Article

Assessment of the Effects of Sensors Misalignment of a Multi-Beam Hydrographic Survey

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Abstract: A hydrographic survey vessel shows three -dimensional movements (Roll, Pitch and Heave) misalignment with respect to the vessel reference unit (VRU) due to environmental effects, such as wind, current, other vessel wakes, etc. These motions if ignored, cause errors in measured depth and in the positioning of the sounding. Hence the need of a motion sensor and gyroscope. However, the alignment of the multi-beam sonar head to the motion sensor and gyro (Octant) is critical to the accuracy of the determined depths. It is not possible to install the sonar head in perfect alignment with the motion sensor and gyroscope to the accuracy required. The synchronization of the GPS time with the Motion sensor and gyro, the latency of the position, as reported by the GPS as well as the velocity of sound in water are important parameters to account for the misalignment of the motion senor and the multi beam sonar head; this is called the Patch Test. In view of this, a patch test was done to ascertain the mounting angles of EMB 2058 Multi-beam sonar with Octan V installed onboard a survey vessel (Bitam). The result of the Patch test gives a row, pitch and heading value of -1.242˚, -4.92˚, and -0.48˚respectively. The speed of sound in water as measured ranges from; 1531.47m/s to 1531.60m/s within a minimum cast depth of 0.49m and maximum cast depth of 16.00m. The statistical analysis gives and average error of 2.642cm/m2 which was within acceptable standard as define by the International Hydrographic Organization (IHO).

Keywords: Patch Test, Multi-Beam Sonar, Motion Sensor, Gyro, Octan V

1. Introduction

Bathymetric survey which is the branch of hydrography involve the determination of the depth of water bodies for such purpose as navigation, construction of offshore and other marine facilities, deep sea oil exploitation and exploration and dredging operations (Guochang, 2010; Ojinaaka, 2007).

Multi-Beam Echo sounder for Bathymetric surveying is gradually replacing the single beam Echo sounder, due to it high level of accuracy to give a complete cover of the seabed by deploying it swath capabilities (Demi and Huibert-Jan, 2021). The environment upon which bathymetric survey is carried out is in continuous motion because of the dynamic natures of the water bodies caused by the ocean current, waves, other vessels wake, tidal stream, and the earth gravitational pull (Torge and Muller, 2012).

This turbulent nature of the water bodies results to three dimensional motions as shown in Figure 1: (Roll, Pitch and Heave) of the survey vessels as she sails along the survey lines (Reha, 2003). This motions if ignored causes errors in the depth and in the position of the sounding. Hence, Motion sensor and Gyroscope (Figure 2) are installed onboard the vessel to measure the three-dimensional motion of the vessel with respect to the vessel reference unit (VRU) and corrections are being applied.
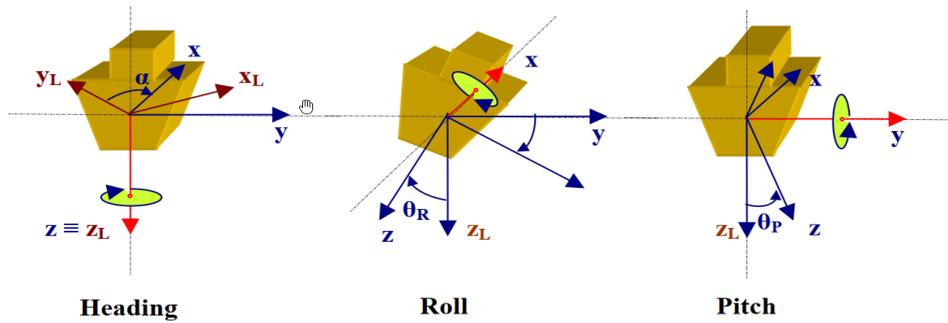
Figure 1. The three-dimensional Motion of a Survey vessel (IHO Manual, 2005).

