation axis). See Figure 3. This also effects on position and the effects become more prominent with the beam angle and water depth (Figure 7).

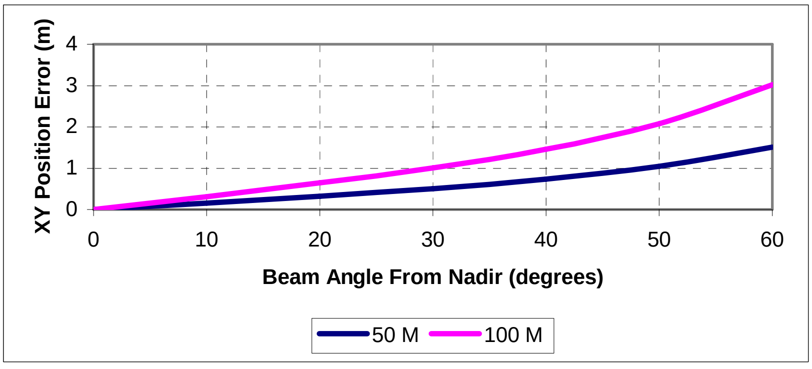

Figure 7: One degree yaw effects on position for different water depths

Here two parallel lines have to be used in same direction with same speed over a slope or a prominent feature, having a considerable overlap in-between (10%-30%). The value is obtained from the following equation:

$$Y = \sin^{-1}\left(\frac{\Delta a/2}{Xi}\right)$$

Where, Y = Yaw in degrees
Δa = Along-track displacement
Xi = Relative across-track distances for i'th beam

3.0 Performance Test

The final step of the MBES calibration procedure is to test its performance, i.e. to check whether it satisfy the survey accuracy requirements. On the other, hand it is a check of all previous tests. The performance test starts with a reference surface survey.

3.1 Reference Surface

The idea of reference surface is to establish a true bottom surface so that another survey line can be compared. It consists of small survey lines over a shallow flat area. The reference survey (Figure 8) comprises of several set of parallel lines run perpendicular to each other. They should maintain a considerable overlap (200%) and the lines should run in same normal survey speed. Also, it is important to have a reliable tide gauge and sound speed measurements.

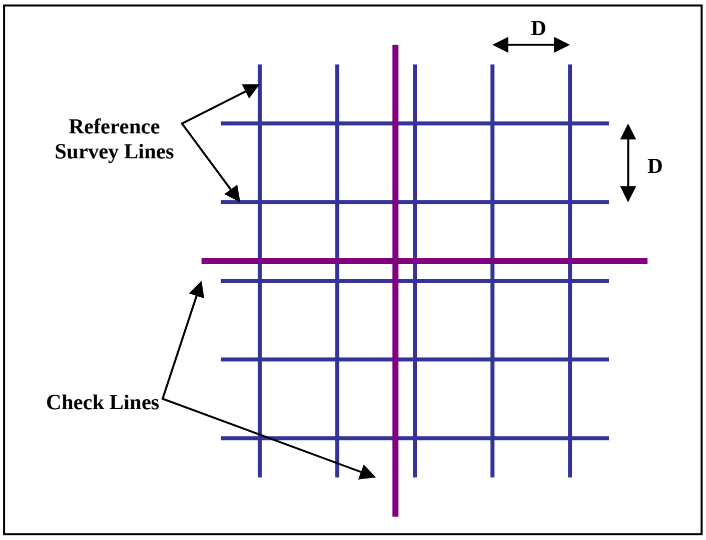

Figure 8: Reference survey lines and cross lines (D= water depth).

3.2 Check Lines

Several single survey lines run over the middle of the reference surface in both directions at the same speed as the reference survey lines (Figure 8). Single beam echosounder can also be used for this case.

3.3 Performance Test Comparison

First the reference survey lines have to be cleaned for outliers and remove the outer beams (>40 degrees). Then generate the reference surface using specially build software for the performance test. Here the grid size should not be larger than the average foot print of the nadir beams and should be binned as cell average value.

Check lines have to be processed similar to the reference surface, accept one has to use all the beams.

Then compare the reference surface and check lines for the followings:

1. Maximum differences between the layers.
2. Mean differences of the two layers
3. Standard deviation
4. 95% confidence level

4.0 Field Work

A complete MBES testing was carried out for UTM survey Boat "SERI MERANTI" in Lido Beach, Johor, Malaysia. RESON SeaBat 8124 was the MBES and QINSy v 7.5 and RESON Patch Test software were used as testing software. Differential GPS was used for positioning.

5.0 Results

5.1 Offset Measurements

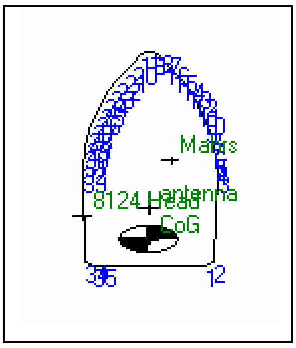

Figure 9:Vessel definition and node measurements of Seri Meranti

Figure 9 shows the vessel definition and other system definitions (nodes) with respect to the vessel coordinate system. COG is the vessel reference point. The GPS antenna, sonar head and MAHRS (motion sensor) locations were also measured.

5.2 Patch Test

This figure shows the final results obtained in the patch test.

Latency -155 ms
Roll -2.85 degrees
Pitch +2.30 degrees
Yaw +3.01 degrees

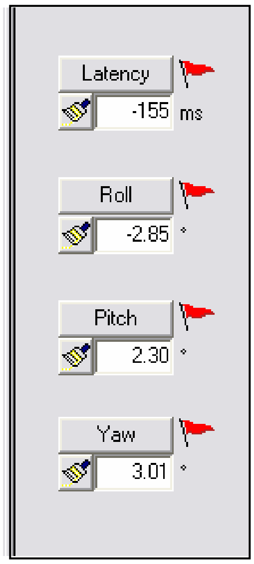

Figure 10: Patch test results

5.3 Performance Testing

The performance test was carried out using Sounding Grid Utility (SGU) in QINSy. The reference surface lines were added to the reference layer and the check lines were added to the survey data layer. Using the volume calculation tool, the desired statistics were obtained for the two layers.

1. Average Difference 0.26 m
2. SD of the difference 0.32
3. 95% Confidence level 0.63

6.0 Conclusion

Most hydrographic agencies carried out the MBES calibration procedure only up to the patch test. But to confirm whether the whole system work accordingly, the performance test should also be carried out. It can be used as a test of previous calibration procedures as well as a test of appropriateness and reliability of the tide gauge and sound speed measurements.

Sometimes one has to carry out successive surveys of the same area like in dredging works, to determine the differences or volume. Here, it is very much important to have an idea of the overall uncertainty of the work. Performance test can successfully be use for these cases.

7.0 MBES Calibration Criteria

Test	When	Test Procedure	Correction Procedure
Static Offset	Initial installation or change of location of the sensor	Measure all distance offsets with respect to the vessel reference point	Apply the values to the survey software
Patch Test	Every installation or different survey environments	Run a small survey of several lines as prescribed and estimate for each inconsistencies	Apply corrections to the survey software
Performance Test	At initial installation or major change in the vessel’s conditions like over haul in dry-dock or change in vessel characteristics	Compare several check lines with respect to a reference surface	Check the static offsets, patch test results, sound speed measurements, tide gauge

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