However, the alignment between the motion sensor, the gyro and the Multi-Beam Sonar head must be accounted for during the installation of these three sensors onboard the survey vessel as it is not possible to mount the sensor sonar head in complete alignment with the motion sensor and gyro. Hence, the need for the calibration of the multi-beam sonar head, which involves the determination of the mounting angles, in terms of roll, pitch and heave together with the latency as furnished by the GPS output files; this is called the Patch Test (Brennan, 2017). The purpose of the calibration is to correct for systematic errors created by the positioning and mounting angles of the different sensors. A correctly calibrated system will show repeatability in the bathymetry data, regardless of the variables such as the speed, direction, and motion of the survey vessel (Shannon and Karma, 2010).
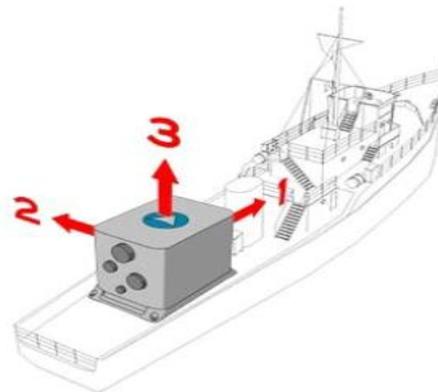
Figure 2. Motion Sensor on a survey vessel (MU-AHRS-AN-002, 2012).

The Patch Test involves collecting data over certain type of bottom characteristics (smooth and rough) terrain and processing the data through a set of patch test tools. There are two primary methods of processing the data that are currently in use: an interactive graphical approach and an automatic, iterative surface match. Each of these techniques has strengths and weakness and the preferred approach is dependent on the types of terrain available to the surveyor (Brennan, 2017).

In this research, an automatic, iterative surface match approach was deployed using the Beam works (Auto Patch) Software. This study seeks to assess the effects of vessel misalignment of a multi-beam sonar sensor with the fundamental objective of determination of calibration parameters.

1.1. Study Area

Bonny Island is situated at the southern edge of Rivers State in the eastern Niger Delta region of Nigeria. It was formally known as Ibani or Ubani town. It lies along the Bonny River (eastern distributaries and 6 miles upstream from the Bight of Biafra. It is located at latitude 04° 26' 57''N and 04° 31' 42''N longitude 07° 03' 8.1''E and 07° 09' 38''E.

The Bonny River flows in a southeasterly direction into a large body of water which also flows almost vertically and slightly southeasterly into the Bight of Bonny. It runs in between the two neighboring estuaries of the New Calabar River to the west and the Andoni River to the east. The Cawthome channel links the New Calabar channel and Bonny River estuary. Bonny covers a total land area of about 651.20km² (Brown and Adekunle, 2015) as shown in Figure 3.

Figure 3. Google Earth Imagery of Bonny Island. Source: Google earth, Date Accessed: 15th Sept. 2022

2. Waves

The three-dimensional motion of the hydrographic survey vessel; the Bow-Stern movement (Pitch), the Port-Starboard movement (roll), and the upward and downward movement (heave) are all a resultant effect of wave actions. The characteristic of a wave depends on three major factors; the type of disturbance initially applied to the water and whether it is continuously applied to produce a forced wave or is quickly removed to allow the wave to propagate away as free wave, the type of restoring mechanism that force the water back to equilibrium and the properties of the wave itself as shown in Figure 4.
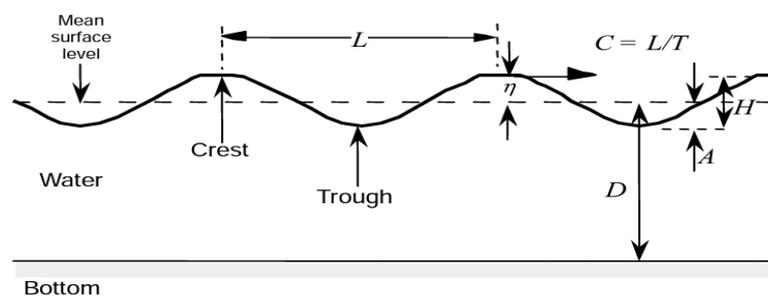
Figure 4. Wave characteristics. (De Jong, et al., 2002).

Assume a wave travel in the x-direction. The vertical displace η of the free surface from the mean level is expressed (De Jong, et al., 2002) as:

$$\eta = A\cos\left\{2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right\} \tag{1}$$

Where x is the actual displacement of the wave, t is the time and T is the period. Using

$$k = \frac{2\pi}{L}, \text{ the radian wave number} \tag{2}$$

$$\omega = \frac{2\pi}{T}, \text{ the radian } (angular) \text{ frequency} \tag{3}$$

The vertical displacement η can be expressed as:

$$\eta = A\cos\left\{kx - \omega t\right\} \tag{4}$$

Where, $kx - \omega t$ is the phase of the wave which varies from 0 to 2π as one goes from crest to the next distance (L). We wouldn't attempt to derive the mathematical complexity of the various factors of ocean dynamics, interested reader can consult (Hudspeth, 2006; De Jong, et al, 2002).

2.1. Patch Test

The multibeam sonar system alignment described here is intended to aid the hydrographer in determining sensor misalignments and timing errors and assumes that factors such as tide, heave and the speed of sound are accurately known.

The orientation of the sonar head must be known to convert the measured slant ranges to the depths and to determine the position of each of the sounded depths. Any error in the measured pitch of sonar 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 0.4m when the sonar head is 25m above the seabed (Brennan, 2017) as shown in Figure 5.
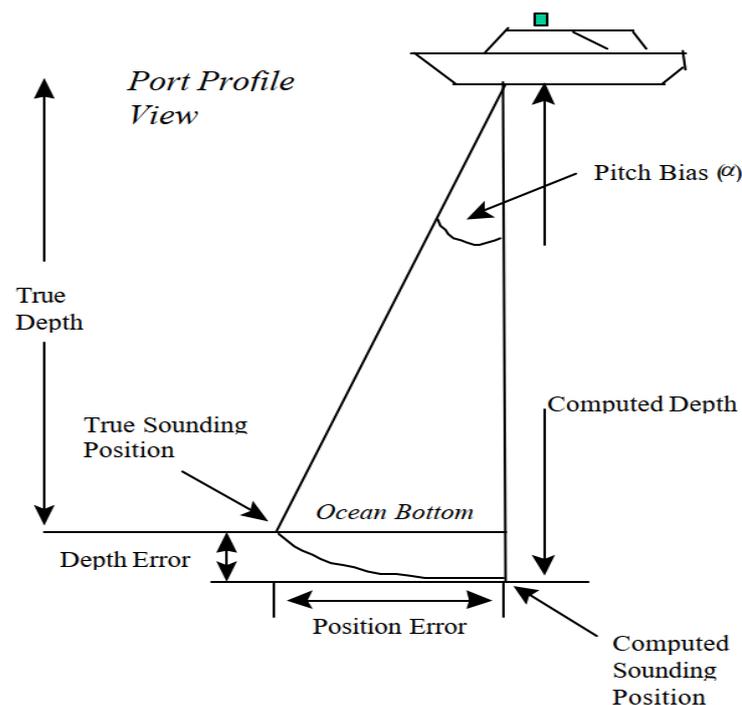
Figure 5. Error induced by a Pitch misalignment (James, et al., 1996).

A roll misalignment introduces both an error in depth measurement and an error in positioning. The error induced by the roll misalignment, or roll bias is greater in the outer beam and increase with water depths. Any error in the measured roll of the sonar head can cause substantial errors in the conversion from range to depth. A roll error of 1˚ on a 50m slang range can cause a 0.6m error in the resulting depth as shown in Figure 6.
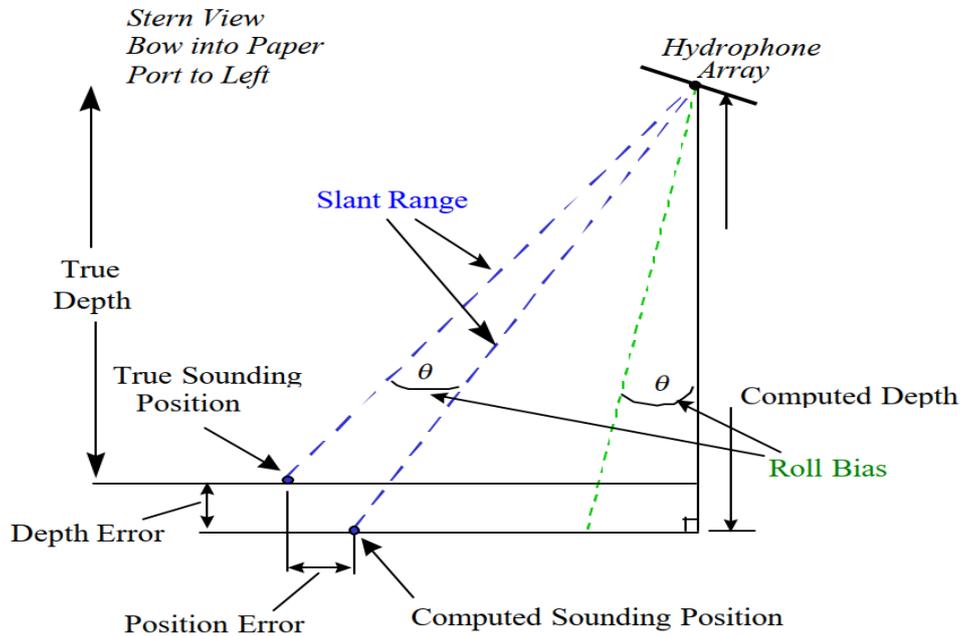
Figure 6. The error induced by a roll misalignment, (James et al., 1996)

A misalignment between the gyrocompass and the sonar transducer produces a horizontal positioning error but does not affect the measured depth. Errors in misalignment of the pitch and roll sensor (Vertical Reference Unit, VRU) induce cross talk error which affect the pitch and roll measurement as shown in Figure 7.
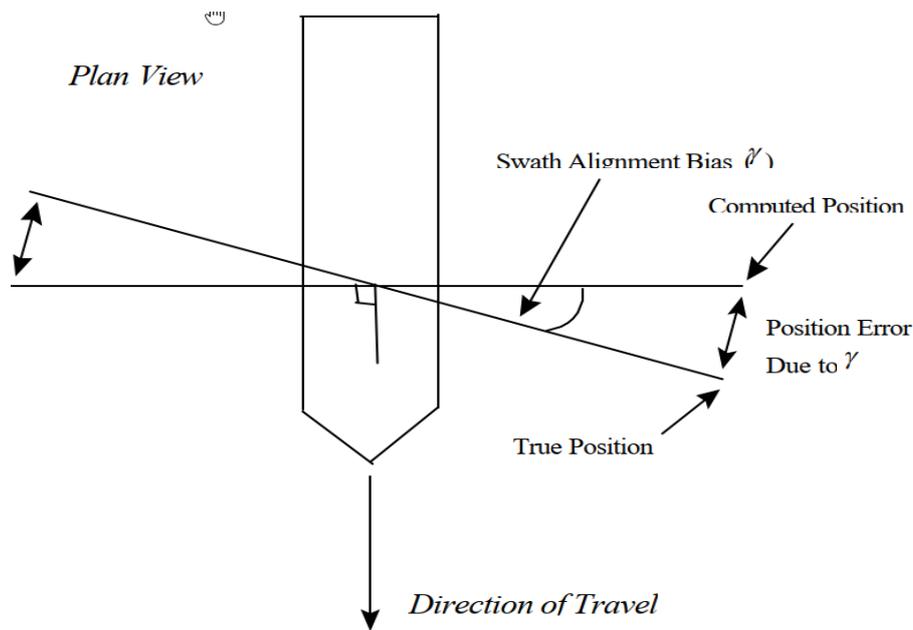
Figure 7. Horizontal positioning error induced by a gyrocompass or transducer heading alignment error.

2.2. Sound Speed error

The increased path lengths of the outer beams in a multibeam system result in greater errors due to ray bending and required a more detailed knowledge of speed through the water column. The propagation of sound in the ocean is distorted because of spatial and temporal variations in water column characteristics which include the salinity, temperature pressure and turbidity. The speed of sound also varies with depth from the surface to the seabed. This result to the refraction of beam signal as it passes through this water column. It is important to have accurate knowledge of the water column around the survey and at the time of the survey. The speed of sound wave was measured using the Valeport sound velocity Probe.

2.3. Timing Error

Proper horizontal positioning of the transducer is dependent on the accurate measurement of sensor offsets and on proper synchronization of the positioning and sonar clocks. In addition, computational delays within the sonar processing software may produce errors even if both clocks are well synchronized. A timing offset of 0.5 seconds between the positioning system and the sonar processing system will produce and error of about 2.5m at about 12 knots speed of the survey vessel. This error increases with survey vessel speed and will exceed 5m at typical surface vessel speed (about 20 knots). Timing error produce a positioning error, which is independent of water depth, but directly related to vessel speed.

3.0. Materials and Methods.

The materials and software used for this research are shown in Table 1 below.

Table 1. List of Materials.

S/N	Equipment	Remark
1	Kongsberg Multi-Beam Echo Sounder	EM 2040C MKII
2	Octant V Subsea	IXblue
3	GNSS Receiver	Septentrio
3	Survey Vessel	Bitan
4	Sound Velocity Probe	Valeport
5	Qinsy Processing Software	Version 9.4
6	AutoPath	Beam works

3.1. Data Acquisitions

This research relies on primary data acquired from Multi-Beam Survey operations done within the Nigerian Liquefied Natural Gas (NLNG) Getty, Bonny Island. The Patch test was done using three sounding lines: a relative plan area, a relative sloppy area. The Survey Vessel sailed along the predefine survey line twice but on same and different directions. Before the survey, the speed of sound wave in water was measured using the valeport sound velocity probe and the data was downloaded to the Quinsy Processing Software (QPS) which was used for the data acquisitions as shown in Figure 8.
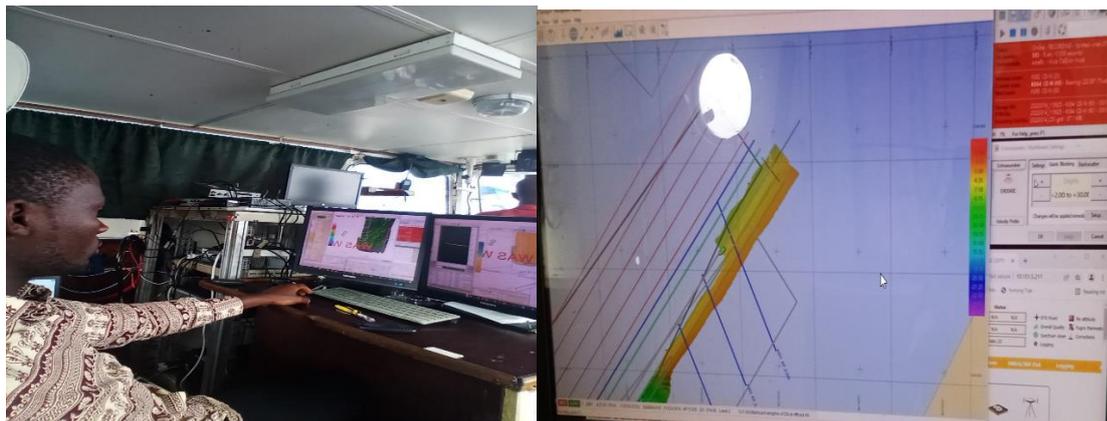
Figure 8. Showing the Qinsy Software Interface**.**

3.2. Data Processing

The acquired Qinsy processing data (qpd) files and the sound velocity profile saved in the *.exe* extension format was exported to Beam Works software (Auto Patch) for the Patch Test calibrations.

4. Result Presentation

The Sound velocity profile was downloaded from the Valeport Sound Velocity Probe as show in Table 2 below:

Table 2. Showing a sample of the Sound Velocity Profile.

Depth (m)	Velocity, (m/s)	Temperature K
0.28,	1531.51,	8.00,
1.49,	1531.47,	8.00,
5.62,	1531.50,	8.00,
10.59,	1531.57,	8.00,
12.02,	1531.59,	8.00,
16.00,	1531.60,	8.00,

The acquired data and sound velocity profile is imported into the Auto-Patch software as shown in the Figure 9 below.
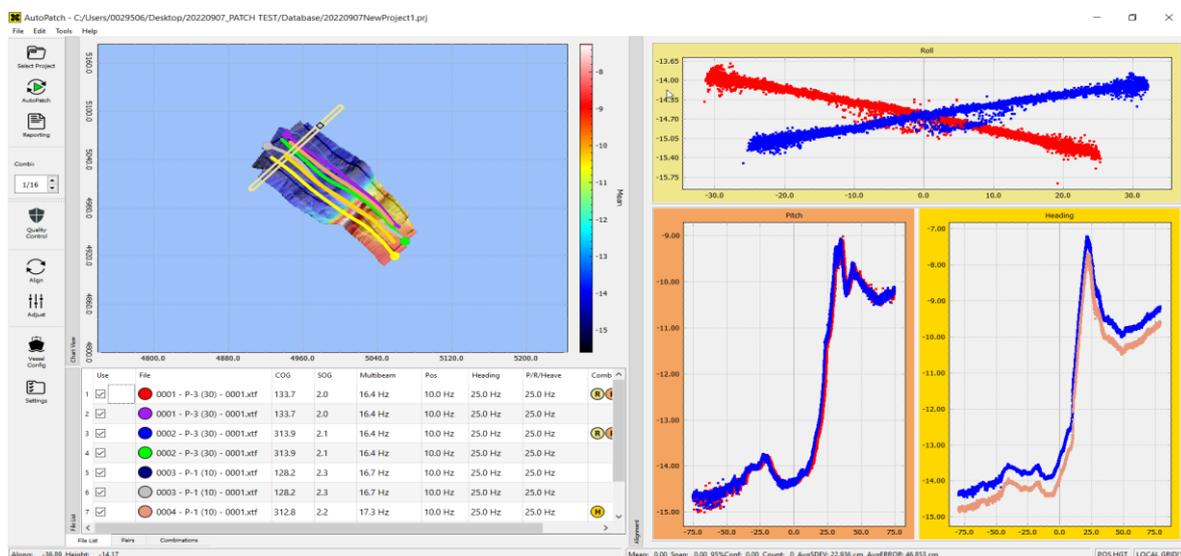

Figure 9. A graphical misalignment of the bathymetric Data; The effect of Roll, Pitch and heading.

To determine the effect of waves resulting to the three-dimensional motion of Roll, Pitch and heave, the sounding lines are sail twice but in opposite directions. The mismatch of the bathymetric data as show in Figure 9 shows the implications of roll pitch and heading.

The autopatch command which is based on an iterative algorithm of the least squares estimate is used to determine the unknown parameter for Roll, Pitch, and headings. This is as shown in Figure 10.
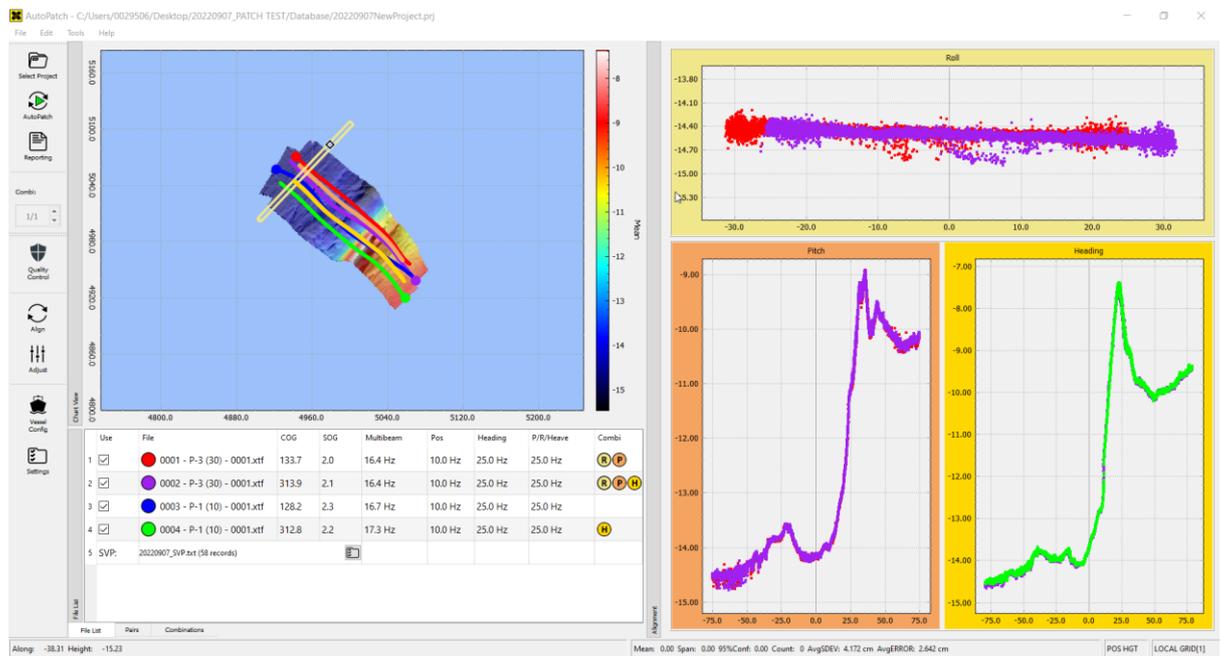

Figure 10. A graphical model of the bathymetric Data; The effect of Roll, Pitch and heading having been calibrated.

The result of the patch test, which involves the determination of the unknown parameter of the mounted angle between the multi-beam sonar head and the Motion sensor is as give in Table 3.

Table 3. The Calibration Result for Row, Pitch and Heading

Calibration Offset Results					
Roll-Pitch	Hdg	Roll	Pitch	Heading	
01-Feb	02-Apr	-1.242°	-4.92°	-0.48°	Advised Mounting Angles
	Preset	0.000°	0.00°	0.00°	
	Average	-1.242°	-4.92°	-0.48°	
	Sdev	0.000°	0.00°	0	
Average error		**2.642 cm/m2**			

4.1. Discussion of Result

The standard speed of sound wave in water is 1500m/s; however, this value varies with temperature, pressure salinity and turbidity. The temperature of the ocean ranges within -2° to 36°C. The speed of sound wave for the Bonny region was found to be within 1531.47-1531.60m/s on a temperature of 8°C as shown in Table 2. Figure 9 show the non-matching of acquired bathymetric data, this shows the implication of the effects of Roll, Pitch, heave and heading. And the attendant need for this parameter in any bathymetric campaign. The calibration was carried out using the automatic, iterative matching method yielding; -1.242°, -4.92°, and -0.48°for roll pitch and heading respectively, the average error

of the calibration is 2.642 cm/m² as given in Table 3. As can be seen in Figure 9, the data where matching having applied the corrections.

The result of this research shows the criticality of applying corrections for roll pitch, heave and heading in all hydrographic surveying operations which is usually not the case in most single beam bathymetric survey. Thereby, reducing the accuracy of single beam bathymetric. With the development of relatively less expensive fiber-optical gyroscope and motion sensors, the effect of ocean dynamics can be accounted on proper calibration for both single beam and multi-beam bathymetric survey.

4.2. Conclusion

This research has been able to examine some of the critical error in a multi-beam hydrographic campaign which when not properly calibrated will reduce the accuracy of the bathymetric data. It will no doubt be a veritable resource for hydrographer in the determination of alignment errors before conducting a Multibeam Hydrographic survey.

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